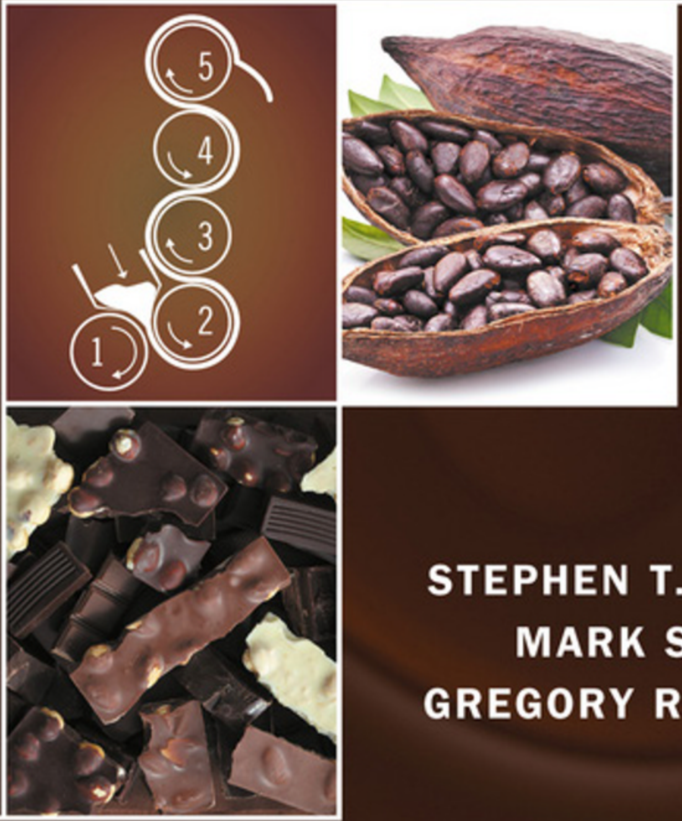
BECKETT'S
Industrial Chocolate Manufacture and Use

FIFTH EDITION



Edited by

STEPHEN T. BECKETT
MARK S. FOWLER
GREGORY R. ZIEGLER

WILEY Blackwell

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Contributors

Stephen T. Beckett, BSc (Durham) D.Phil. (York) in physics, worked for eight years on research into asbestosis. The interest gained here in particle size distribution measurement, together with its effect on flow properties, has continued into the confectionery industry. Here he worked for more than 27 years, initially for Rowntree Mackintosh and subsequently with Nestlé. The work was primarily concerned with research and development, but also included a period as Process Development Manager. He has given several lectures on different aspects of chocolate making at Leatherhead in the United Kingdom and ZDS, Solingen in Germany, as well as two presentations at the PMCA conference in the United States. He has written a book on the science of chocolate as well as many published technical papers and is the named inventor in numerous patents. Since retiring from Nestlé in 2006 he has been involved in research into microencapsulation using pollen particles and has been awarded the Fellowship of The Royal Society of Chemistry and become an honorary professor at the University of Hull.

Marcel Aebi is a classically trained confectioner–patissiere from Switzerland. After several years travelling around the world working in the confectionery industry, he joined Nestlé in 1978. For the last 25 years he has worked in the area of new product development and process application in panning, both in America and Europe. He is currently based at Nestlé Product Technology Centre, York, UK.

Faith Burndred has a BSc in Chemistry from the University of York. She joined Nestlé in 1992 and since then has held a variety of technical roles supporting the confectionery business, including factory quality management. She currently works at the Nestlé Product Technology Centre in York and has spent time providing technical support and training to confectionery factories worldwide in food safety matters.

Fabien Coutel obtained a Master's degree in Food Science and Technology in 2002 from ENSCBP in Bordeaux. He has worked for Chocolat Weiss as a production manager before joining Nestlé's Research and Development centre at York in 2007, where he has been in charge of various projects related to chocolate and cocoa processes and products. From 2012 he has been working at Nestlé's Chocolate Centre of Excellence in Broc, Switzerland, as a cocoa expert where he also contributes to the group's sustainability program, the Nestlé Cocoa Plan. He is a member of the ICCO Ad Hoc Panel for Fine or Flavour Cocoa.

Patrick J. Couzens joined Nestlé's confectionery business in 1991 after obtaining a doctorate in physical chemistry from the University of York. For the first few years he worked as a research scientist and published studies of lipid migration in confectionery products. He then moved into product development, specialising in panned confectionery. In 2005 he presented a lecture on the science of chocolate at the Royal Institution in London. In recent years his career has moved into the field of intellectual property. He was a Technical Intellectual Property Manager for Nestlé Confectionery in York before moving to Switzerland where he currently leads the Patents, Regulations and Scientific Intelligence group at the Nestlé Research Centre in Lausanne. Patrick is a European Patent Attorney.

Stuart Dale joined Rowntree, later Nestlé, in 1979 as a research assistant conducting chemical analyses. He continued to study Applied Chemistry on a part-time basis before graduating from Leeds Metropolitan University and is a Member of The Royal Society of Chemistry. In 1984 he joined the Chocolate Research team of Dr Steve T. Beckett, first in Rowntree Group Research and later at the Nestlé Product Technology Centre in York. He has since specialised in the manufacture and processing of chocolate and chocolate compounds. From 1995 he has been based in Melbourne, Australia at a Nestlé confectionery factory, improving processes, developing new products and, since 2005, as Production Manager.

Mark S. Fowler studied at the University of Oxford where he obtained a degree in zoology. He joined Rowntree in 1977 and spent several years forecasting the size of the West African cocoa crop. He participated in a cocoa quality improvement project working directly with farmers in Cote d'Ivoire. After some time in technical management in confectionery factories, he joined Nestlé's Product Technology Centre in York. He led the Cocoa and Chocolate Research programme before becoming head of Applied Science. He is now an independent consultant in cocoa, chocolate, food science, health and nutrition.

Michael P. Gray graduated as an industrial chemist from Loughborough in 1970, followed by an MSc in microbial biochemistry from Imperial College, London. He started with Cadbury Schweppes R&D in 1972, working on milk powders, and moved to Rowntree Mackintosh in 1979, spending 15 years in a general confectionery factory, both troubleshooting and seeking ways of making chocolate more efficiently. He joined Nestlé's R&D in York in 1998 following three years in France working on ice cream and ice cream coatings. He then spent a period involved in providing technical assistance to factories worldwide prior to retiring.

Meriel L. Harwood received a BSc in Food Science and Industry from Kansas State University. She then went on as PMCA Tresper Clark fellow at the Pennsylvania State University where she earned a MSc in Food Science researching sensory methodologies in chocolate applications. In 2013 she joined Mars Chocolate North America as Sensory and Consumer Insights Scientist and recently moved into her current role as Product Development Scientist.

John E. Hayes earned his BSc and MSc in food science from Cornell University and his PhD in nutritional sciences from the University of Connecticut before completing a National Research Service Award (NIH T32) fellowship in behavioural genetics and alcohol addiction at Brown University. He joined the Penn State faculty in 2009, where he runs a multifaceted research programme that applies sensory science to a diverse range of problems, including work on chemosensation, genetics and ingestive behaviour, as well as the optimisation of oral and non-oral drug delivery systems. He has authored more than 60 peer-reviewed articles and book chapters, and his work has appeared on CNN.com, in the *Wall Street Journal*, *The Atlantic*, *The Guardian*, *Popular Science* and *Vogue*, among others.

Randall (Randy) Hofberger is currently assisting the confectionery industry with his company R & D Candy Consultants. Prior to that he held technical and quality assurance positions with Nestlé, Peters Chocolate, Ward-Johnston Candy and Carnation Co. He has a food science BSc degree from the University of Wisconsin–River Falls and a MSc in Food Science from the University of Illinois. Randy is active in industry organisations such as AACT, RCI, UW candy course and PMCA, where he assistsd with various technical presentations and classes. He is an inductee of the 2014 Candy Hall of Fame.

Richard Hogg is Professor Emeritus of Mineral Processing and Geo-environmental Engineering at The Pennsylvania State University and is a member of the National Academy of Engineering and the Society for Mining, Metallurgy and Exploration. His primary research interests lie in colloid science and particle technology with emphasis on characterisation, mixing, agglomeration and fine grinding of powders.

Sophie Jewett has more than 15 years' experience in the food and drink industry in product development, retail, hospitality and market research. Sophie is the creator and owner of the York Cocoa House. Established in 2011, York Cocoa House is a chocolate-based business located in York, with café, retail and educational facilities. As well as hand-making all of their own products, the company offers educational and engagement activities to visitors to learn more about the chocolate industry and the role York has played in the development and growth of that industry. Sophie advises, lectures and tutors at all levels within the chocolate industry, drawing on historical development and methodology to improve understanding of the evolution of the industry today in mature and emerging markets. Sophie currently lectures with the University of York specialising in the relationship that sociological, economic and technological drivers have with consumer behaviour in the chocolate industry. Areas of specific interest focus on emotional connectivity, artisan quality and the role of story-telling in driving consumer behaviour and developing sustainable brands.

Carl E. Jones joined Nestlé Research and Development in 1987 where he trained as a food technologist before completing the Institute of Packaging Diploma in 1990, winning the award for best essay. Since 1991 he has been based in York in Nestlé's lead Reseach and Development Centre for the global confectionery business. During his time in York he has travelled worldwide installing new wrapping lines, participating in asset utilisation projects, performing packaging materials optimisation studies, providing training ranging from packaging materials to optimised sealing jaw set-up and maintenance for flow wrap operations. Recently he has been responsible for developing a standardised pack seal integrity methodology for cold seal flow wrap packaging.

Henri J. Kamphuis (MSc and PhD) studied food technology at Wageningen Agricultural University, The Netherlands. Having obtained a doctorate he joined Gerkens Cacao BV, a Cargill Foods company, in 1992 and worked for 15 years within the Quality and Application Department. Currently he is Director Quality, Food Safety and Technical Service within Cargill Cocoa.

Kerry E. Kaylegian is the Dairy Foods Research and Extension Associate at the Pennsylvania State University, Department of Food Science. She has a BS and MS in Food Science from the University of Wisconsin, a PhD in Food Science and a post-doctoral fellowship from Cornell University. Kerry provides technical support to the dairy industry on dairy product manufacturing, quality and food safety. She is the director of five short courses annually and conducts custom training on dairy foods manufacturing. Kerry judges cheese and dairy products at national competitions and developed the annual Pennsylvania Farm Show Cheese Competition. She received the 2014 Marie Kelso Memorial Award from the Pennsylvania Manufacturing Confectioners Association for her talk on dairy ingredients for confectionery products.

Christof Krüger studied chemistry and sugar technology at the Braunschweig Institute of Technology. After his graduation as "Diplom-Chemiker" (MSc), he worked for German sugar companies and was the first applications manager in the German sugar industry. Concurrently with this function he was a senior manager of a company producing caramel colours and sugar syrups and was involved in the commercial and technical planning of a new liquid sugar plant. For seven years, he was chief chemist at Rowntree Mackintosh, Hamburg, where his responsibilities included management of the laboratories, quality control, product development and the sensory department. He also worked actively on the scientific committee of the Association of the German Confectionery and Chocolate industry, who appointed him as research representative in the confectionery section. In 1986, Christof Krüger joined the Finnish Cultor group, formerly the Finnish Sugar Corporation. He began as technical applications manager at Finnsugar Xyrofin, became technical director of Xyrofin GmbH and in 1996 vice president for Technical Applications of Cultor Food Science GmbH in Hamburg. In this capacity he advised customers in the confectionery and chocolate industry worldwide, in the use of different bulk sweeteners. He frequently presented papers and acted as moderator in international symposia at the Central College of the German Confectionery Trade (ZDS) at Solingen.

Joshua D. Lambert is an Associate Professor in the Department of Food Science and a member of the Center for Molecular Toxicology and Carcinogenesis at the Pennsylvania State University. Dr Lambert received a BSc in Biochemistry from the Pennsylvania State University in 1997 and a PhD in Pharmacology and Toxicology from the University of Arizona in 2001. Prior to joining the faculty in the Department of Food Science at the Pennsylvania State University in 2008, Dr Lambert conducted post-doctoral research on cancer prevention in the Department of Chemical Biology at Rutgers University. He has published more than 75 peer-reviewed scientific papers and 10 book chapters on the prevention of chronic disease by polyphenol-rich foods and food ingredients, including cocoa. In 2014, Dr Lambert was selected by Thomson Reuters for inclusion in The World's Most Influential Scientific Minds. His research group has received funding from the National Center for Complementary and Alternative Medicine, The National Cancer Institute, The American Institute for Cancer Research, as well as various commodity boards and industrial partners.

Ulrich Loeser (PhD in Food Engineering, Dresden University of Technology) is currently Manager Research andDevelopment Chocolate Process Capabilities EEMEA at Mondelēz Deutschland R&D GmbH in Munich, Germany. From 1976, his last year of study in Chemical Engineering for Food Material, he has worked on many of aspects of chocolate technology. In 1990, after seven years at the Plant Engineering and Construction Department of Maschinenfabrik Heidenau, a machine manufacturer, he joined Jacobs Suchard, Operations Plant Loerrach, Germany. Subsequently with Kraft, he moved from process optimisation engineering, plant management, ISO systems implementation to become a Technical Leader for confectionery. Ulrich transferred into the Research and Development team in 1996 and has promoted the use of new innovative digital analysis/process control methods. He is author and co-author of various granted patents and patent applications. Examples are: (i) operator-less refining using self-optimising control, (ii) use of 2D infrared imaging on the product just after leaving cooler and on its position in the mould to predict fat bloom formation during shelf life, (iii) a completely new way to determine factors affecting product quality using cooling data from tunnels, containers and air conditioned rooms. In addition he is a co-author of two chapters in "*Grundzüge der Lebensmitteltechnik*", 3rd edition, published by BEHR Verlag in 2004 and is a member of the steering committee for the international congress "*Chocolate Technology*", ZDS Solingen.

Ángel Máñez-Cortell has a degree in biology from the University of Valencia, Spain. He joined Nestlé as a post-graduate student and first worked on research projects on the chemistry of cocoa fermentation in the United States. Subsequent to that he gained experience during three years in the area of cocoa processing. For the last 16 years with Nestlé, his main area of expertise has been closely related to chocolate manufacture and usage. He is currently a product specialist at the Nestlé Product Technology Centre for confectionery in York. As part of his present role he participates in Research and Development projects, provides technical assistance to factories all over the globe and participates in the commissioning of new lines.

Edward Minson is currently Director of Commercial Business Development with Natural American Foods. He has held various commercial and technical management positions with Solazyme Roquette Nutritionals, Corn Products/SPI Polyols, Eskimo Pie Corporation, Grace Cocoa/Ambrosia Chocolate and Ralston Purina. He is currently treasurer of PMCA and is a past president of the American Association of Candy Technologists. Minson was awarded the Stroud Jordan Award in 2005. He holds a MS in Food Science from the University of Wisconsin–Madison, a BS in Food Science from the University of Massachusetts–Amherst and an MBA from Marquette University.

Liz Peace has a degree in microbiology from Edinburgh University. She joined Rowntree Mackintosh in 1982, working as a project microbiologist before moving into Quality Assurance to provide food safety and quality systems support to the United Kingdom confectionery business. She joined Nestlé Product Technology Centre in York in 2002 and currently provides technical assistance and support for new product development to confectionery factories worldwide.

Konstantinos Paggios, MSc (Reading) in Food and Agricultural Biotechnology worked for 13 years in the Center of Excellence of Kraft Foods (now Mondelēz International) on confectionery technology and process development in Munich, Germany. As a senior associate principal scientist, he developed expertise on various fields such as surfactant technology and nanoemulsion technology, rheology, fat crystallisation and precrystallisation processes, grinding technologies, conching, moulding and enrobing processes. In 2011, he joined the Research and Development Department of the Chocolate Manufacturing Business Unit at Bühler AG, Uzwil, Switzerland. His main focuses were commissioning, line assessments and troubleshooting, evaluation of prototype process concepts, collaborations on external research programmes and IP monitoring. Currently, he is leading the technology team and its activities in the Research and Development Department of mass manufacturing which belongs to the Consumer Food Division at Bühler.

Dave J. Peters graduated in Chemical Engineering from Swansea University and joined the Tea and Foods Research and Development Department of Cadbury in 1976. After an initial period supporting recipe and process development for the preserves business, he moved into chocolate process development. He managed product development for Cadbury UK for 10 years before moving to a global role in 2005 advising on chocolate recipe and process development across the Cadbury and Kraft businesses. He was a regular public speaker, giving talks on chocolate manufacture at universities and at the ZDS technical conference and, most frequently, talking about a range of confectionery issues at Leatherhead where he was Chair of the Confectionery Forum. Since his retirement in 2011 he has operated as a technical consultant; supporting small and large businesses and acting as a mentor for chemical engineering undergraduates.

Ian Roberts is the Chief Technology Officer of Bühler. His fascination with chocolate began during his PhD studies with Nestlé PTC York, under the influence of Steve Beckett. In 1997, Ian joined Nestlé in Switzerland and went on to perform a range of roles in innovation, spanning fundamental research to Country Innovation Director and Research and Development Head. He joined Bühler in 2011.

Ulla P. Skytte obtained her MSc in food science from the Royal Veterinary and Agricultural University in Copenhagen (1984). She has more than 20 years' experience in chocolate and confectionery, mainly as an ingredient specialist. She worked for Aarhus Oil (now AAK) as Application Manager within speciality fats and cocoa butter alternatives for five years and a further five years for Danisco Ingredients (now Dupont) with emulsifiers and stabilizers for the food industry, including emulsifiers for confectionery preventing fat bloom (STS) and viscosity reduction (PGPR). In 1995 she took up a position as Research and Development Manager and later Business Unit Manager at Arla Foods Ingredients, responsible for establishing a confectionery team, including a fully equipped pilot facility focusing on sales and development of dairy-derived ingredients for confectionery and nutritional bars. From 1995 to 2000 she was technical committee member in the European Whey Producers Association in Brussels. During her time at Arla Foods Ingredients she developed a close technical network with universities, especially Leeds University and institutions such as Leatherhead Food International. She was (2002–2006) co-chairman with Steve Beckett on the confectionery committee at Leatherhead. She has presented several papers at ZDS in Solingen, Germany, IFT and the American Association of Cereal Chemists, in the United States. In 2006 she left the world of confectionery and took up a position at APV, now SPX Flow Technology, a major global food equipment supplier. She is Global Product Sales Manager for the mixer portfolio, servicing the entire mixing and blending segment.

Marlene B. Stauffer holds a Food Science Degree from the College of Agriculture at The Pennsylvania State University and joined Blommer Chocolate Company in 1982. Blommer is the largest roaster of cocoa beans in North America, selling chocolate and cocoa products to the confectionery, dairy, bakery, functional and snack food industry. Marlene developed all initial quality systems for the Laboratory and Operations to meet the ever-growing facility. Key involvements have been with all aspects from manufacturing, quality systems, product development, to technical assistance for customers. Presently she is the Regulatory Compliance and Regional Quality Assurance Manager for Blommer Chocolate. Certifications include Internal Auditor by SAI Global and Advanced International HACCP Alliance. Marlene has also been active in industry involvement, teaching at several NCA and PMCA classes and speaking at PMCA, BCMA, AACT, RCI and CASA. Memberships include the PMCA Research, Membership and Education Committee, Institute of Food Technologists, American Association of Candy Technologists, the NCA Chocolate Regulatory, Health and Nutrition Committee, and Food Industry Group. She is a past recipient of the Marie Kelso award and is currently Chairman of the Board for PMCA, an International Association of Confectioners.

Geoff Talbot (BSc, FRSC, FIFST, CChem) spent almost 20 years with Unilever Research, studying the use of speciality fats in confectionery applications. Much of this research was directed at the use of cocoa butter equivalents and covered processing and application in chocolate and coatings. He then joined Loders Croklaan as Senior Applications and Technical Service Manager, responsible both for customer development work and for research and development into fat bloom inhibitors and moisture migration barriers which resulted in the products Prestine™ and Cotebar™, both winning the titles of "Most Innovative Food Ingredient". In 2003 he formed his own consultancy, The Fat Consultant, and he now trains clients on the chemistry, processing and, particularly, the application of fats in a wide variety of food products. He writes and lectures widely and has authored and edited books on the application of fats in confectionery, the science and technology of filled and enrobed confectionery, speciality oils and fats and the reduction of saturated fats in food, as well as numerous articles in food trade journals.

Jonathan Thomas has worked in the market research and information field for more than 20 years, having graduated from Aston University in Birmingham with a second-class honours degree in Managerial and Administrative Studies. He currently works as a Principal Market Analyst for Leatherhead Food Research, a post he has occupied since 2001. In this role, he is responsible for researching and authoring market reports on a number of subjects, covering food additives and functional foods, as well as confectionery. He edits the company's monthly *Confectionery Industry Update*, and has spoken at a number of major industry events. Jonathan lives on Barry Island in South Wales.

John H. Walker has over 30 years' experience in the confectionery industry. He began work as a drawing office apprentice with the packaging machinery manufacturer, Rose Forgrove Ltd, in 1967 and moved to Rowntree Mackintosh in 1977. Between 1977 and 1986 he worked on the design of a variety of special purpose machines used in the company's confectionery and grocery businesses. In 1986 he moved to the Castleford factory to take the position of project engineer where he was involved in the manufacture of After Eight™ thin mints. Since 1992 he worked in the Nestlé Product Technology Centre in York, where he was the Head of the Engineering Department. He is the inventor on several patents for the design of equipment now being used for the manufacture of confectionery throughout the world. John is now retired.

Martin A. Wells graduated from Oxford University with a degree in Chemistry and was employed in Unilever Research, Port Sunlight, for 17 years, working for most of that time on the science and development of novel fabric conditioners. The experience gained there on colloid science and rheology in particular was extended when he moved to Cadbury Ltd, Bournville, in 1985. During his time there he developed novel chocolate making processes and in his later years managed research projects with a number of United Kingdom universities as head of the United Kingdom laboratories and scientific services. He has given lectures on chocolate rheology and the science of chocolate crumb manufacture in the United Kingdom and for ZDS Solingen in Germany. Following his retirement in 2004 he has acted as a chocolate consultant for companies in the United Kingdom, the United States and Indonesia.

Erich J. Windhab (Prof Dr-Ing) graduated in chemical engineering at the University of Karlsruhe and then obtained a PhD at the Institute of Mechanical Engineering and Applied Mechanics (TU Karlsruhe). Following research at Berkeley University in California and TU Munich, he joined The German Institute of Food Engineering DIL (Quakenbrück/Osnabrück), becoming the Vice Director in 1985. During this period he built up his own engineering company (LTG Karlsruhe; process plant design/optimisation) and also lectured in fluid dynamics/rheology at the University of Munich. Since 1992 he has been Professor for Food Process Engineering at The Swiss Federal Institute of Technology (ETH), Zürich and Head of the Laboratory of Food Process Engineering. He has published about 200 reviewed papers and more than 60 patents and is a member of many committees, including: President of Swiss Rheology Group/Polymer Society, Chairman of Codex Alimentarius CCPC (WHO/FAO), Director of Swiss Competence Centre of Rheology (SRC), Member of European Academy of Sciences, Member of Steering Board of the Material Research Center, ETHZ (Switzerland) and Member of Expert Commission of Swiss Commission for Innovation and Technology (CTI, Bern). He received the 2003 European Food Technology Award, the 2004 Blaise Pascal Medal (European Academy of Sciences) and the 2005 International Nestlé Innovation Award.

Bettina Wolf graduated in chemical engineering at the University of Karlsruhe (Dipl-Ing) and then obtained a PhD at the Institute of Food Process Engineering at the Swiss Federal Institute of Technology (ETH) in Zurich. Following her graduation from Karlsruhe, Bettina joined Prof. Windhab's group at the German Institute of Food Technology (DIL) in Quakenbrück, where she was introduced to rheology as tool in the structure–rheology–processing triangle. Since then her research has focussed on multiphase systems, including chocolate. Whilst at DIL she was involved in the round-robin trials which resulted in the current set of guidelines for determining the viscosity of chocolate. In 1992 Bettina followed Prof. Windhab to ETH where she completed her PhD on shear induced droplet deformation behaviour in 1995. She remained there until 1997 when she joined Unilever Research and Development (Colworth House) in the United Kingdom, working on flow induced microstructures in biopolymer mixtures. She returned to research on chocolate in 2006 when she accepted an academic post at the Division of Food Sciences at the University of Nottingham. Dr Wolf has supervised several PhD students, published papers and given invited lectures in the field of chocolate rheology and oral processing of chocolate. She has also been on the Council of the British Society of Rheology.

Edward G. Wohlmuth was born and educated in Austria and moved to London in 1952 where he became a pastry chef (French/Austrian style) with training in England, Germany and Austria. In 1972, he moved to the Caxton London Chocolate Company where he was production manager and then the technical services application manager. He continued in this role with Stewart and Arnold Chocolate Company, High Wycombe; then Lesme and Barry Callebaut UK, making technical visits throughout Europe, North America (USA, Canada), Middle East and Asia Pacific (Japan, Australia, New Zealand, China, India, Pakistan, Bangladesh). After retiring he started Wohlmuth Chocolate Consultancy, based in London, with recent work taking him to many companies in the United Kingdom, Ireland, continental Europe, India and South Africa.

Richard Wood is Regulatory & Scientific Affairs Lead for Nestlé Confectionery, supporting innovation and renovation in the confectionery category worldwide, as well as representing Nestlé to the European Union institutions. An expert in food law and regulation, he has worked in food research (advising on food law in Europe, the Middle East and Africa), in retail (managing label compliance for a leading retailer and representing retailers to Government) and in manufacturing for the chilled dairy, ice cream and confectionery sectors. A former member of a number of Industry association committees (including the Biscuit, Cake, Chocolate and Confectionery Association of the United Kingdom and the International Confectionery Association), he is currently chair of the Regulatory and Scientific Committee of CAOBISCO – the Association of the Chocolate, Biscuit and Confectionery Industries of Europe. Richard studied food technology at the University of Reading in the United Kingdom.

Gottfried Ziegleder (Dr Dr-Ing habil), obtained his PhD in chemistry at the University of Munich (1977) and his PhD in food engineering from the TU Munich (1996). He has 35 years of experience in chocolate technology and has published about 150 scientific papers in this area. Since 1977 he was working with the Fraunhofer Institute of Process Engineering and Packaging (Fraunhofer IVV, Freising, Germany) between 1990 and 2009 as Head of the Food Technology Department. The main fields of his research and development activities are cocoa and chocolate flavour and flavour precursors, roasting and conching, tempering and crystallisation of chocolate, rheology, new forming techniques, milk chocolates and amorphous lactose, oil migration and bloom development, the shelf life of chocolates and special aspects of food packaging.

He developed several analytical methods for the evaluation of raw materials and for the rapid control of production processes. A central part of his work was his close cooperation with the industrial group “Chocolate Technology” of the Industrial Association of Food Technology and Packaging (IVLV), Munich, which is organising international pre-competitive research for food industries and machine producers. Between 1996 and 2015 he lectured in crystallisation at the TU Munich and in chocolate technology at the University of Applied Sciences (HSWT, Weihenstephan, Germany). Over 30 years, he was member of the organisation committee, moderator and invited lecturer at the international ZDS Chocolate Technology Conference, Cologne.

Gregory R. Ziegler obtained his BS in food science from the Pennsylvania State University (1980), an MS in food science from Clemson University (1982) and a PhD in food engineering from Cornell University (1988). He joined the faculty in the Department of Food Science at Penn State University in 1988 and currently holds the rank of professor. He has industrial experience in product and process research and development with H.J. Heinz. His current research focuses on the properties of polymeric and particulate foods, with an emphasis on chocolate and confectionery products. He has numerous publications related to confectionery and has presented his work at Schoko-Technik (Germany) and the PMCA Production Conference (USA).

Preface

It is now 27 years since the first edition of *Industrial Chocolate Manufacture and Use* was published and eight years since the fourth was written. It is therefore very gratifying to have been asked to revise it once again and I am very grateful to those authors who have once again updated their chapters. Only one of these in fact contributed to the first edition. My being retired makes producing the book more difficult, so this time I have been aided by two co-editors. Mark Fowler, an international expert on cocoa, has made sure that the importance of this prime ingredient has not been overlooked. Prof. Greg Ziegler, from Penn State University, has added more North American points of view.

As with every other industry, however, both people and technology change and this new edition has had nine of the chapters completely rewritten. In four other cases, the original author has retired and their chapters have been updated by someone still involved with that particular subject. The book has also increased in size and, with four new topics, now has a total of 30 chapters. We took the opportunity to arrange the chapters in a more logical order: raw materials and ingredients, processes and manufacturing, formulation and recipes, quality and safety and finally consumer and legal aspects.

Even though it is very important to the industry, sensory analysis has not until now had a chapter to itself. Likewise aspects of quality control are present in most chapters and a new one has been introduced to present an overview for the different confectionery processes, with particular emphasis on the United States market.

In many countries, the artisan confectionery sales are increasing. This involves different products, throughputs and marketing compared to conventional large scale production and so merits a chapter to itself. The fourth new addition is about compound coatings, which in many countries are a market in their own right, particularly in connection with ice cream manufacture.

It is hoped that the book will continue to provide an up to date scientific and technical approach to the principles of chocolate manufacture, from the growing of the cocoa beans to the packaging and marketing of the final product. As the processes become larger and more complex, the aim is to give the reader the principles behind them in a practical and readable form. As with any multi-author book there are some repetitions, and indeed some apparent contradictions are present. These have been deliberately left, as each author has written according to his or her own experience. They are also an indication that our knowledge remains incomplete and that there is still a lot for researchers into cocoa and its products to do. Mistakes still occur however and I would welcome readers informing me of them. Two letters in fact resulted in entries into subsequent editions. Some time ago I was told that I was incorrect in saying that Daniel Peter invented milk chocolate. This resulted in me going to the Nestlé archives in Switzerland and finding his original notebook, a page from which is reproduced in Chapter 1. Second, a competitor complained that the measurement of thermal conductivity was incorrect. The source of the original entry was traced and admitted that he had not measured it himself. In the end the measurements were made by Leatherhead Food International (UK) and have been included in the table of physical constants.

I would once again like to thank all the authors who have contributed to the book for the care they have taken and the time they have spent in producing their chapters.

Even revising an original chapter can take a considerable effort in confirming new information, updating references and so on. There cannot be many industries where people from competing companies and different continents come together to produce a book. The wide range of knowledge and experience of the different authors has greatly added to its usefulness to people within chocolate making and has resulted in the first four editions being present in factories in Asia, Africa and South America, as well as in those countries in which it was written.

It is sometimes said that the worldwide web will remove the necessity for books. I certainly hope that this is not the case and have not always found the web to be as reliable as you might expect. The website of one major international company once proudly announced that its chocolate was processed in a sea shell, which I very much doubt and suspect the author's misuse of a thesaurus on the word conche. An on-line encyclopaedia on the other hand informed me that most cocoa butter is made by hanging up sacks of nibs in a warm room, so that the fat runs out. I hope that readers will find this book to be much more reliable.

I would also like to thank my co-editors, without whose hard work this book would not exist, the publisher for giving us the opportunity and encouragement to produce this new edition and Dr Peter Ashby for his invaluable help in proof reading and producing the index.

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Cocoa Organization (ICCO), IOI Loders Croklaan, JND Technologies Limited, Lindt and Sprüngli AG, Lipp Mischtechnik GmbH, List AG, Mars, Inc., Micronizing UK Ltd, Mondelēz International, Inc. (Cadbury, Kraft), Nestlé S.A., Royal Duyvis Wiener B.V. (Lehmann, Thouet), S.A. Martin Lloveras, Sollich KG (Chocotech), Spectris plc (Malvern Instruments), SPX Corporation (APV), Unified Brands, Inc (Groen), Wilhelm Rasch GmbH, Wire Belt Company of America (J.W. Greer), Woody Associates, Inc.

CHAPTER 1

Traditional chocolate making

Stephen T. Beckett

1.1 History

As early as 1900 BC cocoa was being used as a beverage by the Mokaya people in Mexico (Powis *et al.*, 2007). Cacao trees were subsequently cultivated by the Aztecs of Mexico long before the arrival of the Europeans. The beans were prized both for their use as a currency and for the production of a spiced drink called "chocolatl". The Aztec Emperor Montezeuma is said to have drunk 50 jars or pitchers per day of this beverage, which was considered to have aphrodisiac properties, a belief still held as late as 1712, when *The Spectator* newspaper advised its readers to be careful how they meddled with "romances, chocolate, novels and the like inflamers …". The chocolate was prepared by roasting the cocoa beans in earthenware pots, before grinding them between stones. The mixture was added to cold water, often with other ingredients such as spice or honey, and whipped to a frothy consistency (Whymper, 1912).

The first cocoa beans were brought to Europe by Columbus as a curiosity, but were later exploited commercially by Don Cortez as a new drink (Minifie, 1980). The Spaniards preferred their drink sweetened, and in this form its popularity spread to Central and Northern Europe. In 1664 it was mentioned in England in Pepys' *Diary*, but was essentially still restricted to the wealthy. The introduction of milk into this chocolate drink was first recorded in the UK in 1727, by Nicholas Sanders (Cook, 1984), although his reasons for doing so are uncertain.

A mixture of the ground cocoa beans and sugar would not by itself produce the solid chocolate so familiar to the modern consumer. Instead it would give a very hard substance which would not be pleasant in the mouth. In order to enable it to melt easily, it is necessary to add extra fat. This can be obtained by pressing the cocoa beans and removing some of the fat content, known as cocoa butter. The ability to extract this fat was developed in 1828 by Van Houten of Holland, and it had a double advantage: the expressed fat was used to make the solid chocolate bars, while the remaining lower-fat cocoa powder could still be

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incorporated into a drink. This “drinking chocolate” was in fact usually preferred, as it was less rich than the original high-fat mixture.

Van Houten’s development is even more remarkable when one considers that his factory and presses were entirely operated by manpower. In 1847, however, in Bristol (UK) Fry used recently developed steam engines to power the first factory to produce tablets of plain chocolate.

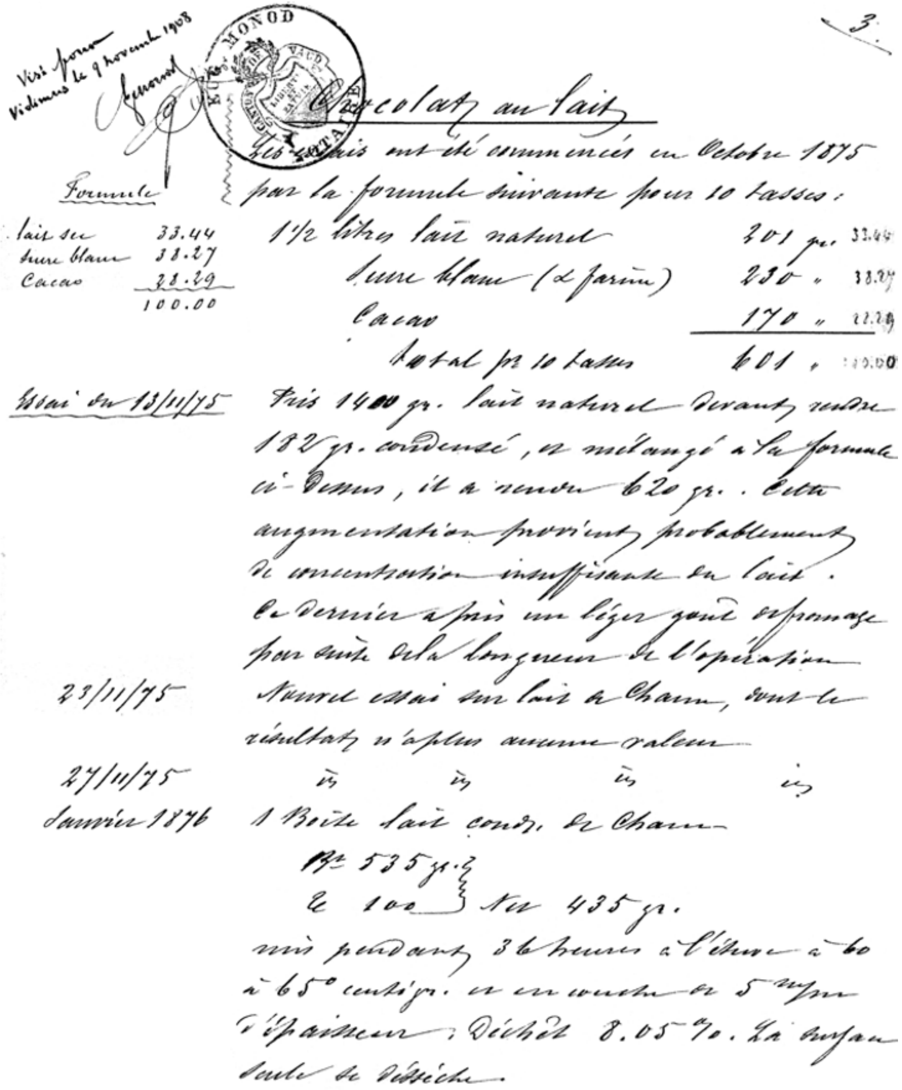
The solid form of milk chocolate is normally attributed to Daniel Peter of Vevey in Geneva (Switzerland) in 1875. In Switzerland, water-powered machines were able to operate for long periods at an economic rate. This enabled the extra water from the milk to be driven out of the chocolate without incurring a large extra cost. Chocolates with moisture contents of above about 2% are normally unacceptable as they have poor keeping qualities, as well as a poor texture. The page of the notebook where he wrote his original recipe is shown in Figure 1.1. In 1908 his invention of milk chocolate was disputed, so this notebook was taken to a lawyer, who placed his stamp at the top of the page.

Over the years many different flavours of both milk and plain (dark) chocolate have been developed. Sometimes there has been a definite policy to develop a “house” flavour within a company, for example in Cadbury’s Dairy Milk, or the Hershey Bar. At other times the flavour is adjusted to complement the centre of the sweet to be coated with chocolate. A very sweet centre such as a sugar fondant may be best complemented by a relatively bitter chocolate and vice versa. For milk chocolate, one of the biggest flavour differences is between the chocolates made from milk powder which are predominantly found in Continental Europe, and the “milk crumb” ones of the UK and parts of America. Milk crumb (see Chapter 6) is obtained by dehydrating condensed milk and cocoa mass. This was developed where milk production was very seasonal. As cocoa is a natural antioxidant, it was possible to improve the keeping properties of the dehydrated form of milk over extended periods without refrigeration. The drying process also produced a distinct cooked flavour, not normally present when the milk is dried separately.

Table 1.1 summarises some of the important dates connected with the history of cocoa and chocolate.

1.2 Outline of the process

Chocolate has two major distinguishing characteristics: its flavour and its texture. Although many different flavours of chocolate exist, all must be free from objectionable tastes and yet incorporate at least some of the pleasant ones, which the consumer will associate with the product. A primary feature of the texture is that it must be solid at a normal room temperature of 20–25 °C (70–75 °F) and yet melt rapidly in the mouth at 37 °C (98.5 °F), giving a liquid which appears smooth to the tongue. The processing of chocolate is related to obtaining these



3.

Visé pour vidimus le 9 novembre 1908

MONOD

Chocolat au lait

Les essais ont été commencés en Octobre 1875 par la formule suivante pour 10 tasses:

1½ litres lait naturel	201 gr.	33.44
Sucre blanc (& farine)	230 "	38.27
Cacao	170 "	28.29
Total pr 10 tasses	601 "	100.00

Formule

lait sec	33.44
Sucre blanc	38.27
Cacao	28.29
	100.00

Essai du 13/11/75 Pris 1400 gr. lait naturel devant rendre 182 gr. condensé, et mélangé à la formule ci-dessus, il a rendu 620 gr. Cette augmentation provient probablement de concentration insuffisante du lait. Ce dernier a pris un léger goût de fromage par suite de la longueur de l'opération.

23/11/75 Nouvel essai sur lait de Cham, dont le résultat n'a plus aucune valeur

27/11/75 id id id id

Janvier 1876 1 Boîte lait condr. de Cham
Bt 535 gr.
T 100 } Net 435 gr.
mis pendant 36 heures à l'étuve à 60 à 65° centigr. et en couche de 5 m/m d'épaisseur; Déchet 8.05 %. La surface seule se dessèche.

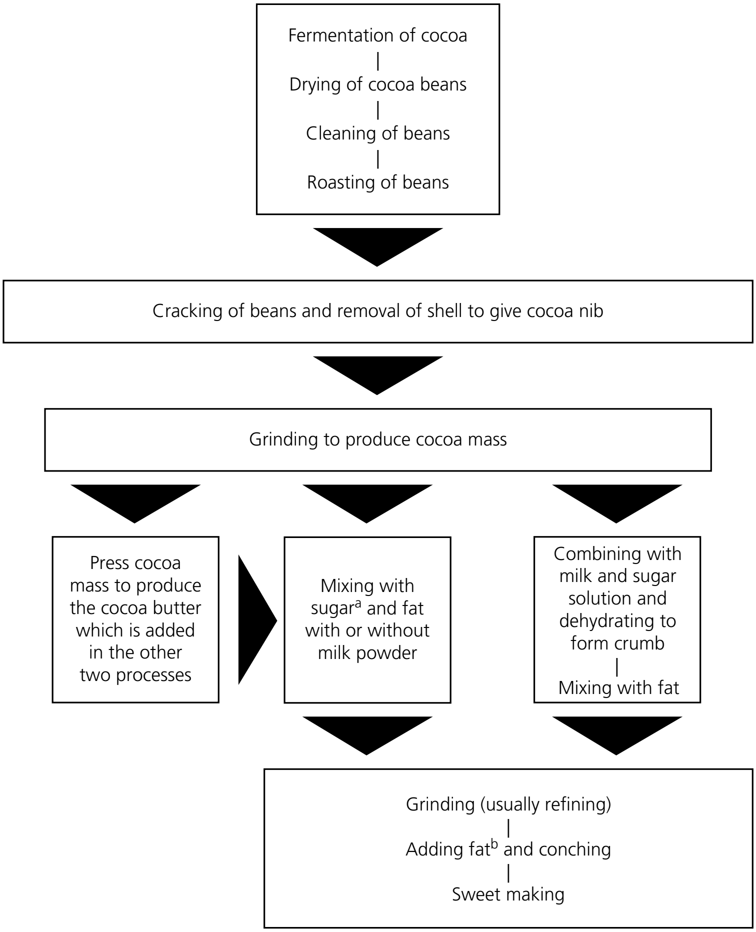
Figure 1.1 Page from Daniel Peter's notebook showing the original milk chocolate recipe. Source: Nestlé historical archives. Reproduced with permission of NESTEC S.A./Nestlé S.A.

two criteria and is therefore devoted either to developing the flavour of the product – using a raw bean would produce a very unpleasant taste – or treating it so that the liquid chocolate will flow properly and be free from large gritty material.

Although many different methods of chocolate-making exist, most traditional ones are based on the process outlined in Figure 1.2 and briefly described below. Further details are given in the relevant chapters of the book.

Table 1.1 Some important dates in the history of cocoa and chocolate.

Date	Event
1519	Cortez discovered that cocoa had been cultivated by the Aztecs more than 3000 years
1528	Cortez introduced a chocolate drink to Spain
1606	Chocolate drinking spread to Italy
1615	Chocolate drinking reached France
1657	First chocolate house established in London
1727	Nicholas Sanders invented a milk chocolate drink
1746	First cocoa planting in Bahia
1765	First chocolate company established in North America
1828	Van Houten patented the cocoa press
1847	Fry's factory established in Bristol to produce eating chocolate
1875	Daniel Peters manufactured milk chocolate
1988	World cocoa grindings exceeded two million tonnes



[a] Milled or granulated
[b] Cocoa butter and/or lecithin

Figure 1.2 Schematic diagram of traditional chocolate-making process.

1.2.1 Preparation of cocoa nib – flavour development

The cocoa tree produces pods containing a pulp and the raw beans. The outer pod is removed together with some of the pulp and the beans are fermented. This enables chemical compounds to develop inside the beans, which are the precursors of the flavour in the final chocolate. Failure to carry out this stage properly cannot be rectified by processing at a later date. This is also true of the subsequent stage, when the fermented beans are dried. Poor control here can give rise to moulds, which give a very unpleasant-flavoured product, even if the fermentation has been carried out correctly. Similarly where beans are accidentally contaminated with smoke from a faulty drier, the resulting cocoa will be unusable. In addition, correct transport conditions are required when the beans are moved from the country of growing to that of chocolate manufacture.

On arrival in the processing factory, it is necessary to clean the beans to remove metal and stones and other extraneous material that might contaminate the product. Further flavour development is subsequently obtained by roasting the beans. This also loosens the shell round the outside of the bean and enables them to break more easily. (Some chocolate manufacturers prefer to heat the surface of the beans, to facilitate shell removal and to carry out the full roasting of the cocoa bean centres, either as whole pieces or as a liquid following grinding. This is described more fully in Chapter 3.) The beans are then broken and the relatively lighter shell particles removed by a winnowing action. The presence of shell in the final chocolate is undesirable as it will impair the flavour, as well as causing excessive wear to the subsequent grinding machine. It should also be noted that the shell content of chocolate is legally restricted in some markets. In some countries the shell itself has found a use in horticulture.

1.2.2 Grinding – particle size reduction

Up to this stage the cocoa is in discrete pieces, several millimetres in diameter. Subsequent processing may take several forms, but all require the solid cocoa particles, sugar and any milk solids to be broken so that they are small enough not to be detected on the tongue. The actual size depends upon the type of chocolate and the market in which it is sold, but in general the vast majority of particles must be smaller than 40 microns (0.0015 inch). The unground ingredients used to make dark chocolate are shown in Figure 1.3.

The most common method of achieving this is by the use of roll refiners. In order to enable the chocolate ingredients to pass through the refiner, however, it is necessary to get them into a paste form. This may be done in a variety of ways. One of the most common is to grind the nib to form cocoa mass, which is a liquid at temperatures above the melting point of cocoa butter, 35 °C (95 °F). This usually involves hammer mills, disc mills, ball mills, three-roll refiners or a combination of the four. The sugar can then be added in a granulated or milled form and the two mixed with extra fat (and milk powder if milk chocolate is being manufactured). The mixing may include some grinding, and traditionally a melangeur

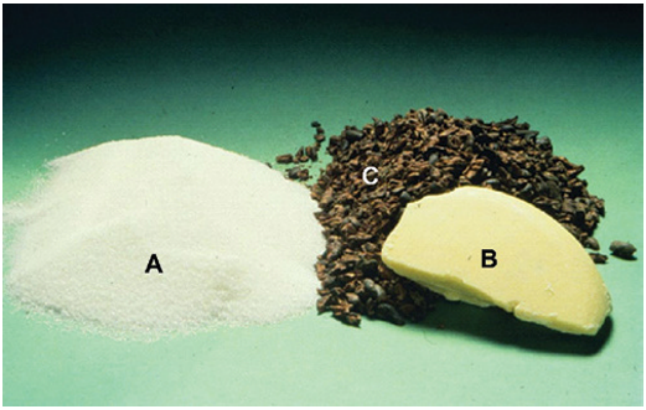


Figure 1.3 A picture of the unmilled ingredients used to make dark chocolate. A is sugar, B is cocoa butter and C is cocoa nibs.

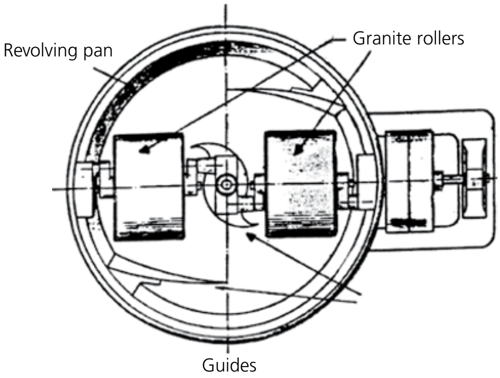


Figure 1.4 Diagram of melangeur pan.

pan was employed for the purpose. This machine has a rotating pan, often with a granite bed, on which two granite rollers rotate. Scrapers ensure mixing by directing the material under the rollers (Figure 1.4). The modern requirement for continuous higher throughput methods has often lead to the mixing and grinding being carried out separately. Probably the most widely used, is to mix the initial ingredients into a paste and then grind this on a two-roll refiner. This gives a sufficient amount of crushing and mixing to provide a particle size and consistency suitable for feeding to the five-roll refiner (see Chapter 9).

Where chocolate crumb is used, this dehydrated mixture of condensed milk and cocoa mass is normally preground to a maximum size of 2 mm (0.1 inch). This is then crushed and mixed with fat in order to provide a suitable paste for processing in a refiner.

The most widely used alternative method is to mill the solid ingredients (i.e. sugar, milk powder and/or crumb) separately and then mix with the liquid components (cocoa mass, cocoa and cow's butter and lecithin) in the conche.

This may result in different flavours from when all the ingredients are processed together. Niediek (1994) attributes this to the fact that, when sugar particle are broken, the surface becomes very reactive and is able to pick up any flavour components in the vicinity. These will be different if the cocoa is present, as in the combined milling, rather than if the ingredients are ground separately.

1.2.3 Conching – flavour and texture development

Although the fermentation, drying and roasting are able to develop the precursors of chocolate flavour, there are also many undesirable chemical compounds present. These give rise to acidic and astringent tastes in the mouth. The object of conching is to remove the undesirable flavours, while developing the pleasant ones. In addition, the previous grinding process will have created many new surfaces, particularly of sugar, which are not yet covered with fat. These uncoated surfaces prevent the chocolate flowing properly when the fat is in a liquid state. Because of this the chocolate cannot yet be used to make sweets and does not have the normal chocolate texture in the mouth. The conching process (Chapter 10), therefore, coats these new surfaces with fat and develops the flow properties, as well as modifying the flavour.

This is normally carried out by agitating the chocolate over an extended period in a large tank, known as a conche. The mixing continuously changes the chocolate surface and this, coupled with some heating and ventilation, enables the volatile components to escape and the flavour to be modified. Some manufacturers prefer to limit the conching time by restricting the conching process to primarily one of liquefying the chocolate. This is made possible by treating the cocoa mass at an earlier stage, in order to remove some of these less desirable volatile chemicals.

1.3 Concept of the book

Chocolate making was, for over 100 years, a traditional industry governed by craftsmen who developed individual methods of working, as well as “house” flavours for products. With increasing economic demands for higher throughputs and less labour, the industrial manufacture of chocolate has become more and more mechanized. There has also been an increased application of science and technology to control production plants and enable them to operate efficiently. In this situation the equipment manufacturers are introducing new machinery, whilst the literature abounds with new methods of manufacture and patents for “improved” techniques. Certain basic principles of chocolate making exist, however, and the aim of this book is to show what these are and how they can be related to the processes used in its manufacture. It has been intended to avoid making the book a catalogue of a selected number of machines and products. In order to try and achieve this and to give the book as wide a coverage as possible, authors have been chosen from a range of industries and research institutions in

Europe, North America and Australia. Chapters have deliberately been kept relatively short, and to a certain extent they follow the order of processing described in this chapter.

Certain topics have been divided into two, for example the chemical changes involved during conching have been presented separately from the physical and engineering aspects, as most authorities tend to concentrate predominantly on one or other of these aspects of conching. In addition to the technical side, plant hygiene, intellectual property and nutritional values have become increasingly important within the chocolate industry. Chapters have therefore been included to provide an overview of these subjects.

The manufacture of chocolate goods would not exist but for the consumer. What is seen on the market shelves is seldom the chocolate itself, but usually the container. For this reason the packaging, marketing and legal requirements for the product is of considerable importance and chapters on these three topics are included in the book.

Every author has contributed to the book as an individual. Each chapter, therefore, is the author's responsibility and may or may not be in agreement with the theories or principles adopted by the company by whom he or she is employed, or by the editors. As the chapters were written concurrently with little contact between the authors, several topics were duplicated. This has been minimised where possible, but retained where authors have given additional or even contradictory information. The latter is bound to occur owing to the present incomplete understanding of the processes involved. Minor differences in machinery or ingredients can produce major changes in the product. Each author, therefore, is merely reflecting his own experience within the wide range of combinations possible in chocolate making. The multinational authorship of the book highlighted the differences in terminology and units found throughout the industry. For example, the term "refinement" means flavour development in some countries and grinding in others. For this reason, and to aid people unfamiliar with the industry, a glossary of terms has been included at the end of book. The units given are those with which the author is most familiar, but frequently the most widely used alternative is also quoted. In addition, some of the more commonly used physical constants associated with chocolate making have been included in this edition.

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CHAPTER 2

Cocoa beans: from tree to factory

Mark S. Fowler and Fabien Coutel

2.1 Introduction

The earliest evidence of consumption of cocoa is from 1900 to 1750 BC by the Mokaya people, a pre-Olmec culture from what is nowadays the southern part of Mexico and Guatemala (Powis, 2007). Later, cocoa was first cultivated and domesticated by the Mayan and Aztec peoples. It was consumed in various forms: as fresh beans for its sweet pulp or as a cocoa drink after roasting. Beans were also used as a currency until the Spanish conquest (Wood and Lass, 1985). The Spaniards introduced cocoa to Europe where it was first consumed by royals, before becoming a popular beverage by the mid-seventeenth century.

Cocoa is the essential ingredient of chocolate, responsible for its unique flavour and melt in the mouth properties. A manufacturer needs a reliable and sustainable supply of good quality cocoa at reasonable prices. This chapter examines how the growing of cocoa and the fermentation, drying, storage and transport can influence cocoa quality prior to arrival at the factory. Also discussed are the operations of the cocoa markets, quality assessment, sustainability and environmental issues. Finally, the chapter explores the use of different types or origins of cocoa for chocolate.

Cocoa has a long supply chain extending from smallholders, often in remote, less well-developed tropical regions of the world, to factories and consumers mainly in developed industrial countries. Like any crop, it is susceptible to changes in the weather, to pests and diseases and to social and economic factors. The supply of cocoa has continued to grow throughout the past 30 years despite low prices on the world markets since 1990. At the same time, demand for cocoa has kept pace with supply and is growing steadily. About two-thirds of the cocoa crop ends up in chocolate products, with the remainder going mainly into beverage, ice cream and bakery products.

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2.2 Growing cocoa

2.2.1 Where cocoa is grown

Cocoa is grown commercially between 20° north and 20° south of the equator, in areas with a suitable environment for cocoa (e.g. rainfall, soil type). There are three main growing areas: West Africa, South East Asia and South America (see Figure 2.1). The seven largest cocoa producing countries are Côte d″Ivoire (Ivory Coast), Ghana, Indonesia, Nigeria, Cameroon, Brazil and Ecuador, and between them they account for 90% of the world crop (see Figure 2.2). Côte d″Ivoire alone produces over one-third of the world crop. The fortunes of the various countries have changed significantly in recent decades. A main feature of the current pattern of production is the huge concentration (nearly two-thirds) within West Africa. This concentration means that future supply is vulnerable to a number of factors, such as the spread of pests and diseases, weather or climatic variations, political or social change. In many areas, cocoa faces competition from other crops such as palm oil, coffee, rubber, citrus and cloves. About 90% of the world's cocoa is grown by smallholders (Smith, 1994), usually on farms with mixed cropping systems.

2.2.2 Varieties of cocoa: Criollo, Forastero, Trinitario and Nacional

The cocoa or cacao tree (*Theobroma cacao*, L.) originates from South and Central America. It is a small tree up to 15 m height (50 ft; Mossu, 1992) that grows naturally in the lower storey of the evergreen rain forest in the Amazon basin. The leaves are evergreen and are up to about 300 mm (12 in) long. The flowers and hence the fruits (cocoa pods) grow from the trunk and thicker branches (see Figure 2.3).

In the sixteenth and seventeenth centuries cocoa was introduced into Asia. These early movements of cocoa were of a type called Criollo. Criollo cocoa beans have a white or light brown appearance when cut open and a mild, nutty cocoa flavour. The trees are susceptible to diseases and produce low yields. This type is now very rare and only found in old plantations in Venezuela, Central America, Mexico, Madagascar, Sri Lanka and Samoa.

The main type of cocoa is called Forastero and, in the eighteenth century, a Forastero variety of cocoa from the Lower Amazon was introduced into Bahia in Brazil. This variety of cocoa is called Amelonado, named after the melon shape of the pods. From Bahia, cocoa cultivation spread to West Africa in the nineteenth century (Wood, 1991). The Amelonado variety was well suited to West African smallholder cultivation. More recent planting material is based on cocoa collected from the Upper Amazon rainforest and these maybe crossed (hybridised) with the Amelonado or between themselves (called Upper Amazon hybrids). Fresh Forastero cocoa beans have a purple appearance when cut open and generally develop strong cocoa notes after fermentation and roasting.

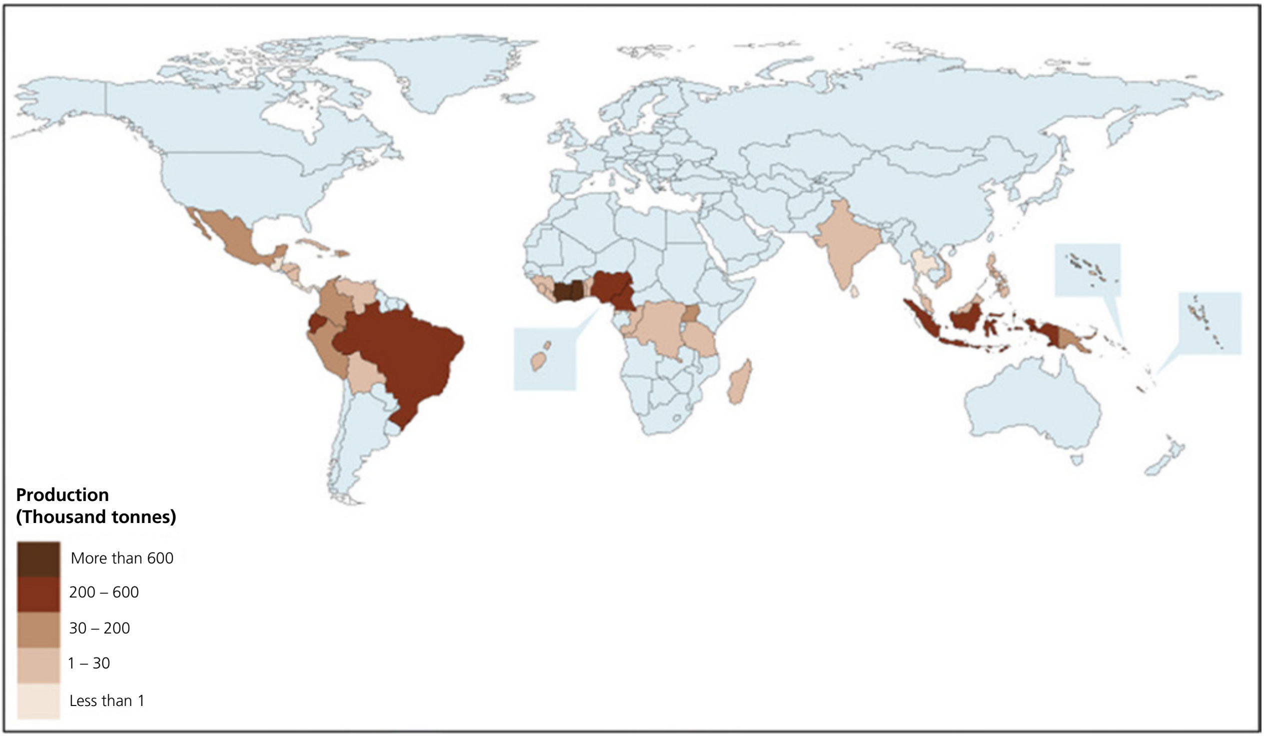

Figure 2.1 Cocoa growing countries.

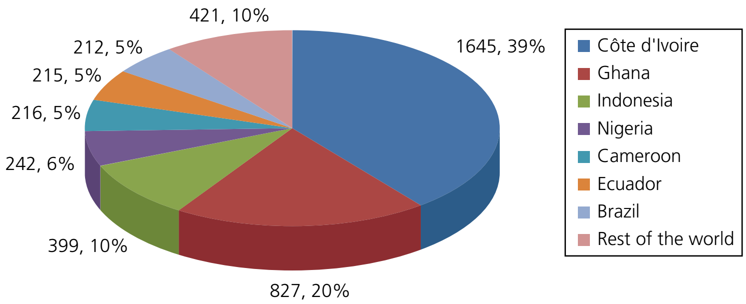

Figure 2.2 Average production of cocoa beans by country (×1000 t and as % of world crop). Data (3 year average, 2011–2015). Adapted from ICCO.

Figure 2.3 Pods grow from the trunk and branches. Reproduced with permission of Fabien Coutel.

The third type of cocoa is called Trinitario. The origin of the Trinitario varieties is usually stated as the result of hybridisation between Forastero and Criollo trees. Consequently, some Trinitario varieties produce cocoas with special flavours such as dried fruits or molasses.

The fourth type is Nacional which is only grown in Ecuador and probably originates from the Amazonian area of Ecuador. Nacional cocoa produces beans with "Arriba" flavour renowned for its floral note (see Section 2.7.8). Nacional is highly susceptible to witches' broom and frosty pod rot *(Monilia)* diseases. Pure Nacional varieties have almost disappeared and the varieties with Arriba flavour in Ecuador are hybrids between Nacional and Trinitario.

Genetic studies propose 10 different groups of cocoa (Motamayor *et al.*, 2008), which include Criollo, Amelonado and Nacional groups; but Trinitario is no longer recognised as a separate group. This genetic knowledge will help with breeding programmes to develop new improved varieties. The objectives of breeding programmes are to produce cocoa varieties that are early bearing, resistant to pests and diseases, drought tolerant, higher yielding and sometimes with better flavour or other quality attributes.

The type of planting material originally introduced into an area has strongly influenced the type of cocoa grown today and hence the quality and uses of the cocoa beans (see Section 2.7).

2.2.3 Climatic and environmental requirements

Cocoa grows in areas of high rainfall, preferably 1500–2500 mm (60–100 in), evenly distributed throughout the year. If there is a dry season of more than three months, some form of irrigation may be necessary. Cocoa prefers high humidity, typically 70–80% during the day and up to 100% at night. Strong dry winds can defoliate the tree and very strong winds or hurricanes can cause physical damage.

The temperature requirements are a mean monthly minimum of 18 °C (64 °F) and a mean monthly maximum of 32 °C (90 °F). The absolute minimum is about 10 °C (50 °F).

Quite a wide range of soil is suitable for cocoa, but it grows best where the soil is deep, with good drainage and a pH of neutral to slightly acidic. Soil influences one important quality aspect of cocoa: the cadmium content. Some soils, especially volcanic ones, can contain high levels of cadmium. If this is in an “available” form, it may be taken up by the plant and become present in the beans (see Section 2.6.4).

2.2.4 Propagation of the planting material

The most common method of propagation is by seed. Good planting material may be obtained from selected parents by using hand pollination. These hybrids may also have hybrid vigour, giving faster growth and earlier bearing. Growing cocoa from seed produces a tree with a straight, single, vertical trunk with branches at around 2 m (6.5 ft) above the ground. This point, where the trunk separates into branches, is called the jorquette. Trees grown from seed tend to be more drought tolerant and require less pruning. However, they often exhibit a great deal of variability in their agronomic characteristics which is not desirable. This can be overcome by using one of the techniques of vegetative propagation such as cuttings, grafting or micropropagation systems. Grafting can be onto young seedlings, small plants or even mature trees. Grafted trees tend to have a more open branching structure, usually without the straight single trunk associated with seedling (hybrid) cocoa.

Micropropagation systems are under development: one system involves culturing some cells and growing them into plantlets, which are then transferred to a nursery. Micropropagation enables more rapid propagation of new varieties developed by plant breeders. The trees have a similar structure to seedling-grown trees. All the vegetative methods produce trees that are identical genetically to the original tree and therefore perform similarly in respect to yield, disease resistance and quality parameters. The plants are initially grown in a nursery and, after 3–6 months, they will be ready to plant out in the field.

2.2.5 Establishment and development of the plants in the field

The selection of a suitable site is very important and needs to take into account local factors, such as weather conditions (especially rainfall, temperature and wind), soil fertility and drainage. Prior to planting, the site is prepared, which normally involves some land clearance and establishing some form of shade (unless it is already present). Shade protects the trees from excessive sunlight and wind. Initially shade requirements are high for young cocoa trees and it is common practice to plant a temporary shade of bananas or plantains (see Figure 2.4).

Cocoa trees are usually planted to achieve a final density of 600–1200 trees/ha (1500–3000 trees/acre). In the first year, the cocoa is often inter-cropped with food crops. Trees come into bearing when they are 2–3 years old and full yield is achieved after 6–7 years. They have an economic life of 25–30 years or more, provided they are consistently looked after with good agricultural practices. Maintenance of the tree is mainly pruning (to keep to a canopy height of 3–5 m (10.0–16.5 ft)) and weed control. Depending on the soils, natural or approved chemical fertiliser may be applied to correct deficiencies and so increase yields, although this is unusual on small holdings.

Figure 2.4 Young cocoa grown under banana shade. Reproduced with permission of Remo Nägeli.

Growth occurs in "flushes" when each shoot on the tree grows a few fresh new leaves at the same time. The timing and extent of this "flush" growth depends on recent rainfall and the state of the tree.

2.2.6 Major pests and diseases

It is generally agreed that about 30% of the crop is lost to pests and diseases. The main pests and diseases are black pod rot, witches' broom disease, frosty pod rot (*Monilia*), vascular streak dieback disease, swollen shoot virus, capsids, mirids and the cocoa pod borer moth. Squirrels, rats and monkeys can consume significant quantities of ripe pods. Further information is given in Table 2.1.

Table 2.1 Major pests and diseases of cocoa.

Name of pest or disease	Distribution[a]	Symptoms or damage	Control[b]
Black pod rot (*Phytothphora*)	World wide	Fungal attack of mainly the pods causing them to go brown and rot	Sanitation (removal of infected material). Regular frequent harvesting of pods. Application of fungicides
Witches' broom (*Moniliophthora perniciosa*)	South America, Caribbean	Fungal attack causing extra growths or "brooms" to develop from leaf buds. Can also affect flowers and pods	Pruning and sanitation (removal of infected material). Application of fungicides
Frosty pod rot, Monilia (*Moniliophthora roreri*)	Peru, Ecuador, Colombia, Central America including Mexico	Fungal attack of the pods causing them to go brown and rot	Sanitation (removal of infected pods)
Vascular-streak dieback	South-east Asia, Pacific Islands	A fungal attack causing leaf fall and dying back of stems	Regular pruning of infected material. Cover nurseries to prevent infection of young plants
Cocoa swollen shoot virus	West Africa	Swelling or thickening of the shoots. The infected tree frequently dies	Eradication of infected trees
Capsids or mirids	World wide	These insects feed by sucking the sap causing direct damage to plant tissue. In addition, this allows entry by fungi that cause stems and pods to rot.	Application of insecticides
Cocoa pod borer	South-east Asia and Papua New Guinea	The caterpillar of this moth bores into the pods and affects the development of the beans	Regular frequent harvesting of pods, pruning, application of insecticides

[a] Distribution: this lists the growing areas where the pest or disease causes significant losses, it may occur elsewhere.

[b] Control methods are not effective or economic in many cases.

Control of these pests and diseases is achieved by a combination of using appropriate planting material, good agricultural practices, sanitation and careful application of approved pesticides. In some areas, cocoa growing is not viable because of the effects of pests and diseases. Due to the cost of pesticides, many small-holders do not use them.

2.2.7 Flowering and pod development

The flowers develop from flower cushions located on the trunk and branches. They are small, about 15 mm (0.6 in) in diameter (see Figure 2.5). Flowering depends on the environment, the condition of the tree and the variety. Some trees flower almost continuously whereas others have well-defined periods (generally twice a year). The flowers are pollinated by small insects such as midges. Out of thousands of flowers, only small proportions are pollinated and develop into pods.

The small pods are known as cherelles. If there are too many for the tree to support through to maturity, the excess stop growing and die (this is known as cherelle wilt). After 5–6 months the pods are fully developed. They measure between 100 and 350 mm long (4–14 in) and have a wet weight from 200 g

Figure 2.5 Cocoa flowers. Reproduced with permission of Ivan Kashinsky.

(7 oz) to more than 1 kg (2.2 lb; Mossu, 1992). There is considerable variation in the shape, surface texture and colour of the pods, depending on the variety.

2.2.8 Harvesting, pod opening and yields

When they ripen, most pods change colour, usually from green or red to yellow or orange (see Figure 2.6). They are cut by hand from the trunks and branches. This is easily done with a machete (cutlass) for the pods that are low on the trunk, but for the pods on the upper branches it is necessary to use a special knife fixed on a long pole. The crop does not all ripen at the same time, so harvesting has to be carried out over a period of several months. Pods are normally harvested every 2–4 weeks (see Figure 2.7). Frequent harvesting reduces the losses to cocoa pod borer moth, rats, squirrels and monkeys. It allows the farmers to sanitise the plantation by removing diseased pods and thus reducing the impact of diseases. In West Africa, the main harvest period is from the beginning of October until December. Cocoa purchased from farmers during this period and up to March is termed “main crop”. This is generally of higher quality than the secondary or intermediate harvest known as the “mid” or “light” crop.

The pods are opened to release the beans, either by cutting with a machete or cracking with a simple wooden club. Pods opened with a machete can result

Figure 2.6 Ripe cocoa pods ready for harvesting. Reproduced with permission of Remo Nägeli.

Figure 2.7 Harvested ripe cocoa pods. Reproduced with permission of Ivan Kashinsky.

Figure 2.8 Fresh cocoa beans before separation and fermentation. Reproduced with permission of Ivan Kashinsky.

in injuries to workers and damaged beans if the machete cut is too deep. It is therefore recommended to use a wooden tool. There are some 30–45 beans or seeds inside the pod attached to a central core or placenta (see Figure 2.8). The beans are oval or a plump almond shape, and covered in a sweet, white mucilaginous pulp. The beans are separated by hand and the placenta is removed.

Each bean consists of two cotyledons (the nibs) and a small germ or embryo, all enclosed in a skin or testa (the shell). The cotyledons serve both as the storage organs containing the food for the development of the seedling and as the first two leaves of the plant when the seed germinates. Much of the food stored in the cotyledons consists of cocoa butter that amounts to about half the weight of the dry seed. The moisture content of the fresh beans is in the region of 65%.

The yields obtained from cocoa trees vary considerably. Yield depends on the variety of cocoa grown, the growing system (tree density, shade levels, fertilisation, irrigation), the age of the trees, the farming practices (e.g. maintenance), the local environment (weather, soil fertility), and losses caused by pests and diseases. Yields of dry beans can vary from 150 kg/ha (132 lb/acre) in a poorly maintained small-holding, through typical West African levels of 250–450 kg/ha (220–400 lb/acre) to that achieved on some plantations, which can be over 2500 kg/ha (2200 lb/acre).

2.2.9 Environmental and sustainability aspects of cocoa cultivation

In the past, expansion of cocoa production has been from new small-holdings in former areas of primary forest that previously have been logged for timber. This is not a sustainable model for the future. There is potential to increase productivity by better control of pests and diseases, improved higher yielding and disease-resistant planting material and better farming practices.

If an area of primary forest has been logged, then cocoa growing becomes one of the most environmentally beneficial uses of the land. Essentially this is because it is a stable tree crop, often grown as part of a mixed cropping system including shade trees. Cocoa farms support a relatively high biodiversity and have been shown to be an important habitat in Central America for migrating birds. Tropical tree crop systems such as cocoa cultivation are important in providing vegetative continuity with residual areas of primary or secondary tropical forests.

Sustainability programmes (e.g. CocoaAction, coordinated by the World Cocoa Foundation) aim at improving the social conditions and livelihood of cocoa farmers, and ensure the long term supply of cocoa to the industry. Most of these programmes involve governments, industry and non-governmental organisations (NGOs) working together in a coordinated manner. To provide consumers with confidence and trust, there are several certification schemes such as Rainforest Alliance™, Fairtrade International® and UTZ Certified™ who carry out inspections and allow their logos to be used on product packs (see Section 2.5).

2.2.10 Labour practices on farms

Cocoa production in West Africa is mainly on small family farms using labour-intensive methods (see Section 2.5). Following media allegations about forced child labour in Côte d'Ivoire there have been some independent studies into labour practices (e.g. Gockowski, 2006; Fair Labour Association, 2012). The vast majority of labour on cocoa farms in West Africa is adult and is in one of three basic categories: full time seasonal, casual labour for a specific task or a share-cropping tenancy (where the share-cropper provides labour on part of the farm in exchange for a share in the crop proceeds). Family children are involved, especially during busy harvest periods and can be exposed to hazardous tasks such as using a machete or carrying heavy loads. Gockowski (2006) also reported that less than 1% of cocoa farms employed adolescent workers, that child slavery was uncommon and cocoa producing households sent more of their children to school when compared to non-cocoa producing households. There is no doubt that cocoa growing provides significant benefits to many rural economies. Most sustainability programmes include elements on the elimination of child labour.

2.3 Fermentation and drying

The immediate post-harvest processes of fermentation and drying are normally carried out on the farm. They are essential steps during which the cocoa flavour precursors are formed. Drying produces a stable, non-perishable commodity making the crop ideal for small-holders in remote locations.

2.3.1 Fermentation

Fermentation is carried out in a variety of ways and some of the common practices will be described below. The fermentation stage is usually very simple (see Figure 2.9). The fresh beans are heaped in a pile or in a wooden box, typically for five days. Natural yeasts and bacteria multiply in the pulp, causing the breakdown of the sugars and mucilage. Much of the pulp then drains away as a liquid. Different types of cocoa require different amounts of fermentation.

If the fresh beans are dried without any fermentation, the nib will be a slaty, grey colour rather than the brown or purple-brown colour of fermented dried cocoa beans. Chocolate made entirely from slaty, unfermented beans tastes very bitter and astringent with little cocoa flavour. It also has a greyish brown appearance. Beans from some origins are only partially or insufficiently fermented. Generally these beans can be used to manufacture cocoa butter, but if they are used to make other cocoa products, they require blending with fully fermented cocoas.

In West Africa, where smallholders grow nearly all the cocoa, fermentation is usually done in heaps enclosed by banana leaves. Heaps can be used to ferment any quantity from about 25–2500 kg (55–5500 lb) of fresh cocoa beans, although intermediate amounts are desirable. Some farmers will mix the beans on the second or third day. The fermentation usually lasts about five days and the end point is determined by experience. This traditional low input system produces well fermented cocoas.

In plantations, fermentation is normally carried out in large wooden boxes that typically hold 1–2 t of wet/fresh beans. Well-designed boxes have provision for the liquefied pulp (the sweatings), to drain away and for entry of air. This is usually achieved by means of small holes in the bottom of the box or preferably through a floor of slats each separated by about 6 mm (0.25 in). Boxes usually measure 1.0–1.5 m (3.3–5.0 ft) across and may be up to 1 m (3.3 ft) deep. However,

Figure 2.9 Cocoa fermentation. Reproduced with permission of Ivan Kashinsky.

shallow bean depths (250–500 mm; 0.8–1.5 ft) are preferred, especially at the start of fermentation, to promote good aeration which is needed for fermentation. To increase aeration and ensure uniformity of fermentation, the beans are usually transferred from one box to another each day. The length of fermentation is the same as for smallholders, but some plantations ferment for longer periods such as 6 or 7 days.

2.3.2 Microbiological aspects of fermentation

Micro-organisms are responsible for the breakdown of the pulp that surrounds the beans. Their activities result in the death of the bean embryo and they create the environment that enables the formation of cocoa flavour precursors (see Chapter 8).

The pulp is an excellent medium for the growth of micro-organisms since it contains water and 10–15% sugars. When the beans are removed from the pods, the pulp is inoculated naturally with a variety of micro-organisms from the environment. The fermentation process can be considered in three stages:

Stage 1 – Anaerobic yeasts. In the first 24–36 h, yeasts convert sugar into alcohol under conditions of low oxygen and a pH of below 4 (i.e. quite acidic). Bean death usually occurs on the second day and is caused by acetic acid and alcohol (the rise in temperature is relatively unimportant).

Stage 2 – Lactic acid bacteria. These are present from the start of the fermentation, but only become dominant between 48–96 h. Lactic acid bacteria convert sugars and some organic acids into lactic acid.

Stage 3 – Acetic acid bacteria. These are also present throughout the fermentation, but become more significant towards the end when aeration increases. They are responsible for converting alcohol into acetic acid. This is a strongly exothermic reaction that is mainly responsible for the rise in temperature. This can reach 50 °C (122 °F) or higher in some fermentations.

In practice, there is considerable overlap between the stages. The types of micro-organisms vary between fermentations and between regions.

2.3.3 Development of cocoa flavour precursors

Development of the cocoa flavour precursors occurs in the cotyledons during fermentation and drying (see also Chapter 8). There are two important types of cells within the cotyledons: the storage cells containing fat and proteins and the pigment cells containing polyphenolic compounds and methylxanthines (theobromine and caffeine). During fermentation, there is firstly the initiation of germination of the seed. This causes the uptake of water by the protein vacuoles within the storage cells. Later, after bean death has occurred, the cell walls and membranes break down, allowing the various compounds and enzymes to react together. These reactions produce the cocoa flavour precursors (see Figure 2.10). The reaction rates are determined by the temperature and the level of acidity.

There are several groups of compounds responsible for flavour. The methylxanthines impart bitterness. During fermentation, their levels fall by around 30%, probably due to diffusion from the cotyledons. There are a range of polyphenolic compounds (called flavonoids) which are responsible for the colour, for

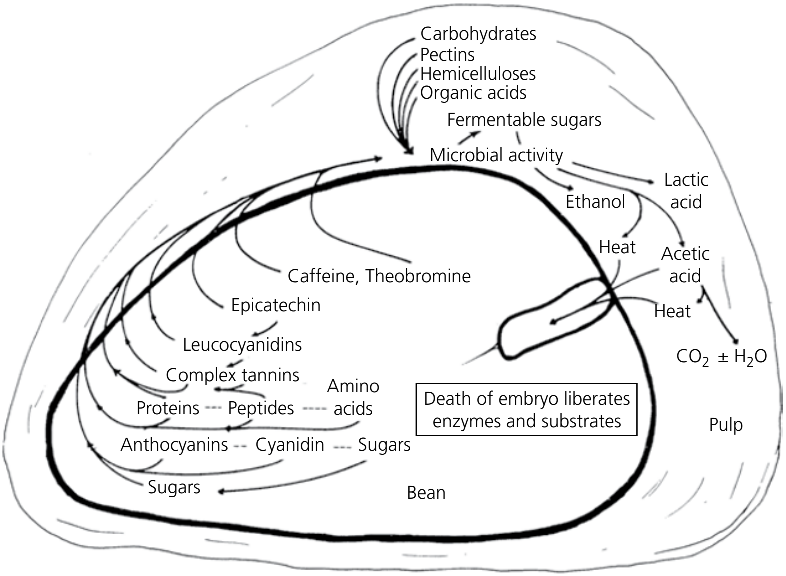

Figure 2.10 Chemical changes within a cocoa bean during fermentation (after Lopez, 1986). Reproduced with permission of The Pennsylvania State University.

imparting astringency in the mouth and for the antioxidant health benefits associated with cocoa (see Chapter 22). Their levels drop significantly during fermentation and drying. The anthocyanins (a type of flavonoid) are rapidly hydrolysed to cyanidins and sugars by glycosidase enzymes. This accounts for the bleaching or lightening of the colour of the purple cotyledons in Forastero cocoa. Other enzymes (polyphenol oxidases) convert another type of flavonoid, the flavanols [comprised mainly of (–)-epicatechin] to quinones. Proteins and peptides complex with the polyphenolic compounds to give the brown or brown/purple coloration that is typical in fermented dried cocoa beans. Another important group of compounds is the Maillard reaction precursors. These are formed from the storage proteins and sucrose. Sucrose is converted by invertase into reducing sugars. The storage proteins are hydrolysed by peptidase enzymes into oligopeptides and amino acids. These cocoa flavour precursors are involved in Maillard reactions during roasting of the cocoa beans to form cocoa flavour compounds.

2.3.4 Drying

When fermentation is finished, the beans are removed from the heap or box for drying. In areas where the weather is comparatively dry at harvest time, the beans are dried in the sun by being spread out during the day in layers about 100 mm (4 in) thick on mats, trays or a terrace on the ground. Sun drying is environmentally friendly, low cost and produces beans of good quality. In West Africa, the beans are spread on any suitable horizontal surface (e.g. a concrete terrace or polythene sheet – see Figure 2.11). The preferred method, which is common in Ghana, is to spread the beans on mats made of split bamboo, which are placed on wooden frames at waist height (see Figure 2.12). The mats can be rolled up to protect the beans when it rains. They have several advantages: the air circulation is improved, it is easier to sort the beans and remove defectives and foreign materials, and there is less risk of contamination compared with beans being dried at ground level. In all cases the beans are raked over at intervals, heaped up and protected at night or when it rains. In Central and South America, a common method is to spread the beans on a floor or platform, with a roof on wheels that can be pushed back over the floor at night or when it rains. Alternatively, the platforms themselves are arranged on wheels so that several can be run under a single roof, one above the other to save space. It usually takes about a week of sunny weather to dry down to the 7 or 8% moisture content needed to prevent mould growth during storage.

Where the weather is less dry and sunny at harvest time, improved methods of solar drying or artificial drying are adopted. Various low technology solar drying systems have been developed. These generally involve the use of a transparent plastic tent or roof over the cocoa and sometimes additional solar energy collectors. In on-farm trials, some of these systems have proved to be very efficient and effective.

Figure 2.11 Cocoa beans drying on tarpaulin on the ground. Reproduced with permission of Fabien Coutel.

Figure 2.12 Drying cocoa beans on table. Reproduced with permission of Ivan Kashinsky.

In some circumstances, artificial drying is the only practical solution. In the simplest form, a wood fire is lit in a chamber below the drying platform and the combustion gases are conducted away in a flue that continues beneath the drying platform before becoming a vertical chimney. Convection and radiation from the fire chamber and flue heat the drying platform. A better system is to use a heat exchanger to create warm dry air that is then passed through the bed of cocoa beans. A well maintained installation will in all cases help reduce the risk of combustion products coming into contact with the drying cocoa, and hence the risk of contaminating the cocoa with smoky notes.

Artificial drying can affect the cocoa quality in two ways. First, the beans may be dried too quickly resulting in very acidic beans. This is caused by the shell becoming hard and locking or trapping the volatile organic acids inside the bean. Acidity can be reduced by using lower air temperatures or an overnight rest period to allow the moisture in the beans to equilibrate. The reduction in drying capacity or throughput is compensated by lower fuel costs resulting from more efficient drying. The second, more serious, problem with artificial drying is that smoke may find its way onto the beans. This problem is most commonly linked to the use of wood fires, and is liable to produce an unpleasant harsh, smoke or tar taste, which cannot be removed from the resulting chocolate by processing. While it is comparatively easy to design a drier in which the smoke is kept away from the cocoa, it is not so easy to maintain one in this state. After a drier has been operated for a number of years, the risk of smoke reaching the cocoa beans too often becomes a reality. This is one of the reasons why cocoas from some areas are in less demand and consequently command lower prices.

Cocoa beans can sometimes be seen drying on the roadsides in areas where farmers do not have sufficient drying facilities. This is to be avoided as it contributes to the contamination of the cocoa beans with chemical residues from the tarmac and vehicle exhausts.

Care is also required not to over-dry the beans. Beans dried to below 6% moisture become quite brittle and are easily damaged in subsequent handling, generating losses. During or after drying the beans, it is necessary to carry out a hand sorting or mechanical sieving/winnowing process to remove debris, clumped and broken beans. The beans are then bagged and may be stored for a short period prior to sale (see Figure 2.13).

2.4 The cocoa supply chain

Cocoa beans have to get from the many small farmers, who are often in remote areas of developing countries, to the cocoa processing factories that may be located in temperate countries. They can pass through a number of intermediaries, each of whom plays an important role. This section describes the steps in the chain, the impact on quality and how the price is determined. The next section

Figure 2.13 Dried cocoa is weighed and bagged. Reproduced with permission of Ivan Kashinsky.

looks at the cocoa value chain and the issue of farmer poverty. The price of cocoa is given in US$ or GB£ per tonne and is determined in the open markets of New York and London. The evolution of prices, production and consumption (demand or "grindings") is given in Figure 2.14. From this graph one can note that production and consumption are closely balanced and have grown steadily at the same rate. However, prices are more volatile and are influenced by production, consumption, stock levels, political, social and economic factors and speculator activity.

2.4.1 Internal market

Typically, the farmer sells his cocoa to a co-operative or a trader (first level collector). The important points for a farmer are the price received (% of world market price) and the level of service provided (location and frequency of collection, availability of "free" credit, technical support etc.). The cocoa will then be taken and sold to a larger trader or collector in the nearest main town. From here the cocoa will go to the port and into the warehouse of an exporter or shipper.

2.4.2 International cocoa markets

Producers (cocoa growers, co-operatives, government marketing boards and exporters) need to be able to sell their cocoa at the best price. The size and timing of the crop vary from season to season and this can affect the price. The users of cocoa (processors, grinders, and chocolate manufacturers) require a regular

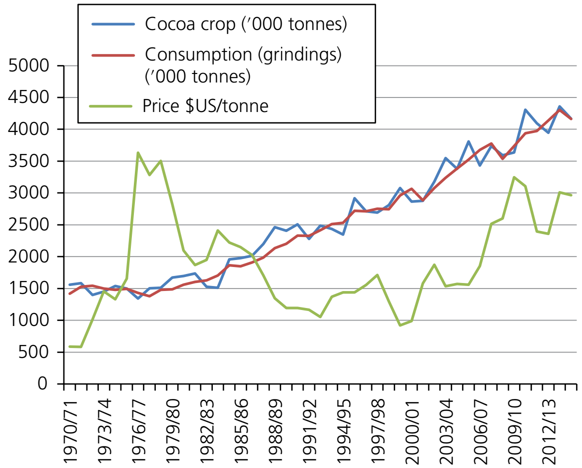

Figure 2.14 World cocoa production, consumption (grindings) and prices. Adapted from ICCO.

supply of cocoa of assured quality at competitive prices into their factories. The international cocoa markets function as intermediaries between producers and users, allowing prices to be established and providing opportunities for risks to be reduced for all parties.

There are two types of cocoa market: first, the "Actuals", cash or physical market and, second, the "Futures and Options" or "Terminal" market.

2.4.2.1 "Actuals" market

Anyone who buys and sells physical cocoa beans can be considered as participating in the "Actuals" market (Dand, 1999). In practice, virtually all business is conducted using standardised contracts for sales that were developed by the cocoa trade associations. These are the Cocoa Merchants' Association of America (CMAA) and the Federation of Cocoa Commerce (FCC) in Europe.

Both associations provide arbitration procedures to resolve disputes. The basis of the contract prices in the "Actuals" market is determined by the price in the "Futures" or "Terminal" market. In the "Actuals" market, it is possible to buy or sell forward, for example to buy cocoa beans in June for delivery in September.

2.4.2.2 "Futures and Options" or "Terminal" markets

These markets can be used to minimise the risk of adverse price movements for the producer, trader and the user. They are primarily "paper" markets in that no physical cocoa usually changes hand. There are two active futures markets run by the InterContinental Exchange (ICE): one in New York and the other in London. The markets have standard contracts, which are restricted to certain weights (multiples of 10 t, the lot size), certain grades or types of cocoa. They also state where and when the cocoa could be delivered. Each trade passes through a central body or clearing house in the market. Trading is conducted openly so the volume, price and delivery dates are public.

Although futures trading rarely results in the delivery of physical cocoa, this possibility means that the price has to remain close to the actual value of the cocoa. This value is determined by supply and demand and the activity of speculators. The role of speculators is often considered to be negative as their aim is to maximise their profit. However, they risk their capital and contribute by bringing liquidity to the market (e.g. by enabling a producer to sell when users are not buying).

2.4.2.3 Example of a simple hedge using the "Actuals" and "Futures" markets

Traders, manufacturers and producers can use a simple hedge to reduce the risks associated with adverse changes in price (adapted from Dand, 1999). For example, it is normal for manufacturers to purchase physical cocoa for delivery in the months ahead. This is to guarantee that the factory will have a supply of cocoa. If we are in May and want to purchase 1000 t of cocoa for delivery in December, we deal with a trader (in the Actuals or physical market) and agree a price of, say, US$ 2000/t. If we believe that prices may rise above this level in the next few months, we could do nothing and come December we would take delivery of 1000 t of cocoa at what would then be a favourable price. If, however we thought prices might fall, perhaps due to an exceptionally large crop, we would turn to the Futures and Options market. In this market we would sell 100 lots of 10 t for delivery in December. The price changes in each market are then likely to offset each other (Table 2.2). This can be seen in the simple example below where the cocoa price declines by US$ 100 between May and December.

In this example the manufacturer has made a profit in the Futures market of US$ 100 000 when he purchased 100 lots to square his position (i.e. to avoid having to deliver the lots of cocoa he sold in May). Whilst this profit is real, had he waited until December to buy his physical cocoa, he would have saved US$ 100 000 over the price he paid back in May. This is given as an assumed loss in the example above. So, the manufacturer has effectively guaranteed the delivery of cocoa in December into his factory but at the same time has cushioned himself (or hedged) against a fall in prices through the Futures market. Hedges can be used by traders, manufacturers and producers to "lock" a price and hence reduce

Table 2.2 Example of a simple hedge to reduce risk.

Month	Actuals or physical market	Futures or Terminal market
May	Buy 1000 t of cocoa at US$ 2000/t	Sell 100 lots at US$ 1950/t for delivery in December
December	Could have purchased 1000 t at US$ 1900/t	Buy 100 lots @US$ 1850/t to square position
	Assumed loss US$ 100 000	Profit US$ 100 000

the risks associated with price fluctuations. In addition to hedging there are several other trading techniques.

2.4.3 Shipment of cocoa

Cocoa is traditionally stored and transported in jute (or occasionally sisal) sacks containing 60–65 kg (132–143 lb) of dry beans. Jute sacks have a number of positive features: they are strong, stackable (do not slip over each other), breathable (allow moisture to pass through) and are made from natural biodegradable fibres. Sacks can be stacked directly into the hold of a ship (break bulk). This method has the disadvantage of requiring significant handling at the ports, which is both costly and time-consuming. Alternatively, sacks can be placed within ventilated shipping containers (12.5 t to a maximum of 18 t of beans per container).

Cocoa beans can also be transported in bulk. Loose cocoa beans can be placed directly into shipping containers (17.5–25.0 t of beans) or directly into the hold of a ship, similar to grain shipment (mega bulk). Up to several thousand tonnes can be transported in one hold. Bulk shipment methods are gaining in popularity, and it is estimated that about 70% of cocoa beans shipped to northern European ports now use one of these bulk methods.

2.4.4 Moisture movement during shipment

Cocoa beans can release water vapour during a voyage. There can be a 1% loss in weight (shrinkage) due to this release of moisture. The West African crop is mainly shipped during the winter months in the Northern Hemisphere. It may be loaded at a temperature of about 30 °C (86 °F). After a few days into the voyage, the temperature both of the air and the sea will start to fall and, within a few more days, on reaching the North Atlantic it may be down close to freezing point. These are the conditions under which moisture will condense onto the cold metal of the ship and drip onto the cocoa. Hence good ventilation is essential, along with the use of absorbent lining materials to prevent condensation from damaging the beans.

Although the cocoa beans are dry, a hold containing 1000 t of cocoa at 7% moisture amounts to 70 000 l (15 000 gal) of water. If the moisture content of the cocoa reduces by only one-quarter percent to 6.75%, this releases 2500 l (560 gal) as water vapour which is available for condensation. This quantity of water, in the absence of good ventilation, is more than sufficient to cause wet patches on the cocoa beans, leading to mould growth.

As well as taking precautions during shipment, it is important to unload the cocoa promptly on arrival. Bags with damp patches can be segregated and dried prior to a decision being made as to their fate. In the case of bulk cocoa, on discharge any damp beans near the edges will be thoroughly mixed back into the bulk during the handling, and the moisture will re-equilibrate quite quickly within the lot, usually before there is time for mould to develop.

2.4.5 Storage of cocoa

Once they have been dried, cocoa beans are quite stable and will not deteriorate for several years, provided they are kept under good conditions. In order to prevent the growth of mould during storage, moisture in cocoa beans must not exceed 8%. High moisture levels can result from inadequate drying, moisture pick-up in humid atmospheres and leaking or damp stores.

Bagged cocoa should be stored off the floor (e.g. on wooden pallets) and away from the walls in dry ventilated warehouses. Individual lots of cocoa should be clearly segregated and labelled. Cocoa beans are susceptible to tainting by uptake of certain odorous substances from some other commodities (e.g. spices) and chemicals (e.g. fuels, paints, agrochemicals and cleaning substances). Therefore, they should not be stored in the same warehouse as these materials. Warehouses should also be free from vermin and infestation (see Section 2.4.6).

In the tropics, when it is very humid (e.g. at night or during rainstorms), ventilation can be temporarily stopped and then restored when the humidity drops again (e.g. during the day or in drier weather). Storing cocoa under polythene sheets is not recommended other than for very short periods of time.

The jute sacks allow water vapour to pass through, so that the cocoa beans gradually come into equilibrium with the humidity in which they are stored. The graph in Figure 2.15 shows the equilibrium moisture content for cocoa beans stored at different levels of relative humidity. To maintain beans below 8% moisture, the relative humidity must be less than about 75% for fermented cocoa beans. Less well fermented beans, such as those from the Dominican Republic and Sulawesi, are more hygroscopic and would need to be stored at a relative humidity below about 65% to maintain moisture of 8% or less. Partially fermented beans are more likely to stick together or form clumps and develop mould during storage and transport.

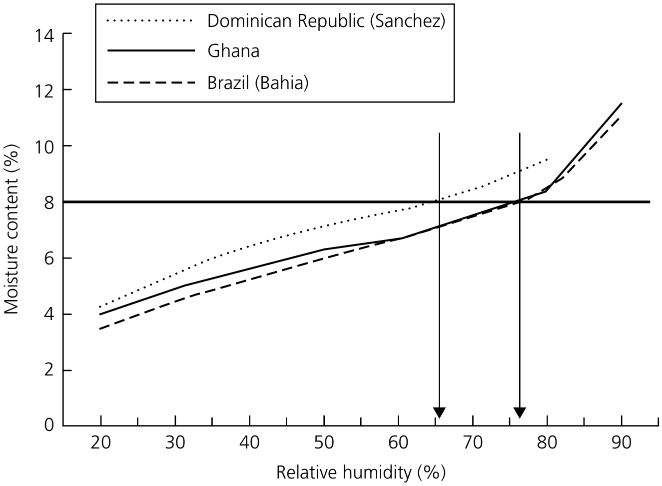

Figure 2.15 Equilibrium moisture content of cocoa beans (after Oyeniran, 1979).

Cocoa can be stored in bulk in large heaps confined by walls to form bays, each bay containing 1000 or more tonnes of beans. A more expensive way of bulk storage is in silos. Storage bays and silos can have forced ventilation systems. This enables control of the temperature and humidity of the beans. It is also possible to apply modified atmosphere – usually air that has a low level of oxygen and a high level of carbon dioxide. This will control any pests within the cocoa (see Section 2.4.6).

2.4.6 Infestation of cocoa

Various insect pests can feed on cocoa beans and many lots of cocoa will have some low level of infestation. However, significant infestations are nowadays quite rare.

Cocoa is vulnerable to a very small moth, the Tropical Warehouse moth (*Ephestia cautella*). The larva (caterpillar) enters a bean, usually where the shell is damaged, and feeds on the nib leaving a residue of silk and droppings. Various beetles and their larvae also feed on cocoa beans. Insect damage will be visible in the "cut test" (see Section 2.6.3).

Some insects only rarely enter the beans, feeding mostly on the residue of pulp adherent to the outside. Their presence can result in a consignment being described as severely infested, even though the cut test on a sample of beans does not reveal any insect damage.

Precautions must be taken to prevent infestation developing during storage and shipment. This should include routine monitoring for the major pest species. Control measures need to be applied as required to the structure of the store or ship. Only pesticides approved for use in food stores should be used.

Cocoa beans can be fumigated with phosphine under gas-proof sheeting. When carried out properly, fumigation is very effective and the cocoa should not need fumigating again. Unfortunately, very few fumigations are carried out effectively and frequently some stages of the insects (e.g. the eggs) survive the treatment. In some countries, there is evidence that some pests are becoming resistant to phosphine. Various alternative solutions are available. Some methods rely on the use of very low temperatures (below freezing) or warm temperatures (around 50 °C; 122 °F) to kill the insects. Another method is to use modified atmosphere, usually oxygen depleted with high levels of carbon dioxide. These methods have the advantage that there are no chemical residues. In any case, insects will be killed and fragments of insects will be removed during the bean cleaning and roasting steps.

2.5 The cocoa value chain: long-term perspectives and challenges

The long-term viability of the chocolate industry depends on a sustainable cocoa supply chain. One of the most fundamental prerequisites for a supply chain to be sustainable is that its participants make a reasonable living from it. The vast majority of cocoa is grown by small-holders for whom it is a cash crop with no food or cultural value. Most farmers live below the poverty line and this does not encourage investment and development of the farms. In many cases, other crops are more profitable or require less labour. Although crop diversification is good, as it provides more stable incomes, there is an issue relating to the small size of many farms which means efficiencies and overall income will remain low. Another crucial element is the poor level of maintenance of the cocoa plantations, including lack of control of pests and diseases. In many areas, a further threat to the cocoa supply chain is that the farmers are ageing and the younger generations tend to migrate to the cities.

Therefore, the challenge is to transform cocoa farming into a more profitable business. This would help to make cocoa more competitive versus other crops. Ultimately, bringing cocoa farmers out of chronic poverty would help to retain or attract young farmers.

Consumers are becoming more aware and conscious of where and how their food is grown and processed. In response to this and other concerns, governments and the industry have implemented sustainability programmes in collaboration with NGOs and certification programmes such as Rainforest Alliance™, Fairtrade International® and UTZ Certified™ (see Figure 2.16). The main objectives of these certification programmes are detailed in Table 2.3.

Figure 2.16 Example of a chocolate manufacturer's sustainability programme. Reproduced with permission of Mark Fowler.

Table 2.3 Objectives of the main cocoa certification schemes (Heise, 2010).

	Rainforest Alliance	**Fairtrade International**	**UTZ certified**
Goal of the initiative	To promote efficient agriculture, biodiversity conservation and sustainable community development by creating social and environmental standards. To foster best management practices across agricultural value chains by encouraging farmers to comply with standards and by motivating consumers to support sustainability.	To improve the position of the poor and disadvantaged producers in the developing world, by setting fair-trade standards and by creating a framework that enables trade to take place at conditions favourable to these producers.	To create an open and transparent marketplace for agricultural products. To achieve sustainable agricultural supply chains where farmers are professionals implementing good practices, which lead to better businesses, where the food industry takes responsibility by demanding and rewarding sustainably grown products, and where consumers buy products which meet their standard for social and environmental responsibility.
Inspection and Certification	Third party certification. Three-year farm certification audit cycle with annual surveillance audits. Certification of the whole farm. Farmers are charged annual certification fee based on the size of the farm.	Third party certification done by FLO-CERT. Control of the entire supply chain. Three-year certification cycle with annual surveillance audits in producer countries. Costs for producer organization: initial application fee and certification costs according to their size, kind of organization and inspection days needed.	Third party certification done by independent, approved certification companies. Annual certification inspections of producers against the code of conduct. Group certification. Annual chain of custody certification.

Even though the main focus of the different programmes vary, most of the schemes supported by the industry aim at developing a sustainable cocoa supply chain through a common approach structured around three pillars:

1. Increasing the productivity: by improving planting material (yield, disease resistance), teaching and implementing good agricultural practices (GAPs), improving the access to fertilisers and the use of irrigation where required.
2. Improving the living standards of cocoa producing communities: by focusing on education, women's empowerment, the elimination of child labour, access to clean water, hygiene and health services.

3 Optimising the supply chain: by making it more transparent and shorter, so that farmers receive a higher part of the cocoa price, and to ensure the required traceability of cocoa beans.

The quantity of cocoa produced under these schemes has seen enormous growth in recent years. In the season 2012/2013 an estimated 1 438 000 t was produced (Fountain and Hütz-Adams 2015). From the statistics it appears that less than half of this cocoa is actually sold as certified cocoa. However, consumption is seeing similar growth, with several companies committing to using 100% sustainable cocoa by 2020 or thereabouts.

The World Cocoa Foundation (WCF), several chocolate manufacturers and the governments of Côte d"Ivoire and Ghana have started to join forces under a common initiative (CocoaAction) in order to build on the strengths and the experience developed through the various individual programmes. This will allow harmonising the companies and private-public partnerships and developing a coordinated strategy.

The challenge for the future is to measure and demonstrate the impact of these programmes for the communities in a harmonised and comprehensible way. Another challenge is also to achieve a sustainable development across the whole of the cocoa supply chain without encouraging over-production of cocoa, by managing production versus demand and thus the price of cocoa beans. This has traditionally been a role of the International Cocoa Organisation (ICCO).

2.6 Quality assessment of cocoa

2.6.1 Composition of cocoa beans

Cocoa beans are essentially comprised of the cotyledons which are protected by the shell. Broken fragments of cotyledon are called nib. The shell is usually considered to be a waste material and is either used as a fuel or composted and sold as garden mulch. However, it can be treated, ground to a powder and sold as cocoa fibre products. These materials can be used as a substitute for cocoa powder or incorporated into chocolate (depending on local regulations).

The nib is the most valuable part of the bean. Roasted ground nib (cocoa mass or cocoa liquor) is used directly in chocolate manufacturing. Alternatively it can be pressed to extract the fat, cocoa butter, an essential ingredient in chocolate (see Chapters 3 and 7). The residue from the pressing stage, the press cake, is then ground into cocoa powder which is used mainly in beverages, baking, ice cream and desserts. Table 2.4 shows the composition of cocoa beans, nib and shell.

2.6.2 Cocoa beans: quality aspects and contracts

Good quality beans are a prerequisite for the production of a good quality chocolate. The quality aspects of cocoa beans can be divided into three areas:

1 *Food Safety.* These are absolute standards. Some of these limits are covered by the national food legislation in the country where the factory is located or

Table 2.4 Composition of cocoa beans.

	Whole dried cocoa beans (as traded)	
	%	Typical range (%)
Water/moisture	7.5	5–8
Shell (dry basis)	12.5	10–16
Nib (dry basis)	80	78–82

	Unfermented cocoa beans (dry, fat free)	Fermented cocoa beans (dry, fat free)
	mg/g	mg/g
Total polyphenols	150–200	40–140
Procyanidins	61	23
Epicatechin	–	3–16

	Nib		Shell	
	Mean (%)	Range (%)	Mean (%)	Range (%)
Water/moisture[a]	3.7	2–5	7	4–11
Fat (cocoa butter and shell fat)	53.5	48–57	2.8	2–6
Protein	12.7	11–16	14.7	13–20
Starch	6.7	6–9	8.1	6.5–9.0
Fibre (crude)	2.5	2.1–3.2	16.6	13–19
Ash	2.9	2.6–4.2	8.2	6.5–20.7
Theobromine	1.30	0.8–1.4	0.87	0.2–1.3
Caffeine	0.22	0.1–0.7	0.13	0.04–0.3

[a] Will vary according to storage conditions and the degree of drying or roasting.

Note: values depend on type of beans and method of analysis.

Polyphenol compositions after Wollgast and Anklam (2000) and Nestlé data.

Nib and shell compositions after Minifie (1989) and Kirk and Sawyer (1991).

where the products are to be sold. Any cocoa failing to meet food safety standards must not enter the human food chain. The fermentation and drying process results in high microbial levels on raw cocoa beans and the occasional presence of *Salmonella* bacteria. This hazard is controlled at the roasting stage and/or by debacterisation prior to or after roasting (see Chapter 25). The presence of *Salmonella* is not a reason to reject a consignment of raw cocoa beans.

2 *Economic factors*. These relate to yield of useful material and are key determinants of the price a manufacturer is prepared to pay relative to other cocoas.

3 *Qualitative aspects.* This includes desirable flavours and absence of off-flavours and some physical properties such as cocoa butter hardness. Qualitative factors determine whether a type of cocoa will be included in blends or recipes for chocolate.

In addition to these three areas, consumers are increasingly concerned about environmental and ethical aspects and some want environment friendly, organic or Fairtrade certification and labelling. This requires total traceability of the cocoa through the supply chain and compliance with the necessary standards (see Section 2.5).

The quality requirements from a manufacturer's view are summarised in Table 2.5. However, most cocoa is purchased using standard trade contracts, which may not include all the aspects considered important by the manufacturer. In Europe, the Federation of Cocoa Commerce (FCC) sets contract standards for cocoa bean quality. In the United States, the Food and Drugs Administration (FDA) and The Cocoa Merchants' Association of America (CMAA) set the standards (see Table 2.6). The cocoa trade associations have arbitration schemes to cover the situation when the lots of cocoa tendered fail to meet the contract terms and this may result in the supplier having to pay an allowance or replace the disputed beans. The producing countries usually have their own internal standards that are often mandatory (ITC, 2001).

2.6.3 Cocoa beans: sampling and the "cut test"

Proper sampling is an essential first step to making an assessment of quality. Cocoa beans in sacks are sampled using a trier or sampling stick, which is inserted between the fibres of the bag. Typically between 20% and one-third of the sacks will be sampled according to one of several prescribed procedures. Alternative arrangements are made for cocoa shipped in bulk. The samples maybe combined and bulked or mixed and then reduced in size ("quartered").

First, beans are classified by weight (usually the number of beans in 100 g (3.5 oz).

Second, the level of unsatisfactory beans (also termed faulty or defective beans) is determined by the "cut test" (see Figure 2.17). This test identifies beans that are visibly mouldy, slaty (i.e. unfermented), infested, germinated, or flat (i.e. containing no nib or cotyledon). The cut test normally uses the same beans that have been weighed and counted. Many methods specify that 300 beans will be cut lengthwise to expose the cotyledon. This is somewhat tedious and the number of beans is frequently reduced, which also lowers markedly the statistical validity of the results. Alternatively, a guillotine device is available (Magra cutter), which will cut 50 beans at a time.

Mould is especially undesirable. Indeed, even as few as 3% mouldy beans can give unpleasant musty or mouldy flavours to chocolate. Some moulds under certain conditions also produce harmful fungal toxins collectively called mycotoxins (see Section 2.6.4). Mouldy beans can have high levels of free fatty acids (FFA) which affect the quality of the cocoa butter (see Section 2.6.5).

Table 2.5 Typical cocoa bean quality requirements for chocolate manufacturers.

Criteria		Specification or limits[a]	Reason/comment
Food safety			
Mouldy beans		<4–5% depending on contract (see Table 2.6)	Off-flavours, potential for mycotoxins, high levels of free fatty acids
Mycotoxins	Aflatoxin	Within limits (<20 ppb in USA in foods)	Carcinogen
	Ochratoxin A	<2 or <1 ppb proposed	Some uncertainty regarding limits. Probable carcinogen
Infested or insect damaged		<3–5% depending on contract	Wholesomeness
Pesticides		Absent or below maximum residue limits/import tolerances/ action levels	
Hydrocarbons	Mineral hydrocarbons	Within limits	Source is from mineral batching oils in jute sacks
	Polycyclic aromatic hydrocarbons	Within limits Proposed 2 ppb for benzo-a-pyrene in EU	Source is from combustion products, e.g. during drying of cocoa
Heavy metals	Lead	Within limits. US FDA guidance for lead is <0.1 ppm in chocolate usually consumed by children	Source is environmental contamination
	Cadmium	New proposal: 0.2–2.0 mg/kg in chocolate (CODEX and EU). No limits for cocoa beans	Source is from the soil
Economic or yield aspects			
Moisture		<7 or 8%	Prevents mould growth, reduces yield of edible material
Bean size and bean size distribution		Typically 100 beans/100 g or 110 beans/100 g. Percentage of beans retained on certain sized sieves	Operation of processing plant. Yield of edible material. Uniformity of whole bean roasting
Shell		Typically 12–16%	Yield of cocoa nibs
Fat (cocoa butter)		Typically 50–57% in dry nib	Economic (amount of added cocoa butter needed to make chocolate)
Foreign materials		Absent or <1.5% (FCC)	Purity, yield of edible material
Infested beans		<4–5% depending on contract (see Table 2.6)	Yield of edible material, purity, wholesomeness (see above)

(Continued)

Table 2.5 (Continued)

Criteria	Specification or limits[a]	Reason/comment
Qualitative aspects (flavour and eating quality of chocolate)		
Unfermented (slaty) beans	For example: <5% (FCC good fermented), <10% (FDA/CMAA Ghana main crop).	Excess slaty beans give an astringent taste and greyish colour to the chocolate. They also contain more antioxidants (polyphenols).
Cocoa flavour and desirable ancillary flavours	Various, often not specified	Flavour
Off-flavours (e.g. smoky, hammy)	Absent	Flavour
Cocoa butter hardness	Various	Eating quality (snap and melting properties) of chocolate. Heat resistance of chocolate.
Free fatty acids in cocoa butter	<1.75% in cocoa butter (EU maximum)	Eating quality (snap and melting properties) of chocolate. Shelf life of chocolate.

[a] Frequently limits are specified for finished products not cocoa beans. Where they are specified for cocoa beans, they often apply to the whole bean (i.e., including the shell).

Table 2.6 Comparison of cocoa bean contract standards (adapted from ITC, 2001).

	Description (example of growth/grade)	Bean count	Cocoa bean faults			Foreign material (%)
			Mould (%)	Slate (%)	Infested (%)	
FCC[a] (Europe)	Good fermented, main crop	100/100 g	5[b]	5	–[b]	<1.5[c]
FDA/CMAA[d] (USA)	Ghana (main crop)	1000/kg	4[f]	10	4[f]	NS[g]

[a] FCC specifies the beans shall be uniform in size, homogenous and fit for the production of foodstuffs. The beans must be virtually free from contamination, which includes smoky, hammy or other off-flavour, taste or smell.

[b] Max 5% defectives (= mouldy + infested).

[c] <1.5% waste passing through 5 mm sieve. Additionally flat beans, bean clusters, broken beans and foreign material must not be excessive.

[d] CMAA specifies that hammy or smoky cocoas are not deliverable.

[f] Maximum amount of mould + infestation is 6% (US FDA defect action levels).

[g] NS = Not specified.

Figure 2.17 Cut test on dried cocoa beans. Reproduced with permission of Remo Nägeli.

Slaty beans are beans in which more than 50% of the cotyledon is grey or slaty in colour. These beans have not undergone fermentation and they have a low level of cocoa flavour with high levels of astringency. The cut test is often used to assess the degree of fermentation by counting the fully brown, brown/purple and purple coloured beans. This is very subjective and is unreliable except when a single assessor is checking beans from a single source. The results do not correlate directly with the quality of the chocolate made from the beans.

Insect-damaged beans are those where the bean has been penetrated by an insect, which feeds on the cotyledon. These should not be present. Any number will involve loss of material and a risk of contamination with fragments of the insects. Germinated beans are those where the seed has started to grow before being killed during the fermentation or drying process and the shell has been pierced by the growth of the first root. In the dry germinated bean, the root usually drops out, leaving a hole, which makes the bean more easily attacked by insects and moulds. Flat beans are those which have begun to form, but have not developed or filled out. There is no useful cotyledon in them so they simply add to the shell content, which is waste.

For the chocolate manufacturer, the yield of nib from a lot of cocoa is economically very important, as is the amount of cocoa butter within the nib. Higher levels of cocoa butter mean that lower amounts will need to be added later on in the manufacturing process. Nib yields are determined in the laboratory, normally by shelling a number of beans by hand. Results are usually expressed on a dry basis (i.e. at 0% moisture). It is important to note that laboratory measurements do not take account of bean cleaning losses and ease of winnowing. Therefore actual yields should be assessed on the production plant (see Chapter 3).

2.6.4 Contaminants and residues

Modern methods of analysis can detect minute or trace levels of undesirable materials in foodstuffs (see Chapter 25). This has given rise both to some legitimate concerns and some "food scares" which were not based on sound rationale.

Heavy metals, such as lead and cadmium, are found at very low levels in many foodstuffs including cocoa products. The source is mainly environmental including soil type, fertilisers, pesticides or vehicle emissions. The levels found depend on the origins of the cocoa materials and the recipe and process. There is a concern that some products could provide a significant proportion of the tolerable daily intake. Therefore, limits on cadmium are proposed, ranging from 0.2 to 2.0 mg/kg, depending on the level of cocoa solids in the product (dark chocolate with >50% cocoa solids will have the high limit). These limits will be applied in the European Union from 1 January 2019.

Mineral hydrocarbons have been used in the past in manufacturing jute sacks. Very small quantities of mineral oil were transferred to the cocoa beans and then into cocoa products. As a result of a joint initiative covering several foodstuffs, the sack manufacturers carried out some developments and have switched to using a food grade vegetable oil.

Polycyclic aromatic hydrocarbons (PAH), such as benzo-a-pyrene [B(a)P] result from combustion products and are generally present at low levels in the environment. In cocoa, the main risk is from artificial drying or sun drying in polluted areas such as roadsides. Hydrocarbons are fat soluble and will be found at higher concentrations in cocoa butter.

Mycotoxins [such as ochratoxin A (OTA) or aflatoxin] are produced by some types of moulds under certain conditions. However, there is no correlation between the level of visible mould revealed in the cut test and the amount of mycotoxins present. Generally, aflatoxin is not a concern in cocoa. OTA is present in cereals and most agricultural commodities. In cocoa, it is frequently present at extremely low levels, and cocoa products are not a significant source of OTA in the diet. OTA appears to develop in damaged pods prior to the fermentation stage.

The manufacturer needs to have a monitoring process in place for these contaminants and also needs to keep aware of new, potential contaminants. In all cases, the manufacturer must ensure food safety and compliance with the relevant legislation.

2.6.5 Cocoa butter hardness

The quantity of fat and its melting characteristics, especially hardness, depends on the variety or type of cocoa, the fermentation and drying and the environmental conditions (see Chapter 7). In particular, the average daily temperature during the last few months of pod development affects the hardness of the cocoa butter. Lower temperatures give butters that are softer or have a lower melting point. Generally, cocoa butters made from Indonesian beans are harder than West African butters, which in turn are harder than Brazilian butters from Bahia region.

Mouldy cocoa beans, caused by inadequate drying, contain high levels of FFA. This also has an undesirable softening effect on the cocoa butter and the level of FFA is limited by regulations in some countries (e.g. 1.75% in the countries of the European Union) and by FCC contract rules.

Quality criteria that can be applied to the semi-processed cocoa materials (cocoa butter, powder and mass) are described in Chapter 3.

2.6.6 Sensory evaluation

Flavour is the most important property for chocolate consumers and hence manufacturers (see Chapter 21). Off-flavours (such as smoke or putrid over-fermentation flavours) can be readily detected by tasting roasted ground nib or cocoa mass (cocoa liquor) directly. Alternatively these can be made more palatable by mixing the mass with finely ground sugar and/or water or preparing a small-scale dark chocolate. These tests are essential for beans from origins that are inconsistent in quality or prone to off-flavours. The level of cocoa flavour and other flavours (such as acidity, bitterness, astringency and any ancillary flavours for fine cocoas) are more difficult to assess. A well-trained sensory evaluation panel with appropriate test designs and statistical analysis of results is required.

2.7 Types and origins of cocoa beans used in chocolate

Chocolate manufacturers need to produce a product of consistent quality from a raw material that may be variable. It is common practice for chocolate manufacturers to purchase cocoa mass or liquor from cocoa processors. Increasingly, these may be situated in the cocoa producing countries (known as origin processors).

The only significant volumes of cocoa exports in the world are from West Africa and Indonesia; the other large producing countries having internal markets for their cocoa products. It is usual to apply some selection to the origin and type of cocoa beans or mass used for chocolate making. Cocoa processors will frequently blend beans from different origins and/or deliveries to achieve a consistent product of the desired quality. In choosing the type of cocoa and the recipe or blend there are a number of factors to consider. These include availability of the required quantity of beans, the reliability of supply, consistency of quality (especially flavour), price, yield (both of cocoa mass and the % fat in the mass) and how easy it is to process. Blending can be carried out before or after roasting. If it is carried out after roasting, this allows different levels of roasting to be used for different types of beans.

2.7.1 Sources of bulk cocoas

Over 95% of the world's cocoa production is classed as "bulk", "basic" or "ordinary" cocoa. This does not refer to the delivery size or method of transportation, neither does it imply cocoa of inferior quality. Bulk cocoas generally come from the Forastero type cocoa trees (see Section 2.2.2). They are used to manufacture milk and dark chocolate, cocoa mass, cocoa butter and cocoa powder. The other type of cocoa is "fine" or "flavour" cocoa (see Section 2.7.9).

Some of the characteristics of the main origins and types of cocoa are described below.

2.7.2 Côte d'Ivoire

Since 1977 the Côte d'Ivoire (Ivory Coast) has been the world's largest producer of cocoa. The country now produces about 1.5 million tonnes of beans each year (ca. 38% of the world crop – see Figure 2.2). The cocoa is nearly all grown by smallholders, many of whom are immigrants.

The type of cocoa grown is Forastero. Originally it was the Amelonado variety but this has virtually all been replaced by improved Upper Amazon hybrids (see Section 2.2.2). Most cocoa is properly fermented in heaps and is sun dried. Cocoa is often not fully dried on the farm. This can sometimes lead to higher levels of both mould in the beans and FFA in the cocoa butter. Cocoa beans are dried to final moisture and blended in the ports to achieve minimum export grade standards. This cocoa tends to have a slightly lower yield of nib and cocoa butter than cocoa from Ghana, a fact which is reflected in the price.

A significant quantity of Côte d'Ivoire cocoa (ca. 30%) is processed locally and the semi-finished products exported. The local market for confectionery is very small. The 2012 cocoa reform by the government has contributed to restoring quality and reducing the vulnerability of the supply.

2.7.3 Ghana

Cocoa first arrived in West Africa in the late nineteenth century from the island of Fernando Po (Bioko) into Ghana. Cocoa growing developed strongly during the twentieth century. Ghana is currently the second largest producer in the world with around 21% of the world crop (around 870 000 t – see Figure 2.2). A large amount (ca. 25%) of the cocoa beans is processed locally.

The Ghanaian farmer uses the traditional heap method to ferment the cocoa and drying is on raised mats in the sun. Due to absence of artificial drying, there is no risk of smoke contamination. The hybrid planting material, based on Upper Amazon Forastero and Amelonado varieties, and the traditional processing methods give a full chocolate flavour, very suitable for the manufacture of chocolate. The quality control in the internal cocoa marketing system is also well established and effective. This has resulted in Ghana cocoa being the world's foremost quality bulk cocoa against which other cocoas are judged. Hence, it commands a price premium on the world market.

2.7.4 Indonesia

Cocoa production in Indonesia expanded rapidly at the end of the twentieth century and is currently around 400 000 t (ca. 10% of the world cocoa crop). Cocoa is grown in most parts of Indonesia, but the principal areas are Sulawesi, Sumatra and Java.

Indonesia is mainly a bulk cocoa producer with the cocoa coming from varieties derived from Upper Amazon and Trinitario types.

In Sulawesi, most of the production is from smallholders but some 95% of the production currently receives little or no fermentation. The cocoa is normally dried in the sun and is consequently free from the smoke contamination frequently associated with artificial drying. The lack of fermentation produces a cocoa that is very bitter and astringent. Fermented or partially fermented Sulawesi cocoa has a medium level of cocoa flavour. It has high shell content and a low percentage of fat in the nib. These factors explain why Sulawesi cocoa is traded at a discount. For chocolate makers, the plus points are the hard cocoa butter (high melting point) and the absence of off-flavours (the bitterness and astringency are flavours normal to cocoa). Sulawesi cocoa can be included in blends with other beans to make chocolate.

Generally, Indonesian bulk cocoa is of variable quality although efforts are underway to improve the quality. The majority of the crop (63% in the 2012/3 season; ICCO 2015) is processed in Indonesia. Purchasers of cocoa materials should note that these factories may also import cocoa from West Africa and other origins, mainly to improve the quality of the cocoa products.

There is a small production of a fine cocoa that is concentrated in Java. This is a light-breaking, "Criollo" type of cocoa (also called Java Fine or Edel cocoa). Actually, this is not a true Criollo cocoa but a Trinitario type that produces white cocoa seeds. Java light-breaking cocoa is mainly used for its colour. A dark chocolate made from these beans has the light brown appearance of a milk chocolate.

2.7.5 Nigeria

Production levels are increasing slowly and now stand at around 244 000 t (6% of the world crop). Cocoa in Nigeria is normally properly fermented and then sun dried on concrete terraces. The cocoa is similar in type and quality to Côte d'Ivoire, although quality is considered by some to be less consistent. Several processors and manufacturers use Nigerian cocoa interchangeably with Côte d'Ivoire or even Ghana cocoa.

2.7.6 Cameroon

Unlike the rest of West Africa, Cameroonian cocoa is of the Trinitario variety. It is generally purchased to make reddish coloured cocoa powder. Very little Cameroonian cocoa is used to make chocolate due to the risk of smoke flavour (from the artificial drying) and the price which is sometimes at a premium. The annual production is between 200 000–220 000 t.

2.7.7 Brazil

Brazil used to be a substantial producer and exporter of cocoa. The largest cocoa growing area in Brazil is in Bahia (around 65%), where cocoa is grown on both medium sized farms and in large plantations. Brazilian production grew strongly reaching just over 400 000 t before declining sharply in the late 1980s and 1990s due to Witches' Broom disease becoming established in Bahia. Production has now stabilised at around 210 000 t.

Brazilian cocoa has a good level of cocoa flavour. It tends to be more acidic than West African due to the fermentation method (in large wooden boxes). In addition, artificial drying is the practice and it is not always done satisfactorily due to the lack of maintenance of dryers. There is a risk of finding smoky flavours, which can be reduced by careful selection of the beans. However about 25% of the production comes from the state of Para where the climate does not require artificial drying. Hence the risk of smoky beans is reduced.

Brazilian cocoa butter from Bahia beans has a lower melting point (i.e. it is softer) than West African.

There is a large local processing industry and market for chocolate products. Consequently there is very little export of cocoa beans and 30 000–60 000 t of beans are imported each year, mainly from West Africa to satisfy local demand.

2.7.8 Ecuador

Ecuador is an exporter of bulk cocoa and the largest exporter of "fine" or "flavour" cocoa (see Table 2.7). Its annual production is around 200 000 t and is foreseen to grow steadily until 2020. There is a small local processing industry. The fine cocoa character comes from the Nacional cocoa and hybrids of Nacional with Venezuelan Trinitario. This cocoa, commonly known as Arriba, has a full cocoa flavour with additional floral spicy notes. Some manufacturers seek and pay substantial premiums for good quality Arriba cocoa for use in speciality chocolate. The availability of this cocoa is limited and is even decreasing, probably representing less than half of the Ecuadorian crop. New plantings of cocoa frequently use the high yielding CCN51 variety. However, this variety does not give Arriba flavour but a rather fruity and acidic flavour.

2.7.9 Speciality and "fine" or "flavour" cocoas

The term speciality cocoa covers a range of types or grades which generally command premium prices over bulk cocoas. They are not traded as a commodity but have their own supply chains which preserve the identity of the individual lots and frequently allow for the purchaser to test the quality prior to delivery. The cocoas may be from specific geographic origins, crops or varieties, or even harvested and fermented in a specific way (see Sections 2.2.2, 2.3.1 and 2.5). The market for chocolate products made from speciality cocoas has been showing strong growth for over two decades (see Chapter 18).

Table 2.7 Export of fine or flavour cocoas by country. Reproduced with permission of ICCO.

Country	Volume of cocoa beans exported (thousand tonnes)[a]	Total exports considered to be fine cocoa (%)[b]	Approximate volume of fine cocoa exported (thousand tonnes)	Special character (taste or colour)
Colombia	43	100	43	Brown fruit, nutty
Costa Rica	0.3	100	0.3	Fruity, nutty
Dominican Republic	60	40	24	Tobacco, fruity, grassy
Ecuador[c]	156	75	117	Arriba: aromatic, floral, spicy, green
Grenada	0.8	100	0.8	Brown fruit, molasses
Indonesia	211	1	2	Java light breaking: caramel, acidic
Jamaica	0.3	100	0.3	Fruity, raisin
Madagascar	7	100	7	Light breaking criollo: nutty
Papua New Guinea	42	75	31	Fruity, floral, acidic
Peru	24	100	24	Brown fruit, acidic, nutty
Saint Lucia	0.1	100	0.1	Fruity, grassy
São Tomé and Principe	2	35	0.7	Fruity, acidic
Trinidad and Tobago	0.4	100	0.4	Molasses, caramel and raisin
Venezuela	15	75	12	Various types exhibiting most of above
Total			263	

[a] Three year average 2010–2013 (ICCO, 2015).

[b] ICCO Council decision May 2008.

[c] The percentage of fine cocoa exported by Ecuador may only be 30–40% due to mixing.

"Fine" or "flavour" cocoas are the oldest and largest category of speciality cocoa. There are various estimates for the export volume of fine cocoas (263 000 t, ca. 9% of the world crop – see Table 2.5). There is no agreed definition of "fine" or "flavour" cocoas except they are purchased at a premium price for their flavour or colour (e.g. light-breaking). Also, according to the ICCO (2010), the difference between fine and bulk cocoa is in the flavour rather than other quality aspects. Fine or flavour cocoas have some ancillary flavours that are described variously as fruity, raisin, brown fruit, floral, spicy, aromatic, nutty, molasses and caramel (Fowler, 1994). They are mainly used to make dark chocolate in which their special flavours or colour can be appreciated. These cocoas generally come from Criollo, Trinitario or Nacional type trees. However, not all cocoas of these varieties are classified as "fine" or "flavour". If they do not have the desirable flavour characteristics or if the fermentation and drying is poor, they are traded as bulk cocoas and may even sell at a discount to the main bulk origins. Prices depend on supply and demand for each type. Typical premiums start from about 20%, rising to double or even treble the bulk cocoa bean prices.

The above definition of "fine" or "flavour" cocoa can be seen as subjective, and people have attempted to find definitions based on scientific evidence. For example Amores *et al.* (2007) found that the theobromine/caffeine ratio can "clearly differentiate fine from bulk cocoa".

The Arriba cocoa (see Section 2.7.8) from Ecuador represents ca. 50% of the worldwide volume of fine cocoa. Amongst other "fine" or "flavour" cocoas, the majority is from varieties of Trinitario trees, but some from Madagascar and Venezuela is from much sought after light-breaking Criollo varieties, although not all their production is of this type. A unique cocoa to be mentioned is the light-breaking cocoa from Java, Indonesia (see Section 2.7.4).

Conclusions

It is impossible to make chocolate without cocoa, and its quality and availability is of paramount importance to the confectionery industry. Therefore, no chocolate manufacturer can afford to neglect this vital ingredient and remain divorced from the issues surrounding cocoa production.

Cocoa makes a substantial economic contribution to many rural economies. There is great potential to improve both yields of cocoa plantings and farmer incomes. These are two challenges that need to be addressed by coordinated actions from the industries, the governments and some NGOs. Also, with the cocoa production concentrated in a few countries in West Africa, future supplies are by no means assured.

Quality, including food safety, traceability, origins, sustainability, living conditions of cocoa farmers and environmental impact are very important and will continue to provide challenging issues to the complex supply chain that exists with cocoa.

Demand for cocoa products is expected to continue to increase, mainly due to the universal appeal of the unique cocoa flavour and the history and myths related to it. The ultimate objective is to ensure that cocoa, and thus chocolate, can be enjoyed by as many consumers as possible. This requires the transformation of the cocoa supply chain into an efficient, profitable and sustainable one. This is in the interest of consumers, the cocoa and chocolate industry and the producing countries.

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Appendix: Abbreviations, acronyms and organisations

Cd	Cadmium (heavy metal)
CMAA	Cocoa Merchants' Association of America
CODEX	Codex Alimentarius Commission: produces international food standards.
ECA	European Cocoa Association
FAO	Food and Agricultural Organization of the United Nations
FCC	Federation of Cocoa Commerce
FDA	Food and Drug Administration of the USA
FLO	Fairtrade Labelling Organisations International
ICE	InterContinental Exchange. Futures trading market.
ICI	International Cocoa Initiative. A partnership between, NGOs, cocoa trade and processors focussing on child labour
ICA (formerly IOCCC)	International Confectionery Association (source of ICA/IOCCC analytical methods)
ICCO	International Cocoa Organisation
OTA	Ochratoxin A (a mycotoxin produced by moulds)
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead (heavy metal)
RA	Rainforest Alliance, a biodiversity and sustainability NGO
UTZ	A certification and traceability scheme
WCF	World Cocoa Foundation

CHAPTER 3

Production of cocoa mass, cocoa butter and cocoa powder

Henri J. Kamphuis, revised by Mark S. Fowler

3.1 Introduction

Cocoa flavour is the most distinctive feature of chocolate and depends, amongst other things, upon the raw materials used, especially the cocoa beans. The processing, in particular roasting, is also very important in developing the desired chocolate flavour.

Following bean or nib roasting, the cocoa nib is ground into cocoa mass, which is a liquid when hot but solid at room temperature. The final intended use determines how finely it is ground. When using the two and five roll refiner system to make chocolate (Chapter 9), the fineness of the cocoa mass is of less importance than when the mass is added directly into the conche, as is the case for the production of high cocoa content chocolates. The latter requires the cocoa nibs to be very finely ground.

Cocoa nibs must also be finely ground when making cocoa powder; otherwise the product may have a sandy mouthfeel or a poor visual appearance.

Cocoa butter is normally produced by pressing, which is often followed by steam treatment under vacuum conditions (deodorisation). Cocoa butter is mainly used for the production of chocolate where taste and solidification characteristics are important. These can be influenced by the choice of raw materials and the processing applied.

3.2 Cleaning of cocoa beans

After harvesting, fermenting and drying, cocoa beans may be exported from the country of origin (see Chapter 2). Transport is in bags, bulk containers, or in ships' holds. For many years the latter has been very popular and is widely used. The "grinding" or processing of cocoa beans in their country of origin has also expanded rapidly. Nowadays the production of cocoa mass, and even

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

chocolate itself, is being increasingly outsourced by many manufacturers to a few specialist producer companies.

Before further processing, beans must always be cleaned to remove non-cocoa components, for example stones and pieces of metal. Impurities may cause wear and damage to subsequent processing machinery. Cleaning is usually carried out in several stages (see Figure 3.1):

- Removal of coarse and fine impurities by sieving;
- Removal of ferrous matter with magnets;
- Destoning and removal of other high density particles;
- Dust collection during several cleaning steps.

A set of vibrating screens removes both very large and very small particles by sieving. Clustered beans, pieces of wood, strings and other large debris are collected by the coarse screens, whereas cocoa beans pass through. Smaller particles are then allowed to pass through finer screens.

Using counter air flow techniques, low density and dust particles are separated from the beans during the cleaning operation. Removal of dust and sand is

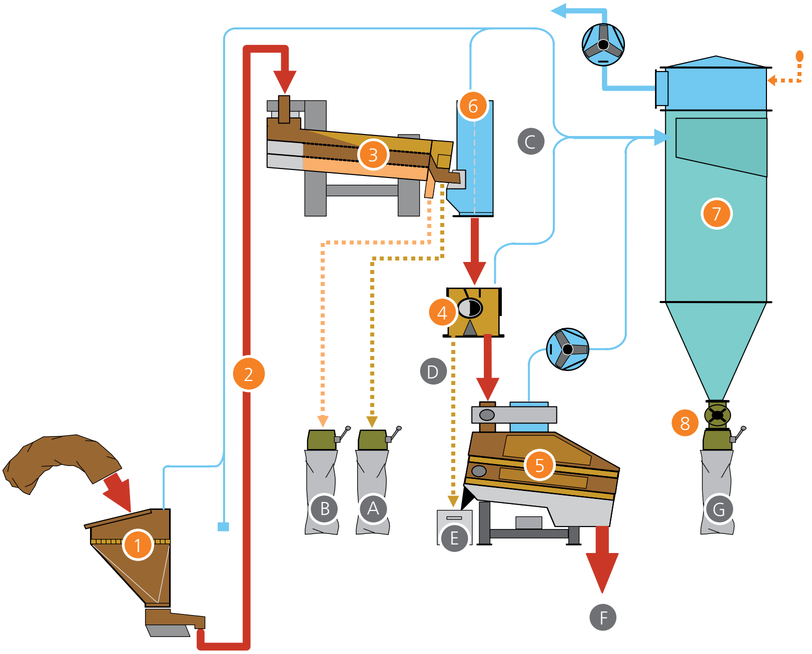


Figure 3.1 Schematic representation of a system for cleaning cocoa beans (Bühler AG). (1) Intake; (2) elevator; (3) separator classifier MTRB; (4) drum magnet DFRT; (5) destoner MTSC; (6) aspiration channel MVSH; (7) aspiration filter MVRT; (8) airlock MPSN; (A) coarse contaminants; (B) fine contaminants; (C) aspiration (dust, shells etc.); (D) metal particles; (E) high density materials (stone, glass etc.); (F) cleaned product (cocoa beans); (G) dust and dirt. Reproduced with permission of Bühler AG, Switzerland.

very important, due to its abrasive nature, which will rapidly wear the balls in ball mills or the surface of refiner rolls.

Ferrous material is removed by magnets, but metal detectors may still be used during further processing. Destoners remove stones and other heavy particles. They operate on the principle of a fluidised bed. The heavy particles (i.e. stones) are vibrated towards the top of the sloping screen with air passing through the screen. The lighter particles remain at the lower end of it.

3.3 Removal of shell

The removal of shell is an important step in the process of making cocoa mass. In the past it was a legal requirement in the European Union (EU), but under the current directive 2000/36/EC, no maximum values are given. However, in the United States maximum values are still set (Codex standard 141-1983, rev. 1-2001). Apart from the legal requirements, proper removal of shell is a prerequisite for a good quality product:

- Shell, by its very nature, is exposed to external factors and will have picked up undesirable contaminants (Knezevic, 1983).
- Shell does not contribute positively to the flavour of the final product and may indeed produce off-flavours.
- Shell is a hard and fibrous material which makes it extremely difficult to grind and leads to abrasion of the grinding equipment.

Moreover, shell separation from the nib influences the yield, and the loss of small nib particles along with the shell is a particularly important financial factor. Ideally the shell should separate cleanly, leaving large pieces of shell and almost intact nib. The shell around some beans cannot be removed easily, however, with certain origins being particularly difficult (e.g. unfermented, small sized and flat cocoa beans).

In practice beans are usually subjected to surface heat treatments to facilitate shell release, such as fluid bed types of dryers, continuous air roasters, infrared dryers or moistening/pre-drying systems. The principle of infrared radiation is based on idea of puffing the shell from the nib (see Figure 3.2). It consists of infrared radiators and a vibrating conveyor belt underneath. The beans rotate on the belt, where they are dried. The moisture in the bean evaporates giving a puffing effect and the heat increases the brittleness of the shell, facilitating easy removal of the shell afterwards. Heat transfer is concentrated on the surface rather than on the inside and unwanted material such as rodent hairs and insect fragments are removed by burning.

An alternative machine is the drum microniser, which has a central infrared radiator within a rotating drum (see Figure 3.3).

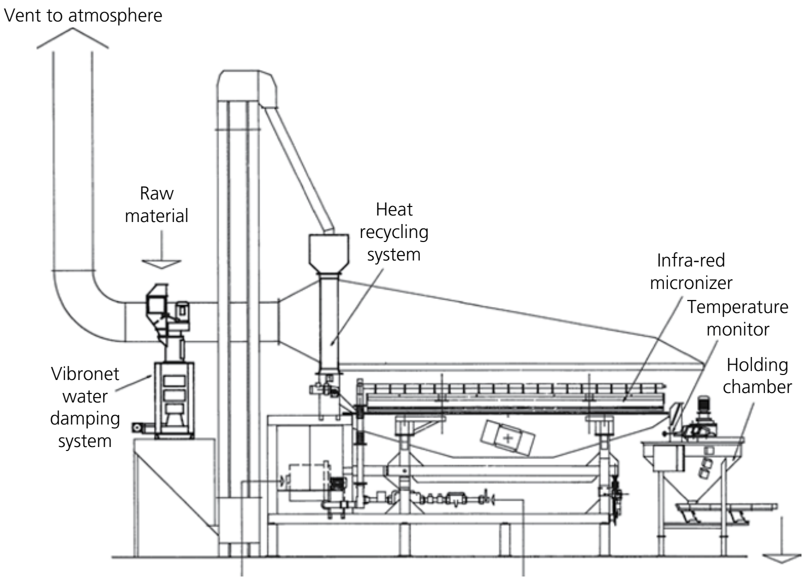


Figure 3.2 Schematic representation of the flat bed micronising unit (Micronising Company UK).

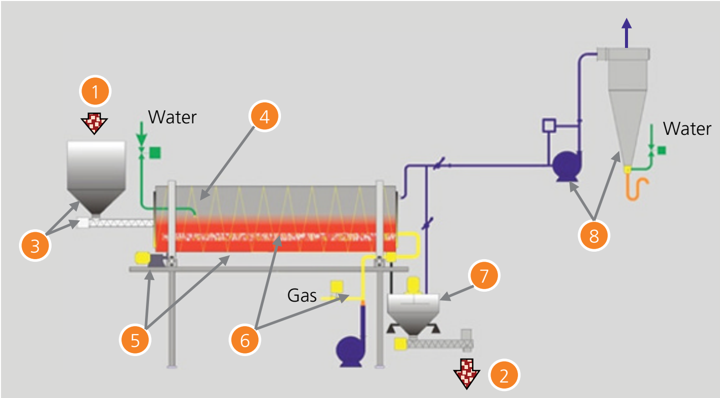


Figure 3.3 Schematic representation of the operating principles of a Barth IR system (Bühler AG). (1) Inlet – raw cocoa beans; (2) outlet – treated cocoa beans; (3) pre-hopper with dosing screw; (4) integrated water spraying system; (5) rotating drum with gear drive unit; (6) gas-fired infrared radiators; (7) weighing hopper; (8) aspiration system with venting fan and cyclone. Reproduced with permission of Bühler AG, Switzerland.

3.4 Breaking and winnowing

Beans are generally broken by a swing-hammer type of breaker. Centrifugal force is used to break the beans against an impact plate from where they leave the breaker due to gravity. The rpm of the wheel providing the centrifugal force, together with the throughput, determine the particle size distribution for a given quality of beans. This distribution should be as homogeneous as possible for optimum separation of shell and nibs. After breaking, the shell and nibs are separated by winnowing and unbroken beans are returned for re-processing.

During winnowing the broken beans are divided into a number of fractions by means of sieves and an air classifier (or sifter) separates the shell from the nib particles. Each section (sifter) has its own optimal air flow, which depends upon the size fraction being treated (see Figure 3.4). The shell itself is used for animal feed, horticultural purposes or energy generation.

3.5 Alkalisation

Alkalisation is predominantly used for the production of cocoa powder (see Section 3.9) where it is used to produce powders of different colours and flavours. The process is generally regarded as an added value step which is proprietary to each supplier. Sometimes, alkalised cocoa mass or alkalised cocoa powder is used in chocolates to introduce specific flavours.

Nib alkalisation can be carried out in a drum, reaction vessel and/or in a screw conveyor. If appropriate, the system can be pressurised. Basically, nibs are mixed with an alkaline solution, for example potassium carbonate and water although other alkalis can be used. This mixture is heated for sufficient time for colour changes to take place. Depending upon the cocoa beans used and the process conditions (i.e. time, percentage alkaline solution, pressure etc.), a specific colour will be produced. After alkalisation the mixture is dried and subsequently roasted. It is also possible, however, to alkalise and roast in a roasting drum, although this may significantly increase the processing time.

Cocoa mass and cocoa cake can also be alkalised, but this is rather limited in terms of colour formation. The addition of the alkaline solution to cocoa mass may result in a high viscous (sticky) product, which is not easy to handle. In this case the removal of excess moisture is very difficult and needs specific equipment. Off-flavours can also easily be formed due to the long heating times required.

The pH of non-alkalised cocoa cake can also be increased by adding dry alkali to it. This results in a higher pH powder after pulverising, but usually there is little effect on the colour and the intrinsic colour of the product is poor. This characteristic is better when alkaline solutions are used.

3.6 Bean and nib roasting

Roasting develops the flavour in the beans from the precursors formed during fermentation and drying. For example, the Amadori compounds, which are extremely reactive, produce a large number of flavours. This subject is dealt with in more detail in Chapter 8.

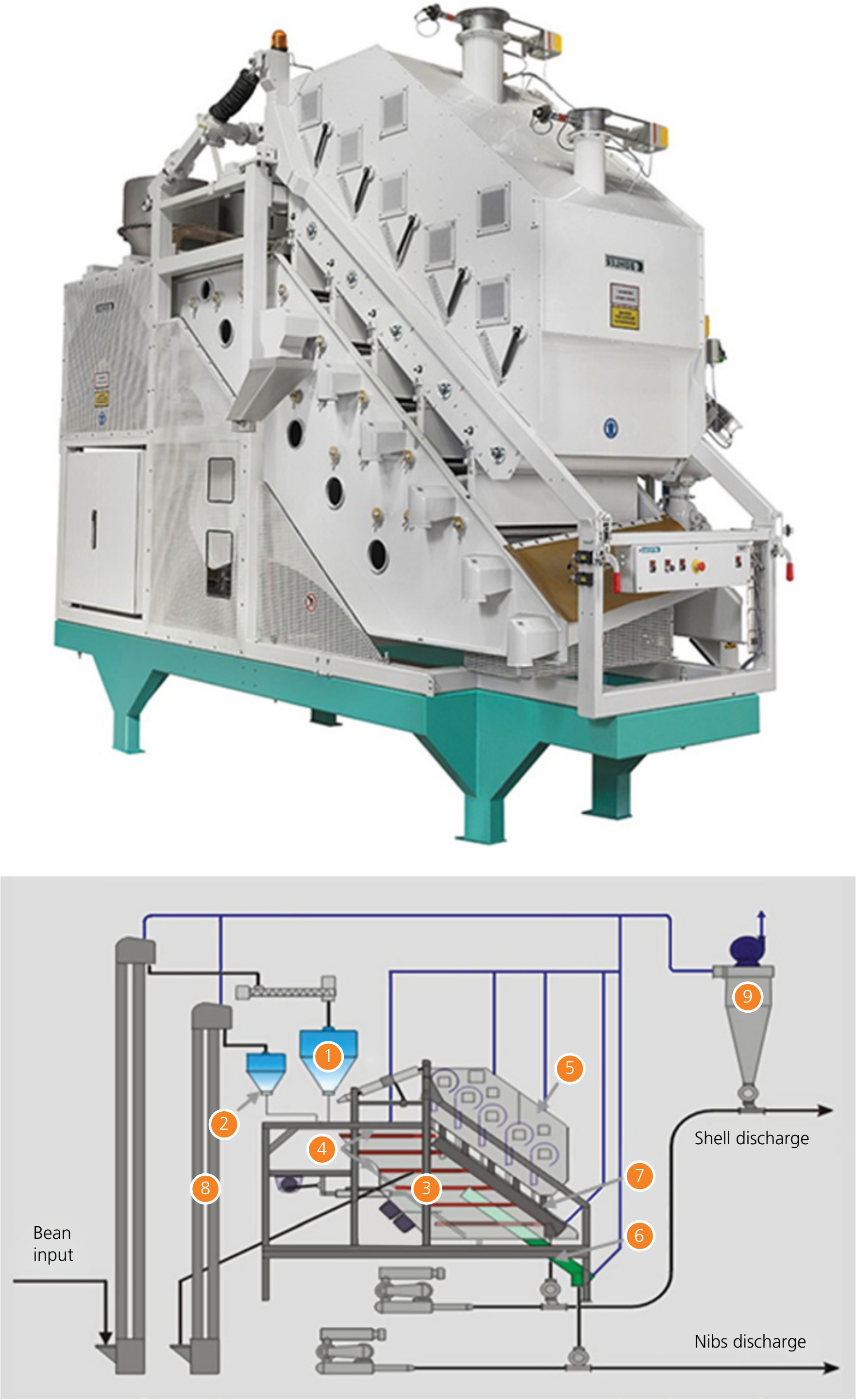


Figure 3.4 Barth winnowing machine and schematic diagram of the process (Bühler AG). (1) First impact crusher; (2) second impact crusher; (3) screening system with sieve decks; (4) oscillating sifters; (5) aspiration system; (6) collecting chute for nibs; (7) collecting chute for shell; (8) return flow elevator; (9) cyclone. Reproduced with permission of Bühler AG, Switzerland.

Ziegleder and Oberparleiter (1996) have proposed a moisture treatment prior to roasting. In this, steam is condensed on the nib, resulting in a water addition of about 15%. This moisture aids the formation of more flavour precursors during the 10–15 min processing time at 40–60 °C (104–140 °F). After drying to 3% moisture at 98–110 °C (208–230 °F) and roasting, this gives a product with a more intense flavour compared with normally roasted beans.

Mohr *et al.* (1978) have demonstrated that a slow reduction in moisture content to about 3% followed by a rapid heating to the final roast temperature is the optimal way of roasting. The highest roasting temperature depends upon the required roast intensity and the equipment used. All types of roaster can be operated over a wide range of roasting conditions.

Whole bean roasting was the original method and often used to produce cocoa masses with delicate flavours, due to the preservation of the volatile cocoa flavour notes within the shell during roasting. Also the removal of the shell after this type of roasting is relatively easy, as the shell becomes loose during the roasting. Currently nib roasting is also widely used, in part due to distinct improvements in cocoa powder obtained with alkalisation of the nib before roasting.

Many different roasting systems are in the market place often using conduction and/or convection as the heat transfer mechanism.

Batch drum roasters are frequently used in the cocoa industry for nib roasting (see Figure 3.5). The principle of these roasters is generally the same. Nib is fed into the drum and depending on taste requirements water can be added and a specific roasting profile will be applied. Roasting occurs by heat from the drum wall and the product tumbles in the drum, thus avoiding burning and localised overheating.

Effective debacterisation can be carried out by adding water and assuring the presence of steam in the drum. Roasting temperatures, holding times and amount of water added vary according to the equipment being used and the desired flavour profile of the product. Generally the final roasting temperature is 110–140 °C (230–284 °F). Microbiological tests must be carried out for each specific roasting profile to ensure that it kills all pathogens (e.g. *Salmonella*) and reduces the total bacterial content (Brenner, 1991; Cerny, 1991; see Chapter 25).

After roasting, the product is cooled down in an external cooler. Using these types of drum roasters it is extremely important to maintain a strict separation between the raw and roasted nibs, because the loading and discharge may occur through the same door and cross-contamination of microbiological material can easily take place.

Alternatively, continuous vertical air roasters can be used for cocoa beans or nibs (see Figure 3.6). This type of shaft roaster is divided into a number of sections; the top sections are used to roast, the lower ones for cooling.

The roaster will be filled from the top and the product cascades down the roaster through a series of shelves. Each shelf tilts to discharge its load onto the one below, after a preset retention time. Hot air passes through special ventilation

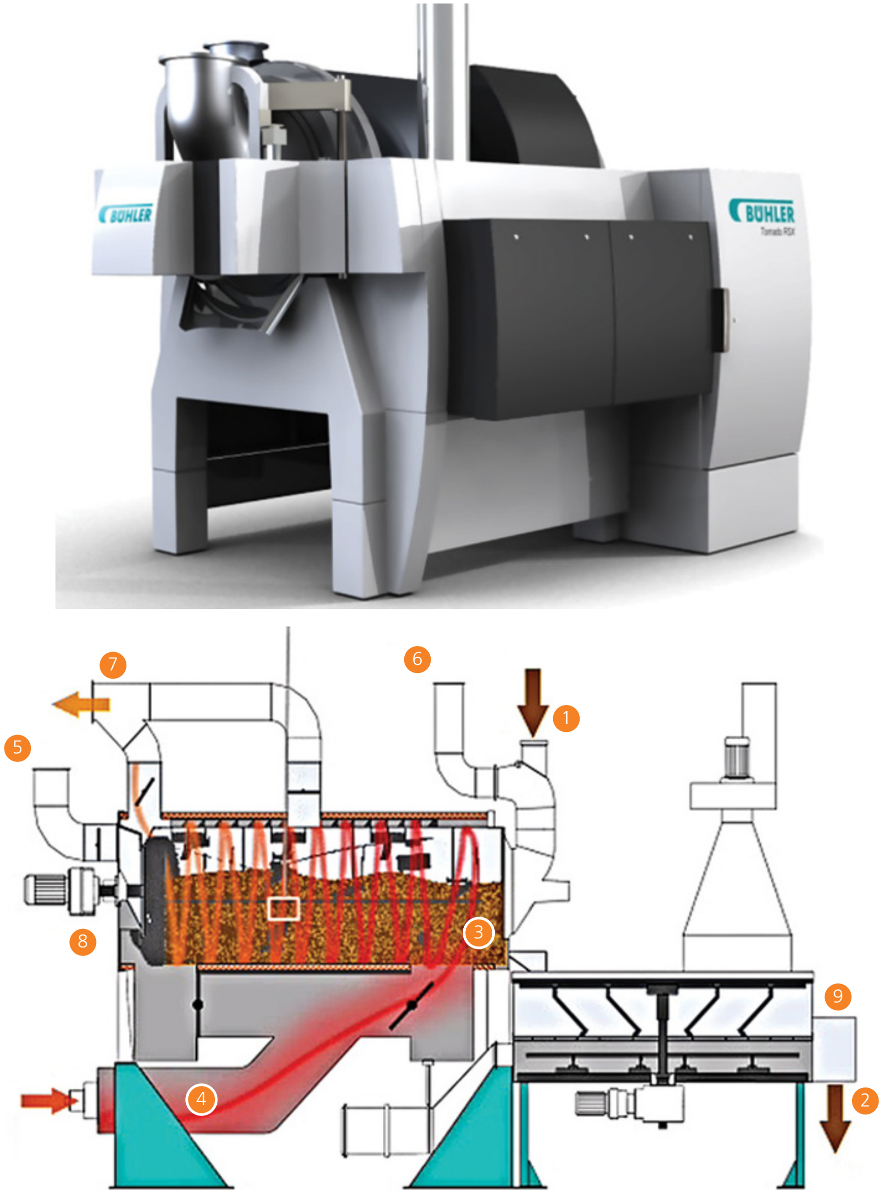


Figure 3.5 Barth Tornado RSX cocoa nibs batch roaster (Bühler AG). (1) Raw cocoa nibs inlet; (2) roasted cocoa nibs outlet; (3) roasting drum; (4) burner chamber; (5) hot air inlet for convective heating; (6) exhaust air from inside drum; (7) exhaust air from outside drum; (8) port for water, steam and other ingredient injection; (9) cooler. Reproduced with permission of Bühler AG, Switzerland.

slots in the shelves, which ensures an even flow of the air in the roaster. The bottom shelves are used for cooling.

Several suppliers also make continuous drum roasters. A continuous flow of nib or beans is fed into a drum, which is heated by a hot air flow. Air temperature and

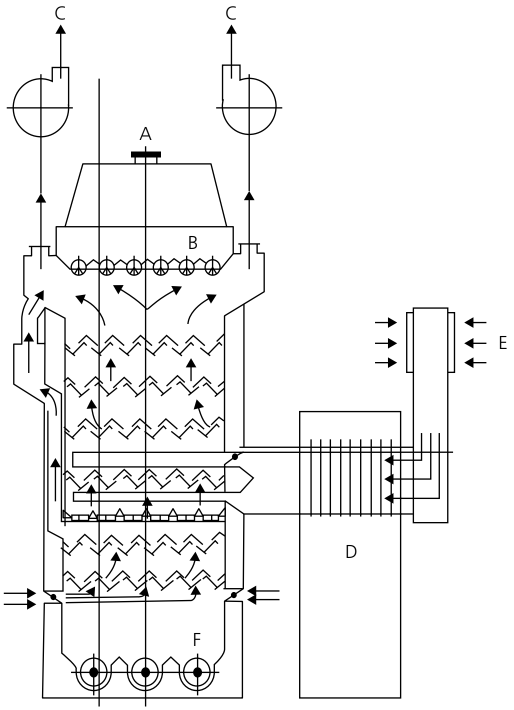


Figure 3.6 Diagram of continuous bean/nib roasting system (Lehmann Maschinenfabrik GmbH, Germany). (A) product feed; (B) feed rollers; (C) exhaust air fan; (D) air heater; (E) air filter; (F) extraction screw.

dwell time regulate the degree of roast. In the JND directly heated continuous dryer/roaster (see Figure 3.7), the process air is typically heated by in-duct gas burners before being channelled through a stationary head plate. As the drum rotates this air is only allowed into those channels that are below the beans or nibs. It then passes through louvres into the beans and partially fluidises them. This cross-flow of air relative to the movement of beans along the drum means that at any point along the length of a section the gas temperature, humidity and flow rate are constant. Usually these types of roasters are divided in two or three sections. Each section can be separately heated and by adjusting the temperature, different flavours can be developed. After roasting the product is cooled in a continuous device.

3.7 Cocoa mass (cocoa liquor)

3.7.1 Grinding cocoa nibs

Cocoa mass is produced by grinding cocoa nibs. Grinding is often a two-stage process: a coarse grinding (see Figure 3.8) followed by a fine grinding stage. As was noted earlier, the fineness to which the mass needs to be ground depends upon its final use. An example of a ball mill used for fine grinding is shown in

Figure 3.7 Schematic diagram of the heated gas flow within a JND Continuous Rotary Louvre Roaster. (JND Technologies Limited, Retford, UK).

Figure 3.9. There are many different mills that are available and the main types are described in Chapter 9.

3.7.2 Quality of cocoa mass for the chocolate industry

The microbiological quality of the cocoa mass is a key parameter for the industry. Due to high total plate counts ($>1 \times 10^6$ colony-forming units per gram; cfu/g) and the presence of *Salmonella* in cocoa beans, heat treatment must be applied to obtain a product which meets the generally accepted cocoa mass specifications given in Table 3.1.

Bean blends are often used to obtain the desired flavour characteristics. Generally West African cocoa beans are used in Europe for chocolate production but, due to the increased interest in high cocoa containing chocolates, South American and/or West Indian cocoa beans are also used in blends (see Sections 2.7.9 and 20.2.3). Recently single origin chocolates have also become very popular. The roasting conditions of the cocoa beans and/or nibs are of great importance to obtain the optimum delicate flavours. When manufacturing high cocoa containing chocolate, the cocoa masses are often added directly into the conche and these must be free from coarse particles to avoid the product tasting gritty. Preferably the particle size of this type of cocoa mass should be around 20 μm (measured by micrometer).

Figure 3.8 Cocoa nib pregrinder (Royal Duyvis Weiner). Reproduced with permission of Royal Duyvis Weiner.

3.7.3 Quality of cocoa mass for the production of cocoa powder and butter

The cocoa pressing industry also selects beans on the basis of their colour forming characteristics, which is particularly important for the production of dark coloured cocoa powders. For cocoa powder production the nibs are normally treated with an alkaline solution. This alkalisation process was developed in the nineteenth century in Holland and for this reason is also called the Dutching process. This results in darker products and, depending on the processing conditions, red and/or brown colours will be formed. It also has an impact on the cocoa flavour and, very often, alkalised cocoa powders are preferred in many food and drink applications.

Figure 3.9 Petzholdt spindle mill containing steel balls for fine grinding of cocoa mass. Reproduced with permission of Hamburg Dresdner Maschinenfabriken GmbH.

The effect on colour is very complicated (Cook and Meursing, 1984; Dimmick and Hoskin, 1981; Kleinert, 1972; Richardson, 1982; Schenkel, 1973; Taneri, 1977). The chemistry of the formation of the cocoa colour is based on a class of components which is rather specific for cocoa: polyhydroxyphenols (tannins). These are based on a basic molecular structure, that is epicatechin.

In the course of cocoa bean growing, fermenting, drying, alkalising and roasting, these compounds oxidise, polymerise (see Figure 3.10) and react with many other cocoa constituents. Thus, the number of chromophoric groups in the molecules is increased, resulting in darker colours but also in various colour hues, depending on the reaction conditions. The alkalisation process requires a lot of experience and skill, in order to obtain end products with a consistent colour in combination with good flavour characteristics. Specifically for darker coloured cocoa powders, the so-called alkaline flavour should not be too strong.

Table 3.1 Quality parameters for cocoa mass (Source: Cargill Cocoa, 2007).

Parameter	Value	Method
Fat content	Minimum 53%[a]	IOCCC 37, 1990
Moisture	Maximum 2.0%	IOCCC 26, 1988
Total Plate Count	Maximum 5000 cfu/g[b]	IOCCC 39, 1990
Moulds	Maximum 50 cfu/g	IOCCC 39, 1990
Yeasts	Maximum 50 cfu/g	IOCCC 39, 1990
Enterobacteriaceae	Absent per gram	IOCCC 39, 1990
Escherichia coli	Absent per gram	IOCCC 39, 1990
Salmonella	Absent per 750 g	IOCCC 39, 1990

[a] May vary due to bean origin and harvest.

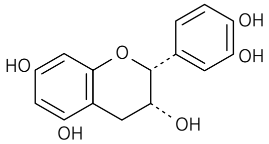
[b] cfu/g: colony-forming units per gram; an indication of the amount of live microorganisms present.

The process is carried out by adding a solution of an alkali (mostly potassium carbonate) to cocoa nibs. This process can be batch (when pressurised conditions are required) or continuous (under atmospheric conditions) as previously explained. Each process has its own advantages and disadvantages and will result in specific cocoa powders with individual flavour and colour characteristics.

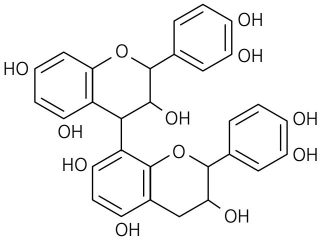
Cocoa mass can be transported and stored either in liquid or in solid form (as a single block or as kibbled pieces) in 25 kg (56 lb) cardboard boxes with a polyethylene liner or a bag inside. Due to the cocoa butter properties and the presence of natural anti-oxidants, cocoa mass has a very good shelf-life. As a result cocoa mass can be stored for several weeks in liquid form or for more than 12 months as a solid, providing that it is kept under suitable conditions.

3.8 Cocoa butter

Cocoa mass usually contains some 47–56% of cocoa butter and this is physically extracted to produce both cocoa butter and powder. Both non-alkalised and alkalised cocoa masses can be pressed using horizontal hydraulic presses (see Figures 3.11 and 3.12). The pre-heated cocoa mass is transferred into the so-called pots (16–18 pots per machine) and when the pressure is increased the butter flows out of the press; the cocoa particles are retained and, in fact, act to filter the cocoa butter. The cocoa particles are compressed in the pots and form cocoa press cake. The remaining fat content of the cake (normally a minimum of 10% using horizontal presses) can be controlled and, when the required level is reached, the press opens and the cake falls out. Hydraulic pressures of up to 540 bar (540×10^5 N/m^2) may be used with cycle times of around 15 min. The pressing procedure is influenced by the previous processing (e.g. the degree of alkalisation and grinding).



Epicatechin



Epicatechin dimer

Figure 3.10 Epicatechin and dimeric form.

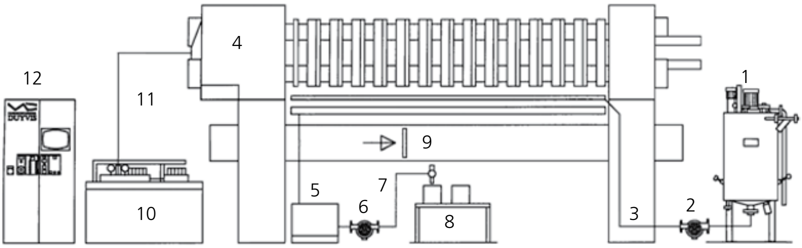


Figure 3.11 Schematic representation of the operating principles of a horisontal cocoa butter press. (1) Cocoa mass conditioning tank; (2) cocoa mass pump; (3) pipe for cocoa mass; (4) hydraulic cocoa press; (5) cocoa butter scales; (6) cocoa butter pump; (7) cocoa butter pipe; (8) cocoa butter blocking off; (9) cocoa cake pushing conveyor; (10) hydraulic pumping unit; (11) hydraulic pipe; (12) electric control with panel; (Royal Duyvis Wiener). Reproduced with permission of Royal Duyvis Wiener.

Cocoa butter is clearly defined under EU law (see Table 3.2 and Section 28.3). Although the process used to separate the cocoa butter is no longer regulated, the Federation of Cocoa Commerce Market rules divide cocoa butter into press cocoa butter (fat obtained by pressing, Figure 3.12), expeller cocoa butter [fat obtained by physical removal using an expeller from cocoa beans, nibs or mass (reduced fat), press cake or any combination of these] and refined cocoa butter (FCC Market Rules, Section 2). The latter includes press, expeller or solvent extracted cocoa butter that has been refined by neutralisation with an alkaline solution and decoloured with bentonite, active carbon and so on. Subsequent deodorisation can also be applied. In addition to these processes cocoa butter can also be obtained by extraction using solvent extraction.

The type of process used may affect the quality of the cocoa butter. For example, a too high deodorisation temperature or a too severe alkalisation can

Table 3.2 Definitions and characteristics of cocoa products according to EU Directive 2000/36/EC and Codex standards.

Standard/material	Percentage
EU Directive 2000/36/EC	
Cocoa butter	
Free fatty acids (expressed as oleic acid)	maximum 1.75
Unsaponifiable matter (determined using petroleum ether)	maximum 0.5
– in the case of press butter	maximum 0.35
Cocoa powder	
Cocoa butter content (on dry matter basis)	minimum 20
Moisture content	maximum 9
Fat reduced cocoa powder	
Cocoa butter content (on dry matter basis)	maximum 20
Codex standards	
Cocoa mass (Codex standard 141–1983, rev 1–2001)	
Cocoa butter content (AOAC 963.15 or IOCCC 14–1972)	47–60
Cocoa shell and germ (AOAC 968.10 and 970.23)	maximum 5 (on fat free dry matter)
Cocoa shell (AOAC 968.10 and 970.23)	maximum 4.5 (on fat free dry matter)
Cocoa butter (Codex standard 86–1981, rev 1–2001)	
Free fatty acids (method IUPAC (1987) 2.201)	maximum 1.75
Unsaponifiable matter (method IUPAC (1987) 2.401)	maximum 0.7
– in the case of press butter	maximum 0.35
Cocoa powder (Codex standard 105–1981, rev.1–2001)	
Moisture content	maximum 7
Cocoa powder	minimum 20 cocoa butter (on dry matter basis)
Fat reduced cocoa powder	minimum 10 and <20 cocoa butter (on dry matter basis)
Highly fat reduced cocoa powder	<10 cocoa butter (on dry matter basis)

completely alter its setting (solidification) characteristics. High quality raw materials are needed to make the best quality cocoa butter. Other important factors for high quality are the origin of the beans and the processing conditions used. Press cocoa butter, which is most commonly used in the chocolate industry, is only filtered and partly deodorised to obtain the desired flavour. Table 3.3 lists the quality parameters for cocoa butter. Most cocoa butter is made from alkalised cocoa mass and retains some of the flavours from the cocoa beans, alkalising and roasting stages. The term “natural” cocoa butter usually refers to a butter that has not been deodorised, so it has a full flavour. Fully deodorised cocoa butter has virtually no cocoa flavours. Generally the more highly flavoured cocoa butters are used in dark chocolates and the less flavoured in white chocolate.

Figure 3.12 Cocoa butter presses (Royal Duyvis Wiener). Reproduced with permission of Royal Duyvis Wiener.

Table 3.3 Quality parameters for cocoa butter (*Source*: Cargill Cocoa, 2007).

Parameter	Value	Method
Free fatty acids	1.75%	IUPAC 2.201
Iodine value	33–42	IUPAC 2.205
Refractive index	1.456–1.459	IUPAC 2.102
Moisture content	Maximum 0.1%	IOCCC 26, 1988
Unsaponifiable matter	Maximum 0.35	IOCCC 23, 1988
Blue value	Maximum 0.05%	IOCCC 29, 1988

Cocoa butter is a creamy, ivory colour when solid and it does not contribute to the colour of the finished chocolate. White chocolate can be an exception and it may contribute some yellow colour which may or may not be desirable. A key property of cocoa butter is its melting characteristics and these are described in Section 7.2.

Cocoa butter is transported and stored either in liquid or in solid form (as a single block) in 25 kg (56 lb) cardboard boxes with a polyethylene liner or a bag inside. Due to the characteristics of cocoa butter the shelf life in solid form is good; up to one year when stored under suitable conditions and in practice even up to two years. When cocoa butter has been refined the shelf life is reduced dramatically to a maximum of six months. For liquid cocoa butter the shelf life is up to one month. Nevertheless thin layers of liquid butter may oxidise quickly, so it should never be stored in this way. When liquid cocoa butter needs to be stored for longer periods, the use of nitrogen to prevent oxidation by air is recommended.

3.9 Cocoa press cake and cocoa powder

The pressing operation described in the previous section results in the production of hard discs of cocoa material called cocoa press cake. Usually pin or hammer mills (see Chapter 9 and Figure 3.13) are used to pulverise the cocoa cakes. Preferably after pulverising (milling) the cocoa powder is tempered (cooled) to crystallise the

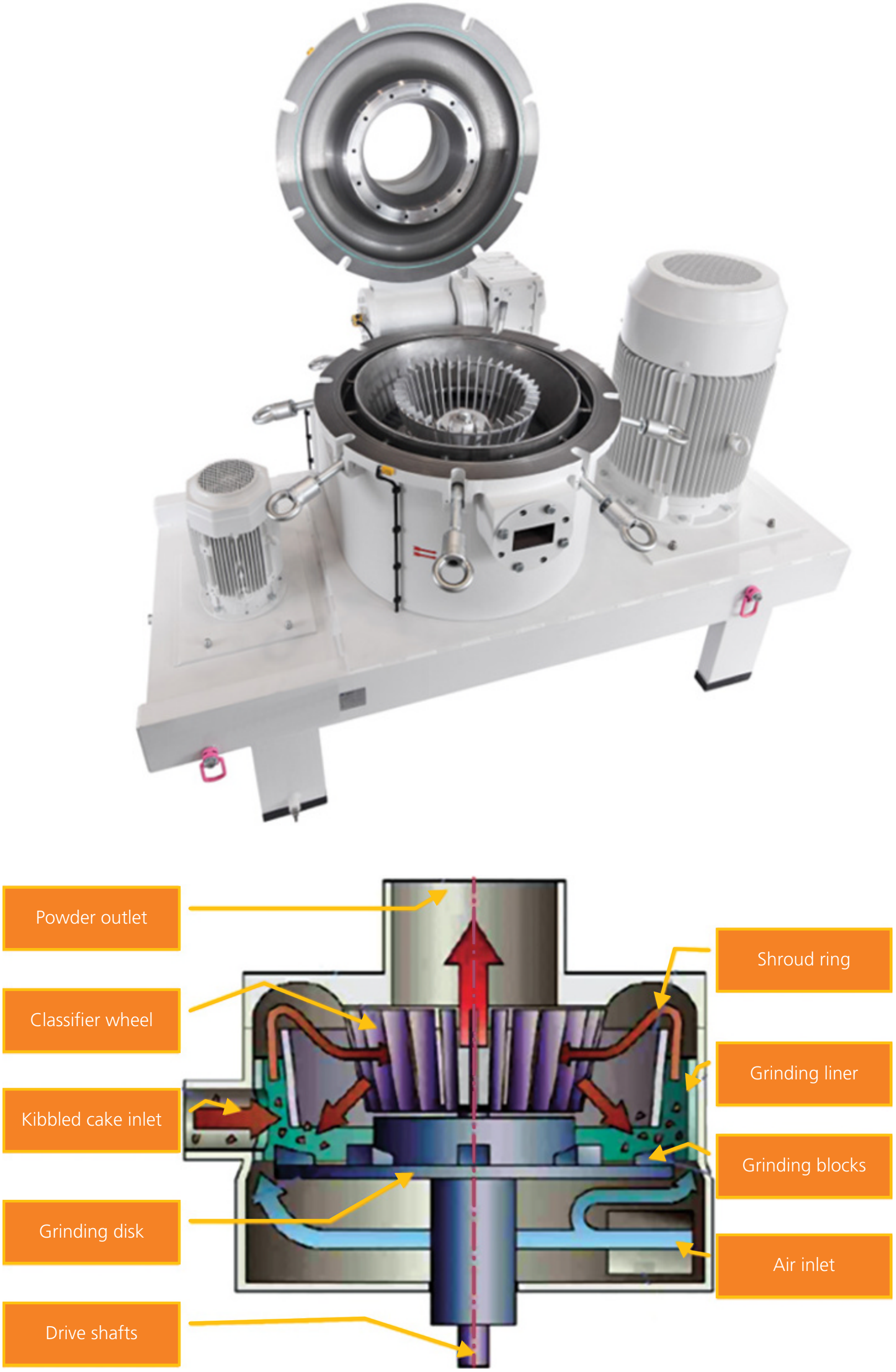


Figure 3.13 Barth cocoa powder mill (Bühler AG) for grinding kibbled cocoa cake into cocoa powder. Reproduced with permission of Bühler AG, Switzerland.

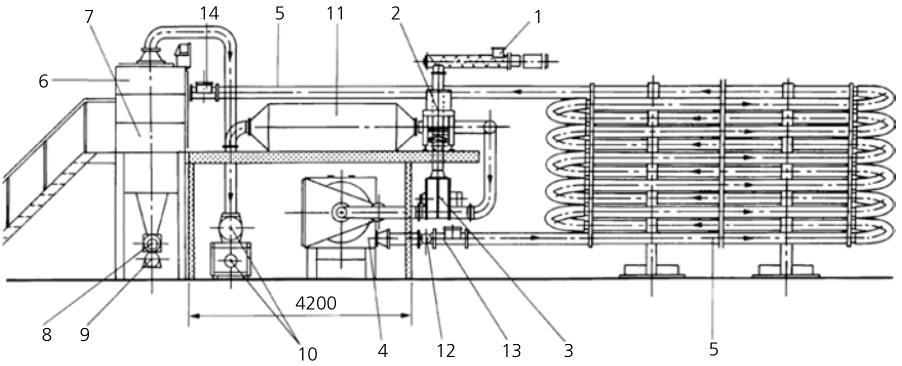


Figure 3.14 Schematic diagram of a cocoa powder milling, sifting and cooling unit. (1) Dosing screw, adjustable for broken cocoa cake; (2) metal detector for broken cocoa cake; (3) rotary valve (blow-through-valve); (4) pin mill; (5) cooling tubes for cocoa powder; (6) cyclone pre-separator for cocoa powder; (7) dust filter for fine cocoa powder; (8) rotary valve; (9) discharge screw for cocoa powder; (10) rotary piston blower; (11) air cooler and dehumidifier; (12) ball valve (cleaning system); (13) sending station for pig; (14) receiving station for pig.

cocoa butter into its stable forms (see Figure 3.14). Incorrectly tempered cocoa powder may result in changes in its visual appearance, so-called “external” colour, and lumps may be formed. The visual appearance of powder will become lighter which is basically fat bloom. It should be noted that the so-called “intrinsic” colour of the powder (colour following use e.g. in a drink or cake) will not change.

For the production of cocoa powders with fat contents of less than 10% further extraction is needed and CO_2 and/or other solvents can be used. Other techniques such as cryogenic grinding of cocoa mass are available to produce cocoa powders with fat contents exceeding 30%. Normally the cocoa cakes produced have residual fat contents of 10–12% or 22–24% and by blending the different cakes in any ratio any cocoa powder type with specific characteristics can be produced. An advantage of this approach is that it is possible to standardise properties such as the colour of a powder.

It is also possible, however, to blend different cocoa masses before pressing to obtain cocoa cakes which can be pulverised without blending, but this is harder to standardise. During the cake mixing process, flavourings and/or lecithin can be added. The latter is added to increase the wettability of cocoa powder for specific applications, for example (agglomerated) dry drink mixes.

3.9.1 Types of cocoa powder

A wide variety of cocoa powders can be produced for many different applications, and the final characteristics may vary in:

- ***Fat content:*** generally ranging from 10–12% towards 22–24%. The following reasons may determine the choice:
  - *Price*: generally low fat cocoa powders are less expensive;
  - *Legal*: in relation with the labelling. See also EU directive 2000/36;

Table 3.4 Quality parameters for cocoa powder (*Source:* Cargill Cocoa, 2007).

Parameter	Value (range)	Method	Remarks
Fat content	10–24%	IOCCC 37, 1990	Depending cocoa powder type
pH	5.0–8.2	IOCCC 15, 1972	Depending cocoa powder type
Moisture	Maximum 4.5%	IOCCC 26, 1988	
Fineness	Minimum 99.8% passing sieve	IOCCC 11, 1970	Wet sieving using 75 μm sieve
Colour	Conform to standard		
Flavour	Conform to standard		
Total Plate Count	Maximum 5000 cfu/g	IOCCC 39, 1990	
Moulds	Maximum 50 cfu/g	IOCCC 39, 1990	
Yeasts	Maximum 10 cfu/g	IOCCC 39, 1990	
Enterobacteriaceae	Absent per gram	IOCCC 39, 1990	
Escherichia coli	Absent per gram	IOCCC 39, 1990	
Salmonella	Absent per 750 g	IOCCC 39, 1990	FDA sampling scheme
Contaminants	Conform EU legislation		Pesticides, heavy metals

  - *Taste*: high fat powders give improved flavour characteristics in certain applications;
  - *Colour*: specifically when "external" colour of powder is important. High fat powders are darker.
- ***Colour :*** the "intrinsic" colour can vary from light brown ("natural", non-alkalised) towards dark brown and dark reddish colours. Even black colours can be produced.
- ***Flavour:*** depending on alkalisation and roasting conditions, customised flavours can be developed. Flavours, for example vanillin, are added if required.
- ***Physical behaviour:*** addition of lecithin to cocoa powder will increase the wettability properties. Also, stabilisers can be added with other ingredients or flavours to produce premixes, for example for the dairy industry.

3.9.2 Quality of cocoa powder

Table 3.4 gives a selection of quality criteria for cocoa powder. These are generally accepted values, although other values may be used and/or added depending on the supplier and/or special requirements of the customers.

To produce products within the agreed specifications it is of great importance to start with good quality raw materials, followed by optimum processing conditions. When appropriate analysis and control schemes are implemented for the semi-finished products, a high quality cocoa powder can be produced. For final product approval it is recommended that relevant quality parameters are determined, for example colour, pH, flavour, fat content, fineness and microbiology.

Salmonella analysis of the final product is of great importance. Due to the nature of the harvest and subsequent fermentation in the country of origin and conditions in the supply chain, the presence of *Salmonella* cannot be excluded. The total bacterial load of cocoa beans can be up to $1–10 \times 10^6$ cfu/g. This can be reduced by roasting and/or nib treatment; both of which can also kill any *Salmonella* present. Besides validated processes it is also advisable to have robust sampling and analysis schemes on the final product for *Salmonella* (see Chapter 25). Unfortunately, when cocoa powder is contaminated with *Salmonella* it is not homogeneously distributed, therefore a sampling scheme such as is proposed by the FDA is recommended. Details about *Salmonella* contaminated products have been published (Gill *et al.*, 1983; Craven *et al.*, 1975; D'Aoust *et al.*, 1975) and it is known that *Salmonella* may survive for many months in chocolate. Additionally, when consumed in chocolate, *Salmonella* is protected by the fat in chocolate against the acidity of gastric juice and consequently relatively low levels of *Salmonella* may cause salmonellosis.

For specific applications (i.e. sterilised dairy products), other microbiological parameters such as thermoresistant spores are important to be determined. The shell content of cocoa powder (as well of cocoa mass) is another important quality aspect. The shell, being the outer layer of the cocoa bean, can be contaminated with sand, pesticides and so on. The shell is very hard and causes wear to grinding equipment. It is technically impossible to produce a completely shell-free cocoa but it should obviously be reduced to an acceptable level.

Cocoa powder is very sensitive to high temperature and to temperature fluctuations which may result in the melting and re-crystallisation of the cocoa butter. This is visible as fat bloom, changing the "external" colour of the powder. Melting and re-crystallisation will also lead to lump formation, a common problem that causes difficulties in processing cocoa powder. Due to the hygroscopicity of cocoa powder absorbance of moisture from its environment should also be avoided and appropriate packaging used. Multiply paper bags (with an inner polyethylene coating, liner or its equivalent) of 25 kg or 50 lbs are most commonly used to pack cocoa powder. Besides this supersacks/big bags (up to 1000 kg, 2204 lbs) and loose bulk deliveries in silo trucks (up to 20 000 kg) are used. Special skills and equipment are necessary when using this type of transport.

When cocoa powder is stored under proper conditions a shelf life of three years can be guaranteed. These conditions are:

- Dry and clean warehouse, free from any foreign odours, rodents, insects and so on.
- The relative humidity of the air should preferably not exceed 50%.
- The temperature in the warehouse should consistently be 18–22 °C (64–72 °F). Sharp fluctuations in temperature should be avoided.
- Exposure to heat sources such as sunlight, lamps and heating systems should be avoided.

Conclusion

The use of good raw material is essential for the production of high quality cocoa products. Many processes can be applied but experience and optimisation of the process conditions are needed to obtain a consistent final quality of the cocoa mass, cocoa butter and cocoa powder. Today cocoa products are available in a wide variety of flavours, colours and other important characteristics, which are then able to be used to produce unique cocoa- and chocolate-containing products.

Appendix: Manufacturers of cocoa processing equipment

There are several manufacturers and many brands of cocoa processing equipment and inclusion/exclusion on this list does not imply any recommendation or otherwise.

Bühler Barth GmbH, Freiberg am Neckar, Germany.

Hamburg Dresdner Maschinenfabriken GmbH, Dresden, Germany (Probat, Petzholdt, Bauermeister and MacIntyre brands).

JND Technologies Limited, Retford, UK.

Micronising Company (UK), (1998) Framlingham, Suffolk IP13 9PT, UK.

Royal Duyvis Wiener B.V. (incorporating FB Lehmann) Koog ann de Zann, The Netherlands.

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CHAPTER 4

Sugar and bulk sweeteners

Christof Krüger

4.1 Introduction

Sugar is a sweet-tasting crystallised saccharide extracted from sugar cane or sugar beet. Both the beet and the cane produce an identical natural substance, which is chemically termed “sucrose” or “saccharose”. Sugar cane has been grown in Melanesia, India and China since prehistoric times. The discovery of sucrose in the beet plant *Beta vulgaris* was made in Prussia in the eighteenth century. The first method of extracting the sucrose from beet was developed by Franz Karl Achard, the director of the Academy of Sciences in Berlin, at the end of the eighteenth century. In 1799 this was even considered by the author of a scientific publication as “the most important discovery of the eighteenth century” (Bruhns, 1997).

Sucrose is a disaccharide composed of the chemically linked monosaccharides glucose and fructose. This linkage, however, may be cleaved hydrolytically by acids or by the enzyme invertase (β-D-fructofuranosidase). The resulting mixture consists of equal parts of glucose and fructose and is called invert sugar.

A great many other saccharides also exist, such as the monosaccharides glucose (dextrose) and fructose, the disaccharide lactose and sugar alcohols, for instance sorbitol and xylitol. For the production of chocolate, sucrose is by far the most important sugar. With the increasing demand for low calorie, reduced glycaemic index or tooth-friendly products, however, other sweeteners are becoming more widely used.

4.2 The production of sugar

For the production of beet sugar, the beets, which contain about 14–18% sucrose, are cleaned and cut into slices. These are then extracted in hot water by counterflow processes. Together with the sugar, mineral and organic substances from the beet find their way into the raw juice produced. Since these non-sugar substances strongly inhibit crystallisation of the sugar, the solution must be purified. This is

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

carried out by adding slaked lime in order to flocculate or precipitate the majority of the water-soluble contaminants and even decompose a small proportion of them. When carbon dioxide is subsequently bubbled through the solution it precipitates the excess calcium hydroxide from the slaked lime in the form of calcium carbonate. This is then filtered off together with the precipitated non-sugar substances.

The clarified weak sugar solution produced in this way has a solids content of approximately 15% and is subsequently evaporated to about 70% dry solids. This solution is then further concentrated under vacuum until crystallisation starts. Cooling this syrup–crystal mix leads to further crystallisation of the sugar. The separation of the sugar from the first molasses or mother syrup is frequently performed in a centrifuging process. Crystallisation always requires several processing stages, since it is not possible to recover all of the sugar in a single step. White sugar therefore has to be crystallised in three or four different steps. Raw sugar factories produce brown raw sugar as an interim product by a simplified crystallisation process. This type of sugar contains impurities that are removed by means of further recrystallisation in sugar refineries. A by-product, called molasses, is the syrup obtained during the final crystallisation step, from which sugar can no longer be crystallised because of the high concentration of non-sugar substances. Beet molasses with about 83% dry solids contains about 50% sucrose and up to 11% inorganic substances, 4–5% organic acids and about 13% nitrogenous organic compounds. In addition, about 1–2% of the trisaccharide raffinose and traces of invert sugar may be found (Hoffmann *et al.*, 1985).

Sugar cane has a sucrose content of 11–17%. The raw juice in this case is manufactured by squeezing the crushed stalks on roller mills or by means of extraction equipment in combination with roller mills. What remains is the so-called bagasse, which serves either as fuel or as raw material for the production of paper, cardboard, hard particle board and so on. Since raw juice from sugar cane contains more invert sugar than the equivalent beet juice, a more gentle treatment is required to clarify the juice. A lime treatment, as used for the beet, would degrade the invert sugar, leading to the formation of undesirable brown colours. The chemical treatment required may be carried out by one of the following methods:

- A gentle lime treatment,
- A lime treatment plus “sulfitation” with sulfur dioxide,
- A lime treatment plus “carbonation” with carbon dioxide. This resembles juice clarification in the beet sugar industry, without, however, using the high temperatures normally employed in the latter.

The chemical juice clarification is preceded by a mechanical separation of suspended plant particles, for example by using hydrocyclones and bow-shaped sieves. Evaporation and crystallisation closely resemble the procedures used for the production of beet sugar. However, special purification, as well as the above clarification steps, are necessary in the refining of raw cane sugar because of the different composition of the non-sugar contaminants. These include carbonation with slaked lime and carbon dioxide or phosphatation, that is a slaked lime phosphoric acid treatment as well as a special colour removal with activated carbon.

Cane molasses of 75–83% dry solids contain about 30–40% sucrose as well as 4–9% glucose, 5–12% fructose, 1–4% other reducing substances (as invert sugar), 2–5% other carbohydrates, 7–15% inorganic substances, 2–8% organic acids and 2–5% nitrogenous organic compounds (Chen *et al.*, 1993).

4.3 Sugar qualities

The sugar industry supplies a wide range of crystallised and liquid sugars. Crystallised sugar is graded according to its purity and crystal size. The purity of all types of white crystallised sugars is extremely good. The sucrose content is generally more than 99.9% and only rarely falls below 99.7%. Any differences in quality result from minute quantities of non-sugar substances, which are mostly present in the syrup layer surrounding the sugar crystals.

In Europe, the quality criteria for sugar are determined by European Union (EU) market regulations and national legislation on sugar types. The EU sugar market regulations break crystallised sugars down into four categories, the quality criteria of which are summarised in Table 4.1.

The degree of optical rotation is a yardstick for the sugar purity. Refined sugar, as a rule, gives values of 99.9°S (this is a purity measurement, not degrees of rotation). The water content must not exceed 0.06% and in general does not exceed 0.03% in good quality crystallised sugar. The amount of invert sugar present should be not more than 0.04%. Once again the values obtained in practice are frequently much lower. Colour in solution is measured in a

Table 4.1 Quality criteria of white crystallised sugar according to EU market regulations.

Category	1 Refined sugar	2 White sugar (standard quality)	3	4
Optical rotation (°S, min.)	—	99.7	99.7	99.5
Water (%, max.)	0.06	0.06	0.06	
Invert sugar (%, max.)	0.04	0.04	0.04	—
ICUMSA colour type colour type unit (max. points, 0.5 units = 1 point)	(2) 4	(4.5) 9	(6) 12	—
Ash by conductivity (%); (max. points, 0.0018% = 1 point)	0.0108 6	0.0270 15	—	—
Colour in solution; ICUMSA units, max. points (7.5 units = 1 point)	(22.5) 3	(45) 6	—	—
Total score according to EU Point score (max.)	8	22	—	—

Table 4.2 Different grades of sugar according to their particle size.

Grade	Particle size
Coarse sugar	1.0–2.5 mm grain size (0.04–0.1 in)
Medium fine sugar	0.6–1.0 mm grain size (0.02–0.04 in)
Fine sugar	0.1–0.6 mm grain size (0.004–0.02 in)
Icing sugar	0.005–0.1 mm grain size (0.2×10^{-3} to 0.004 in)

50% solution with a pH value of 7.0 at a wavelength of 420 nm. The coefficient of extinction established in this way and multiplied by 1000 represents one ICUMSA unit (International Commission for Uniform Methods of Sugar Analysis). The ICUMSA colour type (Braunschweig system) is determined by visual comparison with calibrated colour standards, which may be obtained from the Nordzucker AG ITB (formerly The Institute for Technology of Carbohydrates – Sugar Institute, Braunschweig, Germany). The ash content is determined in a 28% solution by conductivity measurements as the so-called "conductivity ash". According to the method employed, 1 μS/cm in a 28% solution represents 5.76×10^{-4}% ash. The values thus determined are converted into points and the points added up to give a total score for the sugar. As a rule, category 2 sugar is used for the manufacture of chocolate. Category 3 sugar is slightly cheaper and of a quality, which in most cases suffices for the manufacture of chocolate. It is, however, not available in many countries.

White crystallised sugar should be free flowing and have crystals of uniform particle size. There are no legal stipulations regarding grains or particle size. Nevertheless, the following grading may be carried out by sieving and is more or less generally accepted (Table 4.2; Diefenthäler, 1974).

The manufacture of chocolate masses is predominantly based on the use of medium fine sugar. Some chocolate manufacturers, however, insist on certain specifications concerning the particle spectrum. For example, some factories which refine masses in a two-step procedure (see Chapter 9) specify a spectrum of 0.5–1.25 mm (0.02–0.05 in) with an amount of fine grain [<0.2 mm (<0.008 in)] up to, but not exceeding, 2%.

4.4 The storage of sugar

In most cases, sugar is delivered to the chocolate industry by means of road tankers and not, as in the past, in bags or sacks. The sugar is pneumatically discharged from the vehicles into silos, where it is stored until further processing. Four factors are important in the silo storage of crystal sugar (Kelm, 1983): grain structure, moisture content, apparent of bulk density and angle of repose.

The grain structure of crystallised sugar is determined by the grain size, shape of the grains and the grain size distribution. The sugar industry supplies sugar that has been sifted to well-defined particle sizes, shows a good fluidity and is thus suitable for silo storage. In European countries, such as the UK, France and Germany, the chocolate industry is mainly supplied with sugar within the size range 0.5–1.5 mm (0.02–0.06 in). The amount of dust [grain size ≤0.1 mm (≤0.004 in)] is generally below 1% at the time of delivery in a road tanker.

The sugar should, if possible, consist of regular-shaped individual crystals, since irregular conglomerates have a detrimental effect on the bulk sugar's rheological properties. Problems may also arise from sugar dust. This may be formed during pneumatic handling because of friction against the inner surfaces of pipelines, especially at the site of manifolds. The amount of fine grain [<0.2 mm (<0.008 in)] and dust [<0.1 mm (<0.004 in)] present in the sugar correlates with its flowability and both should therefore be kept as low as possible. With 10% dust, storage and discharge problems are likely to occur. At dust levels of 15% or more, proper silo storage becomes impractical (Gaupp, 1972). Thus, special attention should be paid to ensuring an optimum layout of handling equipment, such as pipeline design, manifold radius and feeding rate, in order to keep the mechanical breakage of the sugar as low as possible.

A minimum feed rate of about 11 m/s (36 ft/s) is required for sugar transport. However, the handling conditions should be designed in such a way that the feeding rate does not exceed a speed of about 22 m/s (72 ft/s; Tills, 1970).

The moisture content of sugar is extremely low. Its actual level, however, has a decisive influence on its storability. After drying and cooling, freshly produced sugar has a total water content of about 0.1%, which is further reduced to 0.03–0.06% by conditioning in the silo of the sugar factory.

The surface moisture of the sugar changes as a function of the relative humidity of the ambient air. Figure 4.1 shows this dependency by means of the sorption isotherms of sugars of differing purities at 20 °C (68 °F; Kelm, 1983). Each sorption isotherm is a function of the sugar's purity and also of its ash content, traces of invert sugar and crystal size. As may be seen, the curve runs almost parallel to the abscissa at 20–60% air relative humidity. This implies that there is practically no water uptake even when the relative humidity of the air is increasing. Only when the relative humidity of the air exceeds 65% water is increasingly absorbed on the crystal surface. This implies that proper storage requires a temperature of 20 °C (68 °F) and a relative humidity ranging from 20 to 60%.

A relative humidity of more than 65% exponentially increases the water content in the sugar. Wet sugar must be avoided at all costs as it can become chemically and microbiologically contaminated. In addition, if wet sugar is stored at a relative humidity below its equilibrium relative humidity (ERH) the sugar will cake during drying and become lumpy.

Purer sugars (category 1 with lower ash content) and sugars with a coarser particle structure possess superior storage properties. On delivery, the surface water content of any sugar should not exceed 0.03% (Neumann, 1974).

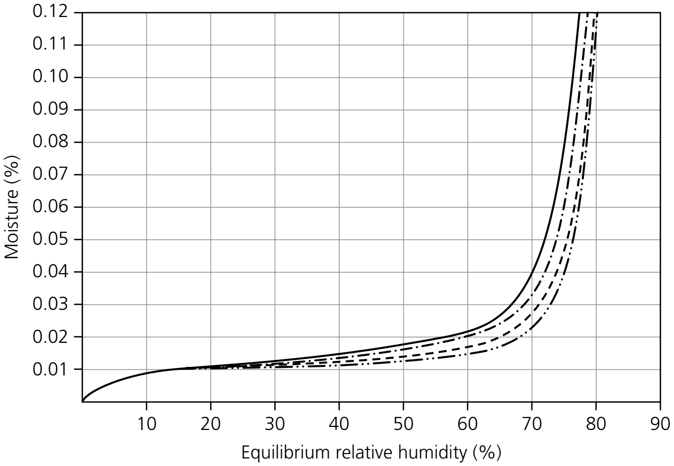


Figure 4.1 Sorption isotherms for crystallised sugars at 20 °C (68 °F; Kelm, 1983). Key: —, white sugar, fine, 0.0130% ash content; — · — · —, white sugar, coarse, 0.0135% ash content; ------, refined sugar, fine, 0.012% ash content; — · · — · · —, refined sugar, coarse, 0.0012% ash content.

According to 1972 EU sugar regulations, the water content in crystallised sugar, measured by loss on drying may reach a maximum of 0.06%.

External sugar silos should be equipped with adequate insulation as well as with heating elements in the silo walls to avoid the problem of condensation. However, some outdoor silos are constructed without insulation but the head-space in the silos is continuously filled with dried air, fed in through pipelines. Sometimes only the supporting case is heated.

The bulk density depends on crystal size and size distribution, but for a typical standard white granular sugar the maximum bulk density may be taken to be 850 kg/m^3 (53 lb/ft^3). When designing silo systems in practice, however, it is somewhat less and only reaches 750 kg/m^3 (47 lb/ft^3) during filling. At a surface moisture of 0.02–0.04%, the angle of repose of the sugar varies between 35 and 41°. The layout of sugar silos is often based on an angle of repose of 45–50°, with the discharge level in the tapered part being inclined at least 55° towards the horizontal. If the discharge angle is too small, proper discharge may be impeded. This may even lead to partial segregation, since larger crystals fall out more easily, whereas the smaller ones stick to the slip plane where they build up into a layer.

4.5 Sugar grinding and the prevention of sugar dust explosions

In contemporary chocolate production a two-stage refining process is normally used (see Chapter 9). This employs a two-roll pre-refiner to pre-grind granulated sugar together with other solid ingredients, which then become the feed

Table 4.3 Classification of sugar mills according to their operating mechanisms.

1. Mills with stress exerted by means of one solid surface or by the collision of two particles
    - **1.1.** Mills with rotating grinding devices
        - **1.1.1.** Mills with a grinding track
            - Hammer mill
            - Turbo mill
            - Impact pulveriser
        - **1.1.2.** Mills without a grinding track
            - Pin mill
    - **1.2.** Mills without moving mechanical parts
        - Air jet mills
2. Mills with stress exerted between two solid surfaces
    - Roll mill
    - Ball mill

material for a five-roll operation. More traditionally, in some chocolate factories the sugar is still pre-crushed to powdered or icing sugar, before being mixed with the cocoa mass, the milk powder and other ingredients and then roller refined in a single-stage process. Crystallised sugar is a brittle, medium-hard material. Its crushing during grinding takes place following fracturing processes, triggered by elastic tensions within the crystal. These fractures start propagating in the areas of minute structural flaws, which are always present in solid bodies. Since the frequency of such structural flaws is reduced with decreasing particle size, a higher energy input is required for the production of new interfaces when very fine sugar is required.

Three stress mechanisms are involved in the crushing of solid bodies by mechanical means (Rumpf, 1959):

- Compression crushing between two solid surfaces,
- Impact crushing by a solid surface or by particle–particle collisions,
- Using the surrounding medium to shear the material (i.e. solid surfaces are not involved).

Impact stressing is the most effective way of crushing sugar (Niedieck, 1971, 1972), and crushing by impacting with a single solid surface is the most common principle of present-day sugar mills. Table 4.3 shows a classification of sugar mills according to the type of breaking mechanism employed (Heidenreich and Huth, 1976).

Obtaining a closely defined particle spectrum during the grinding process is a major objective in the crushing of granulated sugar, because it results in improved flow properties of the chocolate mass produced. However, each mill will give its own particle size distribution in practice (see Chapter 9). For organoleptic reasons the maximum particle size should not exceed about $30\,\mu\text{m}$ (1.2×10^{-3} in) in chocolate. On the other hand, $6\,\mu\text{m}$ (0.5×10^{-3} in) is the minimum size, if optimum flow properties are to be achieved in the chocolate mass (Niedieck, 1971, 1972;

see Chapter 11). Numerous attempts have been made to fine-grind crystallised sugar within these limits. However, practice has shown that these restrictions are extremely difficult to conform to, even when the grinding process is combined with a separation/classification stage. It is equally impractical to achieve a controlled crystallisation of the sugar within this narrow particle range at the production stage in the sugar factory (Heidenreich and Huth, 1976). Also for taste reasons it is not advisable to use sugar ground separately to its final fineness (see Section 4.6). In order to obtain ultimate fineness in chocolate with a satisfactory texture, the mass containing relatively coarse sugar is normally processed by means of roller refining.

Icing sugar shows a tendency to form lumps. This is because freshly ground crystallised sugar possesses amorphous surface layers, which are able to take up moisture at higher rates and lower relative humidities than is the case for the crystallised parts. Those amorphous surface layers take up water vapour until they recrystallise, expelling water in the process. This leads to the formation of sugar solution, which bonds the particles together and becomes even firmer as the solution solidifies on drying. It is these solid bonds between the particles that cause a hardening of the icing sugar (Roth, 1977). It is thus advisable to process any ground sugar as speedily as possible and to use a tank with an agitator and screw discharge.

The risk of sugar dust explosions calls for special attention. The explosion of a sugar dust/air mixture may be triggered when a minimum concentration of sugar dust has been reached simultaneously with high ignition energy. This may be due to electrostatic charging, friction or impact sparks. Only particle sizes of about 400 μm and bigger cannot cause explosions (Beck and Jeske, 1996). Tests have shown that a concentration of 30 g/m^3 (0.8 oz/yd^3) of sugar dust with particle sizes up to 250 μm (0.01 in) is sufficient to cause an explosion (Schneider, 1969). These conditions can be roughly determined by visibility. With a concentration of 20 g/m^3 (0.5 oz/yd^3), the visibility is 1 m (3.3 ft) at the most. At a concentration of 50 g/m^3 (1.3 oz/yd^3), a 25 W light bulb is barely visible from a distance of 3 m (9 ft; Dietl, 1961).

A great many preventive measures can be taken to avoid explosions and it is not possible to discuss them all here in detail. However, it is useful to briefly discuss some of the most important safety measurers (Schneider, 1969; Barth *et al.*, 1996)).

Powder mills should be situated in separate, enclosed rooms, which should, if possible, have a high ceiling, be well ventilated and situated on the top floor. Massive, sufficiently pressure-proof walls and fire-resistant doors, opening to the outside, should separate these rooms from all other production facilities. A lightweight exterior wall or a “louvered” ceiling, which pressure vents to outside atmosphere, can serve as a pressure release system.

The equipment in the silos, the mill casing and the drive shaft must be electrostatically earthed. The feed devices should be equipped with magnetic solenoids to detect and remove any metal impurities, which might cause sparks, leading to an explosion inside the mill. These magnets should be interlocked with the mill drive in such a manner that the powder mill automatically shuts down under failure. Mill and elevator heads must be fitted with explosion ducts that vent a long distance away over the roof. Any dust accumulation must be removed from the point of formation.

Within the production localities, the concentration of the sugar dust in the air, when kept within normal operating conditions, is far below the level at which explosions can occur. However, dust deposits can give rise to an unexpected danger. This is because they may be carried up within any piece of production equipment by the pressure wave of a primary explosion within that machine and may then ignite themselves. It is absolutely essential to prevent any dust deposits building up in the production rooms. This is achieved by reducing dust production to a technically feasible minimum, frequent cleaning and a high standard of housekeeping. Suitable measures include the installation of air filters and the use of stationary vacuum equipment for the removal of sugar dust from the air and floor (Kordes, 1998).

All electrical installations should be kept out of rooms with an explosion risk. For example, it is preferable to install switches for electric lighting outside the milling rooms.

4.6 Amorphous sugar

Normally sugar is present in the crystalline state. Even the so-called "açucar amorfo" made in Brazil is not a truly amorphous sucrose, but only refined sugar of extremely small crystal size made from crude cane sugar (Bezerra, 1993). Truly amorphous sugar may be produced by spraying a sucrose solution into a hot and very dry atmosphere or by drying a thin film of sucrose solution at an extremely low relative humidity. The material produced in this way is highly hygroscopic (Powers, 1980).

Whilst crystallised sugar produces a sharp X-ray diffraction pattern, freshly prepared freeze-dried concentrated sugar solution, for instance, as well as sugar that has been ground over a longer period of time, does not produce such a diffraction pattern; that is to say it is amorphous. The heat of solution for crystallised sucrose is 16.75 J/g; however, for amorphous sucrose a heat of –41.45 J/g has been recorded (Van Hook, 1981). It is also known that amorphous surface layers are formed when icing sugar is produced by grinding crystallised sugar. The estimated proportion of this amorphous phase comes to approximately 2%, with an average layer thickness of 0.75×10^{-2} μm (0.3×10^{-6} in; Roth, 1977).

Apart from rapid moisture uptake from the ambient air, the other interesting facet of amorphous sugar from the chocolate manufacturer's point of view is its flavour absorption properties (Niedieck, 1981). It has been estimated that about 30–90% of the sugar become amorphous during the roller refining of chocolate masses. This has a decisive influence on the chocolate taste since amorphous sugar can absorb large quantities of different flavour compounds.

Chocolate masse made experimentally with sugar already ground to its final fineness is unsatisfactory in taste. This is thought to be because the amorphous sugar, normally produced during the refining stage, is missing and thus not available for flavour absorption. However, the rate of recrystallisation increases with increasing temperatures and relative humidities. At very high air humidities, the amorphous sugar that has just been produced may recrystallise immediately after passing through the roll refiner. The flavour components absorbed by the amorphous sugar during the refining of the chocolate masse are then released again during recrystallisation. Under normal conditions, even after a storage period, there is still some amorphous sugar in the finished chocolate.

Amorphous sugar may also have a positive influence in improving the heat stability of chocolate (Niedieck, 1981). A heat stable chocolate may be produced by adding 1–10% of finely ground amorphous sugar pastes to the conched chocolate masse. This is then subjected to several days' heat treatment at temperatures between 20 and 35 °C (68 and 95 °F). A network of matted sugar particles is then formed and stabilises the moulded chocolate, which will not soften again even at higher temperatures. The amorphous sugar may be made, for example, from something like a high-boiled candy mass, which includes sucrose and invert sugar or dextrose.

The advantage of some freshly manufactured crumb chocolates, as far as heat stability is concerned (compared with using single components, such as cocoa mass, milk powder and sugar) is that the sugar present in this crumb is at least partially in the amorphous state (see Chapter 6). This may be because the other ingredients of crumb, such as lactoproteins, fat and non-fat cocoa components are likely to have a pronounced retarding effect on the recrystallisation of the sugar.

4.7 Other sugars and bulk sweeteners

Apart from sucrose, there are numerous other sugars, polysaccharides, and sugar alcohols (polyols), some of which are important in the production of confectionery articles or have received special attention in recent years. More often than not they have major differences as far as physical, chemical or physiological characteristics are concerned and not all of them are suitable for the production of chocolate masses.

4.7.1. Invert sugar

Invert sugar is a mixture consisting of equal parts of the monosaccharides fructose and glucose (dextrose) that is produced during hydrolytic cleavage of the disaccharide sucrose, using either the activity of specific enzymes or that of acids. It is commercially available as syrup or as a partially crystallised paste with a dry solids content of 65–80%. Invert sugar is naturally present in many fruits and in honey. This product is not suitable for the manufacture of chocolate because it is almost exclusively supplied as an aqueous solution. Publications from Japan, however, refer to the manufacture of a pseudo-chocolate using freeze-dried dates in which the natural sweetness is almost exclusively made up of invert sugar. The sweetening power of invert sugar corresponds closely to that of sucrose (Anon., 1981).

4.7.2 Glucose

The monosaccharide glucose, also known as dextrose, is present in nature where it is found, together with fructose, in many fruits and in honey (invert sugar). Since it was prepared in the past from grapes, glucose is also known as grape sugar.

Today, glucose is normally produced industrially by an extensive hydrolysis of starch into high-conversion glucose syrup, from which it is crystallised in the form of glucose monohydrate. About 9% water is retained as a constituent of the glucose. Part of this water of crystallisation is released at temperatures that are commonly reached during the conching and produces an adverse effect on the rheological properties of the chocolate (see Chapter 11). It is preferable, therefore, to use glucose with no water content (anhydrous dextrose) for the manufacture of chocolate (Hogenbirk, 1985).

Although there have been many attempts to produce glucose chocolate, chocolates sweetened with only glucose have never become very popular because their taste characteristics differ from the standard product. This, however, does not prevent glucose being used in small quantities together with sucrose for the sweetening of chocolate. The sweetening power of glucose is only slightly more than half of that of sucrose. The current EU regulations allow for it to replace any or all of the sucrose in any chocolate recipe.

A variety of glucose syrups (corn syrups) with solids contents of about 70–80% may be produced by means of partial saccharification of starch. These syrups, together with glucose, may also contain maltose and other saccharides of higher molecular weight. Furthermore, syrups with various degrees of fructose are made by means of partial enzymatic isomerization of glucose. Glucose syrups are not used commercially to make chocolate on account of their water content, and nothing has yet been reported concerning the use of spray-dried glucose syrups in chocolates. On the other hand, large amounts of glucose syrup are used for the manufacture of hard-boiled candies, toffees, fondants and so on.

4.7.3 Fructose

Fructose is a monosaccharide, also known as fruit sugar, which is present, together with glucose, in almost all fruits and in honey (invert sugar). Fructose is currently produced in most large-scale processes by isolation and subsequent crystallisation from fructose containing glucose or invert sugar syrups. Fructose is naturally hygroscopic. The sweetening power of fructose is usually considered to be higher than that of sucrose. This, however, depends on a number of different factors (see also Section 4.9). The sweetening character of the monosaccharide fructose is somewhat different from that of the disaccharide sucrose (see also Section 4.10). Fructose is of importance for the manufacture of chocolates with low or reduced glycaemic response and suitable for diabetics. This is because there is only a low blood sugar increase in the body after eating fructose, unlike sucrose or glucose. Fructose is absorbed more slowly than glucose and only a small proportion is converted into glucose during absorption. This slow absorption, as well as the speedy metabolism, of the fructose reduces any rapid peaks in blood glucose concentration. Furthermore, fructose is mainly metabolised in the liver, that is without insulin involvement, whereas the corresponding glucose metabolism reaction depends on insulin. This makes fructose a valuable sugar substitute in low glycaemic diets. It should, however, be used only in moderate quantities in order to avoid overstressing the fructose metabolism.

Certain factors need to be taken into account when fructose is used in the manufacture of chocolate. For instance, the water content of the other ingredients, such as milk powder, should be kept as low as possible and the temperature during the conching processes should not exceed 40 °C (104 °F). Failure to do so may result in a gritty mouthfeel and/or the formation of degradation or reaction products that give off-flavours. This risk is very high since fructose caramelises and takes part in Maillard reactions fairly easily.

4.7.4 Tagatose

Tagatose is a monosaccharide, which has a similar structure to fructose. Traces of tagatose can be found in heat-treated dairy products, for exampe sterilized cow milk and milk powder (Levin *et al.*, 1995). It is produced from lactose, by enzymatic hydrolization to glucose and galactose, which are separated by a chromatographic fractionation. Then galactose is isomerized to tagatose under alkaline conditions, using calcium hydroxide. By treatment with carbon dioxide the suspension is neutralized and the calcium carbonate that is formed is then removed by filtration. Tagatose is a reducing sugar with a sweetening power of 92% compared to that of sucrose (Arla, 2004). However, as a monosaccharide it has a somewhat different sweetening character than sucrose (see Section 4.10).

Tagatose is metabolized like fructose, but only 15–20% of the tagatose are absorbed in the small intestine. The major part of ingested tagatose is fermented in the colon by the indigenous microflora (Calorie Control Council, 2004). Therefore tagatose has a low calorific value, prebiotic effects and a low glycaemic response (Arla, 2004). However, it has a similar laxative potential to the sugar alcohols (Levine *et al.*, 1995).

Tagatose can be used for tooth-friendly confectionery products (Nordzucker InnoCenter, 2005). Like fructose and other monosaccharides, it has a sweetness character with some scratchy and burning aftertaste, particularly when used to make chocolate. However, the sweetness profile of chocolates made with disaccharide alcohols or combinations of these sweeteners with polydextrose and sweetened up with intense sweeteners can be further improved by adding a small percentage of a monosaccharide, for example about 6% tagatose (see Section 4.10). Here tagatose has the advantage of being tooth-friendly and, because it is a reducing sugar, it also possesses flavour-enhancing properties.

4.7.5 Lactose

Lactose, also called milk sugar, is a disaccharide consisting of the monosaccharides glucose and galactose and is an integral part of all types of milk. In cow's milk it amounts to about 4.5%. The present-day large-scale production of lactose is based on whey, from which it is isolated to a very high degree of purity following several purification steps (see Chapter 5). Lactose crystallises with one molecule of water as a monohydrate. It does not expel this water, even when heated to 100 °C (212 °F). Lactose has been used traditionally in the production of milk chocolate as a constituent of full cream milk powder, skimmed milk powder or chocolate crumb. However, pure lactose has more and more frequently been added in small quantities to sucrose in the manufacture of chocolate (Hogenbirk, 1985).

Lactose monohydrate is non-hygroscopic and forms crystals harder than those of sucrose. Compared with sucrose, its sweetening power is very low.

4.7.6 Isomaltulose

Isomaltulose, which is also known by the trade name "Palatinose", has been detected in very small quantities in honey and cane sugar extract. It is produced by enzymatic conversion from sucrose (Weidenhagen and Lorenz, 1957). Isomatulose is a disaccharide made up of the monosaccharides glucose and fructose that crystallises with one molecule of constituent water. It has less sweetening power than sucrose. Like sucrose, isomaltulose has a calorific value of 4 kcal/g but it has a lower glycaemic response than sucrose, is tooth-friendly and well tolerated. It has been recommended as a sugar substitute for confectionery and chocolate items (Kaga and Minzutani, 1985; Beneo-Group, 2010).

4.7.7 Trehalose

Trehalose is a naturally occurring disaccharide consisting of two glucose molecules, which recrystallises as a dihydrate. It is found in small quantities in mushrooms, honey and shrimps and is produced enzymatically from starch. It has less sweetening power than sucrose. Trehalose, like sucrose, has a calorific value of 4 kcal/g. However, it has a lower glycaemic response than sucrose and is described as having "less cariogenicity" (Figura and Michaelis, 2003).

4.7.8 Polydextrose

Polydextrose is made up of glucose and small amounts of sorbitol which, because of its manufacturing process, also contains minor residues of citric acid. It is sold as an amorphous powder in several different quality standards. The original grades were not only hygroscopic, but also contained relatively large amounts of citric acid and had a tart and slightly bitter aftertaste. Newer grades, for example Litesse®II and Litesse®Ultra™, are much improved. They have a clean, mildly sweet flavour and can be used satisfactorily in chocolate when combined with other bulk sweeteners (e.g. lactitol) and further sweetened with an intense sweetener (Krüger *et al.*, 1996, Krüger and Fairs, 2000). Because polydextrose types such as Litesse®II, can caramelise, the flavour of chocolates made with polyols is enriched when these sweeteners are used together with a suitable polydextrose grade. The further developed Litesse®Ultra™ does not caramelise and therefore cannot participate in this Maillard reaction. It is, however, used in combination with sugar alcohols for the manufacture of sugarless and non-cariogenic chocolates (sometimes for flavour reasons blended with one of the caramelising polydextrose grades). Because polydextrose is an amorphous powder, an exothermic reaction takes place when it dissolves in water. This means that there is a "warming sensation" when it is dissolved in the saliva in the mouth. This can be used to offset the heat of solution of sugar alcohols when they are used together with polydextrose in chocolate. This means that sometimes undesirable "cooling effects" of sugar alcohol-sweetened chocolates can be overcome (see Section 4.10).

Since polydextrose is only partly metabolised in the human body, it is also used as a bulking agent for low calorie food. The FDA has recognised it as containing not more than 4 kJ/g, whereas sucrose and other carbohydrates contain about 17 kJ/g (Liebrand and Smiles, 1981). Polydextrose is also regarded as either a resistant polysaccharide (RP) or resistant oligosaccharide (RO), providing those physiological benefits associated with fibre (Craig *et al.*, 1996) and prebiotic effects (Probert *et al.*, 2004; Stowell and Krüger, 2006; Lahtinen *et al.*, 2010). It is in fact classified as a fibre and prebiotic ingredient in a number of countries.

Generally polydextrose can be eaten in larger quantities than sugar alcohols. In the EU and other European countries no laxative warning label is necessary for products containing even more than 10% polydextrose. During the last few years polydextrose has been particularly used for calorie reduced, "low carb", as well as low and reduced glycaemic products. It is also a suitable ingredient for tooth-friendly chocolates (Roulet *et al.*, 2001).

4.7.9 Inulin

Inulin is a naturally occurring carbohydrate mixture of oligo- and polysaccharides. These are composed of fructose units, mainly with an end standing glucose unit. Its degree of polymerisation ranges between 3 and 60 (Beneo-Group, 2012). Inulin functions as a carbohydrate reserve in thousands of plants and is produced commercially from chicory roots, which contain about 17% inulin. Nutritionally it is classified as dietary fibre and a prebiotic and low calorie ingredient (De Soete, 1996; Franck, 2002). It cannot be used to make tooth-friendly chocolates (Krüger, 1997), however, because it can be fermented by oral microorganisms. A lower percentage of inulin can be used in combination with sugar alcohols in “no added sugar” chocolates or with fructose or sugar alcohols in low glycaemic chocolates.

4.7.10 Sorbitol

Sorbitol is a monosaccharide alcohol that is present in small quantities in numerous fruits. The commercial production process is based on the catalytic hydrogenation of glucose. Sorbitol is hygroscopic and its sweetening power is about half that of sucrose. The heat of solution of sorbitol is such that it generates a slight cooling effect when it dissolves in the mouth. In the past sorbitol was one of the sweeteners used in the production of “no sugar added” chocolates (Caliari, 1983). Nowadays, “no sugar added” chocolates are more often produced with disaccharide alcohols, for example isomalt, maltitol or lactitol, often in combination with polydextrose.

4.7.11 Mannitol

Mannitol is a monosaccharide alcohol present in manna, the dried juice of the flower or manna ash. Its large-scale industrial production is a catalytic hydrogenation process based on pure invert sugar, which results in a mixture of sorbitol and mannitol, from which mannitol is separated in a multistep process. Mannitol has a low solubility and its sweetening power is comparable or slightly less than that of sorbitol. In combination with sorbitol and enhanced in its sweetening power by intense sweeteners, it was occasionally used for the production of “no sugar added” chocolates. However, of all the sugar alcohols, mannitol manifests the greatest laxative effect; the safe daily intake for adults is only about 10 g (0.35 oz; Kammerer, 1972).

4.7.12 Xylitol

Xylitol is a monosaccharide alcohol, which has only five carbon atoms unlike sorbitol and mannitol, which have six carbon atoms each. Xylitol is a naturally occurring sweetener and is present in numerous mushrooms, vegetables and fruits. Furthermore, xylitol is an inherent part of the normal human metabolism. Every human generates between 5 and 15 g (0.2 and 0.5 oz) of xylitol every day as part of the normal carbohydrate metabolism. The large-scale production of xylitol is based on birch wood, corncobs, straw and other plant material containing a high amount of xylan. Xylan, a polymer of xylose, is hydrolysed to xylose by means of acids once it has been isolated from the raw material. Following further isolation and purification of the xylose, it is hydrogenated into xylitol. Now xylitol is also produced by enzymatic conversion of glucose.

Xylitol is non-hygroscopic and has a very high heat of solution (153.1 J/g), which results in a remarkable cooling effect when melted in the mouth. The sweetening power of xylitol is the highest of all sugar alcohols and comparable to that of sucrose (Pepper and Olinger, 1988). However, as a monosaccharide, xylitol has a somewhat different sweetening character than sucrose (see also Section 4.10).

Xylitol's excellent characteristic is its prophylactic benefit with respect to dental caries. It inhibits the growth of the cariogenic bacteria *Streptococcus mutans* and other closely related bacteria in the oral cavity (Mäkinen *et al.*, 1989). As the highly publicised Turku studies proved, the progression of caries was arrested in people eating xylitol-containing sweets over a period of 2 years (Scheinin and Mäkinen, 1975). Furthermore, two extensive studies initiated by the World Health Organisation, each encompassing more than 900 school pupils in Hungary and Polynesia over the period 1981–1984, showed that caries progression may be significantly slowed if 15–20 g (0.5–0.7 oz) of xylitol in the form of xylitol containing chocolate and candy is eaten together with a normal, sucrose containing diet (Scheinin *et al.*, 1985; Kandelmann *et al.*, 1988). Chocolates may be manufactured with xylitol without any special processing. However, these have a noticeable cooling effect in the mouth.

4.7.13 Erythritol

Erythritol is a monosaccharide alcohol, which has only four carbon atoms. It occurs naturally in many fruits and vegetables. It is produced industrially by fermentation of glucose with an osmophile yeast.

Erythritol has a very high heat of solution (191.3 J/kg), which results in a strong cooling effect when melted in the mouth. Its sweetening power is about 70% of that of sucrose (Cerestar, 2004). As a monosaccharide with a very low molecular weight, erythritol has different sweetening characteristics from sucrose. This is perceived particularly in chocolates as a "burning, scratchy" aftertaste. Depending upon their lower molecular weight, this is a sensory property of monosaccharides (see Section 4.10).

Erythritol has however very different metabolic properties. It is absorbed very quickly from the small intestine and after absorption, about 80% of the erythritol remains unmetabolized and is excreted unchanged in the urine (Bornet *et al.*, 1996). This is not only the reason for its very low calorific value, but also for its high digestive tolerance. Erythritol has a very low calorific value of only 0.2 kcal/g, a glycaemic response of 0 and is tooth-friendly (Cerestar, 2004). Like xylitol it can significantly reduce the caries bacteria *Streptococcus mutans* (Mäkinen *et al.*, 2005).

Milk chocolates made with erythritol can be conched up to 70 °C (158 °F) and plain chocolates up to 80 °C (176 °F; Bechert and Wastijn, 2002).

4.7.14 Maltitol

The disaccharide alcohol, maltitol is produced by hydrogenation of maltose. Maltitol is non-hygroscopic and is slightly less sweet than sucrose, but sweeter than sorbitol and is suitable for "no sugar added" confectionery items. Although oral lactobacilli may ferment maltitol, it is not fermentable by streptococci and that is why maltitol is considered a tooth-friendly bulk sweetener (Lichtel, 1985). Because it is an anhydrous sweetener, maltitol can be conched at temperatures up to 80 °C (176 °F; Happel, 1995). In order to compensate for a sweetening power that is slightly inferior to that of sucrose, intense sweeteners are sometimes added to chocolates sweetened with maltitol. In combination with polydextrose, maltitol has been used to produce "low carb" chocolates.

4.7.15 Maltitol syrup

Maltitol syrups are hydrogenated maltose syrups containing maltitol, hydrogenated higher polysaccharides and sorbitol. They are commercially available under different trade names. The product is used for hard-boiled candies and as a crystallisation inhibitor of other sugar alcohols in tooth-friendly confectionery articles. Maltitol syrup cannot be used in chocolates because of its high moisture content. However, it can be used in chocolate fillings.

4.7.16 Isomalt

Standard isomalt is a mixture of equal parts of two disaccharide alcohols. It is produced by means of enzymatic conversion of sucrose to isomaltulose, which is then hydrogenated. One of these two sugar alcohols crystallises with two molecules of water, the other exhibits an anhydrous crystallisation. The total bound water content of the product reaches 5%. Isomalt is non-hygroscopic and about 40% as sweet as sucrose. It is used for the production of tooth-friendly candy and confectionery articles, which are also low or reduced glycaemic index. Isomalt also has prebiotic properties (Gostner *et al.*, 2006). The low sweetening power of isomalt in chocolate can be offset by means of intense sweeteners. Because standard isomalt loses its water of crystallisation at relatively low temperatures, the conching temperature of isomalt chocolates may not be higher than 45 °C (112 °F). Recently isomalt variants for special applications, including one for chocolates, have been developed and marketed. The dried quality "Isomalt LM" does not contain more than 1% moisture and can be used for plain chocolate masses to be conched up to 80 °C (176 °F) and milk chocolate masses to be conched up to 70 °C (158 °F; Palatinit GmbH, 2004). However, even with this isomalt it is advisable to conche milk chocolate masses containing high milk powder contents below 60–65 °C (140–149 °F) to avoid gritty agglomerates. A maximum conching temperature of 75 °C (167 °F) is however possible when using isomalt milk crumb (Bollinger and Keme, 1988).

The higher hygroscopicity of "Isomalt LM" has to be taken into consideration when it is being stored.

4.7.17 Lactitol

Lactitol is a disaccharide alcohol produced by the hydrogenation of lactose. It can be crystallised out as a mono- or dihydrate as well as in an anhydrous crystalline form. Lactitol is not hygroscopic and has a sweetening power of about

40% of that of sucrose. Lactitol monohydrate and anhydrous lactitol are suitable for the production of no sugar added chocolates and tooth-friendly confectionery when combined with intense sweeteners. Lactitol has prebiotic properties (Probert *et al.*, 2004) and can be used to produce low or reduced glycaemic index products. Lactitol monohydrate does not lose its water of crystallisation very easily, which means that conching temperatures up to about 60 °C (140 °F) can be used without any adverse effect on the flow properties of the chocolate. Chocolates made with anhydrous lactitol can be conched at temperatures as high as 80 °C (176 °F). Lactitol chocolates have viscosities comparable to those of sugar chocolates (Arntzen, 1992). Chocolates produced using lactitol, polydextrose type Litesse®II and the intense sweetener aspartame were found to be not significantly different from sucrose-sweetened chocolate when evaluated by a trained sensory panel (Krüger *et al.*, 1996).

4.8 Physiological characteristics of sugars, bulk sweeteners and special polysaccharides

Bulk sweeteners are sugar alcohols, also known as polyalcohols or polyols. Polydextrose and inulin are special polysaccharides. Because of their sweetening power and/or their lower calorific value, they are used as sugar substitutes. Sugar alcohols and polydextrose are applied in “no added sugar”, sugarless, “low carb”, low or reduced glycaemic index and calorie reduced confectionery and chocolate products. Fructose, isomaltulose and tagatose can be used for low or reduced glycaemic index products. In addition, sugar alcohols, polydextrose, isomaltulose and tagatose are tooth-friendly sugar substitutes as they are scarcely, if at all, converted into acids by oral micro-organisms, unlike sucrose, fructose and other saccharides.

Conventional milk powder cannot be used for tooth-friendly milk chocolates because the lactose in the milk powder is cariogenic. Therefore a lactose free skimmed milk powder substitute must be used. This is available by spray drying a solution of non-cariogenic sweeteners, for example lactitol, milk proteins and milk minerals, which are necessary for a good milk flavour. Milk fat can be added to the conched masse (Roulet *et al.*, 2001).

It is important to take into account the laxative effects of the sugar alcohols and tagatose. The EU Scientific Committee on Foods has emphasised that the laxative effect of sugar alcohols should not be neglected and stated that “consumption of the order of 20 g (0.7 oz) per person per day of polyols is unlikely to cause undesirable laxative symptoms. The safe level for individual polyols ingested singly is higher in many cases”. The Committee was fully aware that most people will tolerate sugar alcohols even at levels of 30–50 g (1.1–1.8 oz) per day without any laxative effect (van Esch, 1987). The sugar alcohol erythritol, has an even higher digestive tolerance (Cerestar, 2004).

Table 4.4 Amounts of sugars, sugar alcohols (Kammerer, 1972) and polydextrose (adapted from Craig *et al.*, 1998) that can be tolerated in the diet. Reproduced with permission of Food and Agiculture Organization of the United Nations.

	Average daily intake in g/day (oz/day)		
	1 kg (2.2 lb)	**70 kg (154 lb)**	**20 kg (44 lb)**
	Body weight	**Body weight (adult)**	**Body weight (child)**
Mannitol	0.14	10	2.8
	(0.005)	(0.35)	(0.1)
Sorbitol	0.43	30	8.6
	(0.02)	(1.1)	(0.3)
Xylitol	0.43–0.71	30–50	8.6–14.3
	(0.02–0.025)	(1.1–1.8)	(0.3–0.5)
Fructose	0.71	50	14.3
	(0.025)	(1.8)	(0.5)
Sucrose	1.00–1.28	70–90	20–25
	(0.035–0.045)	(2.5–3.2)	(0.7–0.9)
Polydextrose	1.28	90	—
	(0.045)	—	—

A daily consumption of about 50 g (1.8 oz) of polydextrose, even consumed as single dose, is unlikely to cause gastrointestinal effects. The mean laxative dose of polydextrose is 90 g (3.2 oz) per day (Pfizer, 1978).

Table 4.4 summarises daily intake values as a function of body weight to illustrate the levels at which some of the sugar alcohols and polydextrose can be eaten without any undesirable side effects (Kammerer, 1972; Craig *et al.*, 1998).

All sugar alcohols have less metabolizable energy than sugar. This fact has been taken into account by legislative bodies. The current EU Nutritive Labelling Directive designates an energy value of 2.4 kcal/g (10 kJ/g) for all sugar alcohols, which is 40% less than the value for sugar, which is 4 kcal/g (17 kJ/g). A summary of European and USA legislative calorific values for sugar substitutes is given in Table 4.5. The glycaemic response and the suitability of these ingredients for tooth-friendly products is presented in Table 4.6.

Foods with low glycaemic effects (blood glucose raising ability) have been scientifically validated as having an important role in the dietary management of weight reduction, diabetes and reducing the risk of heart disease (Leeds *et al.*, 1996). Sugar alcohols, polydextrose, inulin, as well as fructose, tagatose and isomaltulose provide a means to producing low or reduced glycaemic index confectionery products because they have low glycaemic responses, as can be seen on Table 4.6.

It should be noted that there is no correlation between the glycaemic response of polyols or speciality carbohydrates and their molecular weight or number of

Table 4.5 Calorific value of sugar substitutes (kcal/g).

Sugar substitute	Europe	USA
Isomaltulose	4.0	4.0
Maltitol	2.4	2.1
Lactitol	2.4	2.0
Isomalt	2.4	2.0
Sorbitol	2.4	2.6
Xylitol	2.4	2.4
Tagatose	[1]	1.5
Erythritol	0.0	0.2
Polydextrose	1.0	1.0
Inulin	1.0	[1]

[1] No current legislation.

Table 4.6 Glycaemic response and suitability of sugar substitutes for tooth-friendly chocolate.

Sugar substitute	Substance group	Glycaemic response versus glucose = 100[1]	Suitable for tooth-friendly chocolate
Sorbitol	Sugar alcohol	<5	+
Mannitol	Sugar alcohol	<5	+
Isomalt	Sugar alcohol	4.7	+
Maltitol	Sugar alcohol	34	+
Lactitol	Sugar alcohol	2	+
Xylitol	Sugar alcohol	8	++
Erythritol	Sugar alcohol	0	+
Fructose	Saccharide	19	—
Tagatose	Saccharide	3	+
Isomaltulose	Saccharide	32	+
PDX Litesse®II	Polysaccharide	7	+
PDX Litesse®Ultra	Polysaccharide	4	+
Inulin	Polysaccharide	4	—

[1] Foster-Powell *et al.* (2002), Sydney University Glycaemic Research Service, personal communication, Cerestar (2004), Beneo-Group (2010).

carbon atoms per molecule. Molecular size is a poor indicator of physiological properties. The glycaemic response depends strongly upon the rate and efficiency of digestion by microbiological fermentation in the colon and its absorption and metabolism (Mitchell, 2002).

Even sucrose sweetened chocolates do not have a high glycaemic index. But using suitable sugar replacers can significantly reduce it even further. This is demonstrated in Table 4.7 for milk chocolates made using the recipe given in Table 4.8.

Table 4.7 Glycaemic response of milk chocolate made with 45% sucrose or sweeteners (Sydney University Glycaemic Research Service, personal communication).

Sweetener	Response
Sucrose	37
Maltitol	19
Lactitol/polydextrose	6

Table 4.8 Milk chocolate made with sucrose and sweeteners.

Sweetener	%
Cocoa liquor	11.00
Cocoa butter	22.00
Full cream milk powder	20.00
Skimmed milk powder	1.48
Sugar/Sweetener[1]	45.00
Lecithin	0.50
Vanillin	0.02

[1] 1. 45% sucrose, 2. 45% maltitol, 3. 33.00% anhydrous lactitol with 11.85% polydextrose, 0.13% aspartame, 0.02% acesulfame K.

4.9 The sweetening power of sugars and bulk sweeteners

In the sensory evaluation of the sweetening power, sucrose generally serves as a standard to which the sweetness of the other bulk sweeteners is compared. “Sweetening power” and “degree of sweetness” are the terms employed. The sweetening power is the intensity of sweetness expressed as a percentage in comparison with sucrose, which is assumed to be 100%. The degree of sweetness expresses the intensity of the sweet taste as a fraction of the sucrose’s sweetness, which is equal to 1.00. Table 4.9 lists the degrees of sweetness of important sugars and sugar alcohols (Hyvönen *et al.*,1977; Carpenter, 1984; Krüger *et al.*, 1996; Franck, 2002).

As can be seen from Table 4.9 fructose is sweeter than sucrose and the sugar alcohol xylitol is as sweet as sucrose. This table is representative of many publications. However, it only provides guideline values for the confectioner, because many comparisons were apparently based on aqueous solutions of pure sugars and, more often than not, statements regarding the solids content of the sampled solutions are missing. It is, moreover, important to remember that the sweetening power of various sweeteners does not increase linearly with concentration and is dependent on temperature and other raw material ingredients in the foodstuffs, as well as the pH value.

Table 4.9 Relative degree of sweetness of different saccharides and sugar alcohols (adapted from Hyvönen *et al.*, 1977; Carpenter, 1984; Krüger *et al.*, 1996; Frank, 2002).

Sugar	Relative sweetness
Sucrose	1.0
Xylitol	1.0
Fructose	1.2
Maltitol	0.8
Erythritol	0.7
Sorbitol	0.6
Mannitol	0.6
Isomaltulose	0.5
Isomalt	0.45
Lactitol	0.35
Inulin	0.10

There are also synergistic effects. These phenomena cause sugars in mixtures to mutually enhance their sweetening power as well as their other sweetness characteristics. Fructose in milk chocolate has been found to taste only slightly sweeter than sucrose, yet mixtures of fructose and sucrose were very much sweeter. Even though glucose in a 10% aqueous solution shows a markedly lower sweetening power than sucrose, milk chocolates sweetened by anhydrous dextrose tasted almost as sweet as those made with sucrose. The sweetness also increased when part of the sucrose was replaced by anhydrous dextrose. However, glucose leaves a burning taste in the mouth, which rather enhances the impression of sweetness instead of moderating it. Fructose also gives a "pungent" sweetness in milk chocolate, but is felt to be pleasantly mild in, for example, chocolate drinks (Krüger *et al.*, 1987).

At present, theoretical calculations are unable to predict the sweetness of cocoa containing, or other products, in which some or all of the sucrose is replaced by another type of sugar or by a sugar substitute. They can only provide rough guidelines and it is always necessary to carry out sensory evaluation on actual samples of the product. In order to obtain the best results, a range of recipes should be tested.

4.10 Other sensory properties of sugars and bulk sweeteners

Sweeteners differ not only in their degree of sweetness but also in their sweetening character (Krüger and Fairs, 2000). There is a very important difference between monosaccharides and monosaccharide alcohols on the one hand and disaccharides, disaccharide alcohols and polysaccharides on the other.

Table 4.10 Molecular weights (MW) of sugars and bulk sweeteners.

Poly-/disaccharides	MW	Monosaccharides	MW
Polydextrose	~2000	Sorbitol	182
Lactitol	344	Glucose	180
Maltitol	344	Fructose	180
Isomalt	344	Tagatose	180
Sucrose	342	Xylitol	152
Lactose	342	Erythritol	122
Isomaltulose	342		

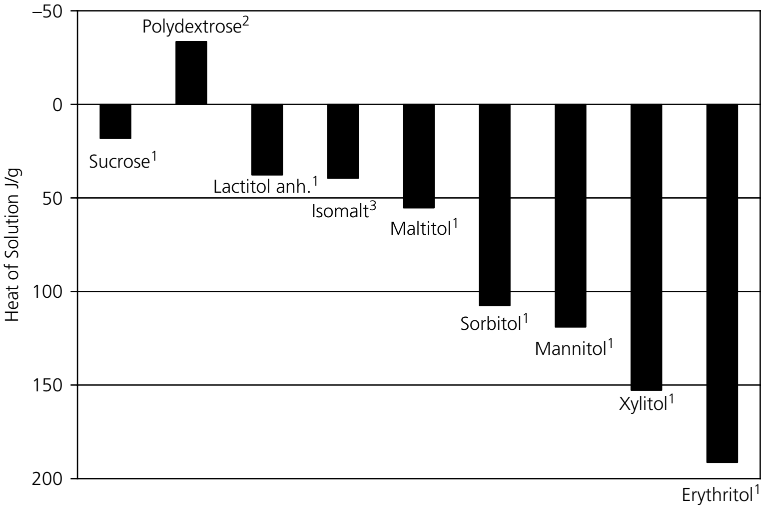
Monosaccharides, like the sugars glucose, fructose and tagatose and the monosaccharide alcohols sorbitol, mannitol, xylitol and erythritol, have a "burning, scratchy" aftertaste in chocolates and fat fillings. Disaccharides (such as sucrose and lactose) disaccharide alcohols (such as maltitol, isomalt and lactitol) and polysaccharides (such as polydextrose and inulin) have a mild sweetness and no aftertaste in chocolates and fat fillings. This is possibly a result of the higher osmotic pressure caused by the dissolution of the monosaccharides in the saliva compared with that of the disaccharides and polysaccharides. The osmotic pressure depends on the molecular weight of the dissolved substance; the smaller the molecular weight, the bigger is the osmotic pressure at the same concentration. Compared to disaccharides and disaccharide alcohols, monosaccharides and monosaccharide alcohols have significantly smaller molecular weights, which cause higher osmotic pressures. This means, the smaller the molecular weight of a sweetener is, the more it causes a "burning scratchy" aftertaste.

On the other hand chocolates made with polydextrose and/or disaccharide alcohols and sweetened with intense sweeteners, like aspartame, sucralose, stevia and so on often have a somewhat "flat" sweetness. This can be improved by using about 6% fructose or about 5% xylitol or about 4% erythritol.

Table 4.10 gives the molecular weights of common sugars and bulk sweeteners.

As noted earlier, a further sensorial difference between sugar and sugar alcohols is in their heats of dissolution in water. In the case of erythritol and xylitol, for example, this produces a noticeable cooling effect in the mouth. In contrast, polydextrose and inulin release heat of solution (De Soete, 1995). The heat of solution of common bulk sweeteners and sugars in comparison to sucrose is given in Figure 4.2.

In comparison to sucrose, erythritol, xylitol and sorbitol have strong cooling effects. This can be advantageous for the production of refreshing peppermint or fruit fillings for pralines and filled chocolates. In unfilled plain and milk chocolate tablets and bars, a cooling effect is not expected and therefore normally considered undesirable. In this case the cooling effect of



References: [1] Gehrich, 2002; [2] Craig *et al.*, 1996; [3] Sträter, 1989.

Figure 4.2 Heat of solution of bulk sweeteners and sugars.

the various polyols or fructose can be balanced by combining these sweeteners with polydextrose or inulin.

4.11 Solubilities and melting points of sugars and bulk sweeteners

The solubility and melting point of a bulk sweetener are very important from a processing point of view. High solubilities or low melting points can result in gritty agglomerates at higher conching temperatures. Table 4.11 lists the saturation concentrations of sucrose and the common bulk sweeteners, whilst Table 4.12 gives their melting points.

4.12 Maximum conching temperatures of chocolate masses with different bulk sweeteners

In addition to solubility and melting point, the presence or absence of water of crystallisation determines the maximum temperature at which a chocolate containing a bulk sweetener can be conched. At higher temperatures this water can be released, risking the formation of gritty agglomerates and producing unsuitable chocolate flow properties. Although the amorphous polydextrose cannot be completely dried, it can be used at temperatures of up to 80 °C (176 °F) when combined with anhydrous lactitol (Parsons and Fairs, 1998). Table 4.13 lists the maximum conching temperatures for chocolates masses made with different bulk sweeteners.

Table 4.11 Saturation at 20 °C (68 °F).

Sugar/sweetener	Saturation (g/100 g solution)
Sucrose	66.7
Fructose	78.9
Tagatose	58.0
Glucose	47.2
Glucose syrup	Non-crystallising
Lactose	16.0
Sorbitol	68.7
Xylitol	62.8
Maltitol	62.3
Maltitol syrup	Non-crystallising
Lactitol	56.5
Isomaltulose	29.0
Isomalt	24.5
Mannitol	14.5
Erythritol	37.0
Polydextrose	Non-crystallising

Table 4.12 Melting points of sugars and bulk sweeteners.

Sugar/sweetener	Melting point	
	°C	°F
Lactose (monohydrate)	>200	>392
Sucrose	185–186	365–367
Mannitol	165–169	329–336
Lactitol (anhydrous)	149–152	300–306
Dextrose (anhydrous)	146	295
Isomalt	145–150	293–302
Maltitol	147	297
Tagatose	133–137	271–279
Erythritol	126	259
Polydextrose	125–135	257–275
Isomaltulose	120–128	243–259
Fructose	102–105	215–221
Lactitol (monohydrate)	94–100	201–212
Sorbitol	92–96	198–205
Xylitol	92–96	198–205
Dextrose (monohydrate)	83	181

Table 4.13 Maximum conching temperatures of chocolate masses with different bulk sweeteners.

Sweetener	Water of crystallisation	Anhydrous	Maximum temperature with conventional conching	
			°C	°F
Fructose		+	40	104
Sorbitol		+	40	104
Xylitol		+	50	122
Standard Isomalt		+	40	104
Isomaltulose		+	60	140
Tagatose		+	60	140
Erythritol		+	70	158
Isomalt LM		+	80	176
Maltitol		(+)	80	176
Lactitol monohydrate		+	60	140
Lactitol anhydrous		+	80	176
Polydextrose (in combination with anhydrous lactitol)		(+)	80	176

4.13 Separate conching process for "no sugar added" chocolates

A special conching process has been developed, which enables the taste and texture of "no added sugar" chocolates to be improved and gritty agglomerates avoided. In this process the mixture of cocoa liquor and milk powder, with a proportion of the cocoa butter, is conched at any temperature without the sweetener and before roller refining to remove the moisture from the milk powder. The sweetener is roller refined separately with portions of the cocoa butter and lecithin and then mixed together with the conched masse with the rest of the cocoa butter and the lecithin (Krüger *et al.*, 1996).

4.14 Pre- and probiotic chocolates

Prebiotic ingredients increase the growth and/or activity of probiotic bacteria in the gut. With the growing market demand to combine indulgence with healthy ingredients, chocolate products provide a good opportunity in which to add a combination of prebiotic ingredients and probiotic cultures. Inulin, polydextrose, tagatose, isomalt and lactitol are already used as bulk sweeteners with prebiotic properties.

The stability of the probiotic bacteria is mainly dependent upon the ingredients and water activity of the product as well as the temperature and relative humidity during production and storage. The water activity of the chocolate must be as low as possible. The separate conching process (see Section 4.13) should therefore be used, with the probiotic cultures being added at the beginning of tempering and the chocolate masses maintained at temperatures no higher than 30–32 °C (86–90 °F). A storage test for one year at 22 °C (72 °F) of a milk chocolate with polydextrose and lactitol as prebiotics and *Bifidobacterium lactis* and *L-Lactobacillus acidophilus* showed an excellent stability and survival rate of the probiotic bacteria (Danisco, 2007; Krüger and Philipp, 2007).

Conclusions

The past few years have seen many developments in the field of bulk sweeteners and speciality carbohydrates, with regard to their processing and the quality of the product. The advances have been such that it can now be very difficult to distinguish a "no added sugar" product from a standard one in taste and texture. There is still the remaining problem of limited tolerance due to the laxative side effects of sugar alcohols. In recent years some progress has been made by combining sugar alcohols with better tolerated sugar substitutes like polydextrose and fructose or the use of isomatulose.

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CHAPTER 5

Ingredients from milk

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5.1 Introduction

Milk chocolate is the most popular type of chocolate, the favourite of more than 50% of adult consumers (Global, 2011). Milk ingredients are essential in delivering the desirable flavour profile and texture that is characteristic of milk chocolate. Milk ingredients influence the flavour, colour, texture, flow properties and gloss, provide nutrition and improve the storage stability of milk chocolate (Campbell and Pavlasek, 1987).

The typical composition of cow milk is approximately 87% water, 4.9% lactose, 3.5% fat, 3.2% protein and 0.7% minerals. Milk is a biological product, so some variation in overall component concentrations and variation within components are to be expected. The fat and protein components show the most variation, which is influenced by breed, animal to animal differences, stage of lactation, feed, season and location. From an industrial ingredient perspective, some of this variation is minimised because ingredient processors typically use large volumes of commingled milk. However, for some ingredients this natural variation can have a great impact on ingredient functionality.

The incorporation of milk components into chocolate has both functional and legal limitations. The high water content of milk requires that it be processed into concentrated ingredients prior to incorporation into chocolate and the addition of too much milk fat can interfere with cocoa butter crystallisation. Milk chocolate typically contains 20–25% milk solids, and the legal minimum content of milk solids differs among countries. In the European Union, milk chocolate is required to contain at least 14% milk solids and not less than 3.5% milk fat. The milk solids may be obtained by partly or wholly dehydrated whole milk, semi- or full-skimmed milk, cream, dehydrated cream, butter or milk fat. The Codex standards (Codex, 1999b) specify a minimum milk solids content of 12–14% and a minimum of 2.5–3.5% milk fat. The United States requires a minimum of 3.39% milk fat. In many countries, milk fat is the only fat other than cocoa butter that is permitted in pure chocolate.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Other dairy ingredients such as whey protein, demineralised whey or lactose may be added to milk chocolate. The limiting amount is determined by taste, processing, economic benefits and legal regulations. For example, up to 5% lactose may be substituted for sucrose, and whey-based powders are legally accepted up to 5%, but they must be declared as an added other foodstuff (Bolenz *et al.*, 2003).

Technologies such as spray drying, membrane separation, fat fractionation and crystallisation allow for the production of dairy ingredients that are optimised for functional performance in chocolate. The processes used to produce milk ingredients are summarised in Figure 5.1. Continuing advancements in spray drying and membrane processing technologies result in improved processing efficiencies and the creation better ingredients for chocolate applications. The key to the success of designing milk ingredients for chocolate is understanding the requirements of the final application and manipulating the processing parameters to produce ingredients with the optimal properties for the specific application.

This chapter focuses on industrial milk ingredients used in chocolate. The chapter begins with a review of the major components of milk and their influence on chocolate. The composition, manufacturing processes and process variables that influence the functionality of concentrated milk fat-based ingredients and milk powders are discussed. Other factors that need to be considered when using these ingredients in the chocolate manufacture are also addressed.

5.2 Milk components

5.2.1 Milk protein

Milk protein contributes to the flavour, colour, flow and texture in chocolate (Keogh *et al.*, 2002). The total protein in milk is made up of two categories, the casein and the serum (whey) proteins. Each category is broadly defined by their chemical composition and physical properties and contains several proteins with different amino acid compositions and functional properties. More than 30 specific proteins have been identified in milk (Yamada *et al.*, 2002). Milk protein contains the nine essential amino acids required by humans. Milk protein is considered to be a good source of quality protein, adding to the nutritional profile of chocolate.

5.2.1.1 Milk protein composition

In cows' milk, the casein accounts for approximately 82% of the protein and the serum proteins are approximately 18%. The casein proteins contain phosphorus and coagulate at pH 4.6, their isoelectric point. The serum (whey) proteins do not contain phosphorus and remain in solution at pH 4.6. The term serum and whey are often used interchangeably to refer to the soluble proteins in milk. The

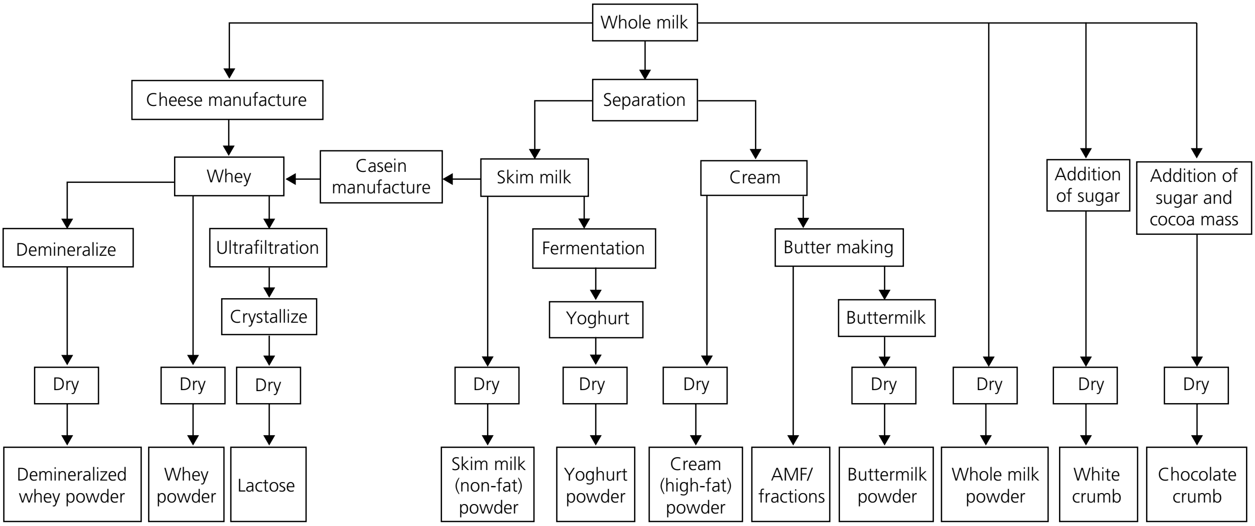

Figure 5.1 Flow chart of dairy processes and products used in milk chocolate.

term “serum protein” is used when referring to these proteins as they are found in native milk, whereas “whey protein” more accurately reflects the proteins when they have been recovered from the whey stream after cheese making.

The caseins (α_{s1}, α_{s2}, β, κ) are found in milk in the form of an open micelle structure suspended in the serum (aqueous) phase. The casein micelle is made up of small submicelles held together by calcium phosphate bridges. The casein micelles coagulate to form gels, either driven by acidification to the isoelectric point or by enzymatic processes (e.g., the rennet coagulation in cheese making). The serum proteins consist of β-lactoglobulin, α-lactalbumin, immunoglobulins, lactoferrins and other minor proteins. The serum proteins contain a large amount of disulfide bonds that yield a more compact, globular shape than the caseins. The serum proteins denature and unfold at high temperatures, unlike the casein proteins which are stable to heating.

5.2.1.2 Flavour contribution of milk proteins

Milk proteins contribute to the flavour of milk ingredients and chocolate through two mechanisms. The first being the Maillard reaction, which is a reaction between a reducing sugar and amino acids. The milk proteins serve as a source for the amino acids and the naturally occurring lactose in milk is a reducing sugar. The chemistry underlying the Maillard mechanism is extremely complex and a result of many different types of reactions that create desirable flavours in chocolate.

Milk crumb chocolates (see Chapter 6) are characterised by the more pronounced toffee flavours. Analyses have identified multiple components that are characteristic for toffee and malty flavours, among those are maltol, 3-methyl butanal furanones and pyrazines (Kriebardis and Wedzicha, 2005). Milk manufacturers wanting to produce crumb-like milk powders are looking to maximise those profiles during processing. Patents for processing those kinds of flavours have been issued (Hansen *et al.*, 2003). The essence of the patents is the addition of Maillard flavour components, like the Strecker aldehydes, or hydrolysed casein, whey or ketose saccharides to get the process started. Using intense heating of milk or enhancing pH in the milk prior to pasteurisation and drying have been investigated (Skytte, 2006), however few reports on the commercial success for those products are available.

The second mechanism whereby proteins contribute flavour is the breakage of disulfide bonds in the serum proteins during heat-induced denaturation that results in desirable cooked flavour notes in heated milk (Caric, 1994).

5.2.2 Milk fat

Milk fat contributes to flavour and texture and helps inhibits fat bloom in chocolates. Milk fat is found in fluid milk in the form of globules. The globule has a fat core surrounded by a protein and phospholipid membrane that keeps it emulsified in the serum phase. The phospholipids in the globule membrane are mainly lecithin (1% of the milk fat content) and provide emulsifying properties that lower the viscosity in chocolate (Beckett, 2000). Milk ingredients based on native fluid milk, such as cream and milk powders, contain milk fat in globular form. In the processing of concentrated milk fat-based ingredients, such as butter and anhydrous milk fat, the globule structure is broken and the membrane components are removed, leaving the core fat.

5.2.2.1 Milk fat composition

Milk fat has the most complex chemical composition of the edible fats and contains a high proportion of short-chain fatty acids (C4–C8). The core of the milk fat globule is predominately triglycerides, with small amounts of mono- and diglycerides, free fatty acids, sterols and the fat soluble vitamins (Table 5.1; Mulder and Walstra, 1974).

There are approximately 20 fatty acids that make up the majority of the fat content in milk, although over 400 different fatty acids have been identified (Jensen and Newburg, 1995). The typical composition of milk fat that is reported in the literature is shown in Table 5.2 (Mulder and Walstra, 1974). The C4–C14 and some of the C16 fatty acids are synthesised in the mammary gland of the cow (McGuire and Bauman, 2003; Parodi, 2004). The short-chain and odd carbon number (C15, C17) fatty acids are generated by fermentation of feed components (German and Dillard, 2006). The remaining C16:0 and the long-chain fatty acids originate in the diet and from lipolysis of adipose tissue (Parodi, 2004). Milk fat is comprised of fatty acids that are 65–70% saturated, 27–33% monounsaturated and 3.5–5.0% polyunsaturated. About 2–5% of the total fatty acids are *trans*-fatty acids that occur naturally due to bacterial metabolism in the rumen (Parodi, 2004).

The content of the individual fatty acids in milk fat can be greatly influenced by breed, stage of lactation, genetics, animal differences, feed and season. The influence of season is usually correlated with changes in feed – "summer milk fat" often referring to when the cows are on pasture and "winter milk fat" referring to

Table 5.1 Components of milk fat.

Component	Weight (%)
Triglycerides	98.3
Diglycerides	0.3
Monoglycerides	0.1
Free fatty acid	0.1
Phospholipids	0.8
Sterol	0.35
Carotenoid	Trace
Vitamins (mainly A, D and E)	Trace
Flavour compounds	Trace

Table 5.2 Fatty acid composition of milk fat.

Fatty acid	Typical composition[1]	Summer milk fat[2]	Winter milk fat[2]	Summer milk fat, minimum[3]	Summer milk fat, maximum[3]
C4:0	4.1	4.2	4.6	2.93	4.88
C6:0	2.4	2.3	2.7	1.54	2.65
C8:0	1.4	1.3	1.5	0.82	1.71
C10:0	2.9	2.6	3.4	1.77	4.08
C10:1	0.3	—	—	—	—
C12:0	3.5	3.0	4.2	1.99	4.69
C14:0	11.4	9.6	11.6	7.10	12.34
C14:1	—	—	—	0.51	1.04
C15:0	—	1.1	1.1	0.76	1.10
C16:0	23.2	23.3	29.1	24.95	32.08
C16:1	—	1.0	0.7	1.21	1.49
C17:0	—	0.8	0.9	0.41	0.57
C18:0	12.4	11.9	9.5	9.92	15.36
C18:1	25.2	28.1	21.3	21.22[4]	31.59[4]
C18:2	2.6	1.3	1.6	2.29	4.53
C18:3	0.9	1.1	1.4	0.20	0.64
C20:0	—	—	—	0.09	0.13
CLA	—	—	—	0.48[5]	1.00[5]
Others	10.0	—	—		

[1] Mulder and Walstra (1974).

[2] Badings *et al.* (1983). Summer and winter milk fat from The Netherlands.

[3] Kaylegian *et al.* (2009). Summer milk fat from the United States.

[4] C18:1 is a total of all C18:1 isomers reported.

[5] CLA is a total of all CLA isomers reported.

when cows are fed rations. The milk fat from cows on pasture in the summer contains higher amounts of unsaturated fatty acids (Badings *et al.*, 1983; Salamon *et al.*, 2006) and more carotenoids, resulting in a softer milk fat that has deeper yellow colour than milk fat from cows on rations. This is observed by chocolate makers when comparing functional differences between anhydrous milk fat (AMF) from the United States to AMF from New Zealand. Even within the same season the composition of individual fatty acids can vary quite a bit. Kaylegian *et al.* (2009) sampled milk from 45 farms in three regions across the United States in the same summer and reported ranges of C4 from 3.25% to 4.88%, C16 from 24.95% to 32.08% and C18:1 from 18.79% to 25.86% (Table 5.2). Differences in milk composition due to stage of lactation is illustrated by Lynch *et al.* (1992) who reported a change in C4 concentration from 4.5% at the beginning of lactation to 2.5% at the end of lactation and a C16 content that went from 24% to 35% from beginning to end of lactation.

The stereospecific position of fatty acids on the triglyceride molecule has an important relationship to its flavour, crystallisation and melting properties. The large number of fatty acids identified in milk fat yields over 100 000 individual triglycerides that are not well characterised for milk fat (Larsson,1994). In contrast, cocoa butter has a much simpler fatty acid composition and a known triglyceride profile (Longchampt and Hartel, 2004; see Chapter 7). The fatty acids in milk fat are esterified to the triglyceride structure in the mammary gland following a general order that is not random (Kaylegian and Lindsay, 1995; MacGibbon and Taylor, 2006; Parodi, 2004):

- C4 (butyric) and C6 (caproic) are in the sn-3 position.
- C8 (caprylic) is located in the sn-2 and sn-3 positions.
- C10 (capric) is located preferentially in the sn-2 position.
- C12 (lauric) is located preferentially in the sn-2 position.
- C14:0 (myristic) is in the sn-2 position.
- C16:0 (palmitic) is almost equally distributed in the sn-1 and sn-2 positions.
- C18:0 (stearic) is in the sn-1.
- C18:1 (oleic) is in the sn-1 or sn-3 position.

5.2.2.2 Flavour contributions of milk fat

One of the most important functions of milk fat in chocolate is its role in flavour – it directly provides flavour compounds, serves as a flavour precursor and as a flavour carrier. Free fatty acids, lactones, ketones, esters, aldehydes and carbonyls are important compounds from milk fat that contributors to flavour. Flavours derived from milk fat are generated by a number of mechanisms that occur during the manufacture of chocolate, including heating, hydrolysis or lipolysis, dehydration and decarboxylation. Milk fat is delicate and susceptible to deterioration upon rough handling, exposure to light, heat, and oxygen, which can cause undesirable flavours.

Lactones and methyl ketones are thought to be important in the flavour of milk chocolate. These compounds are formed from β-hydroxy fatty acids released from the triglycerides when milk fat is heated.

Although lipolysis is considered to be undesirable in most dairy products, it can be used to an advantage in milk chocolate. Fresh milk contains lipases, which hydrolyse the triglyceride molecules and release fatty acids including butyric, caproic and capric acids. These volatile flavourful fatty acids can impart a “buttery”, “creamy” flavour in milk chocolate. The natural milk lipase is normally inactivated during pasteurisation. In some cases, heating applied during some chocolate processes may be sufficient to release these fatty acids. Hydrolysed milk fats have been produced to enhance the buttery flavour of milk chocolate (Campbell and Pavlasek, 1987). The controlled use of lipolysis of milk fat is normally associated with chocolate manufactured in the United States and the reaction is used at lower levels in many European chocolates. The lipolysis reaction needs to be carefully controlled to avoid the cheesy and soapy flavours that are characteristic of a high degree of lipolysis, often referred to as lipolytic rancidity.

Oxidation of milk fat occurs when the unsaturated double bonds in the fatty acid are broken through a variety of mechanisms, including auto-oxidation or by exposure to light, heat and oxygen. The compounds formed as a result of oxidation may be low in concentration and individually undetectable. As the oxidation reactions progress, off-flavour compounds are formed in higher concentrations that are as described as cardboardy and fishy. To avoid the cardboardy flavour sometimes found in chocolate, exposure to oxygen should be avoided during storage by using appropriate packaging materials. This is of concern particularly in white chocolate where the natural anti-oxidants found in non-fat cocoa solids are not present.

5.2.2.3 Interactions of milk fat and cocoa butter

Milk fat is compatible with cocoa butter to a limited extent and is able to become part of the continuous fat phase of chocolate. Milk fat and cocoa butter have different stable crystal forms and, therefore, the two fats will not mix completely in the solid state (see also Chapters 7 and 13). Milk fat alters the temperatures at which the various crystal forms of cocoa butter occur. Milk fat slows the rate of cocoa butter crystallisation in mixtures of cocoa butter and milk fat, and this occurs in chocolate containing mixtures of these two fats (Timms, 2003). Increasing the amount of milk fat added to the blend alters the physical and functional properties of chocolate including hardness, ability to temper and melting point (Barna *et al.*, 1992; Full *et al.*, 1996).

The solid fat content of cocoa butter is much higher at ambient temperatures than most other natural fats, as shown in Figure 5.2. Milk fat is unlike cocoa butter in that it contains numerous different fatty acids, especially short-chain fatty acids. However, the compatibility of milk fat with cocoa butter is not caused by unique milk fat triglycerides, but occurs because the milk fat does not change the polymorphic form of cocoa butter at the typical level of milk fat addition to chocolate. The level of milk fat addition to cocoa butter required to cause changes to the crystal forms of cocoa butter is approximately 50% (Timms, 2003). The incompatibility of milk fat and cocoa butter at levels greater than this is not of practical concern to chocolate manufacturers because the level of addition of milk fat is usually limited to 30% of the total fat. At levels of milk fat addition above 30% of the total fat, chocolate becomes soft because more liquid fat is present at these very high proportions of milk fat. Softer products may be less acceptable to consumers and may bloom more readily if subjected to thermal abuse.

Most commercial milk chocolate products are made with a ratio of milk fat to total fat of between 12 and 32%. A general guideline is that, in order to achieve the desired physical properties of chocolate, a minimum solid fat content of 45% is required. Tempering conditions will need to be optimised to achieve this (Yella Reddy *et al.*, 1996).

Timms (1980) has shown that different portions of milk fat have different effects when mixed with cocoa butter. The low-melting triglycerides in milk fat have the effect of diluting the cocoa butter and hence soften the chocolate

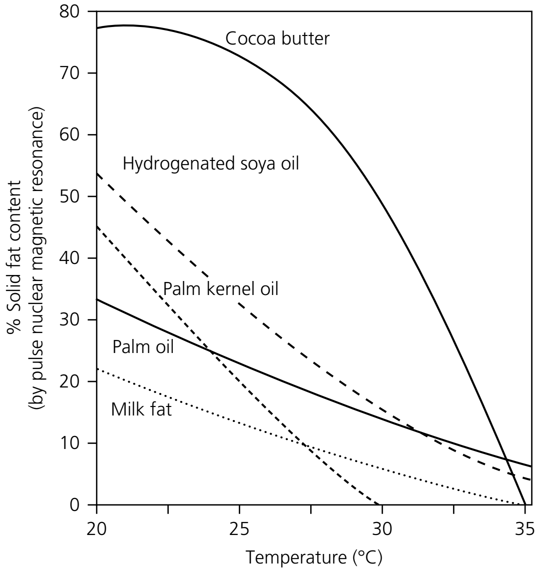

Figure 5.2 Typical solid fat content profiles of different fats at a range of temperatures.

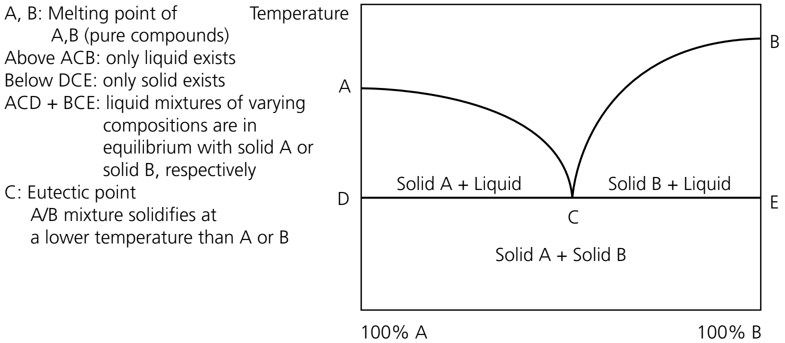

Figure 5.3 Phase diagram of a simple binary system (e.g., cocoa butter and milk fat).

because of their lower solid fat contents. The middle-melting triglycerides form a eutectic between cocoa butter and milk fat; that is, the solid fat content of the mixture of the two fats is less at any given temperature than a simple summation of the contributions to the solid fat content of the two components. The formation of a eutectic is shown in the simplified phase diagram in Figure 5.3. The overall effect of adding milk fat to chocolate is softening because of the low- and middle-melting triglycerides.

5.2.2.4 Free and bound milk fat

Milk fat influences the properties of chocolate depending on the form of the fat. It can be added to chocolate via roller-dried or spray-dried whole milk powder (WMP) and through the use of AMF. Spray-dried WMP, in which most of the fat remains bound, is termed a low free fat system. Replacing spray-dried WMP with skim milk powder (SMP) and AMF, so that all of the milk fat is available as

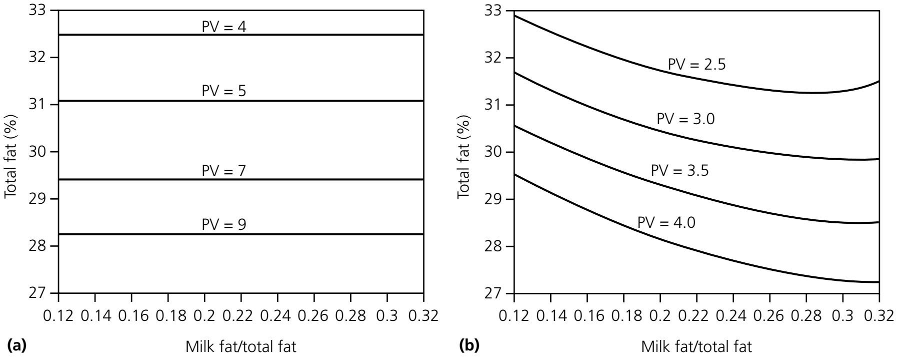

Figure 5.4 Effect of total fat and milk fat/total fat ratio on the plastic viscosity (Pa s). (a) Low free fat (b) High free fat.

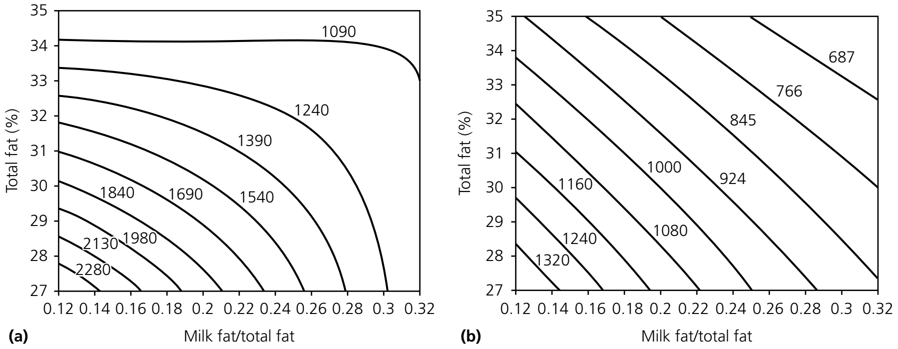

Figure 5.5 Effect of total fat and milk fat/total fat ratio on the chocolate hardness. (a) Low free fat (b) High free fat.

"free" fat, is termed a high free fat system, which results in alteration of the processing and sensory properties of the chocolate. The flavour differences between chocolate made using the two systems may be partly attributed to the different stages of the chocolate process at which the milk fat is added. AMF, when used with SMP in a high free fat system, is usually added at the viscosity adjustment stage, unlike the milk fat present in WMP, which is added at the start of the chocolate process. AMF in the high free fat system is sometimes not present at conching, when heating and some flavour generation occur.

Some manufacturers prefer the flexibility of being able to adjust the levels of SMP and milk fat independently in their milk chocolate formulations. However, this advantage can be outweighed by the need to carry supplies of two ingredients. In addition, specialised systems to handle both powders and liquid fats are required. Figure 5.4 shows the effect on the plastic viscosity (Chapter 11) in milk chocolate for a low free fat system (WMP) and a high free fat system (SMP and AMF). It is clear that there are significant rheological advantages in having a higher level of free milk fat, which also provides the benefit of potential savings in milk fat or cocoa butter. However, this advantage is offset by the softening effect of high levels of free milk fat. Figure 5.5 shows the hardness of chocolate products for a low free fat system and a high free fat system. There is a substantial softening in the chocolate product manufactured with high levels of free milk fat.

5.2.2.5 Fat bloom in chocolate

Fat bloom in chocolate is often characterised by the loss of gloss and dulling of the chocolate surface through to the presence of grey/white clusters that have the appearance of mould (Aguilera *et al.*, 2004; Hartel, 1999; Timms, 2003). Fat bloom also affects the texture of chocolate. Fat bloom can be classified into categories according to the conditions under which it is developed:

- Composition related,
- Processing related,
- Storage related.

Composition bloom occurs because of eutectic formation due to the use of incompatible fats, or levels of fat, in the recipe formulation. If the milk fat used exceeds the eutectic point, the two different fat structures will crystallise in an unstable network and the smaller triglycerides will be more mobile leading to fat migration and separation. Processing promoted bloom is mainly caused by under- or over-tempering of the chocolate (see Chapter 13). Under-tempering happens when the chocolate contains too much of the β′(IV) form and bloom appears in shortly after production when the quick transformation of the unstable β′(IV) to β(V) takes place. Over-tempering happens when too much seed has crystallised or the seeds are too large and bloom develops while the chocolate is solidifying. Over-tempering appears as a dull appearance on the chocolate, while the under-tempered is visible as white fatty spots on the surface (Lonchampt and Hartel, 2004). It can be difficult to predict the right tempering procedure for milk chocolate because of differences in the amount of free fat in the type of milk powder used and the melting point of the milk fat.

Storage-induced bloom occurs in well-formulated and tempered milk chocolate over time because the crystal form β(V) formed on tempering is not the most stable in cocoa butter, so over time the transformation to β(VI) will occur. It can take years for a well-tempered and stored chocolate to bloom, but if the temperatures fluctuate during storage the transformation goes faster and bloom appears sooner.

Its widely accepted that milk fat prevents bloom formation when added to dark chocolate and in compounds based on cocoa butter alternatives (Lonchampt and Hartel, 2004; Timms, 2003). Most of the work on bloom inhibition has been conducted on dark chocolate, in which bloom is more obvious on the dark background and milk fat levels are usually lower than in milk chocolate. The addition of 1–2% milk fat to a dark chocolate formulation is able to delay bloom formation. The higher melting fractions of milk fat (see Section 5.3.1.2) are more effective in preventing bloom than intact milk fat (Bricknell and Hartel, 1998). Lohman and Hartel (1994) reported that high-melting fractions (HMF) inhibit bloom in chocolate containing 30% of the fat as milk fat. Low-melting fractions (LMF) have been shown either to have no effect on bloom inhibition or to actually induce bloom. Lohman and Hartel (1994) have suggested that the reason why lower melting milk fat fractions induce bloom is because the addition of more liquid fat increases the mobility of the unstable triglycerides. Although it appears that it is a high-melting component of milk fat that prevents bloom, the exact components responsible and their mechanism are unknown.

There are various theories on how milk fat prevents bloom. Milk fat crystallises in a solid formation with cocoa butter and the triglycerides that are unique to milk fat prevent or slow down the transformation of the form β(V) crystal structure of cocoa butter to form β(VI) (Timms, 2003). When chocolate crystallises more slowly, as happens when milk fat is present, microscopic cracks are less likely to occur within it (Kleinert, 1961). A further theory claims that milk fat inhibits bloom by maintaining a solution in which the unstable forms of cocoa butter are held (Cook, 1984). Tietz and Hartel (2000) and Wright *et al.* (2000) have shown that the minor lipids of milk fat affect the crystallisation of cocoa butter and milk fat in chocolate and have suggested that the minor components inhibit bloom formation through their influence on the crystal structure of cocoa butter.

Hartel (1999) and Liang and Hartel (2004) suggested that the structure of the non-fat or dispersed phase of chocolate (sugar, milk powders and non-fat cocoa particles) has an influence on bloom formation. The way milk fat interacts with this solid phase may affect the rate of bloom inhibition. The dairy ingredient used, whether it is free milk fat added directly to chocolate or through the use of fat-containing dairy powders, may also have different effects on the bloom stability of chocolate. Further work is still required to fully understand the mechanism of bloom development and the mechanism of bloom resistance by milk fat.

Use of milk fat through a high free-fat system (SMP and AMF) is thought to be more effective than the use of WMP in preventing bloom in products in which oil migration is a likely cause, for example, in chocolates containing nuts (Urbanski, 2000). Liang and Hartel (2004) showed that HFF WMP and SMP and AMF gave a much higher bloom retarding effect than roller and traditional dried whole milk powder.

Other modified fats or compounds are available as bloom inhibitors (Timms, 2003), but many of these do not have regulatory approval in many countries. Milk fat as a bloom inhibitor has the advantage of being able to be legally added to chocolate in most countries of the world.

Lactose crystallisation also seems to influence bloom formation, since milk powders with the same degree of free fat but different degrees of lactose crystallisation influence the bloom development differently.

5.2.3 Lactose

Lactose contributes to flavour, can be used to modify the sweetness of chocolate and contributes to the total milk solids content legally required in chocolate. Lactose, or milk sugar, is a disaccharide synthesised from the monosaccharides, glucose and galactose. The process is unique to the mammary glands and produced under hormonal control (Dijksterhuits, 1990). Lactose can be hydrolysed back into these constituent sugars by the enzyme β-galactosidase, also called lactase.

Lactose and its constituents, galactose and glucose, are reducing sugars that play active roles, along with milk proteins, in the Maillard reaction. Lactose also can undergo caramelisation. Both of these reaction types are essential in achieving the rich, caramelised, cooked dairy flavour typical of milk chocolate.

As lactose is a disaccharide, it responds in a similar way to sucrose when processed in milk chocolate. Lactose is less sweet than sugar, the relative sweetness is about 0.3 compared to 1.0 for sucrose (Timmermans, 1990), and lactose can be used to reduce the sweetness in chocolate. Lactose is a far less water soluble than sucrose (17 g in 100 ml water, compared with sucrose at 67 g in 100 ml water at 20 °C; 68 °F).

The use of lactose in place of milk powder offers chocolate manufacturers a further means of reducing costs, while still achieving levels of milk solids specified in regulations. Replacement of high levels of standard milk powders with lactose does cause detectable changes in the sensory properties of the milk chocolate.

5.2.4 Vitamins and minerals

The vitamins and minerals in milk contribute nutritional benefits to chocolate consumers. Milk is a good source of the water soluble vitamins thiamin, riboflavin and vitamin B12. Milk is an important source of the fat soluble vitamins, such as vitamin A (retinol), vitamin E (α-tocopherol) and D (calciferol). β-Carotene, the precursor to vitamin A, provides the distinctive yellow colour of milk fat.

Milk is an excellent source of important nutritional minerals such as calcium and potassium. Other minerals found in milk in significant quantities are sodium, phosphorus and magnesium.

5.3 Milk-based ingredients for chocolate

Dairy ingredients used for chocolate must first be concentrated to remove water in order to allow for proper crystallisation of the cocoa butter matrix. The composition of typical dairy ingredients used in chocolate is shown in Table 5.3. Note that the maximum moisture of these ingredients in 4.5%. Higher moisture ingredients like cream may be used in truffle fillings, caramels and other confectionery products but these are not covered in this chapter, which is focused on solid chocolate products with a continuous fat phase.

Table 5.3 Typical composition of dairy ingredients used in confectionery.

Ingredient	Protein (%)	Fat (%)	Lactose (%)	Minerals (%)	Moisture (%)
Anhydrous milk fat	0.0	99.8	0.0	0.0	0.1
Butteroil	0.0	99.5	0.0	0.0	0.3
Skim milk powder	33.4	0.8	54.1	7.9	3.8
Whole milk powder	25.0	26.8	39.1	5.8	3.3
High-fat powder (55%)	15.6	54.8	24.3	3.5	1.8
Buttermilk powder	31.6	7.8	50.0	7.4	3.8
Formulated milk powder	12.0	27.4	52.0	5.9	2.7
Whey powder Standard	12.6	0.9	74.5	7.5	4.5
Demineralized[a]	11.0	1.2	82.6	1.2	4.0
Milk crumb	7.6	31.0[b]	7.9[c]	1.7	1.3
Lactose	0.3	0.0	99.3	0.34	0.06

[a] Products with lower levels of demineralization are available.

[b] Includes milk fat and cocoa butter.

[c] Total carbohydrate content 55.8%, including 47.9% sucrose.

5.3.1 Milk fat ingredients

5.3.1.1 Anhydrous milk fat and butteroil

The composition of AMF, the most common milk fat ingredient used in chocolate, is shown in Table 5.3. Butteroil (BO) is similar to AMF in composition and in the way it is manufactured, but has just slightly different fat and moisture contents (Table 5.3). AMF can be prepared using two methods, either from fresh cream or from churned butter. The first method involves centrifugal concentration of heavy cream (40% fat) to a more concentrated cream (75–80% fat). The concentrated emulsion is then inverted from its native oil in water emulsion to a water in oil emulsion using a homogeniser. The water in oil emulsion in further concentrated to butteroil (95.5% fat) using centrifugation. The second method starts with traditionally churned butter as the raw material. The butter is melted and then the fat phase is separated from the aqueous phase. Centrifugation is used to concentrate the product to butteroil (95.5% fat). The production of AMF starts with butteroil, obtained from either method. A vacuum treatment is applied to reduce the moisture content from 0.5% in butteroil to 0.2% for AMF. AMF is typically packed into drums, or in larger bulk packs that contain 1 ton of AMF.

The guidelines for the composition and other properties of AMF according to the Codex Alimentarius (Codex, 1999a) are shown in Table 5.4. AMF is not permitted to contain antioxidants, whereas other milk fat products may contain certain antioxidants up to the levels specified in the Codex standard.

Table 5.5 shows the shelf life of typical dairy ingredients. The main cause of the deterioration of AMF is oxidation. Anhydrous products are not generally susceptible to deterioration resulting from bacterial growth as the moisture content is too low to support micro-organisms. The oxidation of AMF is measured

Table 5.4 Guidelines for the composition and other properties of AMF.

Measured property	Typical AMF specification
Minimum milk fat (% m/m)	99.8
Maximum water (% m/m)	0.1
Maximum free fatty acid (% m/m as oleic acid)	0.3
Peroxide value (milli-equivalents of O_2/kg of fat)	0.3
Taste and colour	Acceptable for market requirements after heating a sample to 40–45°C (104–113°F)
Texture	Smooth and fine granules to liquid depending on temperature
Maximum copper (mg/kg)	0.05
Maximum iron (mg/kg)	0.2

Codex (1999a) standard for milk fat products CODEX STAN A-2–1973, rev. 1-1999.

using the peroxide value. Peroxide values are typically 0.10–0.15 meq O_2/kg in good quality AMF. However, care needs to be taken in using a direct correlation between peroxide value and the shelf life of AMF. The compounds detected in the peroxide value test are intermediates in the oxidation reaction, in the later stages of oxidation, when oxygen is limited, these compounds will have been decomposed to give rise to off-flavours and will be low in concentration themselves. Therefore the peroxide value may be low, but the flavour of the fat may be poor.

Mechanisms that can be used to reduce the rate of oxidation and thereby enhance the shelf life of AMF are:

- Removing the oxygen by flushing with nitrogen,
- Using oxygen barrier packaging,
- Maintaining an appropriate storage temperature [often chilled to 4 °C (41 °F) or frozen],
- Avoiding the presence of oxidation catalysts.

It is nearly impossible to remove all of the oxygen from AMF to prevent oxidation, therefore controlling the storage temperature to reduce the rate of oxidation is recommended for products in which a long shelf life is required.

Copper and iron are catalysts in the oxidation reaction. Their involvement in the oxidation of AMF can be reduced by using stainless steel processing equipment. However, copper processing vessels are often used in chocolate manufacture and are thought to enhance the reaction in chocolate, resulting in the formation of desirable flavour compounds in chocolate and confectionery products. Some wrapping and packaging materials and inks may contain oxidation-catalysing substances. AMF should be kept away from such materials.

5.3.1.2 Milk fat fractions

The traditional high cost of cocoa butter and the legislative constraints on the fats that can be used in chocolate have resulted in considerable interest in replacing cocoa butter with milk fat fractions. Milk fat fractions may also be used to inhibit bloom without the softening effects that occur when intact milk fat is added to chocolate.

Kaylegian and Lindsay (1995) have described the technologies for milk fat fractionation, both of commercial and experimental interest. Milk fractions produced using dry fractionation are available in other countries, but are not currently produced in the United States. The process of dry fractionation, or crystallisation from a melt, starts by heating milk fat to ensure that all the fat crystals are melted. The liquid fat is then cooled to the desired fractionation temperature and crystallised with agitation. The crystal phase, or stearin, is separated from the milk fat slurry using pressure filtration, vacuum filtration or centrifugation. The remaining liquid, or olein, can be further crystallised at a lower temperature to produce further fractions. One of the major advantages of dry fractionation is that there are no additives. One disadvantage of dry fractionation is that some liquid fat remains trapped in the stearin. Dry fractionation is a slow batch process. Membrane filters adopted for milk fat fractionation in the 1980s allow more defined separation of the stearin and olein phases. Membrane filtration of the crystallised slurry also has the advantage that the process can be totally enclosed, therefore minimising exposure of the milk fat and fractions to the atmosphere and potential oxidation.

The chemical, physical and functional properties of milk fat fractions are highly dependent on the physical state of the fraction at separation [i.e., the solid (stearin) or liquid (olein) fraction], the temperatures used for fractionation and the number of steps in the fractionation process. From a functional perspective, milk fat fractions are characterised based on their melting point. Based on an extensive study of commercial and research fraction data, Kaylegian and Lindsay (1995) defined five categories of milk fractions:

- Very high melting fractions (VHMF): melting point above 45 °C (113 °F),
- High melting fractions (HMF): melting point between 35 and 45 °C (95 and 113 °F),
- Middle melting fractions (MMF): melting point between 25 and 35 °C (77 and 95 °F),
- Low melting fractions (LMF): melting point between 10 and 25 °C (50 and 77 °F),
- Very low melting fractions (VLMF): melting point below 10 °C (50 °F).

Many researchers and commercial suppliers use a more simplified definition that has three broader categories of melting ranges:

- High melting fractions (HMF): melting point above 30 °C (86 °F),
- Middle melting fractions (MMF): melting point between 10 and 30 °C (50 and 86 °F).
- Low melting fractions (LMF): melting point below 10 °C (50 °F).

Jordan (1986) showed that the use of an HMF of milk fat enabled a further 3% of milk fat to be incorporated into milk chocolate with no difference to the solid fat content. The solid fat content of mixtures of cocoa butter and milk fat fractions are shown in Figure 5.6. However, the HMF of milk fat does not substantially

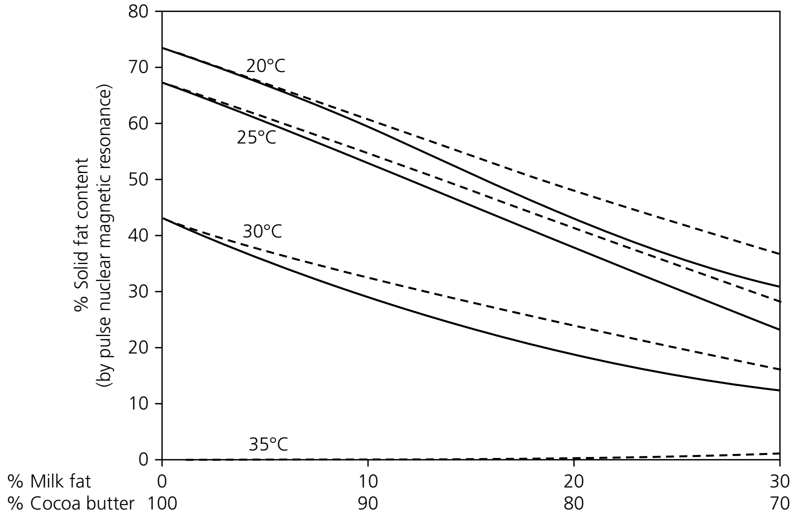

Figure 5.6 Solid fat content values for mixtures of cocoa butter and milk fat or fractionated milk fat.

increase the hardness of chocolate over the addition of an equivalent amount of standard milk fat (Timms, 1980). MMF has been found to soften chocolate to a greater extent than standard milk fat because of the eutectic effect of the middle melting triglycerides. However, MMF may reduce the brittleness of chocolate coatings for frozen confections.

An important benefit of milk fat fractions in chocolate is their ability to prevent the formation of bloom in chocolate, which is discussed in Section 5.2.2.5.

5.3.2 Milk powders

Milk powders contribute flavour and milk solids to chocolate and affect viscosity and texture. Codex (1999b) provides standards for the raw materials and composition of whole milk powder (WMP; 26% minimum milk fat, 5% maximum water content) and non-fat or skim milk powder (SMP; 34% minimum milk protein). Table 5.3 shows the typical composition of milk powders used in chocolate. Milk retentate, milk permeate and lactose are permitted ingredients for protein adjustment and most WMP products have standardised fat and protein levels to overcome day to day and seasonal variations in the raw milk (Caric, 1994). The low moisture content of milk powders provides an environment which keeps micro-organisms from growing and thus contributing to the long shelf life of milk powder ingredients (Table 5.5).

The typical specifications for milk powders for use in chocolate are shown in Table 5.6. The chemical, physical and microbiological properties of the product are all important. The key chemical parameters are titratable acidity and whey protein nitrogen index (WPNI). The WPNI is a measure of the level of preheat

Table 5.5 Shelf life and primary cause of deterioration of milk ingredients.

Product	Typical shelf life[a]	Primary cause of failure
Anhydrous milk fat	12 months in drums at 15–20°C (59–68°F)	Oxidation
Skim milk powder	24 months plus at 25°C (77°F), standard atmosphere	Development of aged flavours
Whole milk powder	24 months at 25°C (77°F) under nitrogen, dry storage	Oxidation, development of aged flavours
High-fat powders	9 months at 25°C (77°F) under nitrogen, dry storage	Oxidation
Buttermilk powder	24 months at 25°C (77°F) under nitrogen, dry storage	Oxidation
Formulated milk powder	24 months at 25°C (77°F) under nitrogen	Oxidation
Whey powder	24 months	Caking, aged flavours
Milk crumb	24 months	Development of aged flavours
Lactose	24 months	Caking

[a] Assumes storage at relative humidity below 65% and in an odour-free environment.

Table 5.6 Typical profile for powder products used in chocolate manufacture.

Property type	Measured property	Typical specification		
		SMP	WMP	BMP
Chemical	Titratable acidity (%)	<0.15	<0.15	<0.15
	Free fat (% powder)	[a]	2.5	[a]
	WPNI (mg/g)	1–6	1.6	[a]
Physical	Insolubility index (mL)	<1.0	<1.0	<1.0
	Bulk density (g/mL)	0.70	0.60	0.65
Microbiological	Aerobic plate count (× 10^4/g)	<2	<2	<2
	Coliforms (per g)	Absent	Absent	Absent
	E. coli (per g)	Absent	Absent	Absent
	Yeasts and moulds (per g)	<50	<50	<50
	Salmonella (per g)	Absent	Absent	Absent
	Coagulase-positive *Staphylococci*	Absent	Absent	Absent

[a] Typically not specified.

Milk powders will also have specifications for flavour, odour and foreign matter.

treatment to which a powder was subjected prior to spray drying. Powders with high titratable acidity levels are an indication of poor raw milk handling procedures prior to powder manufacture. High titratable acidities are often found in products with significant off-flavours.

Spray drying, roller drying and crumb processing are used to produce a variety of milk powders for use in chocolate manufacturing. Milk powder in its simplest form involves solids concentration of fluid milk by evaporation followed by drying and packaging. However, the functional properties of milk powders in chocolate are very dependent upon the specific raw materials, pre-treatment and drying conditions used to make the powder. Milk powders for chocolate applications require different properties than those needed for recombined milk applications and, therefore, manufacturers producing powers for the chocolate industry must understand these differences in order to produce powders that are optimised for chocolate. This may require special installations and manufacturing steps to the standard spray dryers or utilising the higher energy requiring roller drying technique; however, the economic benefits of using spray drying have led to a reducing availability of roller dried powder globally (Aguilar and Ziegler, 1993).

5.3.2.1 Milk powder properties important for chocolate manufacturing

During chocolate processing and in the final chocolate, flow properties, tempering conditions, hardness, sensory impact, storage stability and retention of bloom development are parameters affected by the chosen type of milk powder. Although milk powders may have the same chemical composition, the powder characteristics that influence chocolate are the degree of free fat, particle size, structure, occluded air and bulk density. Table 5.7 shows the characteristics for standard spray and roller dried whole milk powder, compared with crumb powder.

The effect of using different milk powders on chocolate viscosity is shown in Figure 5.6; the powders used were standard spray-dried whole milk powder with low free fat (LSW) and high free fat (HFW), roller dried whole milk powder (RDW) and spray-dried skim milk powder (LSN) with anhydrous butter fat (AMF).

Table 5.7 A comparison of standard milk powder and roller dried milk powder, compared with crumb powder.

Properties	Spray Whole Milk powder	Roller Whole Milk powder	Crumb
Drying temperature in product	<80 °C	>100 °C	70–100 °C
Drying time	From atomizer to fluid bed 2 sec (Hot zone) Agglomeration within 12 sec	2–5 sec	3–8 hours
Particle shape	Globular	Flakes	Network of small crystal
Particle surface	Smooth porous	Rough	Smooth
Occluded air	Varies	Low	Low
Free Fat content	1–10%	80–85%	80–98%
Lactose	Amorphous	Slight crystallized	Crystallised
Moisture	3%	3%	<2%

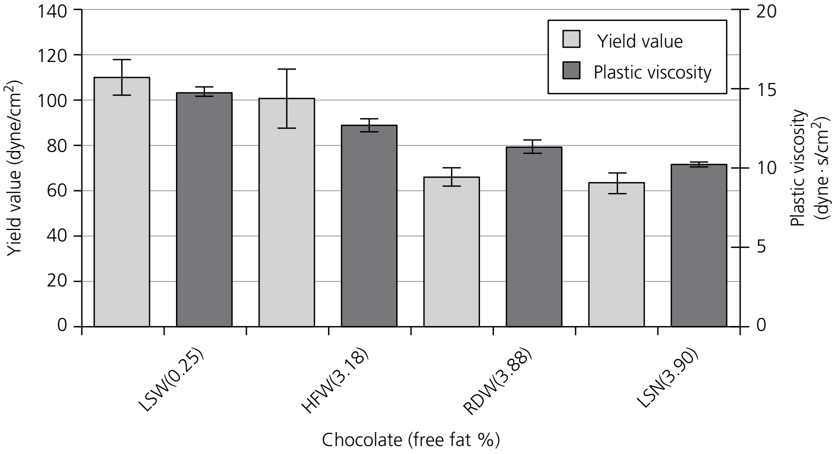

Figure 5.7 Effect of free fat level in milk powder on rheological properties of melted chocolate.LSN: Spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: High free fat whole milk powder. Source: Liang and Hartel (2004). Reproduced with permission of Elsevier.

The chocolates with the lowest yield value and plastic viscosity were those that had the highest free fat level. In the latter with AMF the free fat was 100%, the chocolate made with the roller powder had almost the same yield stress and plastic viscosity. The chocolate made with standard sprayed whole milk powder with low free milk fat had the highest yield value and plastic viscosity (Liang and Hartel, 2004).

Milk powders with different structures and free fat content will lead to differences in tempering requirements, consistency and melt down properties of the finished chocolate. In Figure 5.8 the hardness profile was measured, using a Texture Analyser (model TA-XT2, Haslemere, England) at 20 °C. The chocolate samples were penetrated by a 2-mm stainless steel cylindrical probe at 0.2 mm/s to a depth of 5 mm. Maximum force for penetration was determined as well as the work required for penetration (area under the force curve; Attaie *et al.*, 2003). An increase in free milk fat content led to a decrease in hardness. However the chocolate made with the spray-dried skim milk powder and AMF had higher hardness than expected based on free milk fat content. So the nature of the milk powder particles also has an influence on the hardness of the chocolate (Liang and Hartel, 2004).

Liang and Hartel (2004) reported that the degree of lactose crystallisation increased the degree of free fat (Aguilar and Ziegler, 1994), which effected chocolate particle size formation during refining and bloom formation in the final chocolate. The impact from amorphous or crystalline lactose on the hardness and sensory perception of milk chocolate was described by Bolenz *et al.* (2003), who found that it took longer to melt chocolate and the hardness increased with degree of crystalline lactose content. The rapid drying process used to produce

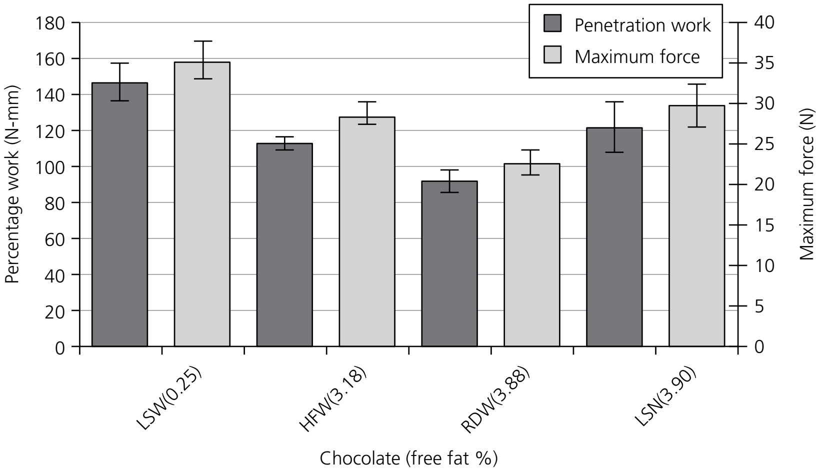

Figure 5.8 Hardness of chocolates made with different milk powders. LSN: Spray-dried skim milk powder; LSW: spray-dried whole milk powder; RDW: roller-dried whole milk powder; HFW: high free fat whole milk powder. Source: Liang and Hartel (2004). Reproduced with permission of Elsevier.

whole milk powder results in amorphous lactose, which forms a continuous matrix in which protein, fat globules and air are dispersed (Siebenga and Timmermans, 1995). The amorphous lactose is unstable and crystallisation will take place if the powder is kept at a higher temperature than the glass transition temperature (T_g). The glass transition temperature is normally above the storage temperature, but amorphous lactose is very hygroscopic and will absorb water if stored under humid conditions and the increased moisture reduces the T_g, allowing crystallisation to take place (Fitzpatrick *et al.* 2005).

Saito (1985) reported that in fresh whole milk powder (WMP) only a few crystalline lactose crystals were found and that crystallisation during storage facilitated movement of free fat to the surface of the particles. Crystalline lactose in milk powder increases the bulk density, but the chocolate viscosity decreases with the degree of amorphous lactose content. Aguilar and Ziegler (1993) stated that the chocolate viscosity increase with degree of crystalline lactose is due to the release of bound water to the chocolate during transformation.

Roller dried WMP contains more crystalline lactose than spray-dried due to the longer holding time on the rollers. Crystalline lactose will not impact the properties the same as spray-dried powders, since crystallisation takes place during production of the powder. Roller dried WMP has a lower bulk density and a higher occluded air content, which does not correlate with its lowering impact on chocolate flow properties in chocolate (Hansen and Hansen, 1990).

A powder with a larger particle size and high occluded air content will break up more easily into smaller particles. A high content of fines, particles less than 10 μm, contributes to an overall larger surface area that needs to be covered by fat during the chocolate processing, thereby contributing to a higher chocolate viscosity and a dryer mouthfeel in the final chocolate (Liang and Hartel, 2004).

A high powder bulk density, expressed as g/ml, reduces the volume and facilitates incorporation during blending, refining and conching (Liang and Hartel, 2004). Low occluded air leads to higher bulk densities, which are influenced by the viscosity in the feed, the atomiser and fluid bed settings during drying (Hansen and Hansen, 1990). High dry matters gives higher bulk densities and so does the use of pressure nozzle atomisers, since the air incorporation is less (Liang and Hartel, 2004), but lower feed concentration is required compared to centrifugal atomisers (Aguilar and Ziegler, 1993).

Keogh *et al.* (2002) investigated the seasonal influence on milk powder properties and reported increased protein content resulted in higher free fat content and a reduced final viscosity in the milk chocolate.

5.3.2.2 The spray drying process

The drying process is a multiple-step process:

1. Concentration of fluid milk through evaporation.
2. Atomisation of the concentrate into very fine droplets in a hot air stream.
3. Water evaporation.
4. Separation of the powder from the drying air.

The first step in the dehydration process always involves an evaporation step, which is necessary to produce high-quality powder. Without prior concentration, the powder particles will be very small with high occluded air content, have a poor blending ability and short shelf life and the process would not be economical (Caric, 1994). Falling film tubular evaporators are generally used for concentration because the vacuum process decreases the boiling point and allows for the use of low temperatures for the process. Falling film evaporators enable highly efficient heat transfer and short residence time.

5.3.2.2.1 Single-stage drying

The simplest installation is the single-stage dryer. The entire drying process takes place in a single unit, encompassing the drying chamber with an atomisation system. The atomiser disperses the milk into the hot air and can be of centrifugal or nozzle type. The centrifugal atomiser system accelerates and atomises the milk using centrifugal forces in a rotating disk. The nozzle atomiser system forces the milk through the nozzle under high pressure. In the bottom of the chamber is a system for collecting the powder from the dry air. A powder with small particle size and high fines content is produced (Anhydro, 2012).

5.3.2.2.2 Two-stage drying

The two-stage system builds on the single-stage system and is extended by means of an external fluid bed dryer and/or a cooler. The powder leaves the drying chamber with higher residual moisture and moves into the fluid bed, where drying happens at relatively low temperatures. In two-stage drying, the fluid bed dryer ensures that the desired residual moisture is achieved and that the powder is cooled. In terms of energy, the two-stage dryer is superior to the single stage dryer because it is possible to work with considerably lower air exit temperatures, increasing the temperature difference between inlet and outlet, thus reducing energy required for drying by 10–15% compared with the single-stage process. The finished products consist mainly of individual particles and the fines separated in the fluid bed. The bulk density is higher and occluded air content is lower in powders produced using a two-stage process compared with those from a single-stage process.

5.3.2.2.3 Multi-stage drying

Multi-stage dryers are a further extension of the two-stage process by adding an integrated fluid bed before the external fluid bed dryer and/or cooler. This method was developed to achieve savings in process costs and to meet various product quality demands more effectively. Fines are led back from cyclones and/or bag filters to the integrated fluid bed. An example of a multi-stage dryer is shown in Figure 5.9 (Anhydro, 2012).

To obtain the correct porosity, the particles must first be dried so most of the water in the capillaries and pores is replaced by air. The particles are humidified so the surfaces of the particles swell quickly, closing the capillaries. The surfaces of the particles will become sticky and the particles will adhere to form agglomerates of free-flowing dustless powder.

5.3.2.2.4 Atomisation

Correct atomisation and air distribution are key the spray drying process – they influence the final powder quality and can be adjusted according to desired performance. In spray-dried whole milk, the milk fat is largely encapsulated inside the lactose–protein structure of the dried milk particles (Aguilar and Ziegler, 1993). Generally, the finer the droplet atomisation, the larger the specific area and the more effective the drying process. The small droplets turn into milk powder particles with spherical form.

There are important functional differences between pressure and centrifugal nozzle atomisation and the principles in the two systems are shown in Figures 5.10 and 5.11 (Anhydro, 2012).

In pressure atomisation, the pressure at the nozzle determines the particle size. The pressure is built up by a high-pressure pump, which is often the homogeniser. At high pressures the powder particles is small with a narrow size distribution and a high bulk density and at low pressure large particles will be formed. In the centrifugal atomiser, the product is fed into the middle of a rotating disc and forced through a number of horizontal passages by centrifugal forces. The disc rotates at speeds of 10 000–20 000 rpm, depending on the diameter of the disc. Increasing the speed results in finer particle sizes, more efficient drying, a decrease in the content of free fat and an increase in bulk density (Sharma *et al.*, 2012).

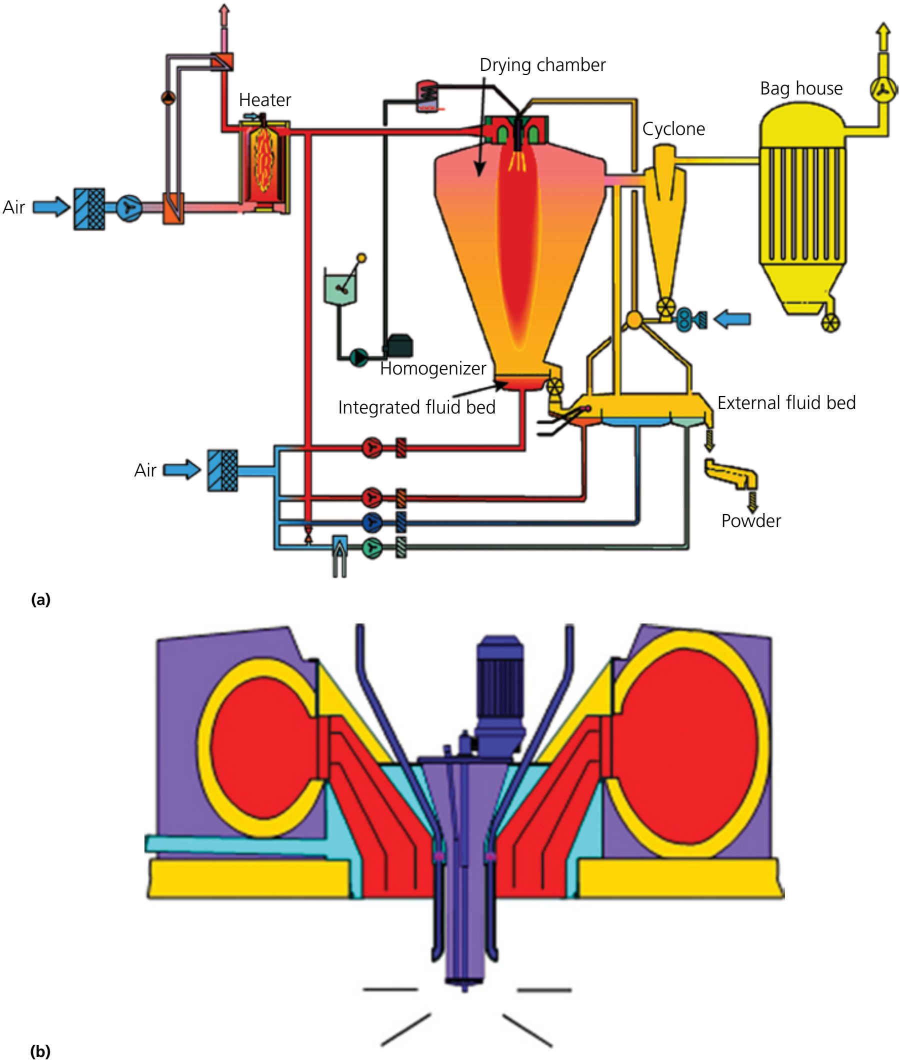

Figure 5.9 (a) Example of a multi-stage spray drying process. (b) Example of a centrifugal atomiser (Anhydro Triple A® spray dryer).

In nozzle atomisers, the particle diameter is inversely proportional to the pressure applied. The higher the pressure, the lower the particle size and the occluded air in the powder, resulting in an effective distribution of fat during the chocolate processing, ensuring a lower chocolate viscosity (Hansen and Hansen, 1990).

5.3.2.2.5 Hydrodynamic cavitation

Hydrodynamic cavitation is a new technology associated with spray dry processing. In recent years new technologies have been introduced to the market with the objective of increasing the dry matter in the feed for the dryer without influencing

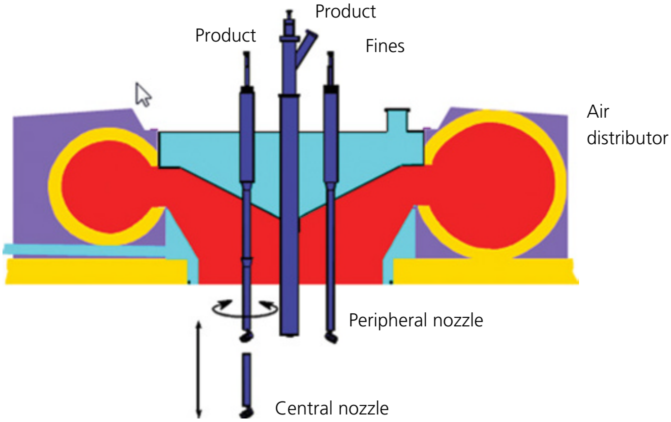

Figure 5.10 Example of a high pressure nozzle distribution atomizer. Source: Anhydro (2012).

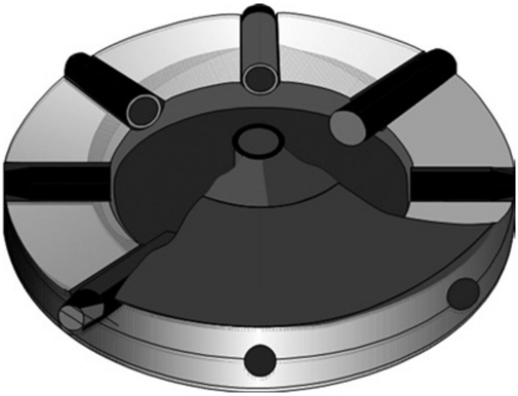

Figure 5.11 Example of a centrifugal atomizer wheel Source: Anhydro (2012).

the properties in the final powder. Feed concentration to spray-drying atomisers is usually limited by the viscosity of the feed.

A new breakthrough technology based on controlled hydrodynamic cavitation has proved its excellence in combined viscosity reduction and microstructural conditioning to the feed. Hydrodynamic cavitation is a process of vaporisation via bubble generation and bubble implosion occurring in a flowing liquid as a result of decreases and subsequent increases in pressure. The (temporary) viscosity reduction enables an increase in the solids level during the spray drying, thereby significantly reducing operational costs and improving sustainability.

The heart of the technology is a rotor with a number of radial holes spinning in a liquid chamber, as shown in Figure 5.12. The spinning action generates internal liquid friction (disk friction) and the holes generate hydrodynamic cavitation. Cavitation occurs when the pressure decreases to some point below the saturated vapour pressure of the liquid and subsequent recovery above the vapour pressure. This technology is used in many areas of the food and beverage industry for hydration and emulsification purposes.

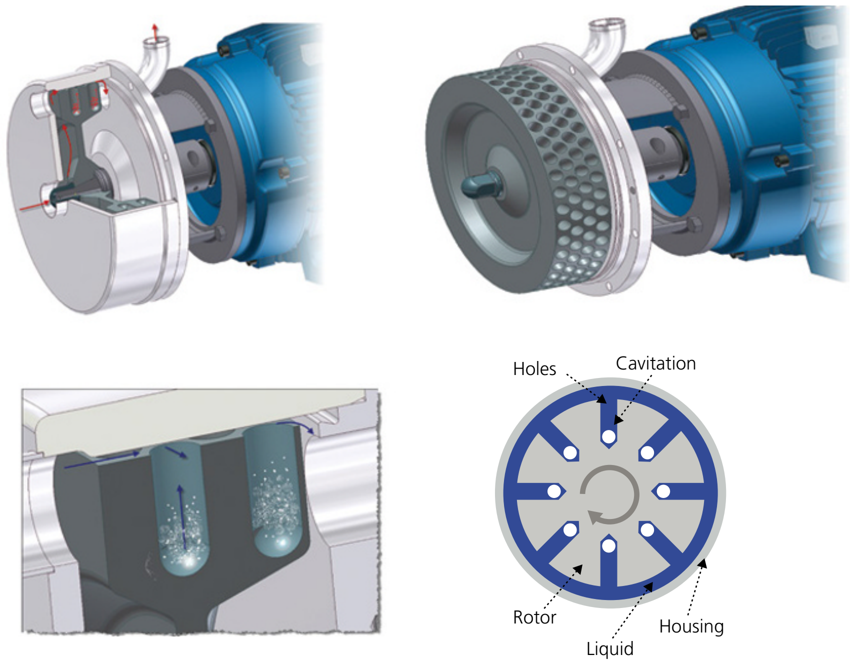

Figure 5.12 A cavitator unit with four rows of holes in the rotor (above) and visual cavitation occurring in the holes (below). Source: Pedersen (2014).

Installing the cavitator downstream of the evaporator and before the high pressure pump to the spray dryer allows for an increase in feed concentration of up to 7% without affecting the feed viscosity. Alternatively, maintaining the dry matter in the feed increases the output from the dryer by up to 10%, due to the reduction in feed viscosity (Pedersen, 2014).

5.3.2.2.6 The effects of spray drying processing parameters on milk powder functionality in chocolate

The difference between inlet and outlet temperature, ΔT, for the dryer sets the drying capacity for the plant. The lower the ΔT the lower the viscosity of the chocolate. Particle size and occluded air increase with ΔT, causing a higher chocolate viscosity, therefore a high drying capacity has a negative influence the performance of the powders in chocolate (Hansen and Hansen, 1990).

The outlet temperature had the highest influence: outlet temperatures above 95 °C result in lower bulk densities and increased occluded air, whereas outlet temperature from 70 to 95 °C lead to smaller particle sizes and lower occluded air (Aguilar and Ziegler, 1993). Sharma *et al.* (2012) reported that higher outlet temperatures led to higher free fat levels, but they did not refer to any beneficial effect in chocolate.

Table 5.8 summarises the processing parameters needed to optimise milk powder characteristics for use in chocolate.

Table 5.8 Spray-dried milk powder properties importance for lowering chocolate viscosity and how to achieve the properties during spray drying of whole milk powder.

Milk powder characteristic	Milk powder properties wanted	Milk powder parameters achieved during spray drying
Free fat	High	Pre-addition of crystalline lactose High pressure homogenization Smaller nozzles higher pressure
Bulk density	High	High viscosity – high dry matter in feed Outlet temp 70–95 °C Low ΔT in dryer Pressure instead of centrifugal nozzle
Particle size	Low	High pressure on atomizer High dry matter in feed
Occluded air	Low	High pressure on atomizer Outlet temp 70–95 °C Low ΔT in dryer Pressure instead of centrifugal nozzle
Fines	Low content	Fluid bed, separation
Lactose	Amorphous	Storage dry and low temperature

5.3.2.3 Whole milk powder

Whole fluid milk is first standardised in order to reach a minimum 26% milk fat content after drying and then pasteurisation at 80–95 °C to meet legal requirements and inactivate the lipolytic enzymes that cause deterioration of milk fat during storage. The fluid milk is normally homogenised between evaporation and spray drying because, if the milk is homogenised prior to evaporation, the free fat content will be lower (Burma, 1971). After concentration to 40–50% the spray drying typically happens in stages; evaporation of the free water in the first step is relatively easy to accomplish, whereas the last stage demands more energy and time.

5.3.2.4 High free fat milk powders

High free fat (HFF) milk powders were developed to fulfil demand from the confectionery industry; there are several factors impacting the degree of free fat in milk powder, with the drying process conditions being the key.

Techniques aiming to provide physical disruption of the milk fat globule membrane during liquid processing have also been used to achieve high free fat levels in WMP. The use of high homogenisation pressure before evaporation is one technique that has been used successfully. However, the highest level of free fat can be achieved in adding pre-crystallised lactose prior to the spraying, since the hard lactose crystals will penetrate and open the fat globules during processing (Aguilar and Ziegler, 1993). The free fat can also be influenced during spraying by using smaller nozzles and higher nozzle pressure. Figure 5.13 shows scanning electron microscopy pictures of the three different whole milk powders described above. The particle shape of roller-dried powders and the spray-dried powder with HFF are equally dimensioned as platelets, whereas the low free fat spray-dried powder are spherical in shape (Attaie *et al.*, 2003).

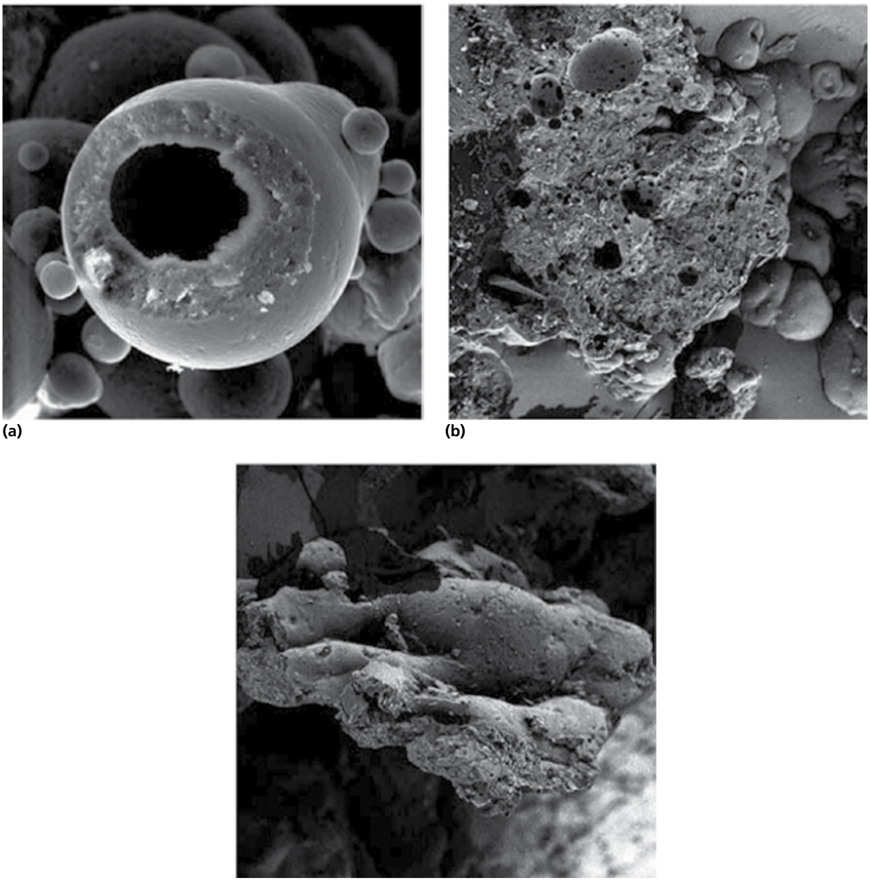

Figure 5.13 Scanning electron microscopy pictures of two spray-dried and one roller-dried milk powder. (a) Spray-dried milk. (b) Spray-dried milk HFF. (c) Roller dried. Source: Attaie *et al.* (2003). Reproduced with permission of International Journal of Food Science and Technology.

5.3.2.5 Skim milk powder

Skim milk powder is used in combination with anhydrous milk fat (AMF), in proportions equal to the composition of whole milk powder in the recipe. The viscosity of chocolate will be lower, as shown in Figure 5.7, and the final chocolate will be softer, the colour a little darker and the milk taste less pronounced, due to the lack of flavour developments in the fat phase during drying (Campbell and Pavlasek, 1987).

5.3.2.6 Roller dried milk powder

Milk for the production of roller dried powder is normally standardised and homogenised prior to concentration. The milk is concentrated by evaporation to a solids content around 33–35% in order to facilitate a fine distribution on the rollers (Caric, 1994). The concentrated milk is distributed as a thin film on rotating steam-heated rollers. As the water evaporates, the vapour is drawn off and then the dried milk is scraped off the rollers and removed by a screw conveyor. The milk powder is broken down into flakes and finally ground. Depending on the desired capacity, the roller dryer is 1–6 m long and with a diameter of 0.6–3.0 m. Dryer performance is dependent on film thickness, roller surface temperature, roller speed and the dry matter content of the evaporated milk.

The high temperature of the heating surfaces (up to 149 °C) and the low speed on the roller forms irregularly shaped particles. Roller dried powder particles have a rough surface and are larger than spray-dried particles, which are spherical with a smooth surface (Caric, 1994).

These conditions used for roller drying cause the proteins to denature and allow for lactose crystallisation. The intense heating and the high dry matter in the flakes promote a Maillard reaction, creating caramelised flavours.

Roller powder is desired in chocolate processing because it has a high free fat content, nearly 70–90%, due to the shearing and scraping action as the film dries on the drum surface (Liang and Hartel, 2004). Milk chocolate made with roller-dried powder will have a lower viscosity and softer mouth feel (Hansen and Hansen, 1990). One concern with powders containing high free fat levels is the fat oxidation leading to off-flavour development and shorter shelf life. However, this is less of a concern for roller dried powder where it is believed that Maillard reaction products provide some anti-oxidant effects (Campbell and Pavlasek, 1987).

5.3.2.7 Milk crumb

Milk crumb was traditionally used in chocolate because it had better keeping qualities than milk powder (see also Chapter 6). The superior keeping quality results from the natural antioxidant properties of components in the cocoa liquor. Crumb manufacture promotes the formation of Maillard products and these may also contribute antioxidant properties. This meant that manufacturers would produce crumb when supplies of milk were plentiful and cheap, ensuring a stock of milk ingredients for chocolate manufacture over a long period. However, as the keeping quality of dried milk powder has increased as a result of improved manufacture and packaging, the advantage that crumb had is no longer the primary reason for its continued use in chocolate.

Crumb provides caramel flavours in milk chocolate. Chocolate made from crumb is thought to have a smoother texture than chocolate made from milk powder. In addition, using crumb results in less cocoa butter being needed in the chocolate formulation than if a low free fat spray-dried WMP is used. The typical composition of crumb is shown in Table 5.3.

The manufacture of crumb is expensive relative to the cost of producing milk powder because of the high capital and running expenses. Mixtures of milk and sugar that have been dried by methods other than vacuum drying may offer economic advantages to chocolate manufacturers, while providing some flavour differentiation over traditional dried milk powders.

5.3.2.8 Other milk powders

Yogurt powder, a low pH fermented product, is primarily used to facilitate the acidic taste in chocolate. Yogurt powder is typically used in white chocolate where no cocoa solids are present, so the main taste is based on milk and sugar. The acidity from the yogurt powder masks the sweet taste.

Buttermilk powder (BMP) is the dried serum derived from cream during the manufacture of butter or AMF. During butter manufacture, the milk fat globule membrane is ruptured, resulting in the release of polar phospholipid material from the globule membrane into the serum phase. Up to 20% of the fat in BMP is dairy phospholipids, which compares with about 3% in standard WMP (Table 5.6). Campbell and Pavlasek (1987) have reported the unique flavour contribution that the inclusion of BMP can make to chocolate products.

Whey, demineralised whey powder, lactose and lactose permeate are all cheaper milk-based ingredients used widely to substitute for whole or skim milk content in chocolate and compound coatings. Whey is a byproduct from cheese and casein manufacture. Whey powder produced from casein has a more neutral flavour impact and a higher mineral content than the whey from cheese production, which is pH-adjusted by adding caustic salts, contributing to a salty flavour impact. Most whey is now being concentrated to higher levels of protein content using membrane separation technologies for use in high-protein products, which are less attractive for the chocolate industry as substitutes for milk solids.

Conclusion

Milk is very important for the overall quality of the final chocolate, the milk ingredients contributing to colour, flavour development, softer consistency, easier melt and improved stability. Premium confectionery will continue to require high-quality ingredients designed specifically for confectionery applications.

The chocolate industry is an important customer for the dairy processor. Milk powder production is highly influenced by a surplus of milk and can change according to market needs, political situations and trade association for milk production expansion. Globally the demand for milk powder has grown steadily over the past decades; most of the demand has come from ASEAN countries like China and India which highly influence the prices. This underlies the importance of focusing on new processing technology with greater output, lower cost and ingredients that temporarily or constantly can substitute for higher-priced components, in an ever changing market.

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CHAPTER 6

Chocolate crumb

Martin A. Wells

6.1 Introduction and history

Milk chocolate crumb is the name given historically to a co-dried mixture of milk, sugar and cocoa liquor whose lumpy, aerated structure resembles bread crumb (Figure 6.1).

Its invention can be traced back to the 1870s when Daniel Peter first attempted to produce milk chocolate in Vevey, Switzerland (see Chapter 1). His main concern was to remove water from the milk that he was using and keep it from developing mould. In the milk processing factory next door Henri Nestlé had solved the problem by condensing milk in the presence of sugar. Daniel Peter found that by drying his dark chocolate paste with Nestlé's sweetened condensed milk he could achieve his aim. In the process he developed the first crumb-based milk chocolate. Peter was also allied by marriage to Cailler, another Swiss chocolate maker. Between them they were able to create a sizeable market for quality milk chocolate, first in Switzerland and then in the United Kingdom. Cailler today claims to make the only Swiss milk chocolate containing condensed milk in its recipe (Cailler, 2014).

United Kingdom chocolate makers introduced their own milk chocolate bars based on milk powder in the 1890s, but the milk powder was of poor and variable quality and the finished units no match for the Swiss imports. The threat, particularly from Cailler's high milk solids version of milk chocolate, led to the development of a fresh milk process and in 1905 to the launch of the highly successful Cadbury Dairy Milk brand. This product was based solely on crumb produced at milk processing factories first at Knighton, then at Frampton, then finally at Marlbrook in Herefordshire. Rowntree first introduced crumb manufacture into Mallow in the Republic of Ireland in 1946 (Fitzgerald, 1995). Meadow Foods (2014) manufacture milk crumb for third parties at Spalding Moor, Yorkshire.

Hershey in the United States also moved into milk chocolate production via a crumb route in the early 1900s. Milton Hershey chose Derry Church,

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Figure 6.1 Typical appearance of milk crumb.

Pennsylvania, for his factory because of the abundance of fresh milk in the area and made his first crumb-based milk chocolate bars in 1905.

In addition to Switzerland, the United Kingdom and the United States, crumb chocolate processes have also been successfully introduced to the Irish Republic and countries belonging to the old British Commonwealth. Cadbury, Nestlé (Rowntree) and Mars have been the main initiators of this expansion. Kraft/Marabou in Sweden also employ a crumb-making process. In a number of these markets the early introduction of crumb chocolates led to market domination, due to their quite distinctive flavour characteristics.

Since the early days, other types of crumb have been developed without either the non-fat cocoa solids or some of the milk components. White crumb comprising co-dried sugar, milk and cocoa butter is currently used by Mars Inc. A similar material has been manufactured by Coberco in Europe (Bouwman-Timmermans and Siebenga, 1995) In addition manufacture has progressed from the original batch processes into continuous ones.

6.2 Benefits of milk crumb

The main benefit of crumb manufacture is still that it offers a unique, fruity, caramelised flavour to milk chocolate that cannot be matched by the use of recipes which add the milk, cocoa and sugar as dry ingredients (Afoakwa, 2010; Stauffer, 2000; Urbanski, 2000). There are also other additional benefits:

- In contrast to dried milk, dried milk crumb can be stored for long periods without fat rancidity or staleness developing. This is because of the presence of polyphenolic antioxidants such as epicatechin in the cocoa.

- This stability allowed the original manufacturers to make use of milk when it was readily available in the 'flush' and safely store crumb for chocolate making in less plentiful milk supply periods. It is possible to store crumb in cool conditions for up to 12 months without perceptible flavour deterioration.
- Chocolate made via a milk crumb process can be more resistant to melting in hot climates, because some of the softer milk fats are bound within the crumb structure rather than in the continuous fat phase.
- A typical crumb recipe contains some 85% of the ingredients for chocolate making. This means that the subsequent chocolate manufacture is simplified to processing crumb, fats and emulsifiers.
- Since most of the flavour of the chocolate has been developed during crumb making it is not necessary to conche the chocolate for long periods of time to initiate Maillard browning and caramelisation reactions (See Chapters 8 and 10). This means that advantage can be taken of some of the rapid chocolate liquefaction techniques described in Chapter 15.

6.3 Typical crumb recipes

Table 6.1 gives the composition of some typical crumb recipes. These assume that full cream milk is used and the cocoa liquor or mass contains 55% cocoa butter. It is perfectly possible to use other ingredients, such as skimmed or partially skimmed milk, cocoa powder and sugars other than sucrose. The regulations in particular countries may also permit the use of separate milk components, such as whey, casein or lactose.

6.4 Flavour development in chocolate crumb

It has been recognised for some time (Hanlon, 1984) that Maillard reactions (Davies and Labuza, 1998) are responsible for the development of flavour in milk chocolate crumb. This flavour is difficult, if not impossible, to replicate by

Table 6.1 Composition of typical chocolate crumbs. All values are percentages.

Ingredient	Full milk crumb	Quarter mass crumb	White crumb
Sucrose	59	67	55
Full cream milk solids	25	28	44
Cocoa solids	15	4	
Water	1	1	1
Lactose	8.9	10.0	15.6
Milk protein	6.4	7.2	11.3
Milk fat	8.0	8.9	14.0
Cocoa butter	8.3	2.2	
Total fat	16.2	11.1	14.0

conching for long times at high temperatures because of the much lower water contents at this stage of chocolate making (see Chapters 8 and 10).

The Maillard reaction is essentially a reaction between a reducing sugar (containing a reactive aldehyde group) and a free amino group on a protein. In the case of milk crumb the reducing sugar is lactose from the milk (see also Chapter 5). The main source of free amino groups comes from lysine and arginine, which are amino acids in the milk proteins. There is also a significant contribution from the cocoa proteins: where cocoa is added in the crumb process there is a definite effect on the final flavour.

Some manufacturers, rather than relying just on flavour development during the crumb process, will pre-treat sweetened condensed milk to caramelise it first. This is a well-known technique to many home cooks, who place a tin of sweetened condensed in a pan of boiling water for up to 2 h to caramelise it before making "banoffee pie".

A much simplified version of Hodge's original Maillard reaction scheme (Hodge, 1953) as it applies to crumb making is presented in Figure 6.2. The initial reaction takes place between protein and sugar to give Amadori rearrangement products. Further reaction then takes place alone or with sugar and amino acids to give the range of flavour volatiles described.

One of the final products is the characteristic brown pigment which explains why the reaction is often called a Maillard or non-enzymatic browning reaction.

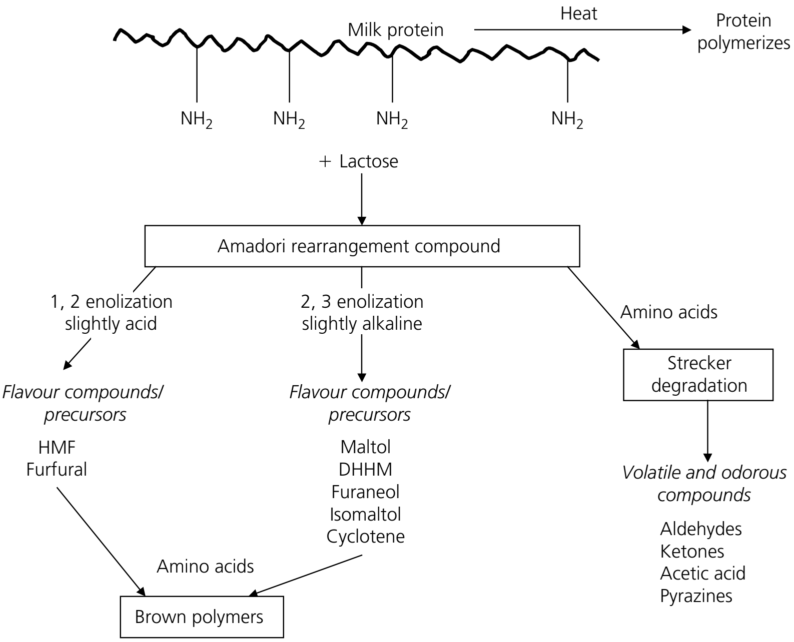

Figure 6.2 Schematic diagram of Maillard reaction.

Many of these compounds have quite characteristic flavours and have been described for example as:
Furfural – "sweet, woody, almond, baked bread".
Maltol – "sweet caramel toffee";
Cyclotene – powerful: "spicy to maple syrup";
Furaneol – powerful: "strawberry, brown fruit, candy floss".

Excessive browning of crumb leads to burnt and bitter flavours, overcoming the pleasant "fruit cake" characteristics.

Many other compounds, as yet unidentified, doubtless contribute to the overall flavour. More details of the chemistry of this complicated set of reactions are found in Chapter 8.

The final crumb flavour is dependent on three major factors:

- Moisture content;
- Temperature;
- Time at each stage.

These three factors are largely determined by the processing equipment chosen to make the crumb.

The effect of moisture content can be as illustrated as shown in Figure 6.3 (Bouwman-Timmermans and Siebenga, 1995).

Initially the crumb mixture contains a lot of water and so the optimum moisture for browning is at quite an advanced stage of the drying process, when the moisture has been reduced to below 10%. The optimum time for other products of the Maillard reaction do not necessarily occur at quite this same moisture content.

The effect of temperature is by far the most significant of the three factors. Figure 6.4 shows the contours of the flavour volatile dihydro-hydroxymaltol (DHHM) with moisture and temperature (Edmondson *et al.*, 2005).

Similar contours were obtained by *tasting* finished crumb paste. Equivalent contours were obtained for the taste descriptors "brown fruit" and "treacle" (Wells, personal communication).

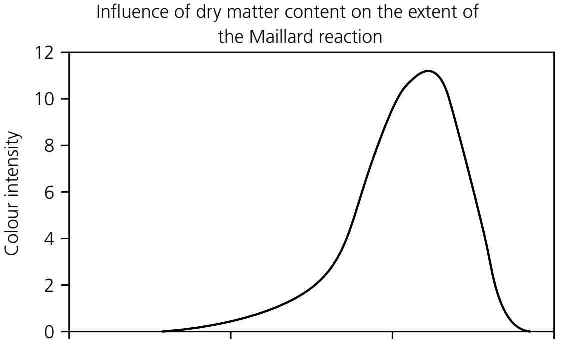

Figure 6.3 Moisture content and the Maillard reaction.

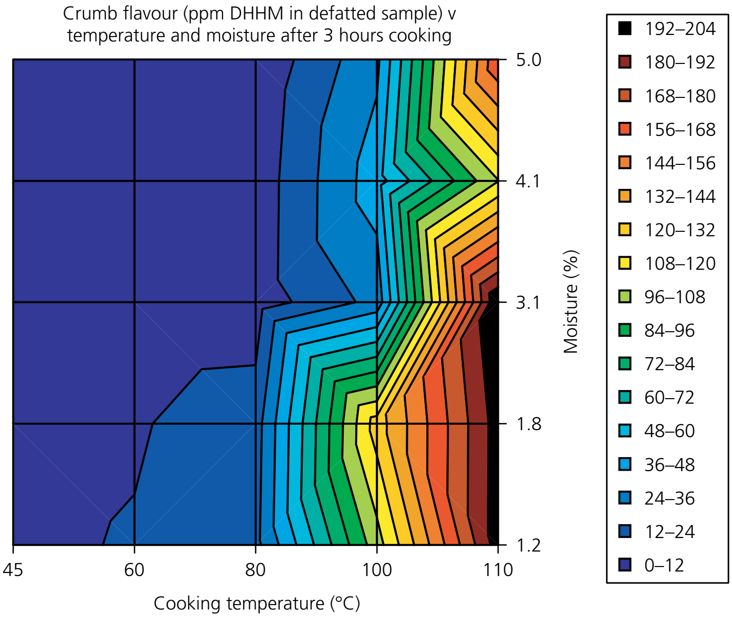

Figure 6.4 DHHM formation during crumb manufacture after 3 h cooking.

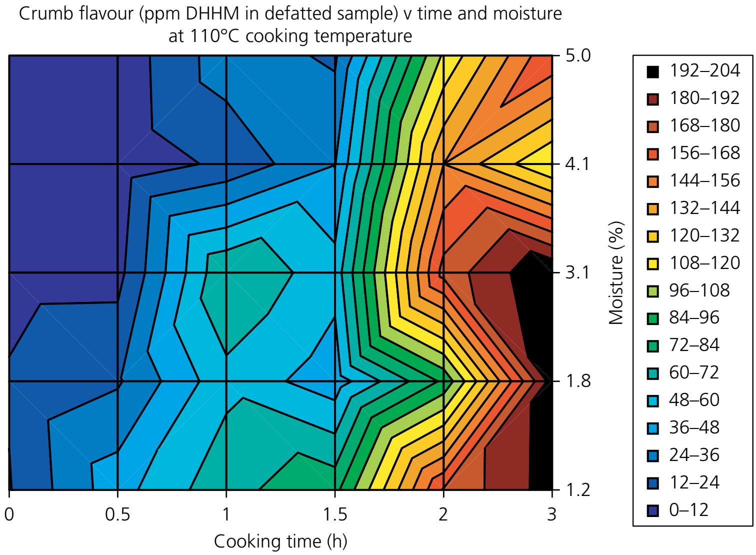

Figure 6.5 Effect of cooking time and temperature on the production of the flavour volatile DHHM.

As expected, the cooking time was also significant, as shown in Figure 6.5.

It can be seen, therefore, that a very wide range of flavours can be produced by the crumb manufacturer, depending particularly on the moisture, temperature and reaction times of the process.

6.5 Sugar crystallisation during crumb manufacture

The state of crystallisation of the sugars in the finished crumb is very important. The ultimate aim is to crystallise both the sucrose and lactose as fully as possible. The benefits of a highly crystalline crumb are:

- It is less sticky and hygroscopic, so is more stable when stored and easier to handle.
- Very little fat is trapped in amorphous glassy sugar so less fat needs to be used to make the correct finished chocolate viscosity.
- The finished chocolate dissolves more readily in the mouth, giving a cleaner and less sticky mouth feel.

The amount of fat bound up within the sugar varies according to crumb type. This is demonstrated in Table 6.2. Total fat in a recipe can be measured by nuclear magnetic resonance (see Chapter 24). Solvent extraction, however, will not dissolve fat which is trapped in amorphous sugar regions. Large differences can be seen from different crumb types. The rework crumb contains a lot of bound fat because there are significant quantities of glucose syrup in the recipe inhibiting sucrose crystallisation. The difference between the Irish and United Kingdom crumbs can be attributed to the higher processing temperature of the former crumb which slows down the crystallisation rate.

Whether sugars crystallise or not is largely dependent on the temperature conditions during the latter part of the process (Ergun *et al.*, 2009; Mohos, 2011). This can be summarised by reference to Figure 6.6, which shows the relationship of temperature and sugar concentration on crystallisation (Schmidt, 2012).

- The upper continuous line defines the maximum solubility of sucrose in water at different temperatures. When processing above this line, all sucrose will be in solution and no crystallisation can occur.
- The lower continuous line refers to the glass transition temperature for sucrose in water. Below this line the viscosity is so high that though there are many crystal nuclei they are unable to grow.
- Optimal crystallisation occurs roughly half way between these two lines as outlined in the diagram.
- To arrive in this area we need to evaporate moisture from the mixture. This can be done by boiling under atmospheric conditions. In this case we would need to achieve a solids content of nearly 97% to reach the optimal crystallisation

Table 6.2 Extracted and bound fat within different types of crumb.

Recipe	Total fat (%)	Extracted fat (%)	% of fat bound within the crumb
Plain chocolate	27.0	27.0	0.0
Crumb milk chocolate	30.0	29.5	1.7
UK crumb	16.2	15.6	3.7
Irish crumb	16.0	12.9	19.4
Rework crumb	24.0	9.6	60.0

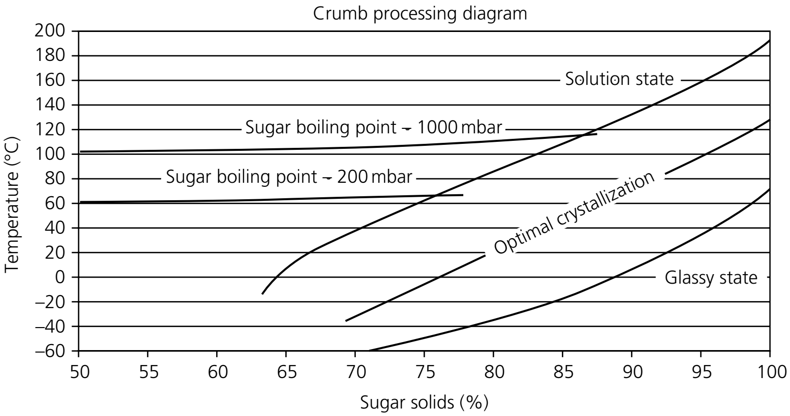

Figure 6.6 The effect of temperature and sugar concentration on crystallisation.

temperature. Product viscosity is then very high and considerable shear is needed to achieve high levels of crystallinity. In addition the high process temperature will lead to high flavour development.

- Alternatively, it is possible to evaporate under reduced pressure. If this is around 200 mbar, optimal crystallisation begins at around 90% solids, at a temperature of about 80 °C (176 °F) and with a manageable product viscosity. Crumb flavour is less pronounced at this temperature and high levels of sucrose crystallinity can be routinely achieved.

To achieve high sugar crystallinity it is helpful also to apply shear while the product is in the optimal region of the processing window just described. In the original batch oven process, this was achieved by mixing the sweetened condensed milk and the cocoa liquor in a melangeur pan (see Chapter 1) until the correct crystal size was achieved according to optical microscope measurements. Modern continuous crumb processes are careful to build in shear steps before the crumb paste becomes too viscous.

Many early batch crumb processes did not incorporate shear during the final production stages and the product was highly amorphous (glassy). This produced a highly viscous chocolate when it was freshly made, so the crumb was "matured" in hessian sacks in a humid atmosphere for several months before it was used. This enabled the glassy particles to absorb moisture and become crystalline, before ejecting the moisture again. "Matured" crumb produced chocolate with a similar viscosity to crystalline crumb, but had the big disadvantage of requiring long storage periods.

6.6 The structure of chocolate crumb

The way the crumb ingredients bind together on the micro and macro scale is crucial to the crumb's behaviour in subsequent handling and chocolate processing. This section deals with this topic.

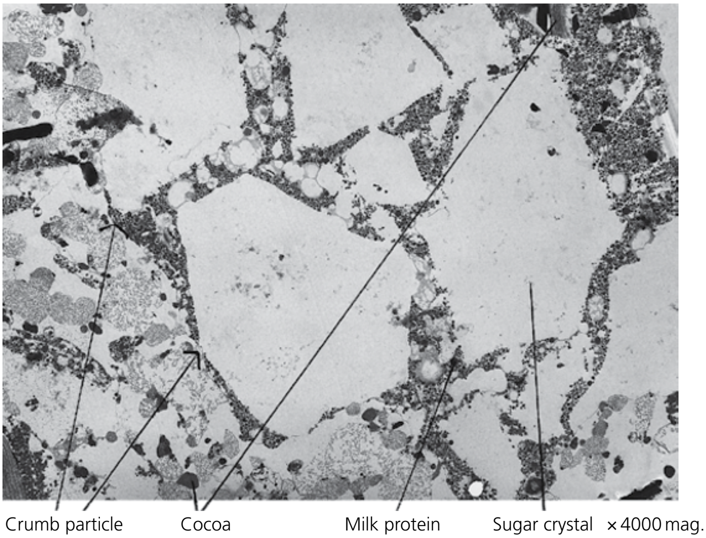

Figure 6.7 Ultra-thin section of crystalline crumb chocolate.

6.6.1 Crystallinity

Figure 6.7 shows the microstructure of a typical highly crystalline chocolate particle obtained from crumb. It is evident that a composite crumb particle is present where sugar crystals are surrounded by milk protein particles at the edge with randomly positioned cocoa fragments.

When significant quantities of glucose syrup are present in the formulation before going through the drying process, a highly amorphous crumb is the result. This occurs with “rework” crumb, whose structure is depicted in Figure 6.8.

6.6.2 Fat availability

If a freeze etch picture is taken of a fracture through such an amorphous crumb, trapped fat globules can be seen within the amorphous sugar matrix (Figure 6.9). This would not be seen in a significant amount in a highly crystalline crumb.

6.6.3 Fat droplet size

Another significant structural factor affected by crumb processing is the size of the fat globules. The original batch oven process added cocoa liquor at a late stage, that is after making sweetened condensed milk. The degree of mixing did not disperse the cocoa butter from the liquor very finely so that, during later chocolate refining, size reduction to about 25 μm was able to release the fat fairly readily (see also Chapter 3). If, however, cocoa liquor is added to the original milk and sugar before evaporation, its cocoa butter is finely dispersed within the crumb structure and is not so easy to release in refining. This is even more the case in a process where a spray nozzle is used to disperse the liquor/sweetened condensed milk into a drying chamber.

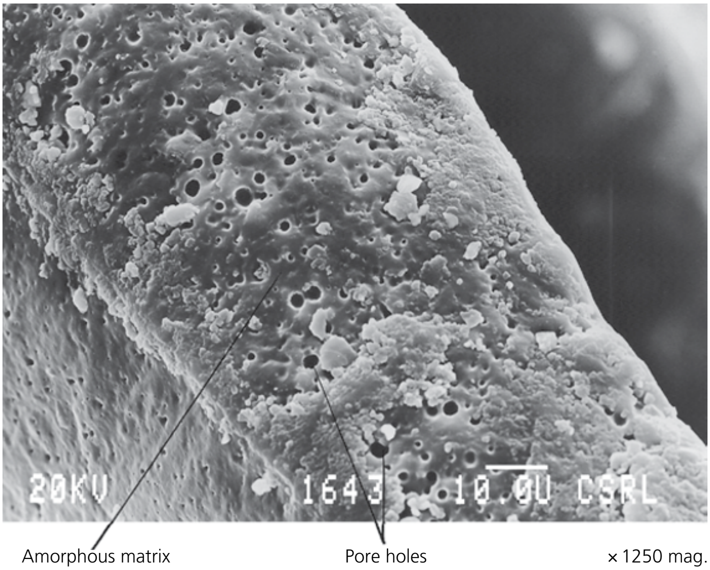

Figure 6.8 Section of amorphous (glassy) crumb.

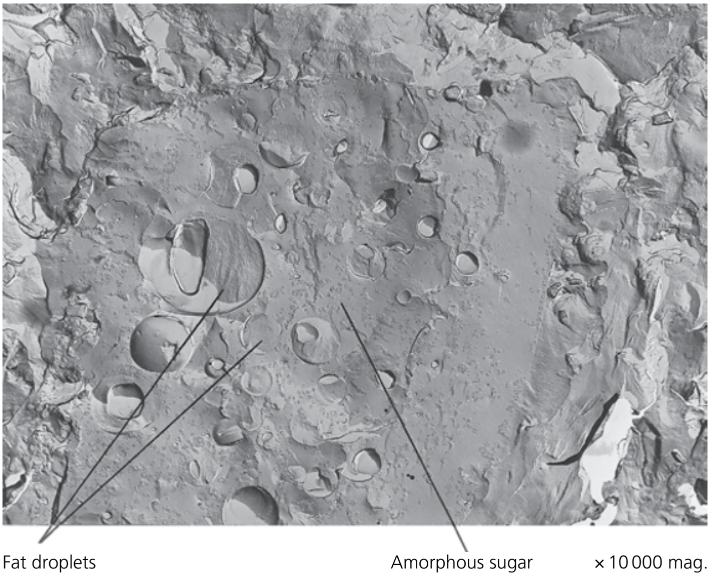

Figure 6.9 Scanning electron microscope picture of freeze etch fracture through amorphous crumb.

6.6.4 Aeration

Original batch oven crumb had a honeycomb texture created by the evaporation of moisture from the stiff kneader paste under vacuum. This made the crumb easy to fracture and easy to mill and refine. This structure is harder to produce in a continuous process unless significant vacuum is used and the crumb is left static during the last stages of drying. This has the disadvantage that it makes the mixture less likely to crystallise.

6.6.5 Overall particle size distribution

The final structural element of crumb that is vitally important is the particle size distribution. The earliest batch oven crumb was composed largely of 1.0–2.5 cm (0.5–1.0 in) lumps with a minimal amount of dust. This is very important to the crumb's handling characteristics. Very dusty crumb cannot be stored in large bulk without severe compaction problems which lead to bridging in hoppers, build up in conveyors and so on. One of the great difficulties with newer continuous processes has been their tendency to create too much dust.

The most successful crumb processes create lumpy product just prior to the final drying stage and preserve it through drying as well. Vigorous tumbling action during drying creates very dusty crumb, which is hard to handle.

One option to eliminate dust problems is to form the finished crumb into uniform sized "briquettes" in a high pressure forming device. Processes to do this are described in the patent literature (Nestec S.A., 1978; Mars Inc., 2000).

6.7 Typical crumb processes and equipment

The different stages of a typical milk crumb process listed in Table 6.3.

The first stage of the crumb process involving pasteurising and evaporating the milk is exactly the same as in other dairy processes. Pasteurisation is ensured

Table 6.3 Crumb processing stages

Material	Process	Solids (%)	Water (%)
Full cream milk		12.5	87.5
	Pasteurising/evaporating		
Concentrated milk		50.0	50.0
	Sugar dissolving		
Sweetened condensed milk (SCM)		72.0	28.0
	Air/vacuum cooking		
Cooked SCM		88.0	12.0
	Cocoa liquor addition		
Crumb paste		90.0	10.0
	Kneading/mixing		
Kneader paste		90.0	10.0
	Air/vacuum drying		
Dried crumb		99.0	1.0

by keeping the milk at 72 °C (162 °F) for at least 15 s. Evaporation is carried out in multiple effect evaporators to the solid content required. Granulated sugar is then dissolved in the condensed milk according to the recipe. Treatment of the SCM from this point onwards varies substantially, the more modern continuous processes having, to differing degrees, all tried to mimic the original batch oven process which will be described first.

6.7.1 Batch oven process

- *Cooking* of the sweetened condensed milk was done in large pans under partial vacuum at around 75 °C (167 °F) with rapid boiling. When the solids reached about 88%, signs of crystallisation could be recognised by a skilled operator through an inspection window. At this point cocoa liquor was put into a heavy duty melangeur pan (Chapter 1) again according to recipe and the crystallising SCM gradually discharged from the vacuum pans.
- *Kneading* of the stiff paste at this point was carried out for about 30 min. Samples of kneader paste were examined under the optical microscope to ensure that crystallisation was extensive and that the sugar crystal size was less than 35 μm. It was believed that coarser particles than this could cause difficulties in later chocolate refining. When the operator was satisfied, the kneader paste was charged onto trays and placed on shelves in a vacuum oven.
- *Vacuum oven drying* reduced the crumb moisture content to around 1%. The drying temperature was varied from 75–105 °C (167–221 °F) depending on whether the shelves were heated with hot water or steam. The drying time was in the range 4–8 h. Virtually all the typical crumb flavours were developed during this last stage.
- *Crushing and storage.* The contents of the oven trays were put through a rotary crusher to reduce the crumb to pieces of 1.0–2.5 cm (0.5–1.0 in) size with as little dust as possible. This material was then stored either in protectively lined bulk storage bags or in cylindrical silos of up to 500 t capacity.

Because of the very large labour input into filling and emptying trays, much effort over the last 50 years has gone into developing continuous processes that can replicate the key steps of cooking, kneading and drying, while producing a similar flavour and texture. Some of the variants will now be described.

6.7.2 Continuous processes

A number of options have been used for continuous cooking of the sweetened condensed milk up to a solids content of around 88%. These include:

- Scraped surface evaporators;
- Falling film evaporators.

These and other processes are critical to the whole crumb process. Many of them are proprietary, however, and so cannot be discussed in detail.

There is much more information on various whole, continuous processes and last stage drying steps from the 88% solids stage onwards. These will now be described.

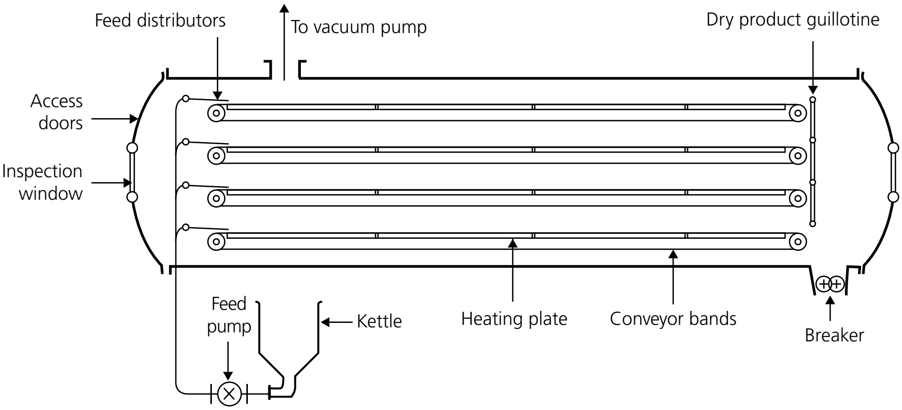

Figure 6.10 Schematic diagram of continuous vacuum band drier.

6.7.2.1 Vacuum or air band dryer processes

This method of treating kneader paste is probably closest to the original batch oven process. The dryer consists of a continuous belt, as depicted in Figure 6.10, running in a long cylindrical vacuum chamber (Minifie, 1977a). The paste can then be extruded as ropes onto the moving belt. The belt may run over a "bed", steam heated internally, or heat may be supplied by radiant heat above. The length and speed are such that drying is completed by the time the belt turns over a spindle for return. The dried crumb breaks off in pieces and falls via an air lock into a chamber from where it passes to storage.

When the drying process is carried out under atmospheric pressure conditions, the equipment is simpler to design, and drying can be carried out using co- or counter-current hot air.

6.7.2.2 Vacuum roll dryer process

This process takes the approximately 90% solids kneader paste through two stages of drying (Powell, 1970). The first dryer consists of two internally steam heated rollers, counter rotating in a heavy gauge metal dome under partial vacuum. Partially dried crumb builds up and falls off as "sausages" located by scrapers mounted at about 60° from the top of both rolls. This material is mechanically conveyed from the base of the oven. The choice of partial vacuum, steam pressure and throughput is such that the paste can be aerated, dried and formed into pieces similar to the crumb obtained in the batch oven process, thus making it suitable for silo storage and bulk transport. The partially dried pieces discharge into air lock chambers and from there into hot air drying towers of large enough capacity to dry the crumb to 1% moisture after 5–8 h residence time. From these towers the finished crumb passes through a 2.5 cm (1 in) breaker and is pneumatically conveyed into storage silos.

6.7.2.3 Atmospheric Groen process (scraped surface heat exchanger)

This process was developed in the late 1970s and has been disclosed in a number of papers (see e.g. Minifie, 1977b; Christiansen,1983). It has two unusual features which make the final product rather different from batch oven crumb:

1. All the ingredients, including the cocoa liquor, are dispersed in the concentrated milk before drying. This produces small droplets of fat.
2. Drying takes place under atmospheric conditions so that process temperatures are much higher than in the processes just described.

The ingredient pre-mix, containing condensed milk, sugar and cocoa liquor is passed into the dual jacketed vertical scraped surface evaporator depicted in Figure 6.11.

The bulk of the water is removed at this stage and the crumb paste exits the top of the evaporator at a temperature of around 125 °C (257 °F) and a moisture content of around 5%. This stiff paste is starting to crystallise and its exit into the crystalliser is mechanically aided. The crystalliser is a water jacketed vertical rotor stator arrangement of intermeshing blades in a progressively narrowing

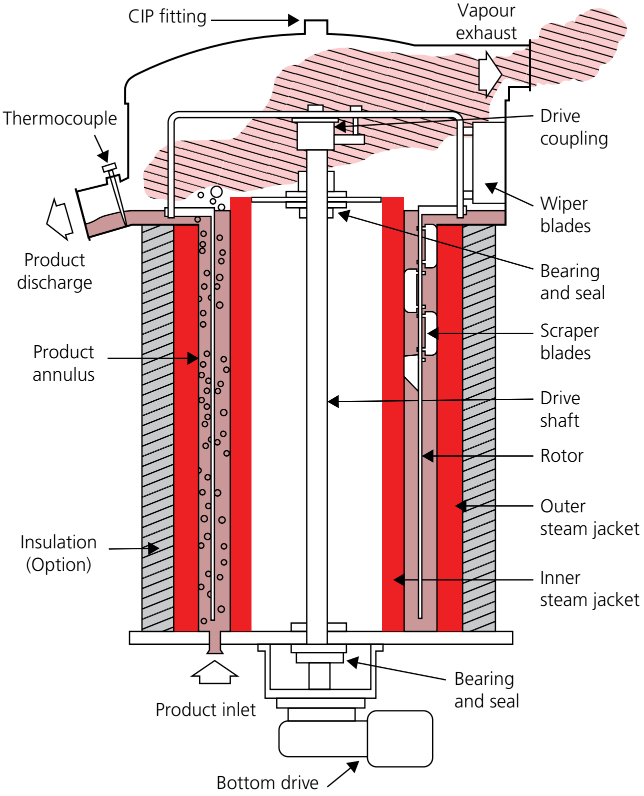

Figure 6.11 Groen DR series scraped surface evaporator.

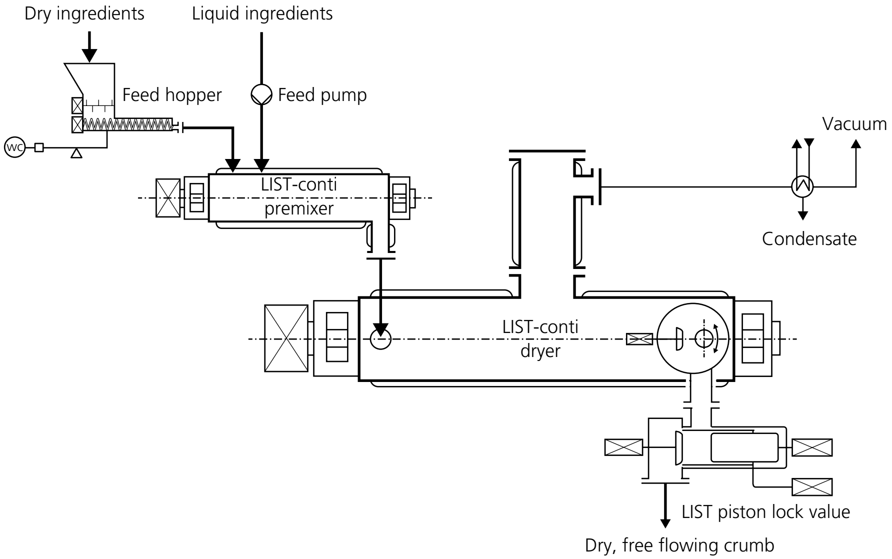

Figure 6.12 List crumb process flow diagram.

annular gap. Rapid cooling is encouraged by the dry ambient air that passes through the annulus and the water cooling. Sensible (specific) and latent heat of sugar crystallisation are removed in this way and the crumb pieces drop at the base onto a continuous air band dryer.

Although the process described was developed for atmospheric pressure, the Groen DR series of scraped surface evaporators are also available for vacuum operation. In addition crystallisers have been designed to operate with less viscous material out of the first dryer.

6.7.2.4 Stirred mixer vacuum process

A number of batch mixers have been designed to operate as semi-continuous crumb making machines. Typical of such processes is that offered by the company List AG. The process flow diagram is shown in Figure 6.12.

The core of the process is the second List dryer which is a heated single shaft mixer operating under vacuum and with sufficient power to convert an incoming paste of 88% solids, through the point of maximum viscosity and beyond to the point where the material becomes a flowing powder. At the correct flow rates it is possible to dry the final powder to around 1% moisture content. Figure 6.13 shows the List single shaft mixer/dryer.

In the early 1990s this type of equipment was being used to make white crumb in a number of companies. Similar semi continuous vacuum mixer/dryers have been used to make milk crumb by one of the major confectionery companies throughout the world.

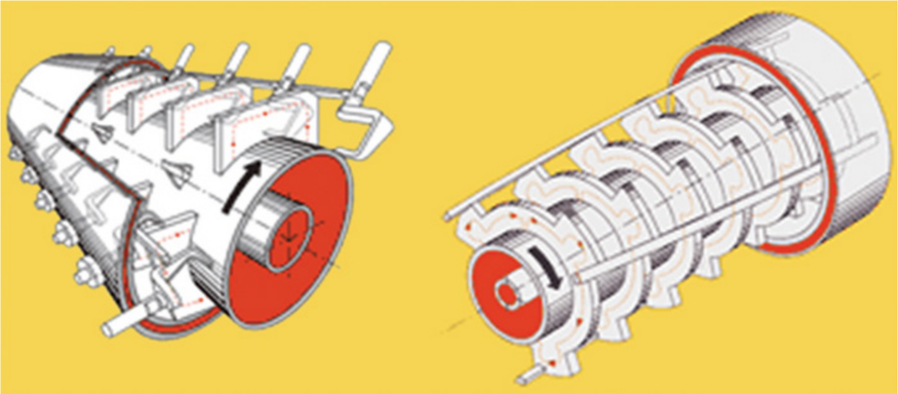

Figure 6.13 Illustration of List single shaft mixer/drier.

Table 6.4 Effect of process upon crumb properties

Process	Level of caramelisation	Degree of crystallinity	Aeration	Fat availability	Lumps/dust
Groen	Very high	Medium to high	Low	Medium to high	Small lumps
Batch oven	Medium	Low to high	High	High	Large lumps
Vacuum band dryer	Medium	High	High	High	Large lumps
Vacuum roll oven	Low to medium	Very high	Medium	Very high	Lumps and dust
Stirred mixer	Medium to high	Medium to high	Low	High	Dust

6.8 Effect of the crumb process upon the crumb properties

The choice of process has a major influence on the flavour and processing characteristics of the finished crumb. Table 6.4 summarises the major differences.

6.9 Changes to crumb during storage

Although originally crumb was chosen as a stable alternative to milk powders, there are limits to its stability in certain aspects.

The fat system in crumb is not in its final stable form immediately after manufacture. Crystallisation of the fats occurs slowly, with a tendency for the fat to migrate to the surface of the particles. It has been found that very fresh crumb requires more energy in later refining and conching, and it is undoubtedly the slightly lower fat availability on particle surfaces which accounts for this.

Crumb has a very low equilibrium relative humidity (ERH, the relative humidity at which moisture is neither taken up nor given out) at normal moisture contents as Figure 6.14 demonstrates.

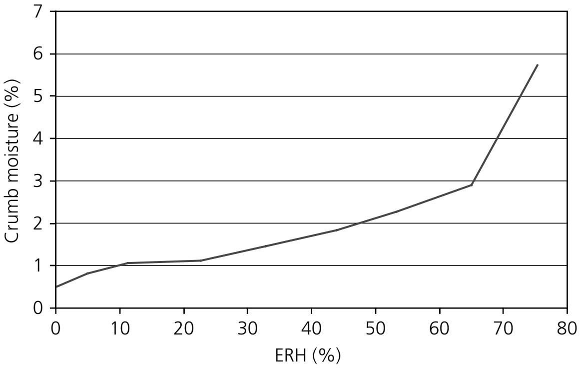

Figure 6.14 The relationship between the crumb moisture content and its equilibrium relative humidity (ERH).

This means that crumb of say 1% moisture can readily pick up more moisture in contact with typical room air of 50% RH. This is unlikely to occur when the crumb is stored in large bulk containers (with a small amount of air), but it can be an issue when it is being transported.

Finally, care should be taken in storing warm crumb in large bulk for long periods. There are a number of reactions going on in crumb which are exothermic and can lead to crumb spoilage. The Maillard reaction itself is exothermic and when the crumb temperature builds up other reactions follow:

- The sucrose and lactose invert to monosaccharides (see Chapter 4);
- The monosaccharides can then dehydrate;
- Finally at temperatures of 120 °C or above, the remaining lactose and sucrose can dehydrate.

The dehydration reactions particularly are highly exothermic, and serious damage can be caused to the crumb. Crumb which is destined for long term storage should be cooled to below 30 °C (86 °F).

Conclusion

There is very little to be found in the literature about chocolate crumb and its processing, indeed very few people outside of the industry know of its existence. It does however permit the manufacturer to make milk chocolate with a much wider variety of flavours. Many "house" flavours are produced by special crumb processes, which make them very difficult to copy. It is interesting to note that, in the United States, Hershey supplements the crumb flavour with milky butyric flavours by lipolysing the milk fat with the enzyme lipase (Hershey, 1931). It is perhaps interesting to conclude by noting that the market-leading milk chocolate tablets in the United States and United Kingdom are crumb chocolates, showing that the consumer appreciates their flavour and texture.

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CHAPTER 7

Properties of cocoa butter and vegetable fats

Geoff Talbot

7.1 Introduction

Apart from milk fat, the fat phase of chocolate and compound coatings is almost exclusively composed of cocoa butter and cocoa butter-like vegetable fats that are given the generic name of cocoa butter alternatives (CBAs). CBAs can be subdivided into three further groups:

- Cocoa butter equivalents (CBEs). These are fats that have similar fatty acid and triglyceride compositions to cocoa butter and, as a result, also have similar physical characteristics.
- Cocoa butter replacers (CBRs). These are non-lauric fats that have a completely different triglyceride composition to cocoa butter although, in some cases, there is some similarity in fatty acid compositions. They do, though, have some physical characteristics in common with cocoa butter.
- Cocoa butter substitutes (CBSs). These are fats based on the so-called lauric fats (predominantly palm kernel oil). They have a completely different fatty acid and triglyceride composition to that of cocoa butter but do share some similar physical properties (notably melting profiles).

This chapter will discuss first the compositional and physical characteristics of cocoa butter (as this is the basic fat in all chocolates) and then move on to look at the compositional and physical characteristics of the three types of CBA and how they interact with cocoa butter when blended together. Finally, it will consider some vegetable fats that have been used in chocolate and compounds to give particular specific characteristics and properties. As the properties of all of these alternatives are, in one way or another, linked to cocoa butter, it is sensible to begin with cocoa butter itself.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett, Mark S. Fowler and Gregory R. Ziegler.

7.2 Cocoa butter

Cocoa butter is the fat phase of beans produced by the plant *Theobroma cacao*. As Chapter 3 has discussed the production of cocoa butter in some detail it is unnecessary to repeat that here. However, it is important to point out that cocoa butter is not a single entity having exactly the same fatty acid and triglyceride composition in all cases. It is a natural fat and, as such, has natural variations in its composition, not least those resulting from its geographical origin.

7.2.1 Fatty acid and triglyceride composition

There are three main cocoa-growing areas in the world – West Africa, Asia, and the Americas (see Chapter 2). These three areas produce cocoa butters with significantly different compositions (and therefore quite different physical characteristics) as well, of course, as there being smaller natural variations between cocoa butters from within each area.

In comparison to many other fats, cocoa butter has a relatively simple fatty acid and triglyceride composition being composed predominantly of four major fatty acids (palmitic acid, stearic acid, oleic acid and linoleic acid) and three major triglycerides: [1,3-dipalmitoyl-2-oleoylglycerol (POP), rac-1-palmitoyl-2-oleoyl-3-stearoylglycerol (POSt) and 1,3-distearoyl-2-oleoylglycerol (StOSt)].

Typical ranges in fatty acid compositions from the three main cocoa-producing areas are shown in Table 7.1.

Although the differences are small between the different origin areas they do, nevertheless, contribute to differences in total SOS and SOO[1] contents which, in turn, affect melting profiles. In general, Asian cocoa butters have lower levels of palmitic acid and higher levels of stearic acid than African cocoa butters resulting in higher StOSt/POP ratios in the Asian butters. South American cocoa butters usually have higher unsaturated fatty acid (C18:1 and C18:2) levels than butters from the other origins, resulting in higher SOO levels and softer cocoa butters.

The differences in the fatty acid compositions are also seen in the triglyceride compositions (Table 7.2) with Asian cocoa butters having higher levels of POSt and StOSt than butters from Africa and South America and South American cocoa butters having higher levels of POO and StOO.

These differences in triglyceride composition then have a knock-on effect on the melting profiles of the different cocoa butters. In very broad terms StOSt melts at a higher temperature than POSt which, in turn, melts at a higher temperature than POP. Therefore, cocoa butters richer in StOSt and POSt have higher solid fat contents, that is Asian cocoa butters have higher solid fat contents than West African or South American cocoa butters. Similarly, triglycerides

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[1] In this context S is the total of all the saturated fatty acids (mainly palmitic, C16:0, stearic, C18:0 and arachidic, C20:0), O denotes oleic acid.

Table 7.1 Typical fatty acid compositions of cocoa butter. Compiled from Lipp and Anklam (1998) and Foubert *et al.* (2004).

West Africa

Fatty acid	Ghana	Ivory Coast	Ivory Coast	Ivory Coast	Nigeria	West Africa
C16:0	25.3	25.8	25.6	26.4	26.5	26.2
C18:0	37.6	36.9	36.5	36.5	37.1	36.6
C18:1	32.7	32.9	34.1	33.5	33.1	33.6
C18:2	2.8	2.8	2.8	2.7	2.3	2.7

Asia

Fatty acid	Malaysia	Malaysia	Indonesia	Java
C16:0	24.9	25.7	26.1	24.1
C18:0	37.4	37.1	37.3	37.3
C18:1	33.5	33.7	33.3	34.3
C18:2	2.6	2.4	2.7	2.7

The Americas

Fatty acid	Ecuador	Ecuador	Brazil	Brazil	Brazil	San Domingo
C16:0	25.6	27.1	25.1	25.1	24.9	26.9
C18:0	36.0	35.4	33.3	34.3	32.9	34.4
C18:1	34.6	33.7	36.5	36.4	37.6	34.8
C18:2	2.6	2.6	3.5	3.4	3.7	2.9

Table 7.2 Typical triglyceride compositions of cocoa butter. Compiled from Chaiseri and Dimick (1989).

Country	POP	POSt	StOSt	POO	StOO
West Africa					
Ivory Coast	19.0	39.6	28.5	1.9	3.9
Nigeria	17.9	38.8	27.8	2.3	5.2
Cameroon	17.9	38.3	27.7	3.0	5.8
Ghana	17.8	39.0	27.5	2.2	4.9
Asia					
Indonesia	19.9	40.6	28.1	1.6	3.6
Malaysia	18.4	40.0	31.1	1.2	2.9
South America					
Brazil	17.9	37.1	26.0	3.9	6.7
Colombia	20.4	39.4	25.0	3.3	4.4
Ecuador	19.2	38.4	26.9	3.0	5.4
Dominican Republic	18.4	38.2	26.5	3.3	6.1

Table 7.3 Solid fat contents[a] (by pNMR) of cocoa butters from different origins. Reprinted with the permission of Loders Croklaan.

Temperature		Brazil	Ghana	Malaysia
°C	°F			
20	68	66.3	76.2	81.2
25	77	60.1	70.4	76.2
30	86	36.9	45.1	54.8
32.5	90	6.6	13.3	19.7
35	95	2.0	0.0	0.0

[a] Tempered at 26 °C (79 °F) for 40 h prior to solid fat content measurement.

that contain higher levels of unsaturated fatty acids melt at lower temperatures. Therefore, South American cocoa butters do, in general, have lower solid fat contents than Asian or West African cocoa butters. These differences can be seen in Table 7.3.

7.2.2 Polymorphism

The relatively simple triglyceride composition of cocoa butter (with approximately 80% of its triglycerides all being of the SOS type; i.e. POP, POSt and StOSt) means that cocoa butter remains hard (high in solid fat) until it reaches a temperature of between 25 and 30 °C (77 and 86 °F). Then it melts very sharply, effectively being completely liquid by 35 °C (95 °F). Another consequence of this simple triglyceride composition is that cocoa butter is a highly polymorphic fat.

Polymorphism is the ability of a molecule to crystallise in a number of different crystal packing configurations. While polymorphism is present in most fats, those rich in symmetrical monounsaturated triglycerides such as SOS are highly polymorphic. This high degree of polymorphism is found not only in cocoa butter but also in those SOS-rich fats used in cocoa butter equivalents (Section 7.3 below).

Historically, six different polymorphic forms have been identified for cocoa butter. Traditionally, the confectionery industry has considered the polymorphism of cocoa butter to be that as defined by Wille and Lutton (1966) in which six forms are given the names Form I to Form VI. In the oils and fats industry the convention is to use the Greek letters α, β, β′ and γ to define polymorphic forms. While Wille and Lutton were using Form I to Form VI to define the polymorphism of cocoa butter, Larsson (1966) was using this Greek letter nomenclature. In general, as we move from γ to α to β′ to β the stability and the melting point of the polymorphic form increases. In tempering chocolate it is necessary to crystallise the cocoa butter in as stable a polymorphic form as possible.

Later work by van Malssen *et al.* (1999), however, suggested a different interpretation of cocoa butter polymorphism from that of both Wille and Lutton and Larsson; both in the assignments of polymorphic form and in the melting points

Table 7.4 Polymorphic forms of cocoa butter.

Wille and Lutton (1966)	Larsson (1966)	Van Malssen *et al.* (1999)	Chain packing
Form I	β'_2	γ or sub-α	Double
Form II	α	α	Double
Form III	mixed	β' range	Double
Form IV	β'_1		Double
Form V	β_2	β_V	Triple
Form VI	β_1	β_{VI}	Triple

Table 7.5 Melting points (°C; °F in parentheses) of polymorphic forms of cocoa butter.

Polymorphic form	Wille and Lutton (1966)	Van Malssen *et al.* (1999)
Form I/sub-α	17.3 (63)	–5 to +5 (23–41)
Form II/α	23.3 (74)	17–22 (63–72)
Form III/β'	25.5 (78)	20–27 (68–81)
Form IV/β'	27.5 (82)	
Form V/β_V	33.8 (93)	29–34 (84–93)
Form VI/β_{VI}	36.3 (97)	

defined for each individual polymorphic form. Van Malssen *et al.* (1999) found only five polymorphic forms in cocoa butter. The assignments of each form by these three groups of researchers are shown in Table 7.4.

The difference between the "traditional" polymorphic assignments and those of van Malssen *et al* is that the latter group found not two β′ forms but a range of these indicating the presence of either five forms (if the range is treated as a single form) or many forms (if the polymorphic forms in the range are treated individually).

Van Malssen *et al.* (1999) also found that the melting points of each of the polymorphic forms had been wrongly assigned by Wille and Lutton and that the melting point of the lowest stability form (Form I or γ/sub-α) was significantly lower than that measured by Wille and Lutton, mainly because this form very quickly transforms into the α form making determination of its melting point quite difficult. For comparison, the melting points assigned to each of these polymorphs by both groups (Wille and Lutton and van Malssen *et al.*) are shown in Table 7.5.

Because of the familiarity in the confectionery industry with the Wille and Lutton convention this will be used in the rest of this chapter interchangeably with the new convention defined by van Malssen *et al*. To allow for the presence of a range of β′ forms as defined by van Malssen *et al.*, Forms III and IV will be treated as a single form when using the Wille and Lutton convention.

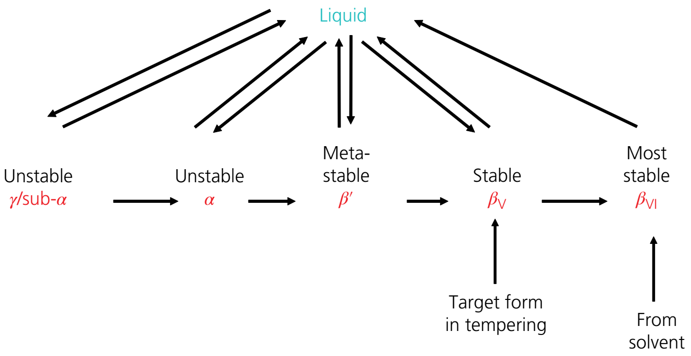


Figure 7.1 Polymorphic changes in cocoa butter. Reproduced with permission of Loders Croklaan.

Form I (sub-α) is produced by rapid cooling at low temperatures. It is very unstable and rapidly transforms into Form II (α). This form will change more slowly into Forms III and IV (β′).

β′ is the polymorphic form which would generally be produced if un-tempered or extremely poorly tempered chocolate were then cooled in a cooling tunnel, as though it were properly tempered. This form will also fairly rapidly (sometimes even before leaving the cooling tunnel) transform into Form V (β).

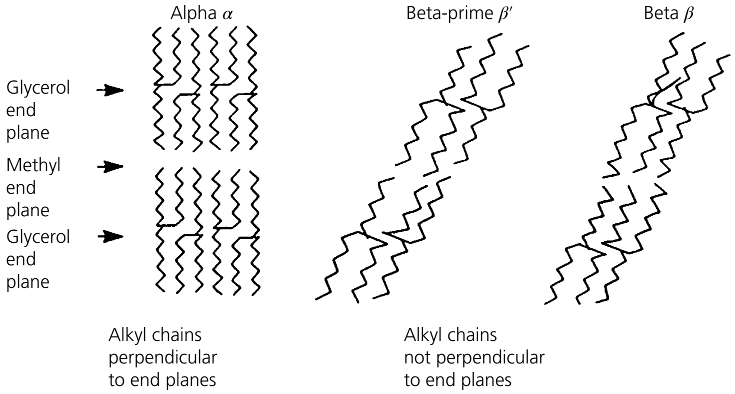
Forms V and VI or the β forms are the most stable forms of cocoa butter. Form V is the state which is produced in a well-tempered chocolate. On lengthy storage this can very slowly transform into Form Vl, a change which is often accompanied by the formation of fat bloom. It is difficult to generate Form Vl cocoa butter quickly and directly, although this has been observed when cocoa butter is allowed to crystallise from a solvent (Figure 7.1)

These different polymorphic forms or packing configurations are characterised by differences in the distances between the glyceride chains and in the “angle of tilt” relative to the plane of the end methyl group of the chain (see Figure 7.2).

The three main polymorphic forms found in fats (not only in cocoa butter): α, β′ and β have crystal packing configurations as shown in Figure 7.2. The α configuration has alkyl (fatty acid) chains which are both straight and parallel to each other, but which are also perpendicular to the end planes of the molecules. If we were to look end-on at the chains they would appear to have a cross-section of hexagonal symmetry reminiscent of looking end-on at a clump of pencils.

The β′ and β polymorphs show considerably more order in their crystal packing. Both display an angle of tilt relative to the end plane of the molecules. This angle is slightly greater (i.e. closer to perpendicular) in the β′ form than in the β form. In the β′ form the chains pack in an orthorhombic sub-cell in which adjacent zigzag fatty acid planes are mutually perpendicular when viewed end-on. In the β form the chains pack in a triclinic sub-cell with all the zigzag fatty acid chains being parallel to each other.

1. Projection showing arrangement of alkyl chains for *α*, *β′* and *β* polymorphs



2. Projection parallel to direction of alkyl chain (i.e. arrangement looking onto ends of chains)

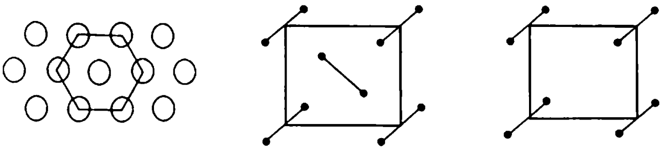


Figure 7.2 Crystal packing of triglycerides. 1. Projection showing arrangement of alkyl chains for α,β and β′ polymorphs. 2. Projection parallel to direction of alkyl chain (i.e. arrangement looking onto ends of chains). Reprinted with the permission of Loders Croklaan.

These polymorphic forms can be characterised by X-ray diffraction and, particularly by their X-ray short spacings, that is:
α Single strong line at 4.15 Å;
β′ Two lines at 3.8 and 4.2 Å;
β One strong line at 4.6 Å.

More subtle differences are observed in the X-ray diffraction patterns of the various sub-forms, for example β_V and β_{VI}. Both these forms show four smaller peaks in addition to the strong peak identified above. In the β_V form (or Form V in cocoa butter) these small peaks are of varying intensities, whereas in the β_{VI} form (or Form VI in cocoa butter) they are of intensities which increase with diffraction angle (see Figure 7.3). Note that in the context of cocoa butter β_2 and β_V are now often used interchangeably as are β_1 and β_{VI}.

In addition to these different polymorphic forms there is a further way in which different triglycerides can pack or crystallise together – the so-called double-chain length (denoted by "-2" after the Greek letter signifying the polymorphic form, e.g. β-2) and triple-chain length packing (denoted by "-3" after the Greek letter signifying the polymorphic form, e.g. β-3). Although such nomenclature can be confusing it should be remembered that β_2 and β-2 mean two different things – the former denotes the less stable of the two β forms,

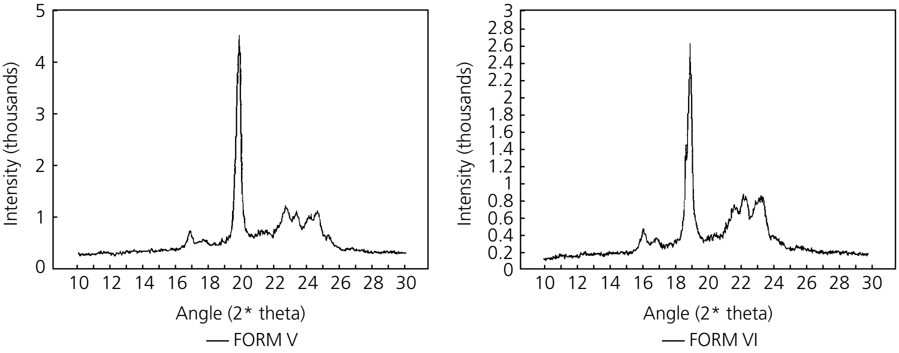


Figure 7.3 X-ray diffraction patterns of Form V and Form VI cocoa butter. Reprinted with permission of Loders Croklaan.

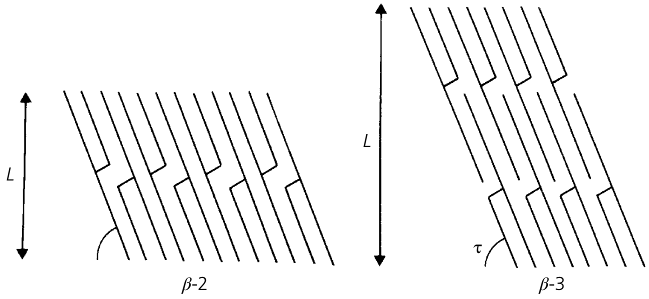


Figure 7.4 Schematic arrangement of triglycerides in the β-2 and β-3 crystalline phase. Reprinted with permission of Loders Croklaan.

the latter denotes any β form in a double-chain length configuration. The molecules shown in Figure 7.2 are depicted in a double-chain system in which the distance from one methyl end plane to the next is approximately the length of two fatty acid chains. Double and triple systems are shown schematically in Figure 7.4. These different types of chain packing are also referred to for each of the six polymorphic forms in cocoa butter in Table 7.4.

The two forms differ, therefore, in that the distance from one methyl end plane to the next is approximately the length of two fatty acid chains in the β-2 system and of three fatty acid chains in the β-3 system. X-ray long spacings will define in which of the two ways a particular fat is packed. The long spacing of β-3 is approximately 50% greater than the long spacing of β-2.

Whether a fat crystallises in a double or triple chain form is usually dictated by its triglyceride composition and, particularly, by the positional distribution of fatty acids on the triglyceride. The triglycerides in cocoa butter are predominantly of the SOS type, that is with the unsaturated oleic acid in the 2-position. The double bond in oleic acid causes an angular change in the fatty acid chain which means that it no longer has the "straight" structure of a saturated chain. If such triglycerides were to crystallise in a double chain form or β-2 the unsaturated acid in the 2-position of one molecule would be adjacent to the saturated acids in the 1- and 3-positions of the next molecule. The stereochemistry would be such that close packing of the triglyceride molecules would not be possible. If, however, these triglycerides pack in the triple chain form or β-3, then the unsaturated chain in the 2-position of one molecule would lie adjacent to the unsaturated chain in the 2-position of the next molecule. It was long thought that they did this in such a way that the positions of the double bonds in the oleic acid chains were next to each other with the chains nesting together, almost like spoons. Recent work by Peschar *et al.* (2004) suggests that this is not the case, but that only the end parts of the oleic acid chain (from the double bond to the methyl end group) are actually adjacent to each other. This enables much closer triglyceride packing and hence much greater thermodynamic stability. It has been shown that in Forms III and IV cocoa butter the triglycerides pack in a double-chain system, whereas in Form V they pack in a triple-chain system. The stereochemical problem of SOS triglycerides packing in a double-chain system accounts for the much lower thermodynamic stability of Form IV relative to the triple-chain Form V.

7.2.3 Minor components

As well as the major triglycerides shown in Table 7.2, other triglycerides are present in cocoa butter in lower amounts. Trisaturated triglycerides can have an important effect in cocoa butter although they are generally present in low levels. The main ones in cocoa butter are PPP, PPSt, PStSt and StStSt. Typical levels in a normal cocoa butter are about 1.4% but these rose to 3.6% in a sample heated under vacuum to 250 °C (482 °F) for 1 h (Timms and Stewart, 1999). Foubert *et al.* (2004) measured levels of these four triglycerides in cocoa butter and found mean levels of 2.11% (SD = 0.57%). Davis and Dimick (1989) also measured the trisaturated triglyceride contents of whole cocoa butter and also of a high-melting fraction. The whole cocoa butter contained 4.47% of PPSt (and OOA), PStSt and StStSt in total, whereas the isolated high-melting fraction contained a total of 65.66% of these triglycerides. The importance of these trisaturated triglycerides and particularly of those found in a high-melting fraction is that, when chocolate is tempered, they can crystallise out early in the process and, in so doing, increase the viscosity of the chocolate without making any contribution to the state of temper of the chocolate.

As well as triglycerides, cocoa butter can contain varying amounts of partial glycerides (mainly diglycerides). It is known that diglycerides can affect crystallisation of fats (Siew and Ng, 1999; Tietz and Hartel, 2000), usually interfering with crystallisation, although Tietz and Hartel (2000) suggest that they can act as nucleation sites when present at low levels. Timms and Stewart (1999) suggest a maximum of 2.5% diglycerides as being acceptable in cocoa butter. Foubert *et al.* (2004) found a mean level of 0.92% in 20 different cocoa butters, with the highest diglyceride level being 2.2%.

Cocoa butter is one of the few oils used in food without refining to remove free fatty acids, pigments and flavours and odours. This is largely because the flavours naturally present in prime pressed cocoa butters enhance the flavour of chocolate. However, this does also mean that varying levels of free fatty acids can be present. Usually a maximum level of 1.75% free fatty acid is defined, often by legislation (Timms and Stewart, 1999; European Union, 2000; Folayan, 2010). As with partial glycerides, too high levels of free fatty acids can affect crystallisation. Foubert *et al.* (2004) found that, of 20 cocoa butters examined, four gave crystallisation problems. Of these four, three had free fatty acid levels above this maximum of 1.75%.

Although no maximum levels are specified, phospholipids are also present in varying amounts. Foubert *et al.* (2004) found levels between 0.006% and 0.16%, whereas Davis and Dimick (1989) found levels of 0.03% in whole cocoa butter and 6.56% in the high-melting seed fraction referred to earlier, suggesting that phospholipids may too have a part to play in early crystallisation during tempering.

Unsaponifiable matter can be present at levels of up to 0.35% in press cocoa butter, as defined by both the European Union (2000) and Codex Alimentarius (2001). In other types of cocoa butters the European Union (EU) permits up to 0.5% unsaponifiable matter and Codex Alimentarius permits up to 0.7% unsaponifiable matter. Foubert *et al.* (2004) found levels ranging between 0.31% and 0.53% in 20 different cocoa butters.

7.3 Cocoa butter equivalents

As defined earlier, cocoa butter equivalents (CBEs) are fats that have similar fatty acid and triglyceride compositions to cocoa butter and, as a result, also have similar physical characteristics. Research into the chemical properties of cocoa butter in the 1950s led to the conclusion that its triglycerides had the unique structure described in Section 7.2.1, and the realisation that, for the formulation of chocolate, any fat intended for use in blends with cocoa butter would need to have triglycerides of a similar structure. Unlike all animal fats, some vegetable oils contained triglycerides of the appropriate structure. This made possible the production of specific fat fractions which, when blended, had properties almost identical to those of cocoa butter itself.

A Unilever patent on the invention was filed in 1956, and CBEs were launched in the British market (Best *et al.*, 1956). They were immediately successful, and a partnership developed between the United Kingdom (UK) chocolate industry and Loders and Nucoline, the Unilever subsidiary specialising in the production and marketing of these new confectionery fats. At that time, and in fact until 1977, there was no official composition for chocolate in the UK, but the major manufacturers agreed to use a maximum of 5% CBE on the total weight of the chocolate.

Because of the successful use of CBEs in British chocolate their incorporation at a 5% level extended into other EU countries, first into Denmark and Ireland and then to Sweden, Austria, Finland and Portugal. Their use was permitted under national regulations but it took until 2003 for there to be an EU-defined set of chocolate regulations.

Purely from a functional point of view a cocoa butter equivalent must meet certain requirements in order to perform satisfactorily in chocolate:

1. It must have a melting range which reflects that of cocoa butter.
2. The fat should have a fatty acid and triglyceride composition close to that of cocoa butter.
3. The fat must be compatible with cocoa butter.
4. The fat should allow processing of chocolate products in an identical manner to that of cocoa butter based products.
5. The fat should crystallise in the same polymorphic form as cocoa butter; that is in the β_V modification.
6. The appearance and bloom free shelf-life of chocolate products containing CBEs should be at least identical to products based on cocoa butter alone.
7. The fat should have good flavour stability.

From a legislative and regulatory point of view further restrictions have been imposed on the use of CBEs in chocolate. In the 2003 EU regulations (European Union, 2000) restrictions were imposed on the basic fats and modification processes that could be used. These fats are described in more detail in the next section. Limits were also imposed on their level of use. No more than 5% CBE (non-cocoa vegetable fat) is allowed to be used in EU chocolate. Even then, there are further limitations. EU chocolate must contain a minimum of 25% total fat and all of that 25% must be from cocoa butter and milk fat. This means that only when the total fat content is higher than 30% can the full 5% of CBE be used. If, for example, the total fat content is 28% then 25% must be cocoa butter and milk fat and only 3% CBE can be used to bring the total to 28%.

It should be stressed that these requirements only apply to chocolate sold within the European Union. Countries outside the EU have their own national regulations. Some countries, such as the United States (US FDA, 2015) do not permit the use of added vegetable fat in chocolate but do allow its use in "chocolate and vegetable fat coatings". Some other countries allow the use of vegetable fats in chocolate without many of the restrictions which the EU place on both its composition and level of use. Insofar as there is any internationally accepted standard for the use of vegetable fats in chocolate, the Codex Alimentarius (2001) standard STAN 87-1981 was revised (Codex Alimentarius, 2003) to permit the use of vegetable fats in chocolate up to a level of 5% of the finished product (after deduction of the total weight of any other added edible foodstuffs, e.g. nuts and raisins). However, as legislation can change, it is advisable to check the legislation within any specific country before including vegetable fats in a chocolate composition (see Chapter 28).

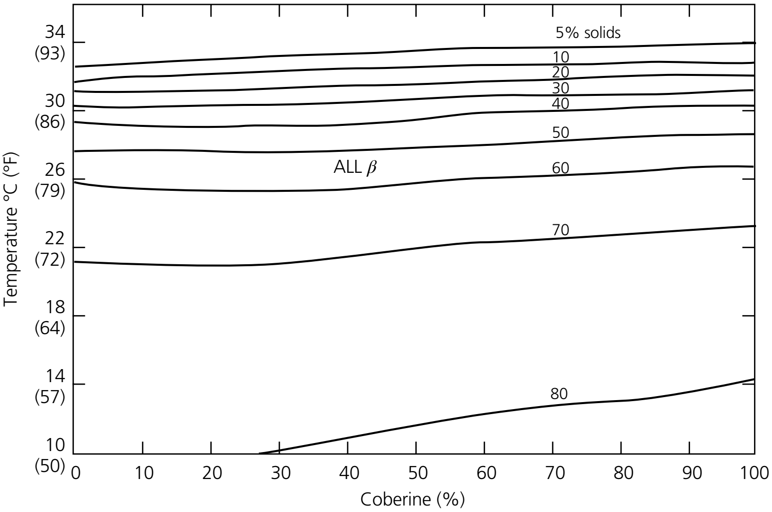


Figure 7.5 Iso-solids phase diagram for cocoa butter and Coberine™ (CBE). Source: Gordon *et al.* (1979). Reproduced with the permission of John Wiley & Sons.

Because the triglycerides used in CBEs are of the same type as those present in cocoa butter, blending them together produces no adverse interactions either in terms of melting properties or in terms of polymorphism. This excellent compatibility between cocoa butter and CBEs can be shown in the form of an iso-solids diagram (Figure 7.5). This shows that cocoa butter and Coberine™ (a well-known CBE) are fully compatible over the complete range of compositions. No lowering of solid fat content at any temperature is detected as one fat is added to the other. In addition, there is no indication of separate phases unique to one or other component.

This complete compatibility allows, in theory, any amount of cocoa butter to be replaced by a CBE. Whilst this is true, in practice, two types of product exist using CBEs. In some countries, as we have seen, up to 5% vegetable fat can be included in chocolate under the standards of identity of chocolate, that is where it is still permissible to call the product “chocolate”. In addition, most countries will also permit much higher levels of inclusion of CBEs in place of cocoa butter, but in this case the product cannot be labelled “chocolate”. These products have been given the name (within the oils and fats and confectionery industries) of supercoatings (see Chapter 19). Both uses will be considered in Section 7.3.4.

7.3.1 Main CBE component fats

The EU regulations relating to chocolate composition (European Union, 2000) permit CBEs to be produced from only six base oils (although they do allow a seventh oil, coconut oil to be used in chocolate on frozen confectionery). The six base oils permitted in ambient chocolate are the ones that are most commonly used in CBEs even where these are permitted outside the EU and are:

Illipe, Borneo tallow or Tengkawang (*Shorea* spp.);
Palm oil (*Elaeis guineensis, E. olifera*);
Sal (*Shorea robusta*);
Shea (*Butyrospermum parkii*);
Kokum gurgi (*Garcinia indica*);
Mango kernel(*Mangifera indica*).

The botanical names above are those quoted in the EU regulations (European Union, 2000). There is some controversy over the correct botanical naming of shea because the variety of shea used in confectionery is actually *Vitellaria paradoxa* (Lovett, 2015).

Further restrictions were placed by the EU on the oil in terms of the type of processing which the vegetable fat was allowed to undergo, limiting this to fractionation and refining. Fractionation is a process of crystallisation and separation in which the SOS triglycerides in these oils can be concentrated to a level similar to that found in cocoa butter. This restriction meant that enzymic rearrangement (see Section 7.3.3), which could be used to produce CBEs from oils grown in temperate climates, was specifically excluded. Although only enzymic rearrangement is specifically excluded, other processes, such as hydrogenation, are also excluded because they are not on the permitted list.

Finally, the vegetable fats must be miscible in any proportion with cocoa butter and be compatible with its physical properties (melting point and crystallisation temperatures, melting rate, need for tempering etc.). Essentially these physico-chemical requirements are much the same as many of those in the list of requirements for a CBE given earlier. From a chemical compositional point of view the main requirement for a CBE is that it matches the triglyceride composition of cocoa butter as closely as possible. This means that, ideally, a CBE should contain POP, POSt and StOSt.

7.3.1.1 Palm oil

Palm oil is rich in POP and contributes the greatest part of this triglyceride to the total composition of CBEs. Typical fatty acid and triglyceride compositions of palm oil are shown in Table 7.6.

The triglyceride composition of palm oil in Table 7.6 clearly shows that, while POP is a major triglyceride of palm oil, it is by no means predominant. If, therefore, POP is needed in greater purity in a CBE composition then it needs to be concentrated further in palm oil. This is carried out by the process of fractionation. Historically, this was carried out in an organic solvent such as acetone but, increasingly these days, dry or solvent-free fractionation is used. In either case, fractionation of palm oil is a two-stage process because, as well as the SOS triglycerides (POP and POSt), palm oil contains a significant amount of trisaturated triglycerides (SSS) and of more unsaturated triglycerides containing in

Table 7.6 Typical fatty acid (Rossell *et al.*, 1983, 1985) and triglyceride compositions (Jurriens, 1968) of palm oil.

Fatty acid	%	Triglyceride	%
C12:0	0.1–0.3	SSS	8.5
C14:0	0.7–1.3	MOP	1.2
C16:0	42.6–47.0	POP	24.1
C18:0	4.0–5.5	POSt	7.0
C18:1	36.6–39.9	StOSt	0.5
C18:2	9.5–12.0	SSO	5.3
C20:0	0.1–0.5	Two double bonds	35.0
		Three double bonds	19.8
		>3 double bonds	0.5

total two or more double bonds. The SSS triglycerides are high-melting and, if retained in the CBE, would crystallise out early in the process of tempering chocolate. All that they would do is contribute to increased viscosity and not to improved temper (Smith and Bhaggan, 2014). The more unsaturated triglycerides will simply soften the CBE so both these and SSS need to be removed by fractionation. Palm oil is first fractionated to remove the more unsaturated triglycerides, effectively producing a palm oleine and a palm stearine (rich in SSS and SOS). The stearine is then refractionated to separate out the SSS triglycerides in a "top-fraction" leaving a mid-fraction rich in POP and POSt. This is then used in CBEs.

7.3.1.2 Shea oil

Shea is a forest crop indigenous to the sub-Saharan savannah lands of West Africa. It has a long history of use locally and is the fat of choice for baking, frying, skin care in those regions. However, it also has a triglyceride composition that makes it suitable for use in CBEs (as well as being a component of many Western cosmetic products). As has been mentioned earlier, there has been some considerable confusion about the botanical nomenclature of shea oil. In the EU Regulations (European Union, 2000), as well as in the United States FDA GRAS listing and the International Nomenclature of Cosmetic Ingredients, this is defined as *Butyrospermum parkii*. However, after considerable debate amongst botanists it is now agreed that shea belongs to the *Vitellaria* genus (group) and consists of two species or types, *Vitellaria nilotica* and *Vitellaria paradoxa*. The background to this is fully described by Lovett (2015). Of these two types, *Vitellaria paradoxa* is the one used in CBEs.

Typical fatty acid profiles and triglyceride compositions of shea (*Vitellaria paradoxa*) from some of the main West African producing countries are shown in Table 7.7.

Table 7.7 Typical fatty acid and triglyceride compositions of shea oil. *Source*: Lovett (2015). Reproduced with permission of Elsevier.

Country	Fatty acid composition				Triglyceride composition[a]			
	C16:0	C18:0	C18:1	C18:2	SSS	S_2U	SU_2	UUU
Gambia	3.8	37.0	49.2	7.7				
Senegal	5.0	39.0	47.0	6.5				
Nigeria	3.9	40.8	46.6	7.1	0.2	45.4	31.6	22.8
Guinea	4.5	41.3	47.3	5.5				
Mali	3.8	42.4	45.5	6.9	0.1	45.6	33.1	21.3
Burkina Faso	3.8	44.1	44.0	6.4	0.0	47.5	32.8	19.7
Ghana	4.0	45.6	43.3	6.3				

[a] S = saturated; U = unsaturated; S_2U includes SUS and SSU; SU_2 includes SUU and USU.

Countries such as Gambia and Senegal produce shea with a much higher level of oleic acid compared to stearic acid (and hence a lower level of StOSt), whereas in Burkina Faso and Ghana there is greater parity between the oleic acid and stearic acid levels and hence a greater amount of StOSt. Despite this there are still considerable levels of the softer SU_2 and UUU triglycerides in shea oil. This means that shea too has to be fractionated to concentrate the StOSt triglycerides to a level suitable for use in CBEs. Unlike palm oil, though, shea oil contains minimal levels of SSS and so a single fractionation stage to separate the StOSt-rich stearine fraction from the more unsaturated triglycerides in the oleine fraction is all that is needed.

7.3.1.3 Illipe

Just as the botanical name for shea oil has caused confusion, there has also been historical confusion over the botanical name for illipe. The one quoted in the EU regulation (European Union, 2000) of *Shorea* spp. is correct but still ambiguous because it implies that all *Shorea* species are illipe when it is clear from the botanical definition of sal oil as *Shorea robusta* that this is not the case. The full botanical name of illipe is *Shorea stenoptera*. There is also confusion in that the name illipe has also been used for the species *Madhuca longifolia*, also called mowrah butter, which is a completely different fat (although one that can potentially also be used in CBEs – see Section 7.3.2). Illipe (*Shorea stenoptera*) grows in Borneo – hence its alternative name of Borneo tallow – and, like shea, is a forest crop. Of all the fats used in CBEs, either in the EU or elsewhere, illipe has the triglyceride composition closest to that of cocoa butter and so could be considered to be the “perfect” CBE component. Unfortunately, availability is unpredictable, largely because it flowers only every six to seven years and availability can vary between 2000 and 25 000 t (Shukla and Nielsen, 1989).

Typical fatty acid and triglyceride compositions of illipe are shown in Table 7.8.

Table 7.8 Typical ranges of fatty acid and triglyceride compositions of illipe. *Source*: Talbot (2015). Reproduced with permission of Elsevier.

Fatty acid	Range (%)	Triglyceride	Range (%)
C12:0	0.0–0.7	Total SSS	3.1
C14:0	0.0–0.3	POP	6.6–13.2
C16:0	13.6–21.9	POSt	34.3–48.8
C16:1	0.2–0.6	StOSt	39.1–49.3
C18:0	37.2–46.0	AOSt	3.5–5.7
C18:1	35.0–38.6	Total SSO	0.4
C18:2	0.1–1.1	POO	2.2
C20:0	0.1–2.9	StOO	6.0
		Other unsaturated triglycerides	2.9

Table 7.9 Typical ranges of fatty acid and triglyceride compositions of sal oil. *Source*: Talbot (2015). Reproduced with permission of Elsevier.

Fatty acid	Range (%)	Triglyceride	Range (%)
C16:0	3.6–10.5%	Total SSS	0.3–2.6
C18:0	32.6–49.3%	POP	4.8
C18:1	32.9–48.2%	POSt	7.4–16.0
C18:2	Trace to 3.8%	StOSt	26.2–44.0
C18:3	0.0–1.2%	AOSt	4.9–11.0
C20:0	3.1–10.0%	Total SSO	1.0
		POO	1.5–4.9
		StOO	10.6–25.8
		Other unsaturated triglycerides	2.0–11.8

Compared with palm oil and shea oil, there are only low levels of non-SOS triglycerides in illipe. This is what makes it so suitable for direct use in CBEs without the need for any further fractionation to remove unwanted harder or softer triglycerides.

7.3.1.4 Sal oil

The sal tree, *Shorea robusta,* is indigenous to India, particularly to the Central Indian states of Orissa, Chattisgarh and Madhya Pradesh. The tree has great cultural significance to both Hindus and Buddhists with it being said that Buddha was born and died beneath a sal tree. The kernels contain between 14 and 18% of sal oil and, like shea, sal seeds produce an oil rich in both oleic and stearic acid, but also with an appreciable amount of arachidic acid (C20:0). Typical fatty acid and triglyceride compositions are shown in Table 7.9.

Table 7.10 Typical ranges of fatty acid and triglyceride compositions of kokum butter. *Source*: Talbot 2015. Reproduced with permission of Elsevier.

Fatty acid	Range (%)	Triglyceride	Range (%)
C14:0	0.0–1.5%	Total SSS	0.0–3.6%
C16:0	0.6–5.8%	POP	0.0–2.0%
C18:0	49.0–67.4%	POSt	7.4–15.0%
C18:1	28.1–49.0%	StOSt	58.0–81.0%
C18:2	0.0–2.0%	POO	0.0–3.0%
C20:0	0.0–1.4%	StOO	12.1–21.0%
		Other unsaturated triglycerides	1.0–2.5%

The triglyceride composition is, like that of shea oil, rich in StOSt and StOO with lower amounts of POSt and AOSt. The total levels of SOS triglycerides can be quite variable and this means that some sal fats with lower SOS and higher SOO need to be fractionated (like shea) whereas others contain sufficient SOS to be able to be used without fractionation (although the presence of the higher melting AOSt will improve the melting profile it is still possible that unfractionated sal oil will give a softer CBE than a fractionated oil).

7.3.1.5 Kokum gurgi

Kokum gurgi, or *Garcinia indica*, is also indigenous to India. The oil is obtained from large black seeds within the fruit that contain between 32% and 40% oil. Like shea oil and sal oil, kokum butter is rich in stearic and oleic acids but the ratio of the two is such that it can usually be used without fractionation. Typical fatty acid and triglycerides compositions of kokum butter are shown in Table 7.10.

The high levels of StOSt in kokum butter are apparent from this table and the low levels of POO and StOO are such that kokum butter can be used directly in CBEs without any further processing. However, very occasionally it is fractionated to give a stearin fraction that is very rich in StOSt and can be used in specific types of CBE to improve heat resistance and bloom resistance (see Section 7.3.4).

7.3.1.6 Mango kernel oil

Mango kernel oil is obtained from the fruit of the mango (*Mangifera indica*) tree, a plant that is also indigenous to India (as well as many other countries). India produces 13–17 million tonnes of mango which is just under half of the total world production (UNCTAD, 2014). As mangos are mainly grown for the fruit, the seeds containing the mango kernel are often discarded, although fruit processors are now more likely to retain them for recycling or further use (e.g. oil extraction). The kernel typically makes up from 45 to 72% of the seed (Hemavathy *et al.*, 1988) and contains almost 15% by weight of mango kernel oil (Nzikou *et al.*, 2010). There are several hundred varieties of mango so, as would

Table 7.11 Typical ranges of fatty acid and triglyceride compositions of mango kernel oil. *Source*: Talbot (2015). Reproduced with permission of Elsevier.

Fatty acid	Range (%)	Triglyceride	Range (%)
C14:0	0–0.8%	Total SSS	0–14%
C16:0	3–18%	POP	24–62%
C18:0	24–57%	POSt	
C18:1	34–56%	StOSt	
C18:2	1–13%	POO	21–61%
C18:3	0–5.3%	StOO	
C20:0	0–4%	Other unsaturated triglycerides	1–34%

be expected, the fatty acid and triglyceride compositions can vary quite widely. Ranges from different published sources are collected together in Table 7.11.

Although the ranges of triglyceride groups are enormous in the published literature the more general compositions of oils used in CBEs are similar to those of shea oil and sal oil and, therefore, are such that mango kernel oil also needs to be fractionated to produce a stearin rich in StOSt.

7.3.2 Other CBE component fats

Although the six oils described in Section 7.3.1 are the main base oils used to produce CBEs in all of those countries around the world that manufacture and use vegetable fats in chocolate, they are not the only ones that have been used and studied for this application. There are a number of other oils that contain sufficiently high levels of total SOS to be considered for use in CBEs – they cannot, of course, be used in the EU. Such oils are:
Pentadesma (*Pentadesma butyracea*);
Allanblackia (*Allanblackiq floribunda*);
Aceituno (*Simarouba glauca*);
Mowrah (*Madhuca longifolia* and *M. latifolia*);
Chinese vegetable tallow (*Triadica sebifera*).

The botanical nature, collection, processing and uses of all of these oils are described in detail by Talbot (2015). Because they are not mainstream base oils for use in CBEs, all that will be described here are their typical fatty acid (Table 7.12) and triglyceride compositions (Table 7.13).

Apart from Chinese vegetable tallow, all of these oils are rich in StOSt and StOO which means that they need to be fractionated into a StOSt-rich stearin fraction and a StOO-rich olein fraction. The stearin can then be used in CBEs. Chinese vegetable tallow is different in that it contains a high level of palmitic acid (C16:0) and a moderate to high level of oleic acid (C18:1) such that the main triglycerides present are PPP and POP. The high level of PPP prevents it from being used directly in CBEs and so it, too, needs to be fractionated but now

Table 7.12 Typical fatty acid compositions of other CBE component base fats. *Source*: Talbot (2015). Reproduced with permission of Elsevier.

Fatty acid	Pentadesma	Allanblackia	Aceituno	Mowrah	Chinese vegetable tallow
C14:0					0–4%
C16:0	2.4–5.4%	0.8–2.9%	10.0–11.5%	20–28%	58.0–77.6%
C18:0	38.4–49.8%	45.0–58.3%	27.5–28.0%	14–22%	1.0–7.6%
C18:1	45.3–57.6%	38.6–51.0%	57.0–59.1%	36.3–49,0%	20.1–35.0%
C18:2	0–1.4%	0–0.7%	2.0–3.3%	9,0–15.8%	0–1.6%
C18:3	0–0.2%	0–0.6%	0–0.3%		0–0.3%
C20:0	0–0.2%	0–0.8%	1.0–1.5%	0–0.5%	0–0.1%

Table 7.13 Typical triglyceride compositions of other CBE component base fats. *Source*: Talbot (2015). Reproduced with permission of Elsevier.

Triglyceride	Pentadesma	Allanblackia[a]	Aceituno	Mowrah	Chinese vegetable tallow[b]
Total SSS			0–1%	0–2.0%	13%
POP	0–0.5%		2.6%	7.0–18.9%	78%
POSt	0.9–3.8%		15.5%	12.0–22.2%	
StOSt	37.1–61.4%	69.1%	21.1%	4.0–10.6%	
POO	0.2–1.5%		12.2%	19.6–45.1%	
StOO	35.1–55.2%	23%	29.5%		
Other unsaturated triglycerides	1.4–6.5%		19.1–25.0%	2.2–14.4%	

[a] Adubofuor *et al.* (2013).

[b] Jeffrey and Padley (1991).

into a PPP-rich stearin fraction and a POP-rich olein fraction with the olein being suitable for use in CBEs. In some instances it might be necessary to doubly fractionate (as with palm oil) and Jeffrey and Padley (1991) obtained a mid-fraction containing 2% SSS and 94% SOS in a yield of 66%. However, when availability, costs and so forth are compared with palm oil which also needs to be doubly fractionated to again obtain a mid-fraction rich in SOS (POP) there is little economic benefit in using Chinese vegetable tallow.

7.3.3 Structured triglycerides in CBEs

Structured triglycerides are triglycerides that, while they may exist in nature, are produced by means of various methods of oil processing. The most common of these methods is enzymic interesterification. Interesterification is a process that has long been used to modify the triglyceride composition and melting characteristics of a fat or blend of fats. Historically it has been catalysed by chemicals such as sodium or sodium methoxide. The interesterification process effectively breaks

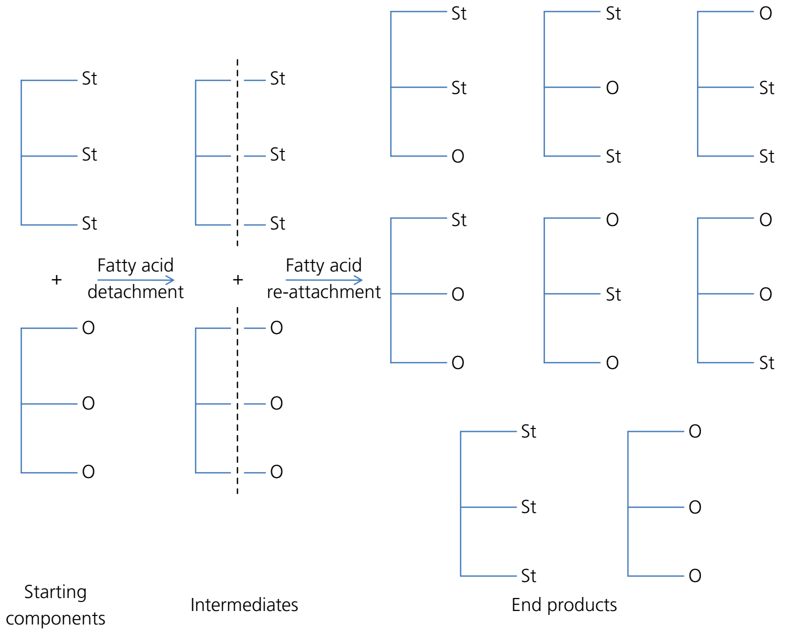


Figure 7.6 Example of random interesterification/rearrangement.

the bonds between the fatty acid acyl groups and the glycerol backbone of a triglyceride molecule and then re-attaches the acyl groups in a random position. So, for example, if 50% StStSt and 50% OOO are randomly interesterified then the end-result is a mixture of 12.5% StStSt, 12.5% StOSt, 25.0% StStO and OStSt, 25.0% of StOO and OOSt, 12.5% of OStO and 12.5% OOO (see Figure 7.6).

More recently, though, an alternative process has been developed using an enzyme (lipase) catalyst. This process was initially developed by Unilever (Macrae and How, 1983) and has been transformed into a full-scale industrial process by Loders Croklaan (Talbot and Bhaggan, 2010). Although lipases can be used as direct replacements of the chemical catalysts to produce a random rearrangement of fatty acid groups as shown in Figure 7.6, there are also regio-specific enzymes that only rearrange the fatty acid groups in the 1- and 3-positions of the triglycerides and have no effect on fatty acids in the 2-position. This allows the production of symmetrical triglycerides of the kind needed in CBEs. The principle of this is shown in Figure 7.7.

The general principle is to begin with an oil that is rich in oleic acid in the 2-position in order to retain that in the final SOS triglycerides. The most usual source of this is high-oleic sunflower oil. This is then mixed with the saturated fatty acids that will form the 1- and 3-positions and the whole mix is then enzymically rearranged. If stearic acid is used in the reaction then StOSt will be the main SOS triglyceride (Favre *et al.*, 2010); if a mixture of palmitic and stearic acids are used then POP, POSt and StOSt will be the main SOS triglycerides

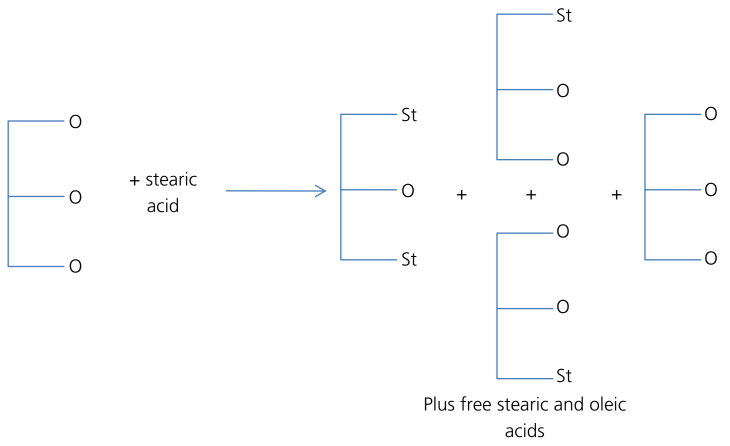


Figure 7.7 Example of regiospecific enzymic rearrangement.

(Ray *et al.*, 2013). In a similar way, palm olein (which is rich in POO and OOO) can be used as the starting triglyceride. When reacted with stearic acid it also produces a mix of POP, POSt and StOSt (Bloomer *et al.*, 1990).

However, in addition to these triglycerides the final mix also contains unreacted starting triglycerides (OOO, POO etc.) as well as triglycerides containing only one saturated fatty acid group in the 1- or 3-position (i.e. SOO or OOS) and free oleic, stearic (and palmitic, if used in the reaction) acids. This means that the end product of enzymic rearrangement then undergoes fractionation to remove the lower-melting SOO and OOO triglycerides and a de-acidification process to remove free acids, leaving the desired SOS triglyceride(s).

Structured triglycerides produced in this way are, however, specifically excluded from use as the vegetable fat part of chocolate as defined in the European Regulations (European Union, 2000). They are, though permitted in some other countries where CBEs are allowed and it is advisable to check local legislation before using CBEs containing SOS-rich structured triglycerides produced using enzymic rearrangement.

7.3.4 Production and uses of CBEs

The oils described in Section 7.3.1 (and Section 7.3.2) are only the starting point of CBEs. It has already been mentioned that many of the base oils used in CBEs contain higher-melting and/or lower-melting triglycerides in addition to the SOS triglycerides needed in CBEs. These oils are therefore fractionated to remove the unwanted triglycerides and concentrate the SOS fraction. Although dry (i.e. solvent-free) fractionation can be used it is more common to use a wet (i.e. solvent) fractionation process. Historically, hexane has been used as the fractionation solvent but nowadays acetone is usually used. The oil is dissolved in acetone and is chilled to a temperature at which the desired triglycerides crystallise. These (the stearin fraction) are then separated by filtration and the

Table 7.14 Typical triglyceride compositions of CBE component fats and fractions (Talbot, 2006). Reproduced with permission of Kennedy's Books.

	Cocoa butter	Palm mid-fraction	Shea stearin	Illipe butter	Sal stearin	Kokum butter	Mango kernel stearin
POP	16	66	1	7	<1	<1	1
POSt	37	12	7	34	10	6	16
StOSt	26	3	74	45	60	72	59
Total SOS	79	81	82	86	81[a]	78	76

[a] Includes 11% AOSt.

solvent is removed from both this fraction and the olein that is still in solution. The reason for using solvent fractionation is that this process gives a "cleaner" stearin fraction with reduced entrainment of olein. Oils such as shea, sal and mango kernel are fractionated once to give a stearin for use in CBEs. Palm oil is fractionated twice to remove both high-melting trisaturated triglycerides and low-melting unsaturated triglycerides. Illipe and kokum are usually used in CBEs without fractionation. Hence, the components available for use in CBE compositions (as permitted in the European Union) are palm mid-fraction, shea stearin, illipe butter, sal stearin, kokum butter and mango kernel stearin. Typical triglyceride compositions of these components in comparison to cocoa butter are shown in Table 7.14.

These compositions are "typical" and can vary not only because they are produced from naturally varying oils but also because the fractionation conditions can be changed to include varying amounts of, for example, the lower-melting fractions of palm and shea in order to obtain different characteristics in the CBE. In order to try to match the triglyceride composition of cocoa butter in a CBE we need POP, POSt and StOSt. POP comes mainly from palm mid-fraction, StOSt from shea stearin, sal stearin, kokum butter and mango kernel stearin, and POSt mainly from illipe. However, illipe is not always available and so, often CBEs are blends of palm mid-fraction with one or more of the StOSt-rich fats.

The more StOSt is included in the composition the "harder" and higher-melting is the resulting CBE blend. This allows a sub-set of CBEs to be formulated with higher melting points. These are called cocoa butter improvers, or CBIs, and are often used where enhanced heat resistance is needed in a chocolate, for example, in warmer Mediterranean countries. The higher-melting points of CBIs also gives an enhanced bloom resistance as well because higher storage temperatures are then needed for the transformation of the fat phase of chocolate from Form β_V to Form β_{VI} (see Figure 7.1).

CBEs (and CBIs) are usually used to replace part (usually, up to 5%) of the added cocoa butter in a chocolate recipe (see Table 7.15 and Chapter 20). Generally speaking, the production and processing of chocolate containing 5% CBE is the same as that required for CBE-free chocolate.

Table 7.15 Typical recipes for chocolate without and with CBEs.

Ingredients	Milk chocolate		Dark chocolate	
	Without CBE	**With CBE**	**Without CBE**	**With CBE**
Cocoa mass	10	10	40	40
Cocoa butter	22	17	12	7
CBE		5		5
Full-cream milk powder	24	24		
Sugar	44	44	48	48
Fat composition				
Cocoa butter	27.3	22.3	33.2	28.2
CBE		5.0		5.0
Milk fat	6.5	6.5		
Total fat	33.8	33.8	33.2	33.2
Expressed as % of fat phase				
Cocoa butter	80.8	66.0	100	85.0
CBE		14.8		15.0
Milk fat	19.2	19.2		

The main adjustments required in tempering chocolate as a result of formulation changes are those needed as a consequence of the inclusion of milk fat. Tempering temperatures should be decreased by about 2 °C when 20% milk fat is included (in the fat phase of chocolate). Most CBEs will tolerate the inclusion of this level of milk fat without any need to significantly alter processing conditions. They will also tolerate somewhat higher levels of milk fat, but the tempering temperature would then need to be decreased (as indeed it would if higher levels of milk fat were used with cocoa butter alone).

CBEs can also be used in products usually called supercoatings or supercompounds. These are coatings which are prepared using real chocolate recipes, where all the added cocoa butter is replaced by a CBE. It was shown earlier that CBEs are compatible with cocoa butter across the whole formulation range (Figure 7.5) and thus supercoatings are equivalent to chocolate in most respects, but must not be labelled as such. Typical recipes for supercoatings are shown in Table 7.16.

As a guide to tempering conditions, a supercoating may have to be tempered at temperatures about 0.5 °C lower than for the corresponding cocoa butter chocolate. However, these figures also depend considerably on the actual recipe used and the tempering equipment, as well as the quality of the cocoa butter. Because of the close chemical similarity of CBEs to cocoa butter, supercoatings also require the same cooling regime. In addition, the equipment used requires no special cleaning when changing from supercoating to cocoa butter chocolate.

Table 7.16 Typical supercoating recipes.

Ingredients	Milk supercoating	Dark supercoating
Cocoa mass	10	40
CBE	22	12
Full-cream milk powder	24	
Sugar	44	48
Fat composition		
Cocoa butter	5.3	21.2
CBE	22.0	12.0
Milk fat	6.5	
Total fat	33.8	33.2
Expressed as % of fat phase		
Cocoa butter	15.7	63.9
CBE	65.1	36.1
Milk fat	19.2	

7.4 Lauric cocoa butter substitutes

Cocoa butter substitutes (CBSs) are fully refined fats produced from palm kernel and/or coconut oil by means of fractionation and/or hydrogenation. In this way fats can be produced which have characteristics in terms of hardness, mouthfeel and flavour release similar to those of cocoa butter.

These fats, however, contain a high level of lauric fatty acids and have a completely different triglyceride composition to cocoa butter. This means that there is a considerable degree of incompatibility between lauric CBSs and cocoa butter. An iso-solids phase diagram of mixtures of cocoa butter and a lauric CBS is shown in Figure 7.8. This confirms the occurrence of mixed crystals over a wide range and indicates a strong depression of melting behaviour in comparison to the mixing of CBEs and cocoa butter. A narrow band of "permissible" compositions is seen at each end of the diagram. Cocoa butter will retain its β-3 crystal form until about 5% lauric CBS is present. Equally a lauric CBS will retain its β′-2 crystal form until about 5% cocoa butter is present. Beyond these tight limits mixed β-3 and β′-2 crystals are formed which will result in processing problems, softer products and a substantial risk of fat bloom. (Crystal forms such as β-3 and β′-2 are described in more detail in Section 7.2.2) Thus, about 5% cocoa butter is the safe maximum level of addition to lauric CBSs. In practice this limits the cocoa inclusion in recipes based on lauric CBSs to low-fat cocoa powder or fat-free cocoa powder rather than cocoa mass. Thus typical formulations are shown in Table 7.17 (and see Chapter 20).

Tempering or any form of pre-crystallisation is unnecessary for enrobing or moulding thin bars. Following deposition, or enrobing, a glossy surface and fine crystal structure is obtained with lauric CBS based coatings by cooling them

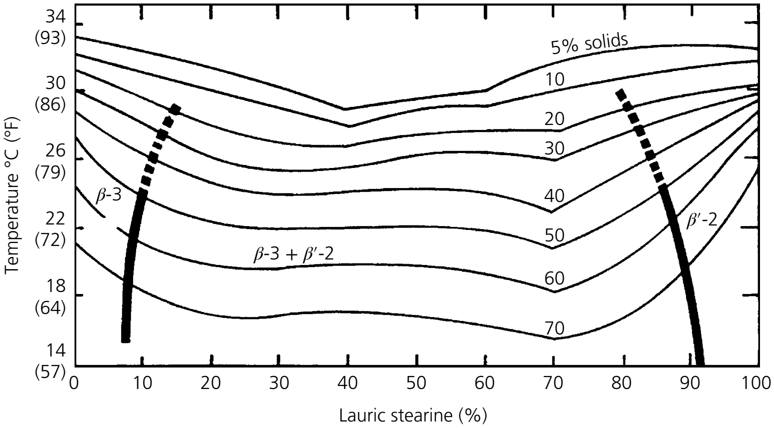


Figure 7.8 Iso-solids phase diagram for cocoa butter/lauric CBS. Source: Gordon *et al* (1979). Reproduced with the permission of John Wiley & Sons.

Table 7.17 Typical recipes using lauric CBSs.

Ingredients	Dark	Milk	White
Cocoa powder 10/12	14	5	
Full cream milk powder		4	
Skimmed milk powder	7	15.5	20
Lauric CBS	31	30.5	32
Sugar	48	45	48
Total fat content	32.5	32	32
% lauric CBS (as % of fat phase)	95.4	95.3	100

rapidly and applying a high wind speed, but taking care to avoid water condensation at the exit of the tunnel (see Chapter 19).

An important feature with coatings based on lauric CBSs is to control the water content and to avoid microbiological contamination of the product. Occasionally chocolate confections, which contain lauric fats, develop a soapy taste and as a result the product becomes unpalatable. In most cases the fat has been split by a lipase enzyme, following microbiological contamination. This soapy taste in compound chocolate based on a lauric CBS can only develop in the presence of lipase and sufficient water. Hence control of the water content and lipase content of the product is of major importance.

7.4.1 Quality control

7.4.1.1 Control of the water content

Normal good quality raw materials, processed according to good manufacturing practice, yield compound chocolate with a water content that is too low to allow microbiological deterioration. Special attention should be paid to the cooling conditions during processing of the coating to avoid condensation of water on the product. Because chocolate is hygroscopic, finished products should be packed in airtight wrapping and stored below 60% relative humidity.

7.4.1.2 Control of microbiological contamination

Generally speaking, most processed raw materials for the confectionery industry are safe to use and are delivered with good microbiological specifications and an absence of active lipase. Post contamination during production and storage can be avoided by following hygienic working practices (see Chapter 25).

7.4.2 Hydrogenated lauric CBSs

CBSs can be produced from coconut and palm kernel oil by hydrogenation alone. A range of products can be produced which have increasing melting points and hardness. Melting profiles similar to cocoa butter can be achieved, but the harder grades of these types of product have a pronounced tail in the melting profile and the mouthfeel is correspondingly waxy. Over the past decade or so, many manufacturers have removed hydrogenated fats from their products because, by and large, they contain trans fatty acids.

Trans fatty acids are produced during partial hydrogenation of vegetable fats and have been implicated in increasing risk of cardiovascular disease because of the adverse effect they have on blood cholesterol levels. Blood cholesterol is composed mainly of two types - HDL-cholesterol which is considered to be “good” cholesterol and LDL-cholesterol which is considered to be “bad” cholesterol. Trans fatty acids lower the “good” HDL-cholesterol and raise the “bad” LDL cholesterol. This is the reason why consumption of trans fatty acids is seen as a risk factor in cardiovascular disease and why manufacturers have largely moved towards replacement of partially hydrogenated fats in their products. This does not necessarily mean that chocolate is completely trans-free because there is a small amount (typically, 3–8%) of naturally occurring trans fatty acid in milk fat which will, of course, then be present in milk chocolate (see Chapters 19 and 22).

In the case of hydrogenated lauric CBSs the amount of trans fatty acid present is usually quite low. One reason for this is that the lauric fat is often completely hydrogenated resulting in a fat which is >99% saturated and <1% trans. This mainly applies to lauric stearines. On those occasions where the oil is only partially hydrogenated the amount of unsaturation naturally present in coconut or palm kernel oil is such that the trans content will be less than 10%. The problem of trans fatty acids is more acute with non-lauric CBRs (Section 7.5).

The long melting tail that is often found when palm kernel oil is hydrogenated can be removed by fractionation. Consequently, fractionated lauric CBSs have significantly improved mouthfeel. The use of hardened lauric oils is identical to that of the fractionated lauric CBSs. They cannot be mixed with cocoa butter to any appreciable extent and the maximum 5% cocoa butter rule applies.

Products made with fats that have not been fractionated have one further major drawback - that is the shelf-life of the coatings is only a few weeks compared with a few months for the corresponding fractionated lauric CBS formulation. This is because the products quickly lose their gloss, become dull and bloom due to crystal modifications which spoil the appearance of the products.

7.5 Non-lauric cocoa butter replacers

Non-lauric cocoa butter replacers (CBRs) are produced from non-lauric oils such as palm oil and soyabean oil, historically, by hydrogenation and fractionation. Because of the issues associated with hydrogenation and trans fatty acids, a newer generation of non-lauric CBRs has been developed. Although both of these types of CBR contain palmitic, stearic and oleic acid, their arrangement within the triglycerides is such that the structure differs considerably from cocoa butter. In addition, a high content of elaidic acid is present in the hydrogenated types. Consequently non-lauric CBRs have a limited compatibility with cocoa butter.

Figure 7.9 demonstrates the effect on melting properties of mixing non-lauric CBRs with cocoa butter. This diagram illustrates not only the formation of eutectics (extra softening due to incompatibility) but also the occurrence of mixed crystals in the critical central area which will provoke loss of gloss and fat bloom formation on the confectionery product. Only the outer areas on the left- and right-hand side of the diagram give fat mixtures which are stable. We may add up to 7% of non-lauric CBR to cocoa butter or we may allow up to approximately 25% cocoa butter in the fat phase of non-lauric fat-based coatings.

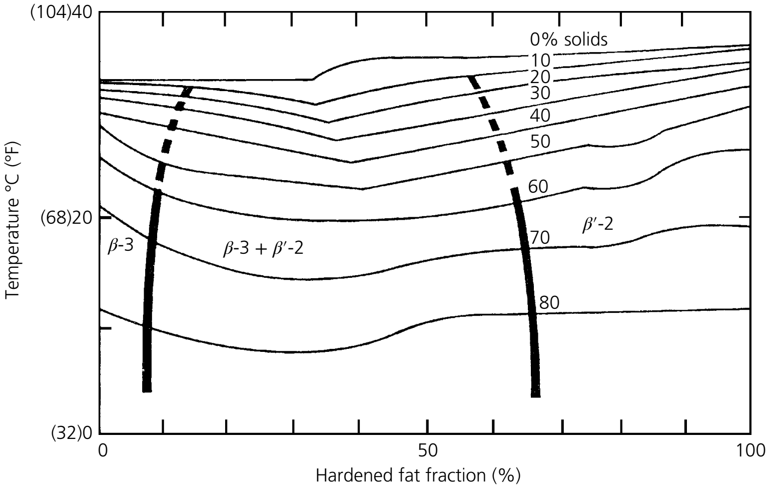


Figure 7.9 Iso-solids phase diagram for cocoa butter/non-lauric CBR. Source: Gordon *et al.* (1979). Reproduced with the permission of John Wiley & Sons.

Table 7.18 Typical recipes using non-lauric CBRs.

Ingredients	Dark	Milk	White
Cocoa mass	10	10	
Cocoa powder 10/12	15		
Full cream milk powder		6	20
Skimmed milk powder		12	5
Non-lauric CBR	28	28	30
Sugar	47	44	45
Total fat content	35	35	35
Non-lauric CBR as % of fat phase	80	80	85.7

As with lauric CBSs the central, unstable region gives mixed crystals, softer products and a likelihood of fat bloom formation. However, the region of stability at the CBR-rich end of the diagram is much broader than with lauric CBSs indicating that non-lauric CBRs have a greater tolerance to cocoa butter. In practical terms, this means that cocoa mass can be used with non-lauric CBRs resulting in a much more "rounded" cocoa flavour than can be achieved using lauric CBSs, where only low-fat cocoa powder is permissible. This allows typical recipes to be used such as those shown in Table 7.18.

The production of these non-lauric CBR based coatings is similar to normal chocolate production, for example mixing, roll refining and conching. A MacIntyre conche or a ball mill can also be used. Following production of the coating the product is ready to be used immediately. No tempering is required and application temperatures for moulding, panning or enrobing may vary from 40 to 48 °C. This non-temper process allows for lower viscosity at the enrobing or depositing stations, which has advantages in certain applications. Non-lauric CBR-based coatings should be cooled under moderate to strong conditions, similar to those commonly applied for cocoa butter-based chocolate.

To address the whole issue of trans fatty acids in non-lauric CBRs oils and fats manufacturers have produced low-trans and, more recently, "no trans" alternatives to their original high-trans CBRs. What is needed is a fat that is stable in the β′ form (so that it needs no tempering). If very specific processing of palm oil is carried out it is possible to obtain a mix of triglycerides that have not been hydrogenated but which are β′-stable. It has already been shown that POP (in palm mid-fraction) crystallises in a β-3 configuration because in this triple chain structure the oleic acid groups in the 2-position all line up more or less adjacent to each other and so can pack closely together. However, a coating based on palm mid-fraction could not be used as a non-temper, non-lauric CBR because, to get this structure, it has to be tempered. But, if POP is blended with PPO, then a crystal structure is obtained which is double-chain packed and in the β′ form because, then, the oleic acid groups in the 2-position of POP line up against the oleic acid groups in the 1- and 3-positions of PPO (Slager *et al.*, 2007). This is the basis of the newer generation of non-hydrogenated, non-lauric CBRs.

7.6 Vegetable fats with specific properties

Apart from the three types of cocoa butter alternative described in the previous sections of this chapter there are also two groups of vegetable fats used in chocolate and compound coatings with specific properties. One group of these fats inhibits the polymorphic transformation from Form β_V to Form β_{VI} and, in doing so, inhibits the formation of fat bloom caused by either higher temperature storage or oil migration from a centre into the chocolate. The other group of fats are intended for use in compound coatings with reduced calorie content.

7.6.1 Anti-bloom fats

Section 7.2.2 describes the polymorphism of cocoa butter and the fact that it can exist in a number of different polymorphic forms (see Table 7.4). When chocolate is properly tempered the cocoa butter will crystallise in form β_V. However, depending on the product's construction and the conditions under which it is stored, this cocoa butter can transform from form β_V to form β_{VI}. This polymorphic transformation is usually accompanied by the formation of fat bloom. The change from form β_V to form β_{VI} occurs more quickly at higher temperatures and is also accelerated by migration of soft oils (e.g. nut oils) from a filling into the chocolate.

It has been suggested that replacing 15% of the cocoa butter in chocolate with illipe can delay the onset of bloom in dark chocolate truffles because of its higher StOSt/POSt ratio (Ali *et al.*, 1998). In a chocolate containing 33% total fat 15% replacement of the cocoa butter in the fat phase with illipe equates to the presence of 5% illipe in the whole chocolate. This is a permissible level in EU chocolate and in most of the chocolates in other parts of the world, where vegetable fats such as illipe are permitted. This principle of increasing the StOSt/POSt ratio to slow down the onset of bloom is also used by incorporating cocoa butter improvers (CBIs) based on high levels of shea stearin or sal stearin. These work on the principle of increasing the level of StOSt in the fat phase of chocolate to increase its melting point. Thus, polymorphic transitions that are faster in the presence of higher proportions of liquid oil (either because part of the chocolate fat has melted or because softer oils from a centre have migrated into the chocolate) take place at higher storage temperatures, giving an extra degree of protection.

Taking this principle a stage further, the Fuji Oil Company in Japan developed a product called BOB or Bohenin (1,3-dibehenoyl-2-oleoylglycerol). Behenic acid is a saturated fatty acid containing 22 carbon atoms and so BOB is an extension of the kinds of symmetrical monounsaturated triglycerides found in cocoa butter and CBEs in which palmitic and stearic acids are replaced by behenic acid. This has the effect of increasing the melting point to about 52 °C (US Pharmacopeia Convention, 2009). It is added to chocolate at the 5% level in the same way as CBEs and CBIs are. If the temperature of the chocolate is raised above its normal melting point but below the melting point of BOB it is claimed that the chocolate does not melt fully and that when cooled down the BOB is able to re-seed the chocolate in a stable polymorphic form (Koyano *et al.*, 1990).

Taking a different principle, various other vegetable fats were developed to inhibit bloom formation in chocolate. Instead of being based on increasing the melting point of SOS triglycerides in chocolate, these were based on $H_2M + HM_2$ triglycerides, where H denotes a saturated fatty acid with a chain length of 16 carbon atoms or longer and M denotes a saturated fatty acid with a chain length of 8–14 carbon atoms (Cain *et al.*, 1995). Initially they were intended for use as a vegetable fat at an inclusion level of 5% in chocolate. However, in the EU, the 2003 chocolate regulations prevented such use because they contained vegetable oils which were not one of the permitted six oils.

The concept has, however, been further developed to take positive advantage of migration of fats from a filling into the chocolate coating. Such migration often results in bloom formation on the chocolate, but if one of these anti-bloom fats is incorporated as part of the filling, it will also migrate on storage with the softer filling fats (Smith *et al.*, 2008). As it migrates into the chocolate it gives the protection necessary to prevent bloom formation. Using the fat in this way also means that it is not restricted by local chocolate legislation, because it is not added directly into the chocolate.

7.6.2 Lower-calorie fats

With the increasing development of lower calorie triglycerides systems, some chocolate manufacturers have used them to manufacture low-calorie confectionery. The two main products in this category are Caprenin™ and Salatrim (now marketed under the name Benefat™). Caprenin™ is a triglyceride produced by Proctor and Gamble, which contains caprylic (C8), capric (C10) and behenic (C22) fatty acids (Peters *et al.*, 1991). It is claimed to have 5 cal/g compared with 9 cal/g for normal fats. The chain length of behenic acid is such that it is poorly absorbed by the body and thus has a lower calorific value than fatty acids such as palmitic and oleic acids. The shorter chain acids, caprylic and capric acids, are metabolised via a different metabolic pathway in the body, which means that they are closer to carbohydrates in this respect.

Salatrim or Benefat™ (Smith *et al.*, 1994), marketed by Danisco, contains short and long fatty acid triglycerides and is also claimed to have a calorific content of about 5 cal/g. The short-chain fatty acids are basically metabolised as though they were carbohydrates and therefore with a much lower calorific value than normal triglyceride systems. As with Caprenin™, the long-chain fatty acids from Benefat™ are less well-absorbed. Benefat™ has been used in some bakery coating systems, chocolate chips and so on.

Conclusion

The scope for producing vegetable fats for use in chocolate and coatings with different melting profiles, crystallisation characteristics, processing benefits and so on, is essentially limitless. Vegetable fats can now be tailored for use both as CBEs (at the

5% level in chocolate) or as coating fats at higher levels of use that give improved viscosity characteristics, improved crystallisation rates, enhanced fat bloom resistance, cool-eating sensations and a host of other processing and consumer benefits. Great strides forward have been made in confectionery fat technology, both in methods of production, and in the understanding of how the triglyceride composition of the vegetable fat relates to the processing characteristics and consumer perception of chocolates and coatings. Undoubtedly further developments will continue to be made in the future ensuring that the vegetable fat which, in many cases, controls the functionality of chocolates and coatings, keeps pace with the demands of both the chocolate manufacturer and consumer.

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CHAPTER 8

Flavour development in cocoa and chocolate

Gottfried Ziegleder

8.1 Introduction

Owing to its unique taste, texture and aroma, chocolate is enjoyed by consumers all over the world. The flavour of cocoa and chocolate is generated by several processing steps, the most important being the post-harvest fermentation and drying of cocoa seeds, the roasting of raw cocoa and the chocolate conching process. To date, about 600 volatile and partly odour-active compounds have been found in cocoa and chocolate, following fermentation, drying, roasting and conching. However, no unique “chocolate compounds” have been identified and most of these substances are also found in other food. But these cocoa volatiles interact and enhance each other to develop a pleasant and unique sensory experience. In chocolate, the flavour/aroma volatiles are active supplementary to the pleasant taste of non-volatile constituents. These range from the typical astringent mouth-feel of cocoa polyphenols to the slight sour taste of cocoa acids and from the bitterness of theobromine to the sweetness of sugar. In addition there is the flavour and creaminess of milk components. The characteristic pleasant mouth-feel is produced by the melting behaviour of cocoa butter. Furthermore, the particle size distribution, the viscosity and the hardness of the chocolate dispersion determine the perceived taste of the final chocolate product (Beckett, 2000). A schematic overview of the various steps of the cocoa flavour development and its conversion into chocolate flavour is given in Figure 8.1.

8.2 Fermentation

8.2.1 The fermentation process

During fermentation of cocoa the flavour precursors are developed (see also Chapter 2). The mucilaginous pulp surrounding the beans undergoes an ethanolic, acetic and lactic fermentation. The acid and heat generated kills the beans,

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Beckett’s Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

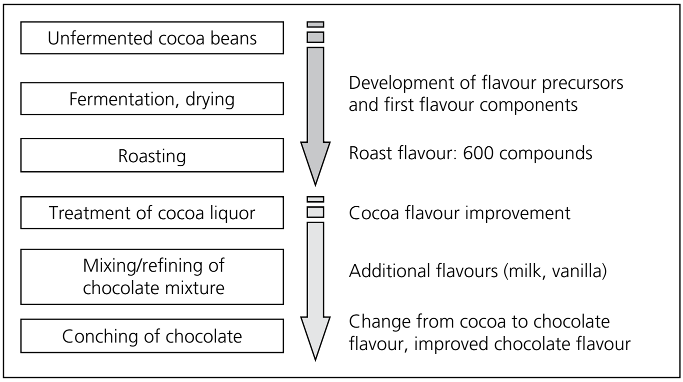


Figure 8.1 Steps of flavour development in cocoa and chocolate (schematic).

which also results in a change in the cell membranes. For Criollo cocoa two or three days of fermentation are sufficient for full development of the flavour precursors. Forastero cocoas are fermented for between five and eight days with periodic mixing to homogenise the treatment and to aerate the fermenting mass. The fermentation together with the subsequent drying is important to ensure browning (Maillard reaction) of the beans and to generate flavour precursors (Biehl *et al.*, 1989; Lopez and Dimick, 1991; Biehl and Ziegleder, 2003; Camu *et al.*, 2008; Afoakwa, 2010; Voigt, 2013). However, the beans must have reached maturity; otherwise no amount of processing can produce the desired flavours. Also, unfermented beans may only develop little cocoa flavour when roasted. After the harvested pods have been cut and broken, the wet cocoa is infected by numerous types of spores from the surrounding airborne micro-organisms (Schwan and Alan, 2004; Nielsen *et al.*, 2013). In the pulp, an anaerobic (oxygen-free) break down of sugar starts. During the first two days, alcoholic fermentation is dominating over the lactic acid fermentation. Ethanol and carbon dioxide are produced, which displaces air from the fermentation box. At this stage the pulp is drained off and most seeds are still alive. With the decreasing rate of sugar break down and the loss of the pulp, more air is absorbed by the beans, giving rise to oxidative formation of acetic acid. Both the temperature increase to >45 °C (113 °F) and the uptake of acetic acid then kill the beans. The average pH value within the beans drops to about 4.5. A large amount of oxygen is consumed in the fermenting pulp, keeping the seeds under anaerobic conditions and allowing post-mortem reactions to take place. After 4–5 days the production of acetic acid slows down and temperature may drop. Now lactic acid is formed. Towards the end of the process, once the pulp has decomposed, air starts to flow from the bottom to the top of the hot cocoa and the beans come in contact with the oxygen in the air. During this aerobic phase, many oxygen-mediated reactions occur, one of the most important being the reduction of astringency by the conversion of soluble polyphenols into insoluble polymers.

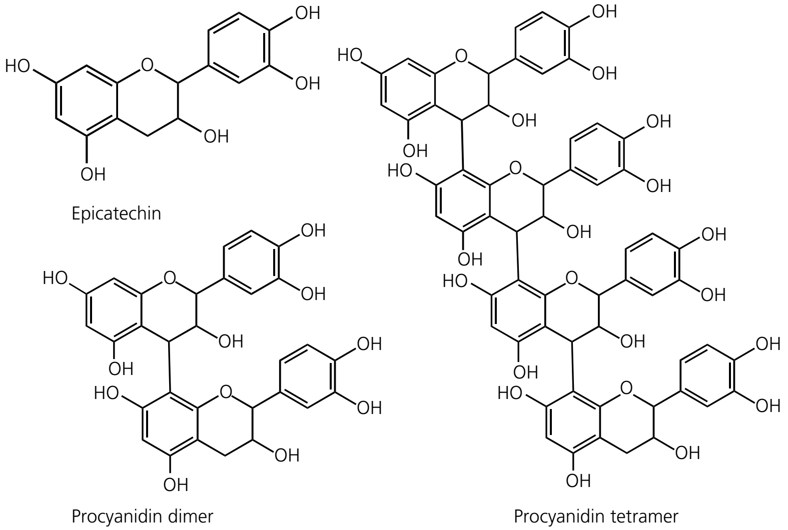
8.2.2 Chemical changes and development of flavour precursors

8.2.2.1 Polyphenols

Cocoa is rich in polyphenols, specifically catechins and procyanidins. They cause astringency and bitterness and may mask fruity flavours (Luna *et al.*, 2002). Polyphenols consist of anthocyanins, causing the characteristic purple colour of unfermented cocoas, colourless catechin and epicatechin, and their dimers, trimers, tetramers and higher oligomers, called procyanidins, as well as polymers. Epicatechin tends to polymerise under the influence of oxygen. Figure 8.2 shows the molecular structure of selected polyphenols, the monomer epicatechin, a dimer procyanidin built up of two epicatechin subunits and a tetramer procyanidin built up of four subunits. Epicatechin and the smaller procyanidins up to three subunits are soluble and therefore cause the astringent taste sensation of cocoa. Molecules, built up of more than three subunits, are insoluble and cause no astringency. During the whole fermentation 50% of the soluble polyphenols are lost by oxidation and polymerisation or by “bleeding” out of seeds (Wollgast and Anklam, 2000; Camu *et al.*, 2008; Payne *et al.* 2010). So, astringency of cocoa is reduced and the colour changes from purple to brown. As expected, a negative correlation between the levels of remaining procyanidins and the flavour potential was found for cocoas from different origins (Counet *et al.*, 2004).

8.2.2.2 Free amino acids

The major nitrogen-containing precursors are the numerous amino acids and peptides (Timbie and Keeney, 1997). Ripe cocoa seeds contain between 10 and 16% (dry wt) of protein and a low level of free amino acids. During fermentation


Epicatechin

Procyanidin dimer

Procyanidin tetramer

Figure 8.2 Molecular structure of some selected polyphenols in cocoa.

Table 8.1 Hydrophobic free amino acids [alanine (Ala), valine (Val), leucine (Leu), isoleucine (Ile), phenylalanine (Phe)] as precursors of volatile aldehydes, acids, alcohols, esters.

Amino acid	Aldehyde	Acid	Alcohol	Ester
Ala	Acetaldehyde	Acetic acid	Ethanol	Ethyl acetate
Val	2-Methyl-propanal	2-Methyl propanoic acid	2-Methyl-1-propanol	2-Methylpropyl acetate, ethyl 2-methylpropionate
Leu	3-Methyl-butanal	3-Methyl-butanoic acid	3-Methyl-1-butanol	3-Methylbutyl acetate, ethyl 3-methyl butanoate
Ile	2-Methyl-butanal	2-Methyl-butanoic acid	2-Methyl-1-butanol	2-Methylbutyl acetate, ethyl 2-methyl butanoate
Phe	Phenylacetaldehyde, benzaldehyde acetophenone[a]	Phenylacetic acid, benzoic acid	2-Phenylethanol, 1-phenylethanol, benzyl alcohol	Phenylethyl acetate, benzyl acetate, ethyl benzoate

[a] Ketone.

seed proteins are degraded by post-mortem enzymatic hydrolysis giving rise to 1–2% (dry wt) of free amino acids. Proteolysis in the seeds mainly takes place within about 24 h after destruction of the cells and acidification by acetic acid. As mainly hydrophobic amino acids are set free, there is a clear difference between the compositions of the protein-bound free amino acids and resulting free amino acids (Kirchhoff *et al.*, 1989; Voigt *et al.*, 1994; Voigt, 2013). Hydrophobic amino acids, especially leucine, valine, alanine, isoleucine, phenylalanine, and hydrophobic peptides are of major importance as precursors for the formation of cocoa flavour (Biehl and Ziegleder, 2003). Table 8.1 shows some examples of volatile derivatives of hydrophobic amino acids.

8.2.2.3 Sugars

Fresh cocoa beans contain 5–9% (dry wt) of starch and 2–4% (dry wt) of free sugars. In early fermentation the major sugar is sucrose; however, it is soon hydrolysed into glucose and fructose as fermentation progresses (Berbert, 1978; Reineccius *et al.*, 1972a). In Sanchez or Arriba cocoas, which are traditionally weakly fermented, up to 1% sucrose is found (Keeney, 1972). The sucrose content in well-fermented raw cocoas, however, is near to zero, but fructose and glucose levels increase up to about 0.6% (dry wt). As the amount of fructose and glucose formed is considerably lower than the decrease of sucrose, it would appear that a substantial proportion must exude from the pulp.

8.2.2.4 Acids

Acetic acid and lactic acid, which are produced in the pulp during fermentation, are assumed to cause the acid and sour taste of raw cocoa. During fermentation, acetic acid affects the nib pH value and consequently enzymatic reactions and flavour precursor formation. This means that the optimum condition for the enzymatic hydrolysis of sucrose and proteins in the beans is in the acid range (Biehl and Passern, 1982; Biehl *et al.*, 1985). According to Jinap and Dimick (1990) cocoa beans from Malaysia or Brazil (Bahia) have low pH (4.7–5.2), those from West Africa or Indonesia medium pH (5.2–5.5) and those from Ecuador, Venezuela or Guatemala high pH (5.5–5.8). The higher pH correlates to a lower fermentation degree. The concentrations of acetic acid and of lactic acid in Malaysian or Brazilian cocoas are 5.2–8.2 g/kg and 2.7–5.0 g/kg, respectively, and in the other cocoas 4.2–5.6 g/kg and 2.1–3.0 g/kg, respectively (Jinap and Dimick, 1990). In heap fermented and dried Ghana cocoas 3.3–7.9 g/kg of acetic acid and 1.9–3.9 g/kg of lactic acid were found, with large differences between one and the next fermentation heap (Camu *et al.*, 2008). Pulp preconditioning by post-harvest storage of cocoa pods for about 10 days leads to the reduction of nib acidification during subsequent fermentation and a reduction of the acid note (Biehl *et al.*, 1989; Jinap *et al.*, 1994a; Ofosu-Ansah *et al.*, 2013).

8.2.2.5 Alkaloids

Cocoa beans contain about 1–3% of theobromine, 0.1–0.2% of caffeine and traces of theophylline, with no quantitative change of the concentration being reported during fermentation and roasting. Owing to its low taste detection threshold of 10 mg/l, theobromine is believed to contribute to the bitter taste. After roasting, theobromine may form chemical adducts with diketopiperazines (see also Figure 8.11 in Section 8.4.3), which seem to have some connection with the characteristic bitter notes of roasted cocoa (Pickenhagen *et al.*, 1975).

8.2.3 Over-fermentation

A detrimental hammy off-flavour defect can arise due to a prolonged treatment following the optimum fermentation time. Over-fermentation is caused by a direct aerophilic microbial attack on the beans, destroying the cocoa flavour potential, increasing the pH value and blackening the beans. This process may arise especially in the wet, well-aerated mass. Aerophilic bacteria metabolise amino acids and peptides. The hammy off-flavour can be explained by the formation of a surplus of propionic acid, 2-methylpropanoic acid and 2/3-methylbutanoic acid (Lopez and Quesnel, 1973). However, some of these acids, in usual concentration levels, were postulated as important in cocoa flavour (Schnermann and Schieberle, 1997; Frauendorfer and Schieberle, 2006). In practice, it is often difficult to distinguish the "hammy taste" and "smokiness flavour" caused by incorrect drying techniques.

8.3 Drying

8.3.1 Influence of drying on flavour and flavour precursors

After fermentation, the beans are dried and this process is also instrumental in flavour precursor development. Indicators of good drying practices, which also relate to the flavour quality of the beans, are a good brown colour and a low astringency and bitterness. For sun-drying, the beans are spread on the ground, on mats or on wooden floors raised from the ground and protected against rain. Five to seven days are usually necessary to reduce the water content to about 7%. In artificial drying, wood fires or oil burners are connected to a flue under a floor of closely spaced slats. Hot air is passed through a layer of cocoa beans.

Flavour assessment of cocoa beans dried using different methods, that is sun drying, air-blowing, shade drying and oven drying, demonstrated that the sun-dried samples rated higher in cocoa flavour development and had fewer off-notes (Jinap *et al.*, 1994b). Excessive heat and rapid drying may not allow for adequate loss of volatile fatty acids (C_2–C_5) and therefore have a detrimental effect on quality. If smoke, during oven-drying, comes in contact with the beans, an off-flavour known as smoky or hammy flavour can result, as cocoa easily absorbs volatile phenols from smoke. Figure 8.3 shows the total amount of volatile phenols in correlation with the sensorial intensity of smokiness (Lehrian *et al.*, 1978). In smoky cocoa beans phenol, methyl-phenols, dimethyl-phenols, 1,2-dihydroxy-benzene, dimethoxy-phenols and 3-methyl-guaiacol have been identified via HPLC in combination with an electrochemical detection, whereas cocoas of good quality are mostly free of them (Sandmeier, 1987). Incomplete drying or rain soaking may result in mould contamination. Heavy mould growth yields high concentrations of methyl-ketones and volatile aldehydes, causing harsh and unpleasant flavours (Hansen and Keeney, 1970; Afoakwa, 2010).

During drying the Maillard reaction takes place and Amadori compounds, the first intermediates of Maillard reaction, have been identified in dried, unroasted

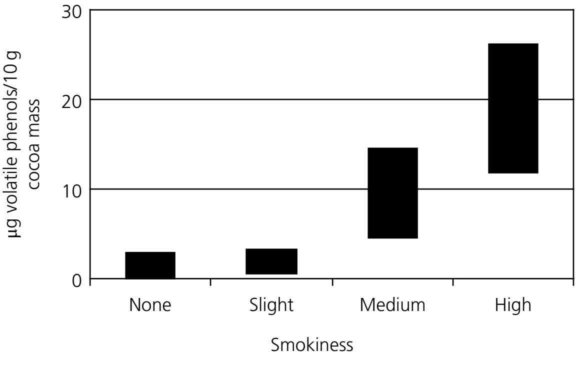


Figure 8.3 Correlation of the total amount of volatile phenols (µg/10g cocoa) and sensorial smokiness of cocoa. *Source* Lehrian *et al.* (1978). Reproduced with permission of John Wiley & Sons.

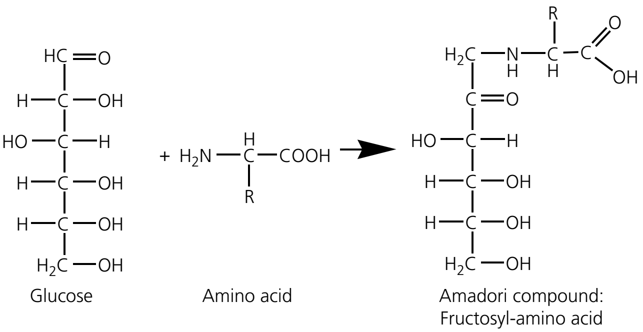


Figure 8.4 Formation of Amadori compounds from glucose and amino acids.

cocoa beans (Heinzler and Eichner, 1991; Oberparleiter and Ziegleder, 1997a). They are the first intermediates of the reaction of free amino acid and glucose. Although the formation of these Amadori compounds is not detectable by colour or odour and may even be reversible at this stage, these initial reactions are important because Amadori intermediates will, during subsequent roasting, decompose into numerous volatile components. The reaction of phenylalanine (Phe) and glucose (Glc), as an example, delivers the Amadori compound fructose–phenylalanine (Fru-Phe). In course of the so-called Amadori rearrangement, the structure of glucose is turned into fructose (see Figure 8.4). It was shown that Fru-Phe after heating produces much more cocoa-like flavour components than the simple mixture of Phe and Glc (Oberparleiter and Ziegleder, 1997a). The Amadori compounds Fru-Thr, Fru-Ser, Fru-Gly, Fru-Ala, Fru-Val, Fru-Ile, Fru-Leu, Fru-Phe and Fru-Abu have been found in dried cocoa, being generated by the reaction of the amino acids threonine, serine, alanine, valine, *i*-leucine, leucine, phenylalanine and α-amino butyric acid with glucose. The concentrations of single Amadori compounds are between 20 and 70 mg/100 g (dry wt) in dry raw cocoa, which means a conversion of about 10% of the single free amino acids into the corresponding Amadori compound. Owing to the high thermal reactivity of Amadori compounds, cocoa flavour may be generated at increased drying or low roasting temperatures. Figure 8.5 illustrates the formation of flavour precursors and flavour components during cocoa processing.

8.3.2 Flavour of unroasted, fermented cocoa beans

The first flavour compounds are developed during fermentation and drying and are predominantly aldehydes, alcohols, acids and acetates (Table 8.1). They derive from the hydrophobic amino acids alanine, valine, leucine, isoleucine and phenylalanine, starting with aldehydes from Strecker degradation (see also Figure 8.6a) and their partial conversion into alcohols and acids. Model reactions confirmed that Strecker aldehydes may be already formed under mild conditions (Pripis-Nicolau *et al.*, 2000). Alcohols were partly esterified by acetic acid to form acetates. In addition, methylbutanoic acids and benzoic acid are esterified by ethanol to form ethyl-methyl-butanoates and ethylbenzoate. In unroasted cocoa beans, quite high

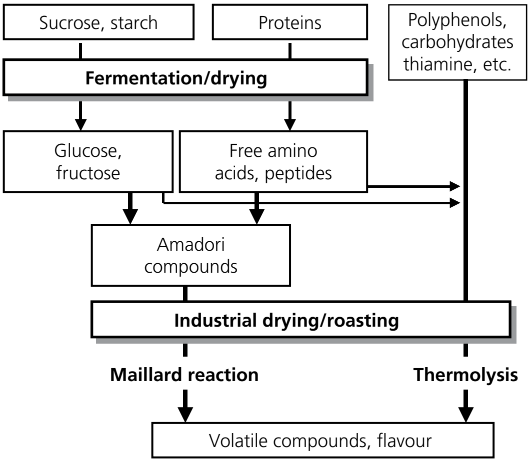


Figure 8.5 Influence of cocoa processing on development of flavour precursors and flavour compounds (schematic).

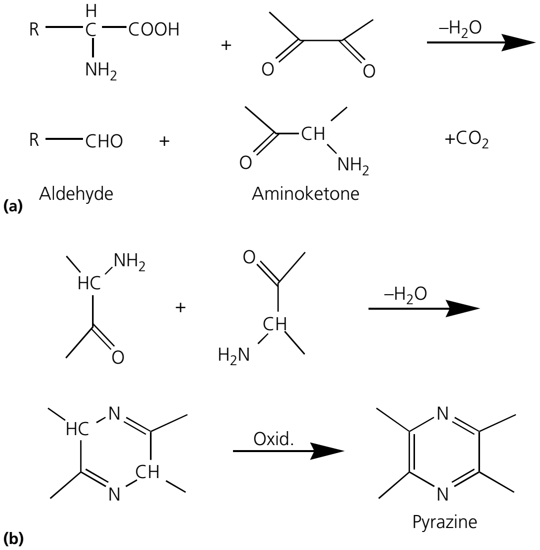


Figure 8.6 (a) Formation of aldehydes and aminoketones via Strecker degradation of amino acids. (b) Conversion of aminoketones into alkylpyrazines.

concentrations were found for 3-methylbutanal (16 mg/kg), 2-phenylethanol (3.5 mg/kg), as well as methylpropanoic acid (9.7 mg/kg), 3-methylbutanoic acid (9.3 mg/kg) and 2-phenylacetic acid with 5.1 mg/kg (Frauendorfer and Schieberle, 2008). Due to their very low odour thresholds between about 10 and 300 μg/kg (according to data of Frauendorfer and Schieberle, 2006), all these volatiles have a high odour activity and contribute to cocoa flavour. Tetramethylpyrazine occurs in relatively high concentrations in fermented unroasted cocoa and is produced microbiologically by *Bacillus* species (Zak *et al.*, 1972; Jinap *et al.*, 1994). Therefore, the level of tetramethylpyrazine was proposed as an index of the degree of fermentation. Also the concentration ratio of primary and secondary methylbutanols in dry cocoa beans may be a useful indicator for controlling the fermentation process (Oberparleiter and Ziegleder, 1997b). 3-Methyl-1-butanol and 2-methyl-1-butanol arise from fermentative degradation of leucine and isoleucine within the seeds, while 3-methyl-2-butanol is formed biosynthetically in the fruit pulp and partly infiltrates the cocoa seeds during fermentation.

Special flavour-grade cocoas, mainly harvested in Venezuela, Trinidad and Ecuador (Arriba), reveal floral, tea-like and fruity aromas and contain significant concentrations (0.5–2.0 mg/kg) of linalool and further terpenoids (e.g. linalool oxides, ocimene and myrcene) which contribute to this pleasant note (Ziegleder, 1990; Pino and Roncal, 1992). Bulk cocoas from West Africa, Malaysia or Bahia carry a fairly strong inherent flavour and have comparably low levels of linalool. Therefore, the authors proposed the level of linalool or the concentration ratio of linalool and benzaldehyde as an indication of flavour-grade cocoas. As Schmarr and Engel (2012) reported, cocoa beans contain linalool primarily as (*S*)-enantiomer, with 0.2–0.8 mg/kg in basic-grade cocoas, 1.2–3.6 mg/kg in flavour-grade Arriba cocoas, but only 0.3–0.5 mg/kg in flavour-grade cocoas from Venezuela and Amazonia. Recently, linalool, ocimene and myrcene were found amongst the main fruit pulp volatiles in the defined flavour-grade cocoa genotypes (varieties) SCA6 and EET62, while they were low in the bulk cocoa CCN51 (Kadow *et al.*, 2013). The migration of these flavour components from the fruit pulp to the cotyledon tissue seems to take place already during fruit ripening and probably in the early stages of fermentation.

8.4 Roasting

8.4.1 The roasting process

The roasting of cocoa develops cocoa flavour, reduces moisture and acidity and releases the beans from the shell (see also Chapter 3). Cocoa is normally roasted at temperatures between 120 and 140 °C (248–284 °F) which is rather a low temperature in comparison to the roasting of nuts or coffee. Using modern equipment, cocoas can be roasted as whole beans (many different sizes), as nibs (broken beans) or as liquid cocoa mass, which is produced by a fine grinding of cocoa and liquefying within its own molten fat. Beans take about 30 min, nibs 12 min and liquor 2 min for roasting. Nib roasting has been associated with several advantages such as a more uniform distribution of heat, rapid evaporation of water and increase of output for the same amount of energy input (Jinap *et al.*, 1998). Special thin-film techniques were developed for the roasting of cocoa mass (Mohr, 1978; Schmidt, 1978; Rapp, 1981). The roasting of cocoa mass has the advantage of a better controlled and homogeneous roasting level,

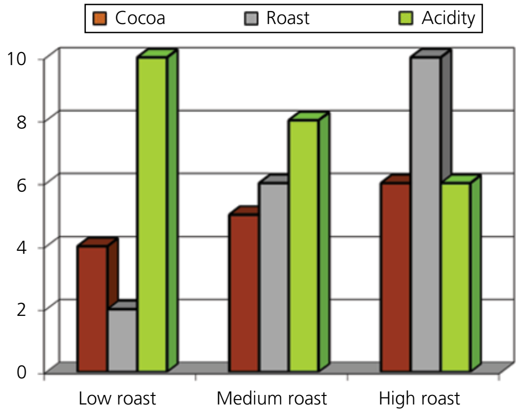


Figure 8.7 The effect of roasting conditions upon the taste of the final chocolate (Beckett and Lemmen, 2004). Partly reproduced from Beckett, S.T., *New Food*, **3**, 28–34, copyright 2006 with permission of Russell Publishing Ltd., Kent, UK.

of a shortened roasting time and of the partial removal of any excess acetic acid. While acetic acid was only slightly reduced (from 6 to 5 g/kg) in the industrial bean roasting (Jinap and Dimick, 1991), it was reduced from 6 to 3 g/kg during cocoa mass roasting (Nuyken-Hamelmann and Maier, 1987).

Prior to roasting, cocoa may taste astringent, bitter, sour, flat, musty or unclean. After roasting, cocoa possesses the typical intense aroma of cocoa and shows a reduced acidity. Roasting at temperatures higher than about 150 °C (300 °F), or for too long a roasting time, results in "over-roasted" cocoas, which have a significant bitter and burnt, coffee-like taste. Before roasting, pre-drying is necessary to reduce water content below 4%, and during roasting the moisture level decreases to about 2%. In industrial roasters, this pre-drying takes place as a separate processing stage. If roasted without pre-drying, cocoa would generate a cooked, flat aroma. As the formation of most flavour compounds is based on condensation or decomposition reactions, a surplus of moisture would hinder these reactions and furthermore evaporate volatile reaction products by steam distillation. For example, pyrazines may develop at low moisture levels only (Hartman *et al.*, 1984). The temperature/time to which the cotyledons are roasted has an effect on the flavour balance of the final chocolate. As the roasting is increased, not surprisingly, the degree of roast flavour increases, but other factors are also affected. As shown in Figure 8.7, the cocoa flavour intensity increases but the acidity decreases (Lemmen, 2004; Beckett, 2006). While specific cocoa volatiles, such as phenylic or furylic compounds, are already developed at low roasting temperatures, other volatiles, like pyrazines, need a higher roasting intensity.

8.4.2 Utilisation of flavour precursors

The flavour precursors interact in the roasting process to produce the desired cocoa flavour. Although the exact percentage of conversion depends upon the roasting parameters, there is a characteristic average for the utilisation of the precursors:

only about 25% of free amino acids (fermented, unroasted: 1–2%, dry weight) are used up and about 70% of the glucose and fructose (fermented, unroasted: 0.6% dry wt; Pinto and Chichester, 1966; Rohan and Stewart, 1966; Reineccius *et al.*, 1972a; Ziegleder, 1991b; Mermet *et al.*, 1992). Reducing sugars as the minor component within the mixture of aroma precursors are converted to a greater extent, while free amino acids, due to their surplus concentration, are consumed to a smaller extent and are partially recycled as part of the chemical reactions. The Amadori compounds (fermented, unroasted: 0.08–0.27%) are highly reactive intermediates and are totally utilised and rapidly decompose into numerous flavour volatiles (Heinzler and Eichner, 1991; Ziegleder and Oberparleiter, 1997a).

It has been speculated that a pre-treatment of unroasted cocoa nibs or mass with water or aqueous precursor solutions might increase flavour development. As reducing sugars have been identified as the flavour precursors that are totally used up, the addition of sugar solutions might promote the formation of desirable flavour components. The preparation of unroasted cocoa mass and the addition of sugar solutions to cocoa mass before thin-film processing was therefore investigated (Rapp, 1981). When cocoa mass is treated, however, the aqueous reagent solution must diffuse across the hydrophobic fat cover. Therefore, the treatment of cocoa nibs was recommended (Kleinert-Zollinger, 1986). After the infiltration of an aqueous solution of 1% glucose into cocoa nibs before roasting, an increased formation of volatile sugar degradation products was found within the roast flavour (Ziegleder, 1993). A pre-treatment of raw cocoa nibs with 15% of water for 15 min at 40 °C (104 °F), followed by drying at 98 °C (208 °F) to 3.5% water content and roasting, brought a more intense cocoa taste and an increased level of roast flavour components compared to cocoa which had been roasted without water pre-treatment. As a consequence of the pre-treatment with water, the consumption of amino acids and reducing sugars was increased, and an increased level of Amadori compounds was temporarily reached (Ziegleder and Oberparleiter, 1997a). Probably the added water temporarily dissolves amino acids and sugars and so supports their reaction.

8.4.3 Roast flavour

The pioneer work on cocoa flavour analysis was performed by Bainbridge and Davies (1912), who isolated about 20 g of an aroma oil by steam distillation of 2000 kg of cocoa beans. Since then several groups have analysed cocoa flavour volatiles and, to date, about 600 components have been found (Van Praag et al, 1968; Keeney, 1972; Maniere and Dimick, 1979; Gill *et al.*, 1984; Hoskin and Dimick, 1984; Carlin et al, 1986; Ziegleder and Biehl, 1988; Ziegleder, 1991a; Mermet *et al.*, 1992; Nijssen *et al.*, 1996; Schnermann and Schieberle, 1997; Jinap *et al.*, 1998; Bonvehi and Coll, 2002; Counet et al, 2002; Luna *et al.*, 2002; Frauendorfer and Schieberle, 2006, 2008; Granvogl *et al.*, 2006; Ramli *et al.*, 2006; Afoakwa *et al.*, 2008; Owusu *et al.*, 2012). These flavour components occur only in traces, mainly at levels of few µg/kg or not more than few mg/kg. Among them, about 100 different pyrazines represent the predominant flavour fraction.

Other significant flavour fractions are aldehydes, ketones, acids, alcohols, amines, esters, sulphur compounds, phenols, pyrroles, pyridines, furans, pyrones, lactones, chinolines, chinoxalines, thiazoles and oxazoles.

Aldehydes and pyrazines are the major groups in cocoa flavour. The main aldehydes in fermented cocoa arise from Strecker degradation of hydrophobic amino acids. The amino acids react with the dicarbonyl part of sugars to form aldehydes and aminoketones (Figure 8.6a). So, the concentration of acetaldehyde, 2-methylpropanal, 3-methylbutanal, 2-methylbutanal and phenylacetaldehyde in fermented and roasted cocoa beans may be higher than 10 mg/kg and therefore greatly exceeds the threshold values (e.g. concentration for 3-methylbutanal 4 mg/kg, threshold value 0.008 mg/kg). The concentration of 3-methylbutanal is strongly increased during roasting and partly decreased due to evaporation together with the roasting gases or due to thin-layer treatment of cocoa mass (Mohr *et al.*, 1968; Mohr, 1978). Also, the level of aldehydes is reduced by every grinding step starting from cocoa beans through nibs to the liquefied masse (Ziegleder, 1982b).

Pyrazines are heterocyclic compounds with two nitrogen atoms in a six-membered ring. Cocoa pyrazines have many different substituents, for example methyl-, ethyl-, propyl-, butyl-, 2-methyl-butyl-, isopropyl-, isobutyl-, vinyl-, isopropenyl-, isobutenyl-, furyl-, methoxy- and acetyl-groups. These alkyl pyrazines are generally considered to be important components contributing to the flavour of roasted cocoa. The odour threshold values of different pyrazines range from 10 to 0.000002 mg/kg depending upon the substitution. Their sensory attributes were varied: pungent, sweet, nutty, chocolate, cocoa, roasted nuts, green, potato-like, earthy, musty and beany (Misnawi and Ariza, 2011). The mechanism usually postulated for pyrazine formation, as shown in Figure 8.6b, is dimerisation of ketoamines to dihydropyrazines with a subsequent oxidation step (Rizzi, 1988; Cerny and Fay, 1995). The variety and quantity of the alkylpyrazine formation depends on the cocoa origin, fermentation, pH, and roasting procedure (Hwang *et al.*, 1995; Jinap *et al.*, 1998; Cremer and Eichner, 2000; Bonvehi and Coll, 2002; Huang and Barringer, 2010; Farah *et al.*, 2012). The total concentration of pyrazines in roasted beans varies according to variety. Ghanaian beans may have about 7 mg/kg, whereas traditionally low fermented Mexican beans may contain as little as 1.4 mg/kg (Reineccius *et al.*, 1972b). Only tetramethylpyrazine (TMP) occurs in large amounts (0.5–2.0 mg/kg) in fermented unroasted cocoa. During industrial roasting it may soon reach its maximum level as it is expelled to some extent with the roasting gases. The concentration of other pyrazines rises with increasing roasting time or temperature. Major quantitative differences involve primarily the dimethyl-, trimethyl- and tetramethylpyrazines whereas other alkylpyrazines appear only at minor level. While the trimethylpyrazine (TrMP) increases steadily, the 2,3-, 2,6- and 2,5-dimethylpyrazines do not increase until strong roasting conditions occur (Figure 8.8). This enables a correlation to be established between the sensorially

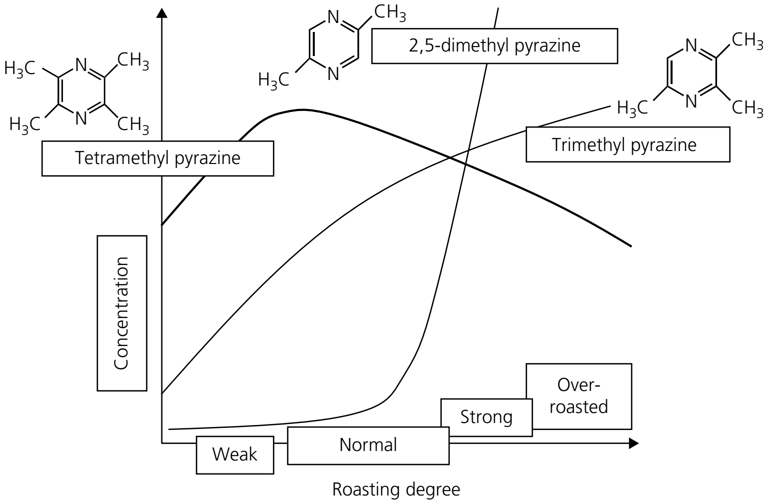


Figure 8.8 Influence of roasting on the formation of selected alkylpyrazines and on the sensorial roasting degree (Ziegleder, 1982b).

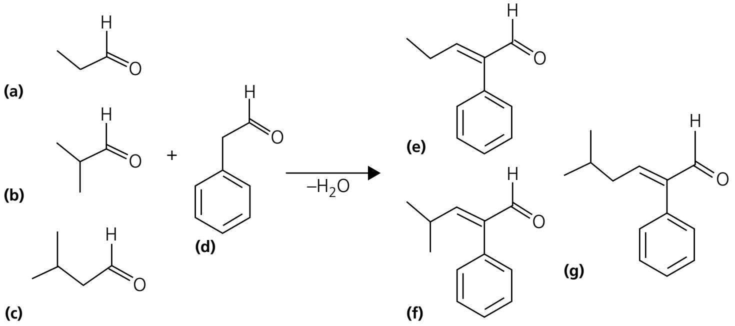


Figure 8.9 Aldol condensation of aldehydes with phenylacetaldehyde to form 2-phenyl-alk-2-enals: (a) acetaldehyde, (b) 2-methyl-propanal, (c) 3-methyl-butanal, (d) phenylacetaldehyde, (e) 2-phenyl-but-2-enal, (f) 2-phenyl-4-methyl-pent-2-enal, (g) 2-phenyl-5-methyl-hex-2-enal.

perceptible roasting degree of cocoa and selected components of the methylpyrazine fraction (Ziegleder, 1982b; Ziegleder and Sandmeier, 1983). The sensory evaluation of different roasted cocoa beans showed that a concentration ratio of TMP/TrMP between about 1.5 and 2.5 was obtained when the degree of roasting was normal. Over-roasted samples have a burnt, coffee-like taste and show significant concentration levels of 2,5-dimethylpyrazine and have TMP/TrMP ratios below 1.0 (Ziegleder, 1982b).

Due to their chemical reactivity aldehydes may be converted during certain secondary reactions. In this way acetaldehyde, 3-methylbutanal and 2-methylpropanal undergo aldol condensation with phenylacetaldehyde to form 2-phenylbut-2-enal, 2-phenyl-4-methyl-pent-2-enal and 2-phenyl-5-methyl-hex-2-enal (Figure 8.9), which carry an odour faintly reminiscent of chocolate (Van Praag *et al.*, 1968) and which significantly increase with roasting time (Meili, 1985; Ziegleder and Biehl, 1988). As intermediates, aldehydes are involved in the formation of pyrazines and further heterocyclic compounds, which are dominant in the flavour of cocoa. Methods for evaluating cocoa bean quality by headspace measurements of 2-methylpropanal and 2-/3-methylbutanal have been suggested (Keeney, 1972; Ziegleder, 1982a).

As demonstrated by Granvogl *et al.*, 2006, a Strecker-type degradation of amino acids may lead to amines as well as to aldehydes. The authors found several amines in cocoa for the first time, such as 2-methylpropyl-, 2-methylbutyl-, 2-methylbutyl-, 2-phenylethyl- and 3-(methylthio)propyl-amine, which derive from the amino acids valine, leucine, isoleucine, phenylalanine and methionine. Only 2-phenylethylamine was already known in cocoa before, and of special interest due to its influence on human physiology (Chaytor *et al.*, 1975). Also, 3-aminopropionamide, a further biogenic amine, was found in roasted cocoa (Granvogl and Schieberle, 2007). Fermentation of cocoa led to amine levels of about 1 mg/kg and subsequent roasting up to 10 mg/kg (Granvogl *et al.*, 2006). While the corresponding aldehydes are potent odorants, the amines have less contribution to the aroma of cocoa. Their reported odour thresholds in oil are comparably high, between 0.3 mg/l for 3-(methylthio)-propylamine and 90 mg/l for 2-phenylethylamine.

Besides amino acids and sugars, other compounds such as peptides, proteins, vitamins, polyphenols and lipids and their oxidation products can enter the roasting reactions and influence the final flavour. In this way, heat treatment may generate specific flavour compounds: 1,2-benzendiol (pyrocatechol) is formed in cocoa by thermal decomposition of catechin, as well as thiazoles by thermal decomposition of the vitamin thiamine. Several pyrones, such as maltol, dihydro-hydroxymaltol, hydroxymethylfurfural and furaneol stem from the degradation of sugar precursors in cocoa (Ziegleder, 1991a). Some of the furaneol and 2,3-dihydro-6-methyl-4H-pyran-4-one has already been formed at earlier moderate temperatures and relatively high humidities (Figure 8.10). This makes these volatiles a useful indicator, whose level can be used for monitoring drying processes or the early stages of roasting (Schnee and Eichner, 1985; Ziegleder, 1991a, b). These compounds decrease slightly during extended roasting, probably as a result of their chemical reactivity. Furaneol has a pleasant caramel taste and may also have a flavour-enhancing effect.

Diketopiperazines, cyclic dipeptides, are generated by the intramolecular breakdown of peptides (Figure 8.11). In cocoa several diketopiperazines [e.g. Cyclo(ALA-VAL), Cyclo(ALA-Gly), Cyclo(LEU-PRO), Cyclo(ALA-LEU), Cyclo(ALA-PHE), Cyclo(PRO-GLY)] have been identified (Pickenhagen *et al.*, 1975; Rizzi, 1989; Bonvehi and Coll, 2000). Model experiments demonstrated that these diketopiperazines, when mixed with theobromine in a 2:1 mole ratio, induce a bitter taste sensation similar to that perceived from an aqueous suspension of cocoa powder (Pickenhagen *et al.*, 1975). Comparison of quantitative data of diketopiperazines

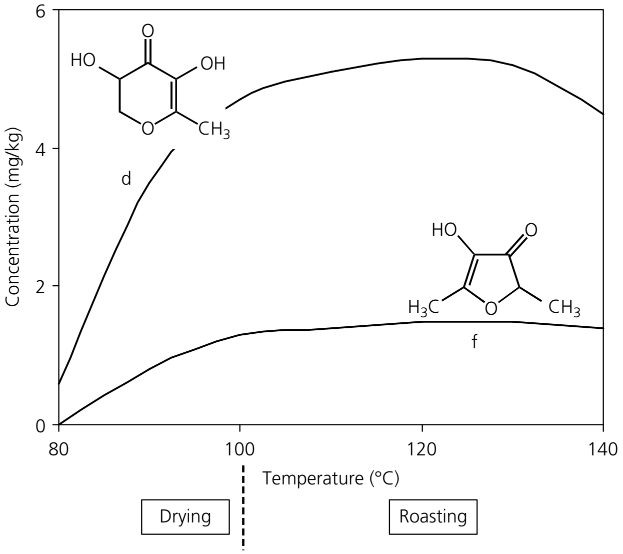


Figure 8.10 Influence of processing temperature on the formation of the sugar degradation products dihydro-hydroxy-maltol (d) and furaneol (f); according to Ziegleder (1991b).

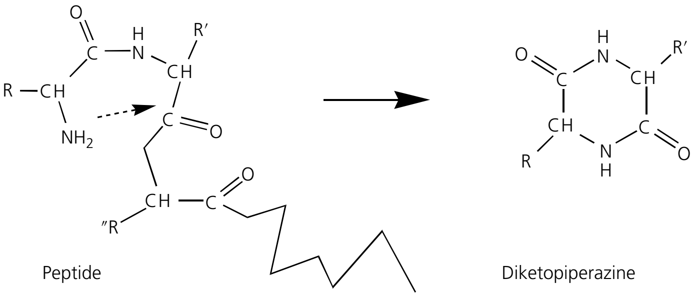


Figure 8.11 Heat-induced formation of diketopiperazines from peptides.

and the sensorially perceived bitter intensity, however, led to the conclusion that further studies are necessary to understand the typical bitter taste of roasted cocoa (Bonvehi and Coll, 2000). Application of chromatographic separation and taste dilution analyses of cocoa extracts recently revealed N-phenylpropenoyl amino acids as powerful astringent components in cocoa. Besides procyanidins a series of different N-phenylpropenoyl amino acids appear to be key contributors to the astringency and bitter taste of non-fermented cocoa beans as well as roasted cocoa nibs (Stark *et al.*, 2005, 2006; Stark and Hofmann, 2005).

The predominant odour-active compounds in cocoa mass and their odour notes (FD factors 32 and higher) as found by aroma extract dilution analysis (AEDA; Schnermann and Schieberle, 1997) are shown in Table 8.2. AEDA is a very good method of screening the most odour-active volatiles in food. It is

Table 8.2 Some selected compounds of the most odour-active volatiles in cocoa mass: their odour quality and FD factors. Source: Schnermann and Schieberle (1997). Reprinted with permission of American Chemical Society.

Odorant	Odour quality	FD factor
2- and 3-Methylbutanoic acid	Sweaty	2048
3-Methylbutanal	Malty	1024
Ethyl 2-methylbutanoate	Fruity	1024
2-Methoxy-isoproyplpyrazine	Earthy, beany	512
Hexanal	Green	512
2-Methyl-3-(methyldithio)furan	Cooked meat-like	512
2-Octenal	Fatty, waxy	512
2-Ethyl-3,5-dimethylpyrazine	Potato chip-like	256
2,3-Diethyl-5-methylpyrazine	Potato chip-like	256
2-Nonenal	Green, fatty	256
Phenylacetaldehyde	Sweet, honey-like	64
4-Heptenal	Sweet, biscuit-like	64
δ-Octenolactone	Sweet, coconut-like	64
γ-Decalactone	Sweet, peach-like	64
Dimethyl trisulfide	Sulfurous	32
Nonanal	Soapy	32
Trimethylpyrazine	Earthy, potato-like	32
2-Ethyl-3,6-dimethylpyrazine	Nutty, earthy	32
2-Phenylethanol	Sweet, yeast-like	32
Ethyl 2-methylpropionate	Fruity	32
2-Decenal	Fatty, green	32
2,4-Nonadienal	Fatty, waxy	32
Ethyl cinnamate	Sweet, cinnamon-like	32
3-Hydroxy-4,5-dimethyl-2(5H)-furanone	Seasoning-like, spicy	32
3-Hydroxy-5-ethyl-4-methyl-2(5H)-furanone	Seasoning-like, spicy	32

based on the extraction of flavour components from food, separation by means of capillary gas chromatography, identification via mass spectrometry coupled with a so-called "sniffing port" to characterise odorants. After several extract dilution steps, only the most potent odorants may be detected at the sniffing port. The number of dilution steps to reach the odour threshold is defined as the FD factor. In general, the odour efficacy of a flavour component is dependent on the ratio of concentration level and specific odour threshold values. Several constituents, that have been previously mentioned, have very significant odours: 3-methylbutanal (malty odour), ethyl-2-methylbutanoate (fruity), 2-and 3-methylbutanoic acid (sweaty) and different pyrazines (earthy, potato-like, nutty, beany; Table 8.2). Although trimethyl pyrazine contributes medium odour intensity, it is relatively less than that provided by other pyrazines with mixed substitutes. The majority of the potent odorants seem to arise from lipid precursors (hexanal, 2-octenal, 2-nonenal, nonanal, 4-heptenal, nonalactone, octenolactone, 2-decenal, 2,4-nonadienal) and carry green, fatty, tallowy, biscuit-like or waxy notes (Schnermann and Schieberle, 1997).

8.4.4 Flavour of alkalised cocoa

The alkalisation of cocoa originated in the early 1800s. It is a treatment of cocoa nibs or mass with aqueous alkali solutions. The aims are to open the cocoa matrix for a better release of cocoa butter during pressing, to enhance the wettability of cocoa powders, to reduce astringency and to develop dark brown or dark reddish colours (see also Chapter 3). Astringency is reduced and colour changed under alkaline conditions, as soluble catechins are partially converted into insoluble procyanidins or oxidised derivatives. So, alkalisation causes a loss in both epicatechin (up to 98%) and catechin (up to 80%; Payne *et al.*, 2010). Also, the flavour formation is affected, and the flavour of alkalised powder is described as mild and mellow, sometimes with alkali undertones (Dyer, 2003). The concentration of alkylpyrazines, aldehydes, nitrogen and sulfur compounds in cocoa is increased as the pH increases. In general, the rate of Maillard reaction is increasing and the formation of flavour volatiles promoted with increasing pH (Davies and Labuza, 1997). In addition, a combined effect of polyphenols and pH on the reactions of flavour precursors during cocoa roasting was reported (Noor-Soffalina *et al.*, 2009). Alkalisation before roasting brought higher levels of cocoa aroma volatiles than alkalisation after roasting (Huang and Barringer, 2010). When alkalisation takes place as part of the roasting process, about 80% of free amino acids may be converted, in comparison to about 25% without alkalisation (Bonvehi and Coll, 2002). Obviously, the temporary influence of aqueous solutions and the presence of alkali enhance the utilisation of flavour precursors. The analysis of the key aroma compounds confirmed the importance of Strecker aldehydes and pyrazines in the aroma of cocoa powder. In comparison to “natural” cocoa, not alkalised, there were higher levels of 2-acetyl-pyrroline and dimethyl sulfide while esters, such as 3-methylbutanoate, were lacking. (Frauendorfer and Schieberle, 2006). In the course of cocoa powder production, 2-phenylethylamine obviously may react with aldehydes, such as benzaldehyde, 2-pyrrolaldehyde and furfural, to form aldimines (Ziegleder *et al.*, 1992). For alkalised cocoa powders a concentration ratio of trimethylpyrazine/tetramethylpyrazine of about 1.0 appears to correlate with normal levels of roasting (Bonvehi and Coll, 2002). For optimally processed cocoa powders without any smoky taste a maximum total of phenolic compounds of 9.6 mg/kg was suggested (Bonvehi and Coll, 1998).

8.5 Conching

8.5.1 Thin-film treatment of roasted cocoa mass

The thin-film treatment of roasted cocoa mass was developed about 1975, largely in order to reduce conching times. During this thin-film degassing, the cocoa mass is spread to a thin layer and thermally treated at 70–90 °C (158–195 °F) for about 1 min (Mohr, 1978; Schmidt, 1978; Kleinert-Zollinger, 1986). The major aim is to reduce acetic acid, because its flavour would otherwise mask the more valuable chocolate notes. Acetic acid and a portion of highly volatile substances may be reduced by about 20–40%, which enables the subsequent conching times to be shortened by about 30%. The degassing is more effective from liquid cocoa mass than from liquid chocolate, because the cocoa mass can be treated at higher temperatures without introducing burnt notes and it also has better flow properties, due to its lower viscosity. In addition, the slightly higher water contents in cocoa masses support the evaporation of acetic acid due to steam distillation and azeotropic effects.

8.5.2 The conching process

Conching can be described as the working of chocolate flake and crumb into a fluid paste, coupled with flavour modification (see also Chapter 10). Typically, conched chocolate is described as having a mellow flavour, compared to an unconched one. The bitterness is reduced, perhaps allowing other flavour notes to be more pronounced. Prior to conching, the basic chocolate masse is normally milled to the required final particle size in a five-roll refiner (see Chapter 9). This produces a dry, flaky chocolate powder. Most of particles have to be smaller than 30 μm (1.2×10^{-3} in), otherwise grittiness will be felt in the mouth (Beckett, 2000). Although many particles are broken under the shear of the refiner gaps, others stick together to form porous agglomerates, which trap and enclose fat. Following refining, the chocolate masse is directly conveyed to a conche, where it is turned into a flowing melt that has an intense, harmonious and long-lasting taste of chocolate.

At the start of conching the mass usually contains between 2 and 5% less fat than the final chocolate. Inner friction raises the temperature steadily, which then causes the evaporation of steam-volatile components. The physical changes brought about by plastification consist of the breakage of any agglomerates and the coating of the non-fat particles by a film of fat. The temperature can rise to 80 °C (176 °F) for plain chocolate, but should not exceed 55 °C (95 °F) for milk chocolate. After plastification, the chocolate masse is liquefied by the gradual addition of the residual cocoa butter under continuous mechanical work. After the addition of an emulsifier (usually lecithin) a chocolate masse with good flow properties is produced. Good flow properties are a prerequisite for optimum manufacturing performance and also for good flavour perception, coupled with a pleasant and smooth mouth-feel (Beckett, 2000). Although conching requires about 6–24 h in modern high-efficiency conches, it often took 72 h in the traditional long-conche.

8.5.3 Effect of conching on aroma development

For decades, there have been many theories about the causes of chocolate flavour improvement during conching. One important factor is the degassing effect, which can be carried out in the conche or, more economically, by means of a pre-treatment of the cocoa mass. Highly steam-volatile compounds and low boiling short chain fatty acids are reduced by about 30%, allowing other flavour notes to be more pronounced and thus provide a more mellow chocolate after conching (Mohr *et al.*, 1968; Maniere and Dimick, 1979; Mohr, 1978; Ziegleder, 1997). The air space immediately surrounding an operating conche smells of acetic acid. The moisture in the finally conched chocolate mass is reduced by about 30%. It is also known that, along with undesirable compounds, some desirable volatiles are evaporated and reduced to some extent during conching, which may have influence on the character of chocolate aroma (Schnermann and Schieberle, 1997; Counet *et al.*, 2002; Fischer *et al.*, 2008; Owusu *et al.*, 2013). Although 2-phenyl-5-methyl-2-hexenal, furaneol and some further volatile compounds may be generated in dark chocolates during conching (Counet *et al.*, 2002), it is unlikely that chemical reactions play an important role for the intense flavour changes. The temperature applied and the concentrations of flavour precursors as well as the water content would be too low for intense Maillard reactions.

Recent findings have shown however that conching results in a re-distribution of the flavour components within the chocolate masse (Ziegleder *et al.*, 2003, 2005; Müntener, 2010; Danzl and Ziegleder, 2014a). At the start of the conching process the chocolate flavours exist only in the cocoa components, that is cocoa particles and cocoa butter, whereas the granulated sugar only has sweet flavours. During conching cocoa flavour components, together with fat, are partially transferred to the sugar surface. This coating of the sugar surfaces results in a more uniform aroma perception and in a reduction of the penetrating sweetness of the roll-refined sugar. The diffusion of flavour is a result of the initial flavour concentration gradient between the different particles or phases. This means that sugar now acts as a flavour carrier. Figure 8.12 illustrates the process schematically, whilst Figure 8.13 shows the different flavour distributions before and after conching. After conching the flavour components in the cocoa solids, fat and at the sugar surfaces have all been evened out. For many years, the role of the physical state of sucrose (i.e., amorphous vs crystalline) in chocolate has been discussed (Martin, 1987). The increased porosity of the sugar surfaces, of which a very thin layer could have been turned amorphous during roll refining (Niediek, 1981, 1991), helps flavour absorption. But amorphous sugar is a metastable form and tends to crystallise rapidly under the influence of temperature and moisture. The earlier experiments were mainly focused on the plain sugars (Niediek, 1981). Later findings showed that no amorphous sugar was present in final dark chocolate products (Gloria and Sievert, 2001). If amorphous sucrose was used for chocolate processing it completely crystallised early in the process, that is during mixing. However, crystalline sugar surfaces may adsorb cocoa butter and flavour substances effectively (Cammenga *et al.*, 2008).

Through flavour redistribution and adsorption by the sugar surface, the flavour concentration in the fat phase decreases during conching (Ziegleder *et al.*, 2003; Danzl and Ziegleder, 2014a). This was proved by separating a representative part of the fat from the finished, melted chocolate masse by

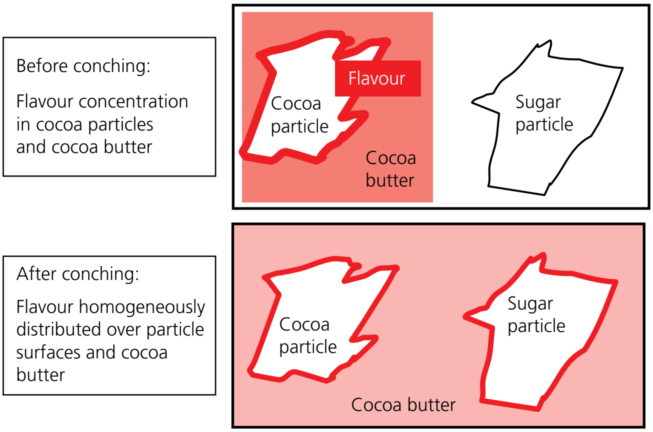


Figure 8.12 Redistribution of flavour within the chocolate masse (between cocoa particles, sugar particle surfaces and cocoa butter) during conching time. Flavour intensity demonstrated by hatching.

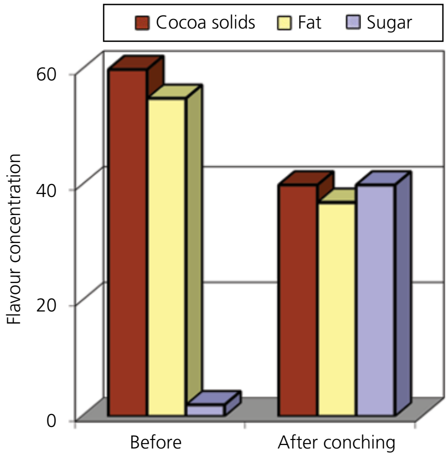


Figure 8.13 Flavour distribution between cocoa solids, sugar particle surfaces and the fat phase before and after conching.

centrifugation. The volatile compounds were then identified and quantified by GC-MS using internal standards. It was found that there was a very significant decrease of flavour in the fat during conching, even though the whole chocolate masse lost only a low portion of flavour due to evaporation. Using this method, conches and conching parameters could be evaluated objectively and an analytical “conching degree” could be defined for the first time, and a good correlation of analytical values and sensory results was achieved. Therefore the melted chocolate has to be separated via centrifugation into the fat phase and the fat-reduced residue. The ratio of the flavour levels, to be measured in both fractions, is dependent on the conching intensity (Ziegleder *et al.*, 2003, 2005). The main factors affecting the flavour change were found to be the dry conching time, total energy/average power, type and rotation speed of shafts, starting fat level, viscosity of chocolate mass, temperature, ventilation, humidity and particle size distribution (Ziegleder *et al.*, 2005; Beckett, 2006; Müntener, 2010). It seems plausible that high particle friction and shear forces facilitate the diffusion and transfer of flavour volatiles. After equal conching times, a modern conche provided a significant higher conching degree and better sensory results than a traditional long-conche (Balimann *et al.*, 2007). This mechanism of flavour redistribution during conching has been found to apply to both milk and plain chocolates. But in the special case of milk chocolate some caramelisation of lactose may occur, depending on the conching conditions.

8.6 Dark chocolate and milk chocolate

8.6.1 Dark chocolate flavour

Owing to their higher proportion of cocoa mass, dark chocolates have a more intense and bitter taste in comparison to milk chocolate. Dark chocolate may show significant variations with respect to sour, bitter, astringent, chocolate, nutty, smoky and burnt flavours (Jinap *et al.*, 2005). There are obvious differences in the flavour of cocoa beans according to where they were grown in the world. The Criollo- and Trinitario-based cocoa varieties are generally known to produce a fine chocolate flavour, often described as a mild nutty and a full flavour, respectively, and are considered "fine grade" cocoas The "bulk cocoas", which make up the vast majority of the world's production, are from Forastero varieties (see Chapter 2). Although they are of good quality and have strong flavour characters, they have less fine chocolate notes when compared to the Criollo type (Cook and Meursing, 1982; Afoakwa *et al.*, 2008; Afoakwa, 2010). This is very pronounced with the so-called "origin chocolates", which contain cocoa mass of only one defined country of origin. As an example, a plain Arriba chocolate will have the typical taste of the mild, floral and earthy notes of Arriba cocoa. Some consumers prefer premium chocolates with high cocoa content, and dark chocolates with about 70% of cocoa and a high portion of flavour cocoa have a small but constant market. These chocolates need specific manufacturing techniques, as their high fat level, due to the high portion of cocoa mass and cocoa butter, causes difficulties during roller refining. They may be produced by the five-roller refining of a chocolate mixture with a reduced portion of the cocoa mass and later addition of the remaining cocoa mass during conching. Alternatively, cocoa powder can be used in the recipe, or the chocolate mixture can be processed in a ball mill (Ziegleder and Balimann, 2007).

8.6.2 Milk chocolate flavour

In milk chocolate there is a balance between the cocoa and milk flavours (Beckett, 2006), and in comparison to dark chocolates they are softer due to their portion of lower melting milk fat (see also Chapters 5 and 6). A harsh cocoa hides the milky creamy flavours, but once the cocoa intensity is reduced, the creaminess comes to the fore (Afoakwa, 2010). Whole milk powders as well as skim milk powders in combination with anhydrous milk fat are used in milk chocolates (Beckett, 2006; Bouzas, 2014). Roller dried milk forms platelet-like particles with most of the fat outside. This helps the chocolate flow properties and the temperatures used create a small amount of cooked flavour. Spray-dried milk has spherical particles, and most of the fat is trapped within the particle and so is unable to aid the viscosity of the chocolate. The free fat content of whole milk powder as well as the particle size distribution are critical parameters that have a significant influence on the performance of milk powders in chocolate (Aguilar *et al.*, 1994; Mongia and Ziegler, 2000; Ziegler *et al.*, 2001; Liang and Hartel, 2004). The important flavour compounds in milk chocolate stem from cocoa mass, but some additional volatiles were found in milk chocolate which may be relevant sensorily. For example, several δ-lactones and further volatiles such as 2,3-butandione, 1-octen-3-one and 5-methyl-2-hepten-4-one are present, which obviously stem from milk powder (Schnermann and Schieberle, 1997). The volatile flavour components in different types of dry milk have been investigated (Shiratsuchi *et al.*, 1994; Karagül-Yüceer *et al.*, 2002). In addition, short-chain free fatty acids appear to have some influence on the sensory properties of milk chocolate (Ziegleder, 1997). Milk chocolates have shorter shelf life when compared to dark chocolates. Off-flavours, which develop during months of age in milk powder, could subsequently be detected in chocolate made from this milk powder (Bouzas, 2014).In stale milk chocolates an increased level of short-chain free fatty acids and volatile lipid oxidation products, 3,5-octadien-2-ones, were found (Ziegleder and Stojacic, 1988). As these compounds are formed under the influence of lipases and lipoxidases, there appears to be a residual enzymatic activity, even though the water activity of milk chocolate is very low.

The chocolate crumb process was developed in the 1930s, when the milk powders had poor keeping properties (Beckett, 2006). There are a number of unique processes for making milk chocolate crumb, all starting with milk, sugar and cocoa mass (Martin, 1987). Briefly, the milk and sugar are mixed and moisture is partially removed. The cocoa mass is then mixed in, followed by a drying process to reach a final moisture content of 0.8–1.5%. The flavour developed during crumb manufacturing utilises the Maillard reaction to produce varying degrees of toasted, cooked or caramelised flavours. Usually, key flavour compounds as furfural, maltol, lactones and methyl-ketones may be generated (Bouzas, 2014). It is interesting to note that the market-leading milk chocolate tablets in the United States, United Kingdom and Australia are based on crumb, showing that the consumer appreciates their distinctive flavour and texture (Wells, 2006).

Caramel flavour is a special topic in milk chocolate manufacturing. Typical sugar degradation volatiles, such as furaneol, maltol, furfural and furfuryl alcohol, which are associated with a sweet caramel-like aroma, may be generated during conching, when temperature and humidity are slightly increased. But due to the much lower water contents and moderate temperatures in a conche when compared to the crumb process it is not possible to develop a similarly intense caramel flavour. It is well-known that a greater portion of lactose is amorphous in dry milk. This amorphous matrix is hygroscopic and tends to absorb water from air humidity or other chocolate ingredients. Absorbed water increases the mobility within the lactose structure ("glass transition") and may induce its crystallisation (Jouppila and Roos, 1994). In the course of crystallisation, water is set free and may start chemical reactions of lactose resulting in caramel flavor (Danzl and Ziegleder, 2011, 2014b). In general, recrystallising amorphous sugars show an increased Maillard reactivity due to the suddenly released water (Davies and Labuza, 1997), and this was proved in particular for lactose in whole milk powder (Thomsen *et al.*, 2005a, b). Caramelisation may start in the milk powder particles, where free water as well as reactive amorphous lactose are available (Figure 8.14). Critical parameters for glass transition in milk chocolate masses are for example 55 °C (121 °F) at a water content of 1.2%, respectively 60 °C (140 °F)/0.9%, or 65 °C(149 °F)/0.5%. Caramelisation in milk chocolates occurs at about 70 °C (158 °F; Stauffer, 2000; Danzl and Ziegleder, 2011, 2014b). While lactose crystallisation is often accompanied by an agglomeration, the intense shear forces during conching help to avoid any agglomeration and thickening (Ziegleder *et al.*, 2004). In detail, different types of chocolate were produced when the cover of a conche was opened or closed during the process. With an open cover, water could evaporate more rapidly and lactose remained amorphous; under a closed cover, humidity forced lactose crystallisation and caramelisation. In these studies, amorphous lactose within the milk chocolate masses was detected via dynamic vapour sorption, and the caramel flavour was verified by means of GC-MS, using maltol, furfuryl alcohol, 2-acetylfurane and furfural as indicative compounds (Danzl and Ziegleder, 2011). Of course, the type of milk powder is of influence. So, lactose had higher tendency for caramelisation in whole milk powders when compared to skim milk powders (Danzl and Ziegleder, 2011, 2014b).

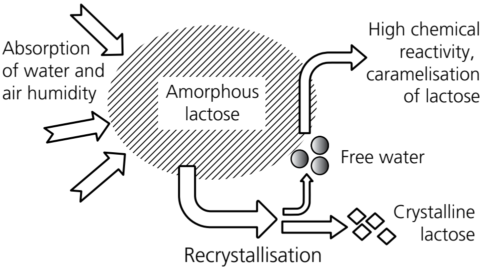


Figure 8.14 Recrystallisation of amorphous lactose (within dry milk particles) and release of water as the starting mechanism of caramelisation of lactose (schematic).

8.7 Flavour release in chocolate

Chocolates are semi-solid suspensions of about 70% in total of fine solid particles of sugar and cocoa (and milk, depending on type) in a continuous fat phase. When eating chocolate it becomes liquid in the mouth, giving a smooth suspension of particulate solids in cocoa butter. Then, flavour is released into the mouth headspace and perceived by human retronasal detectors. The perceived flavour characteristics are due to a combination of the taste, imparted by the non-volatile components, and the smell, imparted by the volatile components during consumption (Beckett, 2003). There is a complex interrelation between melting, salivation and mastication, flow properties and sensory impressions of the chocolate (Figure 8.15). So, chocolate flavour perception is time-dependent, as its structure changes during eating because of several factors (Beckett, 2003). The shape of chocolate pieces can affect flavour and texture perception, too (Lenfant *et al.*, 2013). The dynamic behaviour of perceived sensory attributes in combination with the effect of melting on taste and flavour in chocolates has been investigated using retronasal flavour release and time-intensity methods (Daget and Vallis, 1994; Ziegler *et al.*, 2001). An overview about the aspects of flavour release and flavour perception in chocolate was given by Afoakwa (2010).

Particles must be small enough not to taste rough (usually <25 μm) and indeed below this size the mouth is able to detect differences of about 3 μm in average. Each time a cocoa particle is broken it produces more surface for flavour release. If the same dark chocolate is milled to a finer particle size then the cocoa intensity will increase and the flavour release be enhanced (Beckett, 2006; Afoakwa *et al.*, 2009). The finer the particles are ground the more fat is required to coat the surfaces to enable them to flow past each other. So, the range of particle sizes has

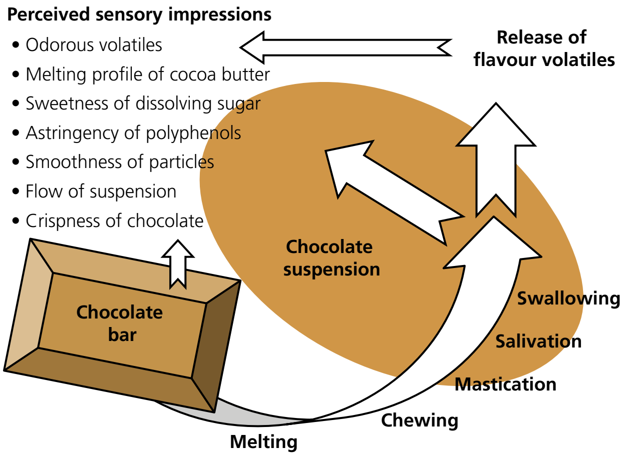


Figure 8.15 Mechanisms of flavour release and perceived taste during consumption of chocolate (schematic).

to be optimised for flow properties and sensory impressions. Volatile release data suggested that chocolates of higher fat content would exhibit greater release of components with cocoa notes and less release of volatiles with caramel-like and honey notes than those with lower fat. Factors such as lipophilicity or lipophobicity of flavour compounds could modulate the effect of fat content on release (Afoakwa *et al.*, 2009). Within the cocoa mass, flavour volatiles are in one part entrapped within cocoa particles where they had been generated during fermentation and roasting and, in the other part, bound to particle surfaces or dissolved in cocoa butter. Hydrophobic flavour substances such as tetramethylpyrazine or linalool are to a greater extent dissolved in the fat, while the hydrophilic ones like 3-methylbutanal or phenylacetaldehyde are mainly fixed in the solid matrix. So, only a part of the flavour volatiles may be perceived in cocoa mass. During conching of chocolate masses, flavour volatiles are increasingly set free from cocoa and transferred to sugar surfaces. So, the conching process brings the optimal flavour distribution within the chocolate masse, necessary for the desired flavour release and uniform aroma perception (Ziegleder *et al.*, 2003, 2005; Danzl and Ziegleder, 2014a). Due to the growing coating with fat and flavouring materials, the intense sweetness of sugar particles is reduced. When we eat chocolate, the cocoa butter slowly melts and the sugar dissolves, so that the flavour volatiles are fully released. When enjoying finished chocolate, one does not recognise “cocoa” and “sugar”, but has the overall impression of “chocolate”.

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CHAPTER 9

Particle size reduction

Gregory R. Ziegler and Richard Hogg

9.1 Introduction

Cocoa nib grinding, chocolate refining and kibble milling are all mechanical size reduction processes that may be observed in chocolate manufacturing factories. Grinding processes should not be considered in isolation, but evaluated in the context of the entire chocolate making system. Kuster (1991) considers the mixing, refining and conching stages of chocolate production as a single process with several steps.

Chocolate refining is affected by product type (milk, dark or compound), the process (crumb vs milk powder) and the ingredients (granulated or powdered sugar). Ingredients may be mixed and then ground (combined grinding) or ground then mixed (separate grinding). The latter allows for the optimisation of size reduction processes for each component individually, but may not produce the same flavour or texture as when the components are ground together. Nib grinding is influenced by (i) pretreatment of the nibs and (ii) the required end fineness dependent on whether the cocoa mass will be pressed or used in chocolate manufacture.

Grinding operations may be evaluated on the basis of their costs (capital, maintenance and energy) or by the product characteristics they produce (particle size distribution, particle shape and minimisation of contamination). Fine grinding of cocoa nibs is used to produce an "optimum" particle size distribution, which is commonly defined in terms of final product characteristics such as flavour, texture, appearance or flow properties. For chocolate, grinding operations may affect product cost through their influence on cocoa butter requirements. Very often the relationship between the size distribution of the ground material and the end-product quality is poorly understood. The outcome of a grinding operation is a particle size distribution, while the real objective is to control the performance of downstream operations or final product quality. The importance of relating particle characteristics to product quality cannot be over-emphasised.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

9.2 Principles of fine grinding

9.2.1 Breakage mechanisms

Fine grinding is accomplished by breaking particles into smaller fragments. Contact forces (compressive or shear) deform particles and generate internal stresses which, when strong enough, bring about fractures. The number and direction of these fractures determine the size distribution, shape and surface characteristics of the fragments. For failure to occur, the strain energy released must exceed the surface energy generated. The magnitude, rate of application and frequency of application of contact forces determines the efficacy of the size reduction process.

How a particle responds to contact forces depends on its material characteristics. Most materials can be classified as either brittle or non-brittle. Brittle materials deform elastically in response to an applied stress, before failing suddenly at stress levels above some critical value. Brittle materials can be broken by simple stress application (usually compressive), and failure occurs as a catastrophic event resulting in a suite of fragments ranging in size from about 30–40% of that of the original down to submicron sizes (Figure 9.1). Internal stress concentrates at imperfections or microscopic flaws in the material such as cracks, air bubbles or foreign inclusions, increasing the probability of failure at these points. As the size is reduced, a grindability limit may be reached as smaller particles contain fewer imperfections and the critical stress increases.

Breakage of brittle materials can occur at lower levels of stress application if the stresses are localised, for example at the edges or corners of irregular particles.

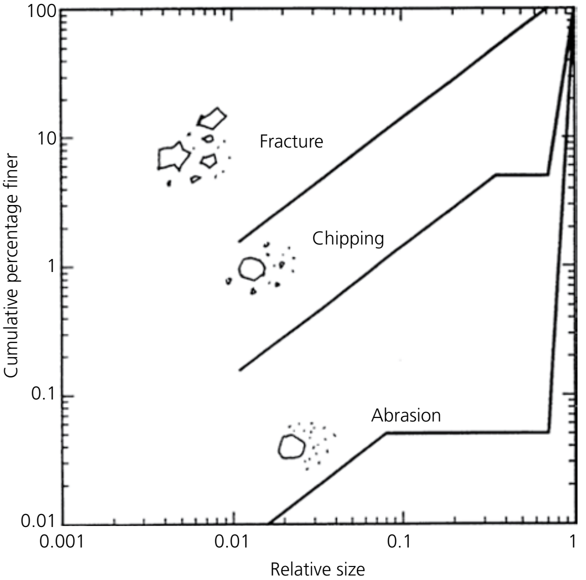


Figure 9.1 Fragment size distributions resulting from different breakage mechanisms (schematic).

This kind of chipping action leads to gradual breakdown of the particle leaving a residual core only slightly smaller than the original and a suite of fragments of much finer size (Figure 9.1). Abrasion of particles, through surfaces rubbing together, should probably be considered as a limiting case of the chipping mechanism (Tangsripongkul, 1993). Brittle materials may exhibit plastic behaviour as the size of the particles becomes small.

Non-brittle materials, classified as either ductile or tough, are more difficult to grind than brittle materials. Ductile materials undergo substantial plastic deformation before simple failure occurs, and tough materials relieve stresses through internal rearrangement. Tough materials, for example cocoa shell and germ, often possess a fibrous structure. Failure occurs as a gradual loss of integrity resulting from accumulated damage due to repeated deformation. The breakage of non-brittle materials often requires the application of shear, although some tough materials exhibit work hardening and can be broken down by repeated application of compressive stress. Cutting actions generally result in the production of relatively few (e.g. two) fragments from each breakage event. The relative size of these fragments may differ widely, so that a set of breakage events on many similar particles can lead to a fairly broad particle size distribution.

Temperature can affect a material's response to stress – tough materials may become brittle at low temperatures and amorphous materials are generally brittle below their glass transition temperature (Blanshard, 1995) – hence the application of cryogenic grinding. A sugar glass may deform plastically above the glass transition temperature. However, brittle fracture may still occur if the critical stress is applied faster than the material can relax. Increasing moisture content generally reduces brittleness and may make some materials more difficult to grind. Temperature control is important for heat-sensitive materials.

9.2.2 Grinding processes

The basic operation of any grinding device involves two aspects: placement or setting up of the particles to receive stress and the stress application itself. Particle placement can be direct (particles are brought to the stressing site) or random (particles arrive at stressing sites by chance). Single-pass devices such as a two-roll refiner involve direct placement where the particles are provided with a single breakage opportunity before exiting. On the other hand, retention devices, such as media mills, mostly rely on random placement and a particle may be subjected to repeated stress application. Direct placement systems make the most efficient use of input energy. Many nominally single-pass devices do include some degree of retention.

The effectiveness of a machine can be characterised, for the single-pass mills by a *breakage probability* that describes the fraction of particles actually broken during passage, or for retention mills by a *breakage rate* that describes the fraction broken during a given time period. For any mill, these quantities are determined by a combination of the effectiveness of the device in placing the particles to receive stress and their ability to provide sufficient stress for breakage to occur. These breakage parameters generally increase with particle size – larger particles are both weaker and easier to find.

Grinding systems that involve a significant contribution from the attrition mechanism (chipping or abrasion) produce quite different breakage rate and breakage distribution relationships. Rates appear to decrease with time, or perhaps more correctly, with the degree of attrition. The gradual removal of prominent protrusions leads to a rounding of particles and increased resistance to further attrition (Tangsripongkul, 1993). Breakage distributions show a bimodal character as illustrated in Figure 9.1. The bimodal form is also reflected in the product size distributions – the existence of such forms provides evidence that attrition plays a prominent role in the grinding process. Such distributions are shown for chocolate refining (Peter, 1994). Similar effects can occur due to variation in the relative strength of the feed particles such that energy input is sufficient to break some, but not all, of the particles. Those particles that do break produce smaller fragments that are readily broken further. Such is the case when sugar and whole milk powder are refined together.

Particle size reduction is very energy intensive, with the energy requirements increasing as the average size becomes smaller. Equation 9.1 is often referred to as the general law of comminution and is the basis for more specific relationships, for example Rittinger's Law ($n = 2$), Kick's Law ($n = 1$) and Bond's Law ($n = 3/2$),

$$\frac{dE}{dx} = -\frac{K}{x^n} \tag{9.1}$$

where dE is the change in energy, dx is the change in size, K is a constant and x is particle size. Fritzsche (1994) in fact demonstrated an exponential increase in specific energy requirements for refining milk chocolate mass as the particle size was reduced. Kuster (1984) presented similar data for grinding cocoa mass, particularly in the size range below 20 μm (8×10^{-4} in).

Breakage of brittle materials is essentially an irreversible process. However, in the case of softer, more plastic substances, agglomeration of the fragments can be significant. In contrast to breakage rates, which generally decrease with decreasing particle size, agglomeration rates and agglomerate strength tend to be higher for smaller particles (Rumpf, 1962). The net effect of simultaneous breakage and agglomeration is an approach to a limiting size at which the growth and breakage rates are equal. The structure of agglomerates differs from that of the original solid particles, so that breakage behaviour can also be expected to be different. In particular, agglomerates tend to be weaker and more plastic than the solid particles. An important consequence is that breakage rates decrease as the solid particles are broken down and then converted into agglomerates, which leads to a situation in which the average particle size first decreases and then begins to increase. At the same time, the size distribution becomes narrower as the fine particles are eliminated by agglomeration (Kaya *et al.*, 1997). It is likely that some agglomeration is taking place at the end stages of chocolate refining, and that conching, in part, disperses these agglomerates, although new agglomerates can also form due to moisture "sticking " particles together (see Chapter 10).

The physical and chemical environment in a grinding device is known to affect grinding. Wet grinding is often considered to be more "efficient" than dry grinding (Bond, 1960). It seems that the primary effects are on the agglomeration of fine particles, since the use of liquids permits greater control over particle dispersion. Chemical additives like surfactants, so-called grinding aids, are believed to function largely through their effects on dispersion and rheology (Klimpel and Manfroy, 1978). Powder slurry rheology is clearly a critical factor in fine-grinding operations. Unfortunately, current understanding of the relationship between particle dispersion and rheology, especially important in conching operations, is rather limited.

9.3 Grinding equipment

The choice of equipment for size reduction depends on many factors, including the feed particle size, the type of material being processed, the final particle size and, as we have discussed, the role the operation plays in the integrated system. It is not surprising that a wide variety of size reduction operations are in use in chocolate and cocoa processing plants. Despite wide differences in the nature and characteristics of the materials being ground, the types of equipment used in industrial applications are remarkably similar.

9.3.1 Crushers

Crushers apply direct mechanical force (primarily compressive) to individual particles or compacted beds. Roll refiners used in chocolate manufacture fall into this category. Machines of this type are relatively efficient in terms of utilisation of energy input. However, their effectiveness tends to fall off drastically in applications to very fine grinding. Individual particle crushing becomes impractical at such sizes and energy is wasted in bed compaction. Disc mills and roll refiners incorporate shear as well as compression in the grinding action and are most effective for brittle materials.

9.3.2 Media mills

The grinding action in media mills is provided by the relative motion of individual loose elements, the grinding media, which may consist of balls, rods or beads. Particle placement is essentially random; stress is applied only to those particles that happen to be caught in contact between media elements or media elements and the mill. In principle, a particle could remain in the mill for a substantial period of time without being subject to stress, while other particles may be subject to repeated stress. To some extent, the breakage probability can be maximised by appropriate control of the ratio of media to particles. A general guide is to maintain the volume of material being ground at about the void volume in the packed media bed.

Media size is an important variable in these mills; smaller media increase the frequency of media–media collisions, but reduce the energy associated with each impact. The result is that smaller media increase breakage rates for those particles that they are capable of breaking, but the limiting size that can be broken is reduced. As a rough guide, a media diameter to particle diameter of greater than about 20:1 seems appropriate. The decreased impact energy of smaller media can be offset by increased overall energy input by increasing impact velocity (mill rotation) or media density.

Stirred media mills increase energy input through agitation by an impeller. They are typically vertical or horizontal cylinders, filled to as much as 90% of the available volume with grinding media (steel balls, ceramic beads, etc.). During wet processing in stirred media mills, the feed material in the form of a suspension is pumped into a grinding chamber and comminuted between the moving media, the stirrer and the grinding chamber by compression and shear. Relative media motion can be maintained throughout the charge and, with high-speed operation, energy input per unit volume can be very high. This leads to high grinding capacity but can also introduce overheating problems. In many applications, it is necessary to use a combination of water jacketing and slurry recirculation for temperature control. Quite high pressures are sometimes required to achieve the necessary feed rates, and contamination due to media wear can be a serious problem. The effects of media size and density appear to follow a very similar pattern to that observed in tumbling mills. Grinding efficiency, particle size distribution and suspension rheology are inter-related. Alamprese *et al.* (2007) provide an example of optimisation of process parameters for the ball milling of chocolate. The relatively large contribution from shear in the agitated media may make these devices especially suited to tough, non-brittle materials like cocoa nibs.

9.3.3 Impact mills

Hammer mills, pin mills and similar devices generally rely on impact with parts of the machine itself to induce particle breakage. Often particles are forced to exit the machine through a grate or screen that serves both as a built-in classifier and as an impact site. Such designs probably include a significant contribution from shear in addition to simple impact thus permitting their use for tough, non-brittle solids. Screen wear can become a serious problem in such applications. The screen openings are limited to relatively large sizes, and small-particle impacts tend to be reduced by their being drawn away in the airstream passing through the mill. Therefore, mechanical impact mills are not generally appropriate for very fine grinding (micron) applications. However, impact devices like pin-disc mills are ideal for pre-grinding of non-brittle material like cocoa nib.

9.3.4 Fluid energy mills

Often referred to as jet mills, the fluid energy devices use a high velocity fluid (usually air or steam) to accelerate particles. Breakage occurs through impact between individual particles (autogenous grinding) or with the walls of the grinding chamber. The absence of grinding media and other moving parts helps reduce product contamination and machine maintenance. It is claimed that these mills produce a relatively narrow product size distribution. This may be due in part to very low breakage rates for the finest particles, but may also reflect a loss of fines in the solid–fluid separation step required for collection of the product. Energy efficiency of these mills is relatively low. A schematic illustration of a fluid energy mill is given in Figure 9.2.

9.3.5 Guidelines for equipment selection

Different types of mill typically involve combinations of mechanisms for particle placement and stress application. While each type has certain advantages and disadvantages for any specific application, there is rarely one particular device that is ideal. Many factors contribute to the choice of an appropriate mill for a particular application. Primary considerations are material characteristics, product specifications and required throughput. In turn, the selection process requires the choice of mill type and mill size. Other features such as reliability and ease of maintenance also vary to some extent from type to type, and may also depend on the specific manufacturer.

The extent of size reduction required, that is the ratio of the feed size to the product size, is also an important consideration for system design. Depending on the material, most mills are effective over a limited range of particle sizes; reduction ratios should rarely exceed 10–20, and 4–7 may be ideal. For this reason, grinding operations are usually accomplished in stages. Higher ratios require two or more mills, perhaps of the same type but different size, but often of different type. Size reduction in stages may help limit the excessive production of fines.

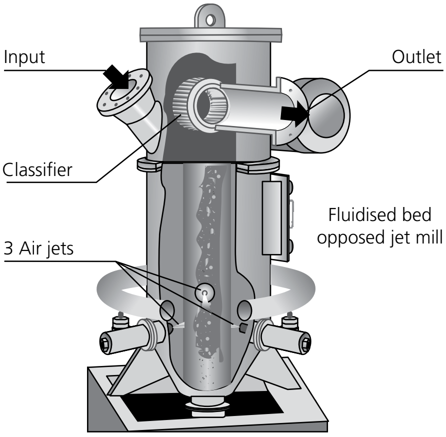


Figure 9.2 Cut-away diagram of a fluid energy mill as manufactured by Hosakawa Micron.

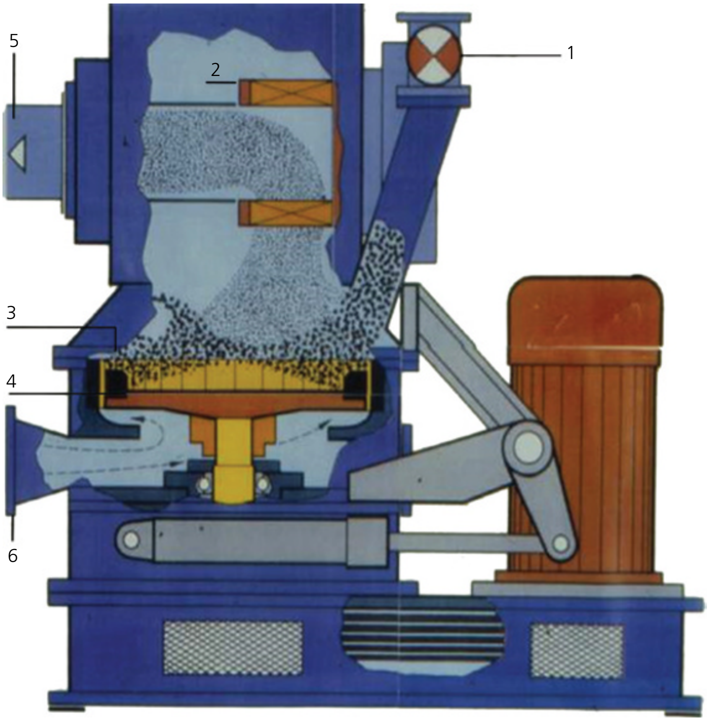


Figure 9.3 Schematic diagram of a classifier mill as manufactured by Hosakawa Micron. (1) Material inlet valve, (2) classifier, (3) milling hammers, (4) milling disc, (5) outlet to cyclones and filter bags, (6) air inlet.

Batch grinding and open-circuit continuous grinding provide little control over product size distribution, other than the "average" size. Closing a continuous grinding circuit with a classifier, or alternating stages of grinding and classification in a batch system, can provide additional control over the product size distribution by reducing over-grinding of product size material. This approach also increases mill capacity and reduces energy requirements and product contamination. Classifier mills have an integrated, internal grinding–classifying circuit. The aim is to prevent over-grinding by the continuous discharge, during grinding, of the product that has reached the desired final size. Larger particles are retained and ground further. Classifier mills are generally not as effective as separate mill and classifier circuits, and are typically limited to dry grinding operations. As fat becomes liquid during grinding, this type of machine is typically used with material with a fat content of less than about 12%, unless cryogenic techniques are applied. A classifier mill which can be used to grind cocoa powder or other low fat ingredients is illustrated in Figure 9.3.

In the design of grinding systems, especially for complex materials and mixtures like chocolate, it is important to recognise that the process may actually serve to perform other functions besides size reduction, for example mixing or surface wetting. These may be deliberate or by accident and may not even be recognised or fully understood. Replacing a mill that is a good mixer with one that grinds more effectively, but provides less mixing action, could have important implications downstream. In other words, while grinding may be an important distinct step in the overall process, it should always be evaluated in the context of other processing steps.

9.4 Cocoa nib grinding

Cocoa nib is ground to cocoa mass for the efficient removal of cocoa butter from within the cellular structure. Cocoa nib is approximately 55% cocoa butter, contained within cells of about 20–30 μm (8–12 × 10^{-4} in) in size (Beckett, 1994). It is the non-fat solids portion of the cocoa cell that must be broken to release the fat. This cell wall material and, more particularly, the cocoa shell and germ are fibrous and tough, so shear is generally required. Final maximum particle size ranges from 15–50 μm (6–20 × 10^{-4} in; by micrometer) and is dictated by the requirements for subsequent use – finer for chocolate manufacture and coarser for pressing. Particles less than 20 μm (8 × 10^{-4} in) will reduce pressing efficiency by plugging the filter, passing through the filter and absorbing excessive amounts of fat (Kuster, 1980).

When cocoa mass is to be incorporated into chocolate, it is advisable to grind nib to the desired end fineness for organoleptic considerations. This assures maximum free fat, minimum viscosity, appropriate texture and flavour. It is difficult to overgrind nib (Niediek, 1994). Shell and germ are particularly difficult to grind, and they cause excessive wear in size reduction equipment. For this reason, effective winnowing is especially important (see Chapter 3). If milling machines are set to adequately size the shell and germ, then the rest of the cocoa structure will be correctly ground (Niediek 1994). Although higher temperatures can be tolerated for nib grinding than chocolate refining, colour and flavour are influenced by high grinding temperatures (Kuster, 1984). Kuster (1980) recommended milling nib to an end fineness 2–5 μm less than the end fineness of the finished chocolate. This is said to reduce subsequent refiner wear, increase refiner throughput and improve finished product flow properties, that is lower viscosity.

Cocoa nib grinding is usually accomplished in at least two steps. Impact mills, for example pin-disc or hammer mills, are typically employed for pre-grinding. The final fineness is achieved using a stirred media mill, corundum disc mill or a three-roll refiner. The high shear of the corundum disc mills and the repeated compressive stress of agitated ball mills make them ideal for tough materials like cocoa nib. Milled cocoa particles appear as small platelets, but also include cocoa starch granules. The latter make up about 7% of the weight of the cocoa mass and from 1–3% of chocolate depending on the cocoa mass content (Schmieder and Keeney, 1980). Cocoa starch granule size varies from 2–12.5 μm (0.8–4.8 × 10^{-4} in; Schmieder and Keeney, 1980), so they could be expected to remain as intact, ellipsoidal particles after milling. The contribution of cocoa starch to the properties of chocolate is largely unknown.

The majority of the world's current cocoa harvest is milled using agitated ball mills (Niediek, 1994). Ball size, ball charge, agitator velocity, height to diameter ratio, feed rate and feed direction all have an effect on the mill efficiency and particle size distribution. Where large quantities of cocoa mass are being processed, it may be more efficient to use a series of ball mills, each successive mill with a smaller ball size beginning with 15 mm (0.6 in) and ending with 2–5 mm (0.1–0.2 in). As ball size is reduced, agitator speed may also be increased (Niediek, 1994). Equipment wear of 20–100 g per 1000 kg of cocoa mass can be expected in ball mills, but staging ball mills also tends to reduce contamination from the grinding media. Ferrous materials can be removed from the finished cocoa mass by magnets located at the mill exit, but non-ferrous contaminants like ceramics are not easily removed. Contamination from grinding media increases subsequent chocolate refiner wear.

The triple mill employs three successive pairs of corundum discs for fine grinding cocoa nib. For each pair of discs, one rotates while the other is stationary. Their capacity is similar to commercial stirred media mills used for grinding cocoa nib, that is 1000–2000 kg h^{-1} (1–2 t h^{-1}). Although operating costs, such as energy and maintenance, may be lower than for agitated ball mills, capital costs are generally greater for disc mills (Niediek, 1994), and temperature control is more difficult. Unlike the agitated ball mill, the feed material may be solid or liquid, although pre-grinding is customary. Figure 9.4 illustrates a typical triple disc mill.

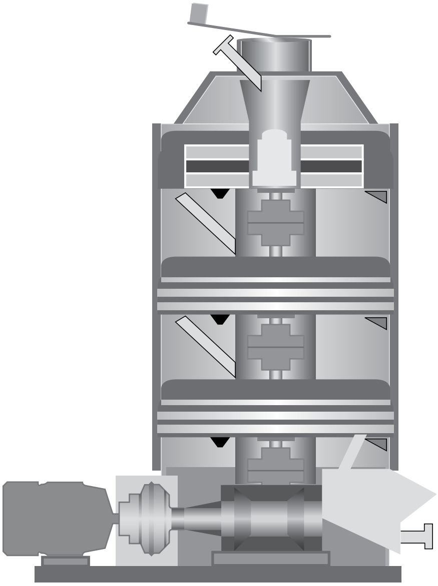


Figure 9.4 Schematic diagram of a triple disc mill (Lehmann).

Unroasted cocoa nib is more difficult to grind than roasted nib, due to a greater proportion of shell and a higher moisture content. This is related to the plasticising effect of moisture on the cellular material. Grinding energy increases with moisture content. Alkalisation of the nib usually makes it easier to grind (Niediek, 1994).

9.5 Chocolate refining

The particle size of the dispersed phase of chocolate, particularly that of the largest particles, must be sufficiently small so that the chocolate does not feel gritty when eaten. Although traditionally continental European chocolate has been described as having a fineness of 15–22 μm ($6–9 \times 10^{-4}$ in) and that in North America as being 20–30 μm ($8–12 \times 10^{-4}$ in; Jackson, 1994), with the increased globalisation of the industry traditional differences begin to blur and specifications become much more product specific. For example, dark chocolate is generally ground finer than milk chocolate, and chocolate for cookie drops can be coarser than solid eating chocolate, since the texture of the cookie will mask that of the chocolate. However, eating quality is not determined by particle size alone, and many other factors, such as fat content, determine the overall texture (see Chapters 20 and 21). In a comparative study of chocolates from the United States and continental Europe, we found the size of the larger particles (d_{90}; i.e. 90% finer than this size, as measured by laser light scattering, which approximates to a micrometer reading) ranged from 20 to 37 μm. To our surprise, both the finest and the coarsest were from the United States.

Provided the cocoa mass has been properly milled, the primary purpose of chocolate refining is to grind the sugar and, for milk chocolate, the solid milk particles. Crystalline sugars behave as brittle materials under mechanical stress. In studies where sucrose–cocoa butter mixtures have been roll refined, chipping and abrasion contributed significantly to the breakage pattern (Aguilar and Ziegler, 1992). This may not be surprising given the jagged, irregular shape of milled sugar. Whole milk powders (28% fat) roll refined with cocoa butter showed a log-normal breakage pattern, characteristic of brittle fracture when ground below their glass transition temperature (Figure 9.5).

Although spray-dried whole milk powder contains 25–29% fat, this fat is trapped in a matrix of glassy (amorphous) lactose as emulsified droplets (Figure 9.6). Milk protein is similarly distributed, principally as casein micelles. The glassy lactose matrix, like window glass, normally behaves as a brittle material during roll refining. This has been confirmed by Bouzas and Brown (1995). While the fat does not plasticise the lactose matrix, these inclusions, along with trapped air, do reduce the hardness of the particle, making whole milk powder easier to fracture in comparison to crystalline sugar. Therefore, when refined together, the milk powder is broken preferentially. Reducing the size of spray-dried whole milk particles liberates fat in a manner similar to reducing cocoa nib, but the effect this has on flow properties is not as obvious (Bouzas and Brown, 1995).

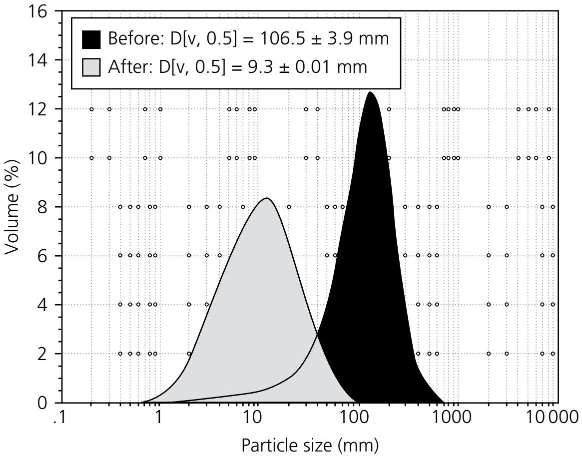


Figure 9.5 Particle size distribution before and after roll refining of spray-dried whole milk powder with an equal amount of cocoa butter.

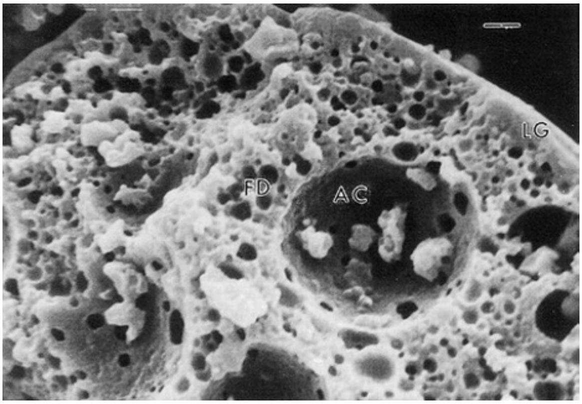


Figure 9.6 Interior surface of a milk powder particle fractured during roll refining. Bar equals 1 μm. AC = Air cell, FD = fat droplet, LG = lactose glass.

As the grinding temperature exceeds the glass transition temperature, either because the roll temperature increases or the glass transition temperature decreases, say because of an increase in moisture content, spray-dried milk particles deform plastically (Figure 9.7a). These highly asymmetric particles (Figure 9.7b) have a deleterious effect on product viscosity and sensory properties.

Spray-dried skim milk powder, or non-fat dry milk (NFDM), behaves somewhat differently. As with whole milk powder, NFDM exhibits brittle fracture below the glass transition temperature, but requires greater force (more energy) to grind since it does not contain the defects introduced by the milk fat droplets. Air vacuoles (Figure 9.8) serve as defects and their volume and distribution will dramatically influence the energy required to grind them. Above T_g, NFDM particles only slightly larger than the gap are distorted as they pass through the roll gap. However, they appear to recover their original shape to a greater extent

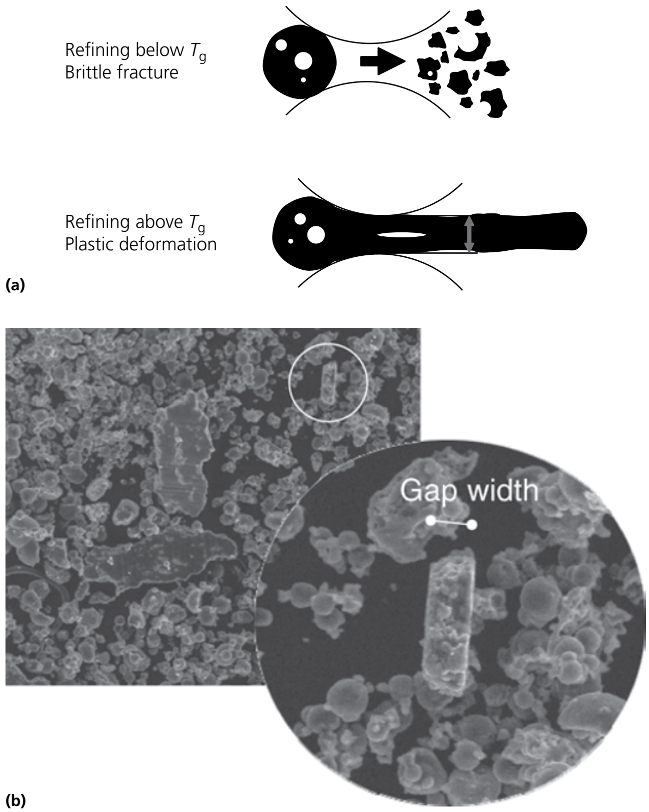


Figure 9.7 (a) Illustration of the effect of the glass transition temperature (T_g) upon the refining process. (b) Electron microscope picture showing asymmetric particles after refining at a temperature above the T_g.

than do particles of whole milk powder, that is they do not show the same degree of permanent plastic deformation that whole milk particles do. However, above T_g, the surface of NFDM becomes sticky and particles agglomerate. The end result is a particle size distribution that may contain agglomerates that are larger than the roll gap.

9.5.1 The five-roll refiner

The fine grinding of chocolate mass is most often carried out using a five-roll refiner. Four grinding rolls, up to 2.5 m (8 ft) in length and 400 mm (16 in) in diameter, aligned vertically form a stack (Figure 9.9). The "feed" roll (R1) is placed at an angle to the lowest stack roll (R2). The feed rate determines the throughput and end fineness of the chocolate, and is adjusted by changing the feed roll gap at a constant roll speed or by changing the roll speed at a constant gap. At a constant gap, faster roll speeds mean greater product throughput and coarser chocolate. At 100–150 μm (0.004–0.006 in), the feed gap does little

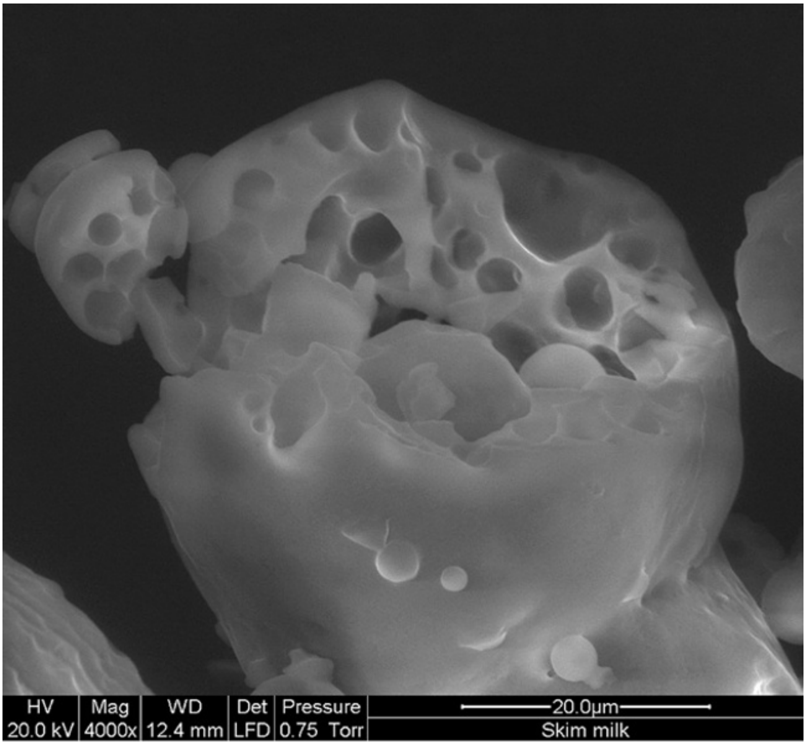
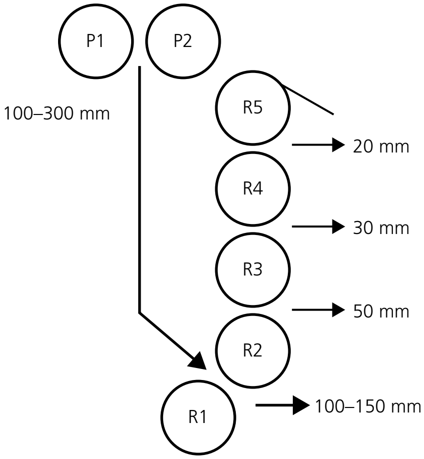


Figure 9.8 Fragment of refined spray-dried skim milk powder.

Figure 9.9 Schematic diagram of a five-roll refiner.



grinding, instead forming an even film of chocolate mass across the length of the rolls. The rotational speed of the rolls gets progressively faster from the bottom (R2) to the top (R5), as the gap gets correspondingly narrower (Table 9.1). The roll refiner is essentially a series of single-pass devices. The film of product

Table 9.1 Example of operating conditions for a five-roll refiner (Peter, 1994).

Roll	RPM	Temperature[1]	
		°C	°F
R1	<58	35–40	95–104
R2	58	35–40	95–104
R3	155	42–48	108–118
R4	268	50–60	122–140
R5	380	35–40	95–104

[1] Recommended for low-fat mixes; subtract 5–10 C (9–18 °F) for high-fat mixes.

exiting each gap is transferred to the faster roll, moving upwards, until it is scraped off the final roll by a stationary knife. Hydraulic pressure is applied to the roll stack to compress the camber (uncompressed, the rolls are barrel shaped) and obtain an even coating across the roll length. Loeser (see Chapter 24) has proposed roll refiner control based on machine vision to monitor roll coverage. Counter-pressure built up by the product ensures a stable roll gap, but alterations in pressure do little to affect the size reduction.

Size reduction occurs as a combined result of compression and shear. The *degree of reduction* in a five-roll refiner is generally 5–10, resulting in a final product with a maximum particle size of in the range 15–35 μm (6–14 × 10^{-4} in). The relationship between final maximum particle size and specific flow rate (kg h^{-1} m^{-1}) is linear (Fritzsche, 1994), with the theoretical fineness being defined by Equation 9.1,

$$S_o = 2\dot{m}/\rho\left(v_i + v_{i+1}\right)b \qquad (9.2)$$

where S_o = theoretical maximum particle size equivalent to the film thickness or gap, $\dot{m}$ = mass flow rate, ρ = chocolate density (approximately 1.2 kg m^{-3}), v = speed of circumference for rolls i and i+1, and b = roll length. This equation has been used to predict actual particle size measured by micrometer with a relatively high degree of accuracy (Fritzsche, 1994), and can be rearranged and used to estimate throughput at a given particle size.

Temperature has a significant effect on the rheology of the chocolate film and thus influences the refining process. Temperature is maintained by circulating water in the interior of each roll. The relative size of the cooling zone (one-half the circumference of the roll) compared to the gap width (a few microns) allows for effective temperature control. The properties of the material being broken may change substantially with temperature and thereby alter the milling process.

The proper consistency for transfer of product from roll to roll is maintained by the appropriate fat content. It is normally advantageous to roll refine chocolate at the lowest fat content possible – in the range of 24–27%. It is said that one-half of all the fat conserved at the refining step is saved during conching (Kuster, 1991), that is if you reduce the fat at refining by 1%, you only need to put 0.5% into the mass at the end of conching to obtain the same viscosity. Bolenz and Manske (2013) demonstrated the influence of fat content on the particle size distribution and flow properties of milk chocolate refined in either a roll refiner or ball mill. As stated earlier, a material's tendency to agglomerate rises with smaller particle size and moisture content. Refining a very low-fat mixture, especially under humid conditions, can result in particle agglomerates exiting the roll refiner.

The recent trend toward high cocoa content chocolates presents a challenge to traditional roll refining, since for example a recipe containing 70% cocoa mass would contain about 38–39% fat, too much for efficient roll refining. Two alternatives are available: use of a stirred-media (ball) mill or roll refining only a portion of the cocoa mass with the remaining portion added during conching, preferably after a period of dry conching. Ziegleder (2006) has demonstrated that, for the first of these alternatives, ball milling, it is advisable to withhold some of the added cocoa butter, if any, until later in the milling process.

For accurate particle size control it is necessary to produce consistent and uniform feed material, which can be produced by intense mixing prior to refining, or perhaps even better by the two-stage refining process. The two-stage refining system employs a two-roll pre-refiner to size the feed material for efficient five-roll operation. Separate sugar pulverisation (as was previously needed with a single-stage refining process) can be eliminated with two-stage refining, allowing for use of granulated sugar in the chocolate formulation. This improves mixing and permits refining at lower fat content. Ideally, the particle size exiting the pre-refiner should be slightly smaller than the feed gap of the five-roll machine and, in practice, no more than 20% greater than the first five-roll gap (Kuster, 1991). Among the potential benefits of two-stage refining are a 10–25% increase in the throughput capacity of the five-roll machine and savings in cocoa butter needed to standardise the flow properties. The latter results from a reduction in the proportion of very fine particles.

At least one roll refiner manufacturer has automated the milling process by incorporating online measurement of film thickness at the final roll (R5). The deviation of the measured value from a set point value is used to control the mass throughput by changing the gap setting at R2, as previously described. In addition, automated feed level control and dry running protection are also available (rolls become damaged very quickly if there is no material between them).

Refiner roll wear depends on the correct adjustment of the hydraulic roll stack pressure and the product recipe. The major contributors to roll wear are shell and silicates (sand) present in the cocoa mass, so efficient cleaning and winnowing of cocoa beans are very important. In general, the greater the cocoa mass content of the chocolate, the lower the anticipated service life of the rolls.

Wear increases substantially with the silicate content of the cocoa mass, the final degree of fineness of the chocolate and the contaminating shell content. The same could be expected to hold true for other chocolate refining devices.

9.5.2 Crumb chocolate

Refining of chocolate crumb is easier, that is it requires less power and results in less wear, provided that the crystallisation of sugars during the crumb-making process is adequately controlled, since only loose agglomerates of sugar, milk solids and cocoa solids are being broken. If the agglomerates are less than about 125 μm (0.005 in) then single-stage refining may be appropriate, otherwise two-stage refining may be necessary. Because fewer primary sugar crystals are being fractured, fewer fines (<5 μm) are present and particles are less jagged in refined crumb chocolate as compared with the milk powder process.

9.5.3 Sugar substitutes

Here we are principally talking about the growing number of alternatives to sucrose. Bouzas and Brown (1995) and Chapter 4 have reviewed the physical and chemical characteristics of sugars and sugar substitutes in relation to their usefulness in chocolate, so we will restrict our discussion to the grinding of these materials. Fructose is particularly difficult to grind due to its hygroscopic nature (Niediek, 1994). Sugars that form crystal hydrates, for example glucose (dextrose) and maltose, may lose their water of hydration during roll refining, causing complications downstream (Hogenbirk, 1985). Anhydrous forms of glucose and maltose can be ground without difficulty, as can anhydrous or crystalline lactose monohydrate. Sucrose-free chocolates containing lactitol monohydrate must be roll refined at temperatures below 60 °C (140 °F), while those containing anhydrous lactitol or maltitol can be refined under standard conditions (Olinger, 1994). Isomalt-, mannitol-, sorbitol- and xylitol-sweetened chocolates should probably be refined at relatively low temperatures (<40 °C; <104 °F) and under dryer processing room conditions than sucrose-sweetened chocolates. Bulking agents like amorphous polydextrose can be roll refined, exhibiting brittle fracture below their glass transition temperature, but the fibrous structure of microcrystalline cellulose makes it difficult to grind.

9.5.4 The refiner-conche

The refiner-conche consists of a drum with a serrated internal surface. Particles are broken as they are forced between spring-loaded scrapers and the interior drum surface (see Figure 10.27 in Chapter 10). Initially, this type of machine reduces particle size rapidly but, as the mass becomes liquid, the few remaining large particles have a lower probability of being caught in the grinding gap and so the resultant particle size distributions are wide (Beckett, 1994). This can be improved by combining these systems with either a ball mill or roll refiner. Higher fat content during grinding is necessary since ball mills require a liquid feed.

Ball mills and refiner-conches are both good mixers relative to roll refiners and, since both employ wet grinding, agglomeration may be lower, leading to potentially shorter conching times. Small-scale processors who wish to manufacturer their own chocolate or producers of high fat, chocolate-flavoured coatings may find so-called "universal" systems an acceptable alternative.

9.5.5 Refining in the presence of water

In their United States patents, Martin and Stumpf (1992) and St. John *et al.* (1995) describe a process for producing chocolate containing 20.0–24.5% fat, comprising the steps of mixing a small amount of water (1–3%) into a sugar–fat mixture, refining the mixture and then evaporating the moisture using heat and agitation. This sugar–fat mixture is then combined with cocoa mass, milk solids and additional fat and lecithin to produce the finished product. It is claimed that the moisture added is sufficient to dissolve the very fine sugar crystals (<5 μm). Upon evaporation this dissolved sugar recrystallises onto larger crystals, resulting in a chocolate or chocolate-like material with improved rheology, that is lower viscosity, and in particular a much lower yield value. It is further claimed that a chocolate of less than 25% fat with flow properties suitable for moulding, extruding or enrobing can be produced.

9.5.6 Milling cocoa powder

Cocoa press cake is first of all coarsely milled, generally in some sort of crusher, to cocoa kibble. These kibble particles are ductile and have the added problem of containing fat that can melt when heated. Furthermore, they are aggregates of smaller particles; cake pulverisers do not further reduce primary particle size, but break up particle agglomerates. Impact milling at low temperatures (5–10 °C; 42–50 °F) is appropriate for cocoa powder production. For grinding 10–12% fat cocoa powder, the air flowing through the mill is usually sufficient to cool it, whereas cryogenic grinding has been used for high fat content cocoa powders.

9.6 Particle size reduction and chocolate flow properties

As stated in the introduction, while the outcome of a grinding process is a particle size distribution, it is important to know the relationship between this distribution and finished product quality. For chocolate products, particle size distribution affects flow properties and sensory perception. The flow behaviour of molten chocolate is important in moulding and enrobing, for proper cookie drop formation and in the design of bulk handling systems. Size reduction operations influence product quality and cost through their impact on chocolate flow properties. It is often desirable for chocolate to have as low a viscosity as possible with a minimum addition of its most expensive ingredient – cocoa butter. Chocolate flow properties are discussed in detail in Chapter 11; and Bouzas and Brown (1995) have published an excellent review of the literature on the effect of structure, including particle size, on chocolate rheology. In order to avoid duplication this chapter will focus on the influence of particle size distribution on flow properties of chocolate as described by the Casson parameters. As the preceding section has shown, there has been considerable attention given to reducing the proportion of fine particles in an effort to control chocolate rheology.

Conventional wisdom assumes that the presence of small particles is detrimental to "flow properties", since smaller particles have a greater surface area that must be coated by fat. However, this is somewhat oversimplified. Typical flow curves for chocolate can be divided into three or four shear rate or, better, shear stress regimes (Windhab, 1995, 1997). At shear stresses near the yield value, particle–particle interactions – friction and adhesion – or "network" effects dominate. The close-packed particles behave like a pile of powder, and particle surface area and surface properties (e.g. roughness) become extremely important. Particle shape is also important in this low stress regime, and rounding of particles due to selective dissolution of protrusions and jagged edges may be as important as reduction of fine particles in the aforementioned patents (see Section 9.5.5). Once flow has been initiated, above shear rates of about 1 s^{-1}, hydrodynamic effects become significant and particle packed volume relevant. Although the Casson model has its limitations, it none the less gives a useful insight into the behaviour of chocolate in the first two stress regimes.

Several studies have been conducted at the Pennsylvania State University to understand the relative influence of particle surface area and packing ability (as affected by particle size distribution) on the Casson parameters for molten chocolate. In general, it is known that the viscosity of a particulate suspension like chocolate decreases as particle size increases, particles become more spherical, the particle size distribution broadens and the solids loading is reduced (fat content increased). The competing effects of particle surface area and packing density on the Casson yield value and plastic viscosity were therefore evaluated for four sweet dark chocolates with distinct particle size distributions, but the same mean diameter (with respect to their volume distribution; mean diameter = 20.1 ± 0.5 μm; Fischer, 1994). The volume histograms for these distributions are presented in Figure 9.10. A bimodal distribution resulted in a much lower Casson plastic viscosity (Figure 9.11a) but higher yield value (Figure 9.11b) when compared with unimodal distributions at the same volume mean diameter. The effect was greater at lower fat contents; little difference in plastic viscosity was observed above 34% fat, while differences in yield value persisted to 45% fat. Figure 9.12 shows the influence particle size distribution had on the apparent viscosity as a function of shear rate. One consequence is that, where polyglycerol polyricinoleate (PGPR) is permitted, it can be used to reduce the yield value and particle size distribution can be manipulated to improve flow at higher shear rates.

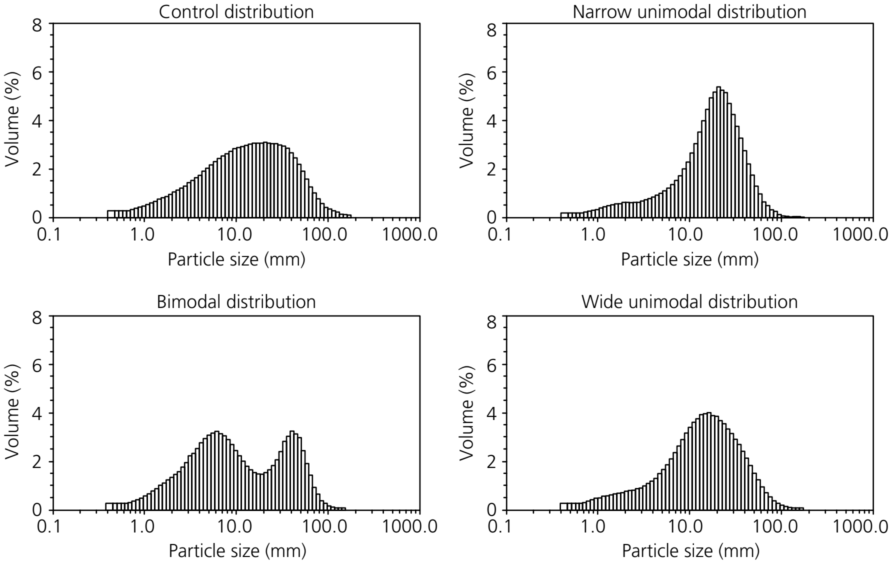


Figure 9.10 Volume histograms of four different dark chocolate samples. The specific surface areas as recorded by the Malvern Instrument were: "Control" = 1.1696 $m^2\ g^{-1}$, "Bimodal" = 1.2676 $m^2\ g^{-1}$, "Narrow" = 0.9342 $m^2\ g^{-1}$ and "Wide" = 1.0512 $m^2\ g^{-1}$.

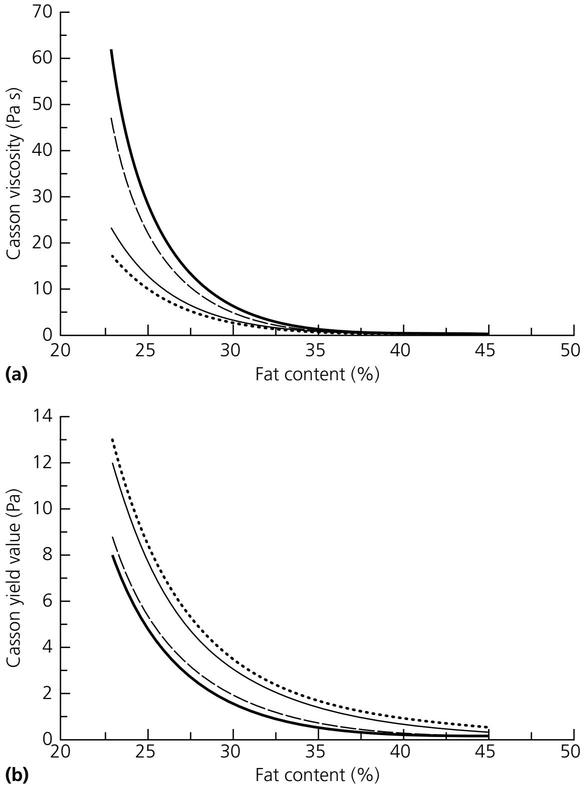


Figure 9.11 (a) The effect of the particle size distribution and the fat content of dark chocolates upon the Casson plastic viscosity. (b) The effect of the particle size distribution (psd) and the fat content of dark chocolates upon the Casson yield value. (——) Narrow psd, (---) wide psd,; (━━) control psd, (···) bimodal psd.

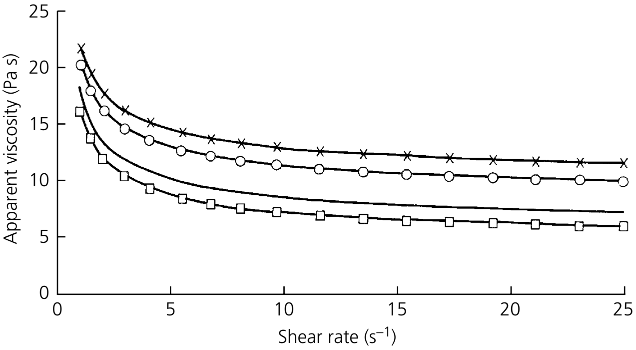


Figure 9.12 The effect of particle size distribution upon the apparent viscosity of a 28% fat dark chocolate. (×) Narrow psd, (○) wide psd, (——) control psd, (□) bimodal psd.

Fat fills the spaces or voids between the solid particles in molten chocolate and reduces the resistance to flow. The void volume in a packed bed of solids depends on the particle shape, size distribution (especially number of distinct sizes) and packing arrangement of the particles. The packing efficiency is defined as the ratio of the actual volume of solids to the volume occupied by the bed of solids (which includes the interparticle spaces). For a given distribution of particles, the packing efficiency can be improved by adding solid particles of sizes corresponding to the size of the voids in a packed bed. Filling these voids with smaller solid particles allows for a higher amount of solids to be present per unit volume and reduces the amount of space to be filled by the fat. The extent of reduction in the void volume depends on the ratio of the sizes, number of distinct sizes and the volume fractions of small and large components (McGeary, 1961; Sudduth, 1993a–c). However, the addition of smaller particles increases surface–surface contacts.

Figure 9.13 illustrates the relationship between particle packing (bulk density) and the apparent viscosity for milk chocolates of equivalent composition, but different particle size distribution. As anticipated from theoretical treatments, apparent viscosity decreases exponentially with increasing solids bed density. Again, this effect would be exaggerated at lower fat content. Particle packing becomes important once flow has been initiated and therefore affects the plastic viscosity component of the flow behaviour. Yield value is affected largely by interparticle contacts and consequently shows a linear dependence on the mean particle size, or more accurately, on the specific surface area (Mongia, 1997; Mongia and Ziegler, 2000).

Although we obtained these distributions through a combination of separate grinding and classification, they may be easily manufactured using conventional equipment like roll refiners. For example, a bimodal distribution containing a ratio of coarse fraction to fine fraction of 2:1 can be obtained by feeding a single conche from three refiners, two set coarse and one fine. The overall throughput of the system is not much different than if all were set to an intermediate size.

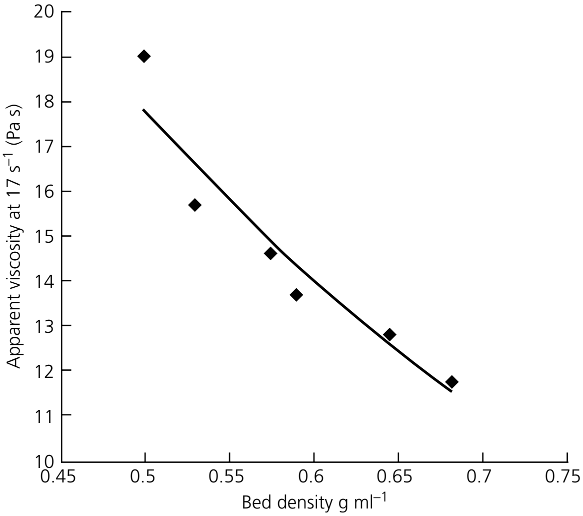


Figure 9.13 The apparent viscosity of a milk chocolate at a shear rate of 17 s^{-1} as a function of solids bed density.

Alternatively, batches of coarse and fine chocolate could be mixed, in theory even after conching. Bolenz *et al.* (2014) demonstrated the practical application of this technique.

9.7 Particle size and sensory properties

Particle size influences not only the sensory perception of coarseness, but also melt, flavour, colour and gloss. According to Niediek (1994), there was no published systematic research on the effect of particle fineness on the flavour of chocolate mass. A study of the effects of particle size on the flavour of milk chocolate has, however, been carried out using time-intensity methods and a trained sensory panel (Mongia, 1997; Ziegler *et al.,* 2001), and in a series of papers Afoakwa and co-workers have investigated the influence of particle size distribution on the rheological and textural qualities of chocolate.

Chocolate exhibits the unique property of melting from the solid state at room temperature to form a smooth dense suspension in the mouth at body temperature. The liquefaction of chocolate in the mouth is defined by the melting characteristics of the fat and facilitates the perception of taste and flavour attributes. The intensity of perceived taste and flavour changes dynamically over time as the chocolate is melted, manipulated and mixed with saliva. Time–intensity methods result in dynamic measurements of changes in sensory perception in the form of time–intensity curves, from which can be extracted attributes like maximum intensity, time to reach maximum intensity and duration of the stimulus.

Sweetness, chocolate flavour and the *effort* required to melt, manipulate and swallow chocolate samples varying in particle size distribution and flow properties were measured using time–intensity procedures. *Thickness* and *coarseness* were measured using traditional descriptive analysis procedures (Mongia, 1997). The mean diameter of the volume distribution (as measured by laser light scattering) ranged from 8.50 to 16.95 μm (0.3–0.6 × 10^{-4} in). This was achieved by varying the size of the sugar only; cocoa solids and non-fat milk solids were of consistent size in all samples. As the average particle size got finer and yield value increased, the time to maximum, intensity of maximum and duration of *effort* required to melt, manipulate and swallow the sample all increased, that is the finer chocolates had a greater residence time in the mouth. While the chocolates all had the same amount and size of cocoa solids, and therefore the *intensity* of chocolate flavour did not differ, the *duration* of chocolate flavour was influenced by the average particle size, with the *chocolate* flavour of finer samples persisting longer than that of coarser samples. This is directly related to the residence time of the sample in the mouth.

Kuster (1980) reported that cocoa mass is sensed organoleptically earlier than sugar or milk powder, and presumed that with lower surface values (greater particle size), the sweetness of the sugar could be diminished. We originally hypothesised that the finer the chocolate, the sweeter the taste, since small crystals dissolve more rapidly that do larger ones. However, the maximum intensity for *sweetness* was greater for coarser samples. As with the *chocolate* flavour, the *sweetness* persisted longer in finer samples. Increasing viscosity is known to reduce the perception of sweetness in solutions and gel products, but not the perception of chocolate flavour in desserts (Pangborn and Kayasako, 1981).

Thickness scores were highly correlated to the Casson yield value ($r = 0.97$) and to the mean diameter over the volume distribution ($r = -0.99$). As expected, the chocolates became lighter (tristimulus L value increased from 34 to 41) as the particle size became smaller. Multivariate regression analysis led us to conclude that yield value and mean particle size are more significant contributors to the sensory perception of chocolate products than, for example, plastic viscosity or the shape of the particle size distribution.

Conclusions

It has long been known that particle size reduction is critical to obtaining desirable liquid chocolate flow properties. However, as has been shown, the affects of particle size are much farther reaching and include influencing the taste and texture of the final product. Developments in engineering design and process control now enable chocolate manufacturers to manipulate the particle size and size distribution, should they wish to do so. However, it must also be remembered that size reduction is only one part of chocolate processing and that the actual grinding equipment used must always take into account the ingredients being processed and downstream operations. The influence of particle size distribution on the flavour of chocolate suggests that deagglomeration occurring during conching may be as important to flavour development as it is to viscosity reduction.

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CHAPTER 10

Conching

Stephen T. Beckett, Konstantinos Paggios and Ian Roberts

10.1 Introduction: the reason for conching

10.1.1 Flavour development

The flavour of a piece chocolate depends upon a series of processes being carried out correctly. Conching is the final one of these and is the last opportunity for a manufacturer to obtain the taste required for a particular product. It cannot, however, correct previous errors, for example off-flavours from smoke or mould due to poor drying of beans, nor can it make an inferior cocoa taste like a perfect one.

This leaves us to look at what a conche actually does. Cocoa mass, even when the beans have been fermented, dried and roasted correctly, has a very acidic flavour which most people find objectionable. It is the function of conching to remove the more distasteful of these flavours and yet retain the more desirable ones. It is possible to "over conche" and produce a very bland product. The actual required flavour, and hence the conching time, will depend upon the initial cocoa flavour intensity and the product in which it is being used. In order to shorten conching times, the cocoa mass may be pre-treated to remove some of the acidic components (see Section 10.4.10), which leaves the conching process essentially to one of liquefying the material from the previous milling procedure. Alternatively, if the chocolate is being used in a product containing a strong flavour, such as peppermint, it may be necessary to retain some of the acidic notes so that the chocolate flavour is not completely overwhelmed.

The actual physico-chemical changes which take place, as described in Chapter 8, are very complicated and not fully understood. However, the objective of conching is essentially the removal of undesirable flavours, the transter of flavour components between the ingredients and in certain circumstances the development of more desirable ones to match the final product. The former is particularly important for dark chocolate and is largely dependent upon conche ventilation and conching time. The development of flavour in milk chocolate, will also depend upon the ingredients being used. Those manufactured from

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Mark S. Fowler and Gregory R. Ziegler.

milk powder may be heated to obtain a more cooked flavour, whereas those starting from crumb (see Chapter 6) already contain a cooked note, although this can be strengthened during conching. This type of flavour development is largely related to conching temperature.

10.1.2 Flow property optimisation

In the majority of chocolate manufacturing plants, the conche is preceded by a roll refiner or a hammer mill. These grind the chocolate mass to produce a crumbly paste or powder. It is the function of the conche to treat this and turn it into a flowable liquid, which can be poured into a mould or over the product centre.

Fat (both cocoa and cow's butter) makes up less than one-third of the weight of the chocolate in a majority of recipes. It is this fat that melts when warm and enables the chocolate to flow into moulds or through an enrober and to have a smooth texture in the mouth. The ground chocolate mass, although containing the majority of this fat, cannot flow as most of the surfaces of the sugar (and non-fat milk solids, when present) are freshly broken and uncoated by fat. The conching process is required to smear the fat over these surfaces, so that the particles can flow past one another. In addition some of the particles form loosely connected agglomerates, perhaps due to the presence of moisture or amorphous sugar on the sugar surface (Niediek, 1970). These too must be broken up by the mixing action of the conche. Some of these agglomerates contain droplets of fat, which must be freed from the surrounding particles and smeared thinly over their surface.

10.2 The principles of conching

10.2.1 Removal of volatiles and temperature control

As explained in Section 10.1.1, it is necessary to remove some of the undesirable acidic flavours from the cocoa during conching. It has been shown (Dimick *et al.*, 1999) that the boiling point of many of these components is very much higher than the temperature of the conche, so what is actually happening is very hard to fully explain.

Another volatile that it is necessary to reduce during conching is moisture. Water has a severe thickening effect upon chocolate and, very approximately, for every 0.3% of moisture left in the mass (above a level of 1%) a further 1% of fat must be added to compensate for it in viscosity terms. Therefore although water may at first sight appear as a "free" ingredient, in actual practice, because of the relatively high cost of fat, its removal is frequently economically very worthwhile. Much of the moisture, below the 1% level, however, is bound into the ingredients for example as water of crystallisation in lactose and so is much less likely to affect the flow properties.

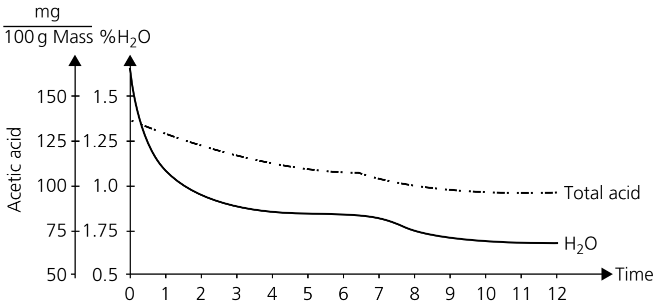

Figure 10.1 Graph showing the changes in moisture and acidity during a conche cycle (time in hours).

Figure 10.1 shows the changes in moisture and total acid during a 12 h conching cycle. As can be seen, the majority of the moisture is removed very early on in the conching cycle. This is because much of the moisture comes from the milk components, and once these have been coated with fat, it is much harder for the water molecules to reach the surface of the mass and be extracted from the conche. It is very likely that this moisture removal also has a major effect upon the chocolate taste by "steam distilling" some of the flavour components. The acidic components however, continue to decrease throughout the conching time and it is possible to over-conche and produce too bland a chocolate.

Adequate ventilation is of paramount importance during conching to enable the moisture and other volatiles to escape. Conche filling is a very dusty and dirty operation and may partially block some of the ventilation ports on a conche. Not only is this a hygiene hazard, but it can also reduce the conche's efficiency and may lead to increased conching times. Forced ventilation, using fans to blow or suck air through conches can effectively shorten conching times, when the ventilation area is small relative to the amount of chocolate inside the conche.

The rate of moisture removal will depend upon the temperature of the chocolate mass. A higher temperature not only makes the water molecules in the mass more mobile, but also lowers the relative humidity in the conche for a given air moisture content, thus in turn speeding up the rate of evaporation. It would appear, therefore, that a high initial temperature would be beneficial to the conching process. This is not the case, however, as this frequently leads to a very high level of free moisture in the conche, which is unable to escape into the room atmosphere. This is instead absorbed by the hydrophilic (water attracting) sugar particles, which then stick together to form large agglomerates (grit). This means that, even when a chocolate has been correctly refined/milled, the chocolate tastes rough to the pallet. This is especially likely to happen when the air in the conche room itself is very humid or when there are cold, unheated metal parts near the top of the conche, on which the moisture can condense and then fall back into it. Gritty chocolate can best be avoided by having the mass temperature high enough to melt the fat, but not so high as to rapidly evaporate the water at the beginning of the conching cycle. This should be coupled with a high ventilation rate, forced by fans if necessary. The temperature should then be raised once the majority of the moisture has been removed (see Figure 10.1).

The actual maximum temperature used depends upon the ingredients used and the type of taste required for the final product (Chapter 20). If cooked (Maillard) flavours are desired, temperatures above 100 °C (212 °F) may be used. The actual flavour depends upon a combination of time and temperature, that is a higher temperature can be used for a shorter time and vice versa. Crumb chocolates frequently contain some of these flavours from their drying process, so may require shorter conching times. For the more milky chocolates, Maillard flavours must be avoided, and the temperature must be kept lower, usually below 50 °C (122 °F). Some sucrose-free recipes containing sugar alcohols require lower temperatures still, to avoid melting and agglomeration of the particles (Chapter 4).

10.2.2 Fat and emulsifier additions

As mentioned previously, one of the main aims of conching is to produce the optimum viscosity for the subsequent processing. The actual viscosity can be reduced by adding more fat (Chapter 11), but as the price of the fat is frequently several times that of the other ingredients in the chocolate, this in turn increases the cost of the product. The aim, therefore, becomes one of obtaining the optimum viscosity at the lowest practical/legal fat content. It thus becomes necessary not only to remove the excess water content, but also to ensure that the fats and emulsifiers used have their maximum effect upon the flow properties.

The most commonly used emulsifier is lecithin (Chapter 11), which is hydrophilic (that is it can attract and hold in moisture). Figure 10.1 shows that the majority of moisture evaporates from the chocolate mass during the early part of conching. If a large amount of lecithin is present at this stage it will hold in the moisture and make the chocolate thicker. Similarly excess fat, present in the early stages of conching, will coat the solid particles, making the removal of moisture significantly more difficult.

The actual amount of fat present at the beginning of conching is to a certain extent determined by the previous milling procedure. If the dry milling method is used (Chapter 9), very little fat is present. When a five roll refiner is used, however, enough fat must be in the mass to prevent the particles being thrown from the rolls and consequently the majority of the fat is already present. In both cases, however, fat is normally added at the beginning of conching. As a general rule, this should be kept to a minimum, but must obviously be sufficient to make the mass thin enough not to stall the conche motor. Fat and emulsifiers added towards the end of conching normally have a much bigger effect on the final viscosity than that added at the beginning. The combination of a two roll and five roll refiner system is frequently able to produce a thinner chocolate than a single five roll system, because the mass being refined has a lower fat content and so more fat can be added later in the process.

The emulsifier used, whether it is lecithin, YN or polyglycerol polyricinoleate (PGPR, see Chapter 11) should also be added towards the end of the conching process. Some authors (Ley, 1994) believe that high temperatures are detrimental to the effectiveness of lecithin and that, when conching at high temperatures, additions should only be made when the chocolate has been cooled. Lecithin is also very effective in reducing chocolate viscosity, being approximately ten times as efficient as cocoa butter. Consequently, additions of it into the conche have to be made very accurately. This is often helped by adding it as a mixture with cocoa butter, so that small weighing errors have less effect. Recently, however, metering pumps have become more accurate and suppliers have produced lecithin in a more liquid form, facilitating direct pumping into the conche.

Not only must the fat and emulsifiers be present in the chocolate, they must also coat the sugar and other solid particles uniformly. The efficiency of this coating action depends upon the mixing action of the conche.

10.2.3 Degree of mixing

In order to coat the particles with fat, the conche must move the particles relative to one another within the liquid fat. There are two different types of mixing (Windhab, 1995; see Figure 10.2):

1. Shear mixing, where the chocolate is between two surfaces moving relatively to one another;
2. Elongational mixing, in which the material is squeezed through or spread over a surface.

Failure to mix the chocolate satisfactorily may not only result in a chocolate which is relatively thick for its fat content, but can also produce an unstable viscosity. This can be the cause of chocolate thickening in storage tanks and giving viscosity readings which change as the chocolate is sheared by the viscometer during the measuring cycle.

10.2.3.1 Shear mixing

In conching this takes place between a moving rotor and the outside walls of the machine. The intensity of the mixing can be quantified by a factor known as the shear rate. In Figure 10.2a, the two surfaces are moving at a relative velocity of $v_1 + v_2$ and they are separated by a distance h. The shear rate is then defined by:

$$\text{shear rate} = (v_1 + v_2)/h \tag{10.1}$$

This rate is in the units 1/time and is normally expressed in s^{-1}.

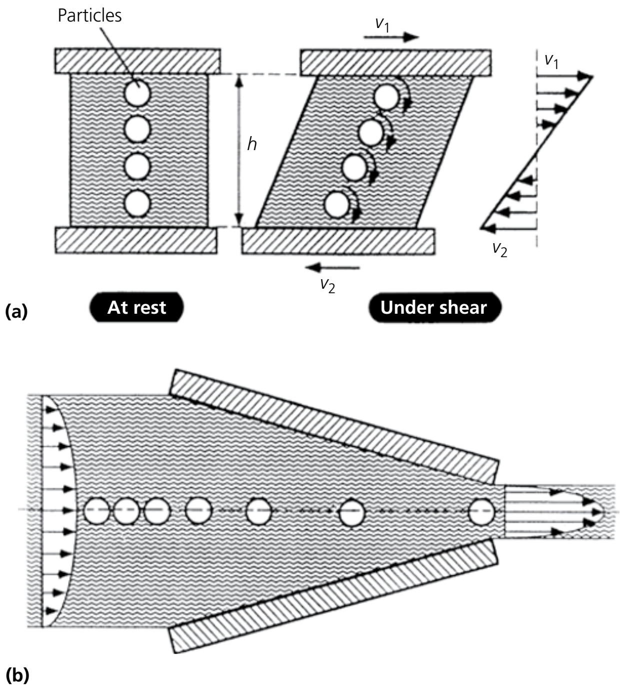

Figure 10.2 Representations of (a) simple shear and (b) elongational flow.

If a chocolate is mixed at a slow shear rate for a long time, the viscosity will come to an equilibrium level and remain there, so any further conching is not worthwhile, other than to bring about flavour changes. If the shear rate is increased this equilibrium viscosity is at a lower value and tends to be reached more quickly (Figure 10.3). Even higher shear rates may produce even thinner chocolate.

What this means for conche design is that higher shear rates, that is more work input into the chocolate produces thinner chocolates. This can be achieved by making the arms of the conche rotate faster or by decreasing the gap between the rotor blades and the conche wall. The former is obviously limited by the size of the motor, especially in the early stages of conching. The latter is limited by engineering precision and the need for a significant amount of the chocolate to be between the rotor and wall. The actual amount of chocolate being sheared by the rotors at any one time will, to a large extent, determine the conching time. Thus a narrow gap will produce a thin chocolate but will increase the time required to do so. There is also little point in having a very large conche when only a very small proportion of the chocolate mass is being sheared at any one time. The ratio of the mass of material being conched to the surface area being sheared is therefore important.

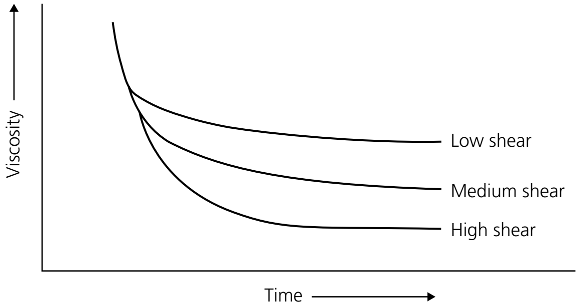

Figure 10.3 Illustration of the change of viscosity with time for conches with different energy inputs.

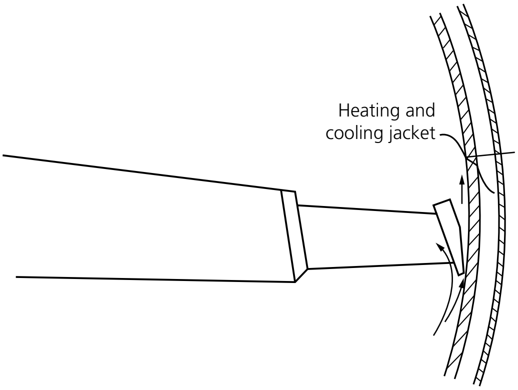

Figure 10.4 The chocolate mass being sheared by rotor arm wedge element against the conche wall.

Another property of high shearing systems is that they produce a lot of frictional heat within the material being mixed. This means that the temperature control system on high shearing conches becomes more critical, especially if a low temperature conching is needed for flavour reasons. In this case the ratio of the mass of the chocolate to the area of the conche wall being covered by it once again is important.

10.2.3.2 Elongational shearing

This action, which is a bit like buttering bread, is also important in that the particles are treated in a different way to that during the simple shearing (Figure 10.2). Some conches are designed to produce this type of shearing during the early part of conching in that they have wedge-shaped ends to their rotors (see Figure 10.4). At the beginning of conching the wedge cuts into the powdery material and smears it along the wall. Once the chocolate has become liquid the rotor is reversed, thus producing a higher shearing action within the mass. Other conches use extruder-type screw elements to smear the chocolate across the conche base.

10.3 The three phases of conching

Traditionally, conching is said to take place in three stages or phases, although not all occur for every recipe and all types of conche. The three phases are:
Dry phase: chocolate mass is crumbly, moisture is removed.
Pasty phase: chocolate is a thick paste, high work input required by the conche.
Liquid phase; high speed stirring to mix in the final fat and emulsifier additions.

The power and temperature curves of a traditional conching cycle are shown in Figure 10.5, together with the approximate times of the three phases.

10.3.1 Dry phase conching

The feed material normally enters the conche as a powdery material. Frequently a small amount of fat (approximately 1%) is placed in the conche at the beginning of filling. This together with the mixing action and rising temperature soon turn it into a crumbly mass.

At this stage it is relatively easy for moisture to escape provided that the conche is well ventilated. The initial moisture content of many milk chocolates is about 1.6% and if possible this must be lowered to less than 1%. Some authors (Ley, 1994) suggest that the viscosity continues to reduce even to a moisture content of 0.6%. Below about 0.8%, however, the moisture becomes very much harder to remove, and it may not be economically viable to do so.

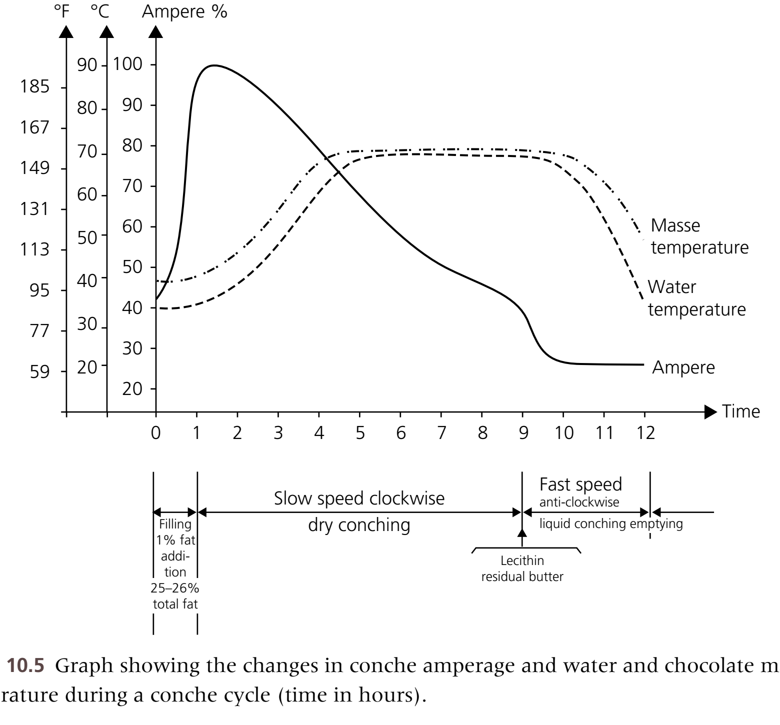

Figure 10.5 Graph showing the changes in conche amperage and water and chocolate mass temperature during a conche cycle (time in hours).

As mentioned earlier, this moisture takes with it many of the unwanted flavour compounds. For dark chocolate, however, the initial moisture may already be below 1% and care must be taken to avoid the chocolate picking up moisture and becoming thicker. It is undesirable to conche dark and milk chocolate in the same room in open conches, as the transfer of moisture and flavour volatiles between the two can give rise to unpleasant flavours and thicker dark chocolate. The temperature must, of course, be increased slowly to enable the moisture to escape and minimise the risk of the formation of agglomerates.

As can be seen in Figure 10.5, as the filling progresses the electrical current drawn by the conche increases and continues to do so throughout the subsequent dry conching phase. This is because the crumbly chocolate is becoming more pasty. This often starts with the formation of small balls 1–4 cm (0.5–2.0 in) in diameter on top of the mass. Sometimes large lumps attach themselves to the mixing elements as the mass becomes pastier and, in exceptional circumstances, the whole mass can turn with the elements, resulting in no mixing taking place. This can be off-set by changes to the temperature and/or fat content.

With certain conches the motors are not sufficiently strong to continue operating as the power increases and fat and emulsifier additions are required very early on in the conching cycle in order to turn the chocolate mass into a thin paste or liquid. In this case there is little or no dry conching. Normally, however, this results in a relatively high viscosity chocolate at the end of processing.

10.3.2 Pasty phase conching

The energy put into the chocolate by the mixing action towards the end of the dry conching and at the beginning of the pasty phase is often so high that the temperature rises rapidly. The water jacket temperature, therefore, has to be several degrees lower than the chocolate, in order to maintain a steady increase to the required conching temperature. The latter has a large effect on the final chocolate flavour and so must be controlled carefully in order to manufacture a reproducible product. This is particularly critical during the pasty phase, when thermostatic water jacket controls capable of reacting to sudden temperature changes should be used.

Once the chocolate has become pasty, the viscosity starts to fall, in part due to continued moisture removal and also because many of the solid particles are now being coated with fat. The actual final viscosity, however, is partly dependent upon the amount of shear/work that can be put into the chocolate (see Section 10.2). In traditional conching (see Figure 10.6), this shear energy input (as denoted by the conche amperage) falls steeply as the chocolate becomes thinner. This can only be off-set by increasing the shear rate through an increase of the speed of the mixing elements or by changing the elements themselves. Figure 10.7 shows the power curves of a conche that has been fitted with a servo-mechanism which changes the speed as the viscosity changes to give a uniform power input.

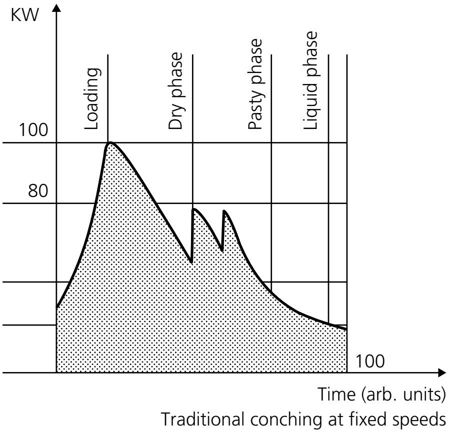

Figure 10.6 A graph illustrating typical conche power amperage during the three stages of conching (conche with two speeds and reverse direction operation).

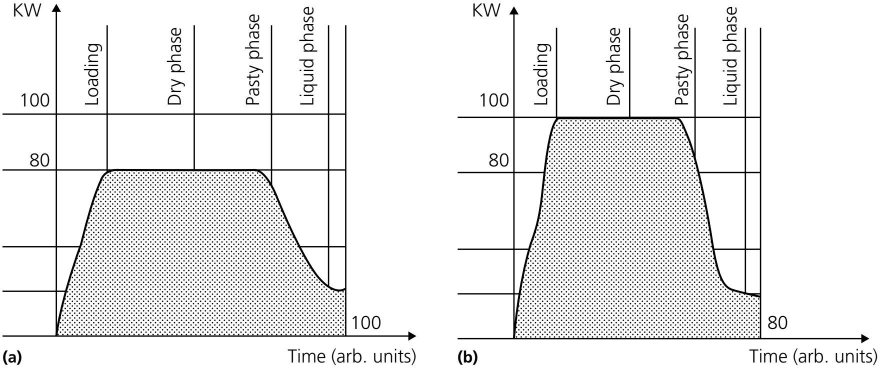

Figure 10.7 A graph illustrating the conche power amperage during the three stages of conching, when the motor speed is continuously adjusted according to the chocolate viscosity. (a) Lower power motor. (b) Higher power motor.

In order to develop a cooked flavour within a chocolate it is necessary to reach a certain temperature for a given time. Within limits it is possible to raise the temperature and shorten the time and vice versa. The same is true for conche power input, and if the power is increased, shorter conching times are possible (Figure 10.7). Once the final additions of fat and emulsifier have been made, however, the chocolate becomes very thin and it is very difficult to put a significant amount of shearing energy into the chocolate.

10.3.3 Liquid phase conching

This phase can be very short and is required to mix in the final recipe additions. Sufficient time must be allowed for the viscosity to reach an equilibrium. As there is little change in flavour or additional work input, however, there is little reason for extending this stage. Research has shown a very big consumer preference for chocolates processed with a long dry conching phase compared with ones which were conched for a similar length of time but with a long liquid phase (Beckett, 2006).

When conching at a high temperature, additional time may be required to enable the chocolate to cool before the emulsifier is added, as some authors have found that lecithin is less efficient when added to chocolate hotter than about 60 °C (140 °F).

The conche is the last major processing stage before the chocolate is used for moulding, enrobing and so on. These processes require a consistent viscosity and some adjustment may be required. One approach is to place a viscometer in the discharge pipe from the conche and then make the necessary fat or emulsifier additions in the storage tanks. An alternative solution is to monitor the conche electrical power curves and use these to make fat adjustments into the conche during the liquid phase (Mars, 1994). Frisse provide a viscometer, which can be fitted inside a conche. This operates by measuring the damping of mechanical oscillations and can give continuous readings, which are recorded by the PC control system.

10.4 Conching machines

10.4.1 History

Conche development has gone through various inventive and innovative phases starting back in nineteenth century. In literature, the longitudinal conche of Rodolphe Lindt is cited as the first conche. Subsequently, rotary conches were developed and introduced onto the market. Initially the conching units were equipped with stone rolls and, later, with various mixing and shearing elements. The next development step was the vertical conches which preceded the introduction of horizontal conches. This was a revolutionary step change in the process of conching as it offered great opportunities in respect to volume capacity increase, production of masses with better flow behaviour and enhanced flavour/aroma profiles. In recent times, continuous concepts have also been generated, and automation (Chapter 24) contributes to the overall control of the conches and the conching process itself. In addition, add-on devices to standard conches have been introduced with the objective of optimising chocolate flow properties and also enhancing particular flavour profiles.

Irrespective of the conche concept or design, the energy intake or energy density (kW/t) is a key factor that is directly linked to the efficiency of the conching process. Currently therefore, machinery suppliers have been targeting their developments to intensify the energy intake within a short time period, whereas in the past a more gentle treatment was taking place in a longer processing time. This impacts significantly upon physical and chemical reactions such as reduction of moisture, degree of de-agglomeration, release of fat, wetting of particles with fat, stripping of unwanted volatiles, flavour redistribution and development and flow properties.

10.4.2 The first conche development

As already mentioned, Rodolphe Lindt is considered as the inventor of the very first conche, the so-called longitudinal conche (1878). The concept was based on a granite roll that was moving in a continuous manner backwards and forwards inside a trough. The conching process lasted up to 96 h and the maximum capacity was about 4000 kg (a four trough setup). Particles were heavily wetted with fat at the early phase of the process (due to mechanical limitations of the design), retarding the rate of moisture reduction and the stripping effects of unwanted volatile components. Furthermore, the longitudinal conche provided low energy input into chocolate, but had a very high energy consumption. Last but not least, the temperature control was focused on the cooling water and not on the mass.

In the following sections, various conche designs will be described and illustrated by commercially available machines. To start with, the different types of conches will be classified according to their design, type of mixing elements and number of shafts.

10.4.3 Classification of conches

Often conches are classified into vertical or horizontal types. In the first case, these are conches in which mixing, scraping and shearing paddles are attached on a shaft that is vertically oriented. Additional mixing elements may perform a planetary motion around the centrally driven paddles. The second case, with a horizontal powered shaft, is now the more widely used. Depending on the design and mixing volume of the paddles, the shearing zone being created between the conching paddles is an important parameter. This is related to the overlapping of shearing elements, which provides additional shearing zones inside the conche vessel. Last but not least, the number of shafts can be used for classification too.

10.4.4 Vertically oriented shaft conches

One of the most widely used vertically shaft conches is the Carle and Montanari-OPM Clover (Figure 10.8). This consists of a jacketed casing in which there are agitators, scrapers and tapered cone-shaped rollers. The chocolate mass is initially mixed in the outer compartment until it becomes pasty enough to be transported by a conveying screw into the inner part of the machine. Here tapered cone-shaped rollers apply an intensive shearing action, squeezing the chocolate mass against the conical inner surface and also throwing it back into the outer compartment. The scraping elements provide further homogenisation and shearing. Throughout the process a large proportion of the mass is exposed to air, resulting in low moisture levels and the removal of volatile aromatic components. The loading capacity is up to 6000 kg (e.g. Clover 30 at 3000 kg, Clover 60 at 6000 kg) and the power varies between 70 and 98 kW.

Figure 10.8 Vertically oriented shaft conche, CLOVER, Source: Reproduced with permission of Carle and Montanari-OPM.

Petzholdt-Heidenauer (Hamburg Dresdner Maschinenfabriken GmbH) also developed vertically oriented conches. Their first concept was the PVS design, which was based on the traditional circular container with horizontal mixing elements. An innovative development was the integration of spraying systems in order to produce a thin film of chocolate, whose large surface area is in contact with the air and where enhanced removal of volatiles takes place. Their next generation of vertical shaft conches were PIV machines. These usually consisted of two or more 1000 kg conching vessels which were able to give a semi-continuous conching process. The diameter of the circular container was smaller than the PVS and extruder-like screws were added to the main mixing element. This configuration was designed to deliver the two different types of shear (see Section 10.2.3). The mixing took place in both vertical and radial directions.

The PIV-HLC model is based on the PVS design combined with two of the PIV extruder-like screws, which are positioned inside the conche beside the main mixing element.

Generally speaking, the limitations of the vertical shaft conches are capacity, temperature control and motor overload. The mixing efficiency is relatively poor as there is limited circular movement of the mass (depending on its consistency), unless extruder-like screws are incorporated. Removal of unwanted volatiles also tends to be slow without thin film or similar devices.

10.4.5 Horizontally oriented shaft conches

Horizontal shaft conches tend to dominate the mass production of confectionery. In general, this class of conches is capable of delivering a better end-product specification (low moisture level, better de-agglomeration, improved flow properties etc.). Increased volume capacity and shorter processing times are often possible due to more efficient mixing, drying and shearing. The design concept mainly consists of a double jacketed vessel in which there are one, two or three processing areas depending upon the number of shafts and the rotational area of the paddles.

Single shaft conches are typically based on a circular shaped vessel in which mixing and shearing elements are attached to a horizontal shaft. Depending upon the design of the paddles, a fluidised powdery mass can be produced with significantly improved drying properties (moisture reduction and stripping of undesired volatiles such as acetic acid). This type of conche has relatively good mixing but this is limited due to shearing only taking place between the paddles and the wall of the vessel. This means that the design of a "smart" shearing element that both mixes and shears is critical. In addition, the vessel may be inclined in order to improve the discharging of the chocolate.

Otherwise, depending upon its flow properties, this mass residue may be as much as 2%.

With two shaft horizontal conches a relatively good drying efficiency can be achieved since air is either drawn into or expelled from the mass. The drying effect is improved due to the rotation of paddles "sprinkling" the powdery mass from top to bottom, ensuring a large surface area of particles in contact with the air. Nevertheless the mixing efficiency is rather low in the horizontal direction. In some designs, the shearing occurs between the paddle and the wall of the vessel, whereas in other designs an overlapping zone between the paddles creates an additional shearing zone. This feature ensures better de-agglomeration performance and consequently, optimum flow properties (Figure 10.9).

The three-shaft conche is however normally considered to have the best drying efficiency since air is passing continuously and simultaneously in and out of the mass (Figure 10.10). This action results in the so-called "breathing" effect as

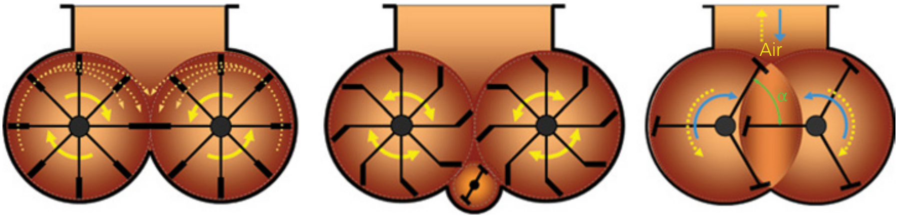

Figure 10.9 Illustration of horizontally oriented shaft conches depicting the movement of mass inside the conche vessel and the direction of the air flow. Source: Reproduced with permission of Bühler AG, Switzerland.

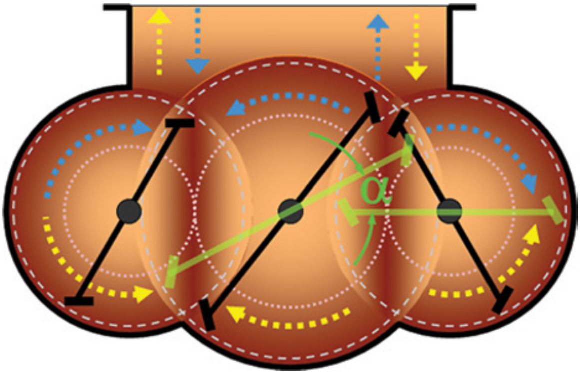

Figure 10.10 Illustration of triple shaft conche mode of operation depicting the movement of the conching paddles and the direction of the air flow. Source: Reproduced with permission of Bühler AG, Switzerland.

the mass appears to exhibit a breathing action as it changes to a pasty consistency. Intense shearing takes place between the conching paddles and against the vessel wall.

10.4.6 Single shaft conches

TNCE 13 (BSA Schneider-Industrie and Vetriebs GmbH) is an example of a single shaft conche. Specially designed conching paddles provide improved drying, plasticising and liquefying. The conche is frequency-controlled and is equipped with a water-cooled three phase motor with an efficient belt drive. The hollow shaft drive is directly connected to the conching shaft. The process is further optimised by incorporating a ventilation hood with a pneumatic flat slide to automatically adjust the ventilation throughout the conching process. Last, the speed of the rotor changes automatically with the load on the motor enabling it to run as fast as possible.

Carle and Montanari-OPM has also introduced a single horizontal shaft conche under the commercial name ALPHA. It has a capacity of 6000 kg. The drive system is electromechanically controlled for the main movements and the product discharge valve is pneumatically controlled. The rotation speed of the stirrer is adjusted by an inverter and it is automatically managed by the PLC in order to keep constant the absorbed power to the set limit value.

Thouet (Royal Duyvis Wiener Company) is an established chocolate machinery manufacturer making a single shaft dry conche type RC where the shaft is placed horizontally in the conching vessel which is made of thick walled tubular steel. Six specially profiled conching elements are mounted on the conching rotor at a fixed distance from the front wall of the vessel (Figure 10.11). This concept is claimed to work without pre-charging fats and surfactants/emulsifiers (e.g. lecithin, PGPR etc.). The agitator arm scrapes off the mass and distributes it evenly inside the vessel. Good final flow properties are achieved by using this dry concept followed by shear forces during the later stages. As agglomerates are broken and fat is released, a well dispersed suspension with a rich flavour is developed. The single shaft conche type RC can dry conche at both slow and

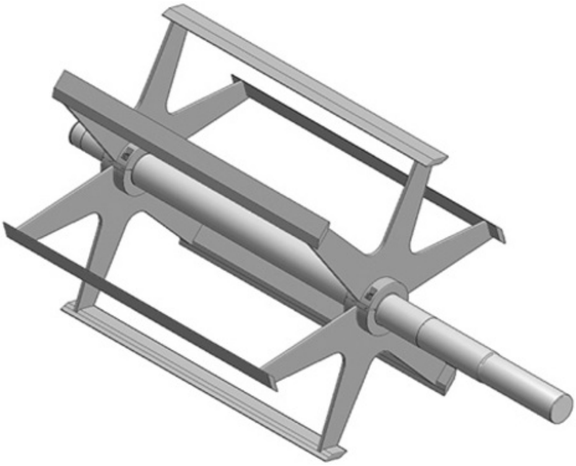

Figure 10.11 Conching paddle of type RC conche (Thouet, part of the Royal Duyvis Wiener Company).

high speeds. Different batch sizes are commercially available (1000–12 000 kg) and vessels are equipped with main drives with different power outputs (30–250 kW), depending upon the size.

The rotor of the single shaft conche Type RC has the same design and operation as the rotors of the two- and three-shaft conches of Thouet (Figures 10.17 and 10.19). Since there is only one large conching rotor, the drying phase may last longer than in the two-shaft execution. There are no significant differences in liquefaction times.

The Frisse-ELK single shaft conche (Bühler AG) has a unique design of conching paddles that can carry out the three key operations of mixing, shearing and aeration/drying.

As the mass is subjected to different conching phases the conching paddle's mode of operation changes. For instance, whenever the paddle or tool moves forward with the pointed part (R-tip) ahead, then mass is subjected to a kind of fluidisation due to the geometry of the ELK shovel design. Consequently, good drying and aeration takes place leading to a reduction of moisture and the stripping of unwanted volatile components. If the paddle or tool moves backwards with the wide curved part (L-tip) backwards, then shearing and plasticising are the main effects between the tool and the vessel wall (with strong particle–particle interactions) ensuring a good energy transfer irrespective of mass consistency (Figure 10.12).

During the process, several parameters are continuously monitored, for example the drive current, mass and water temperatures, motor speed and so on. During the feeding/filling phase, powder chocolate is conveyed into the vessel and then fat and/or emulsifier/surfactant additions such as lecithins, ammonium phosphatide and so on are added. The motor current is used to control the speed of the shaft in order to maintain a given mass consistency (providing a constant energy intake over time). As conching progresses, fat is eventually

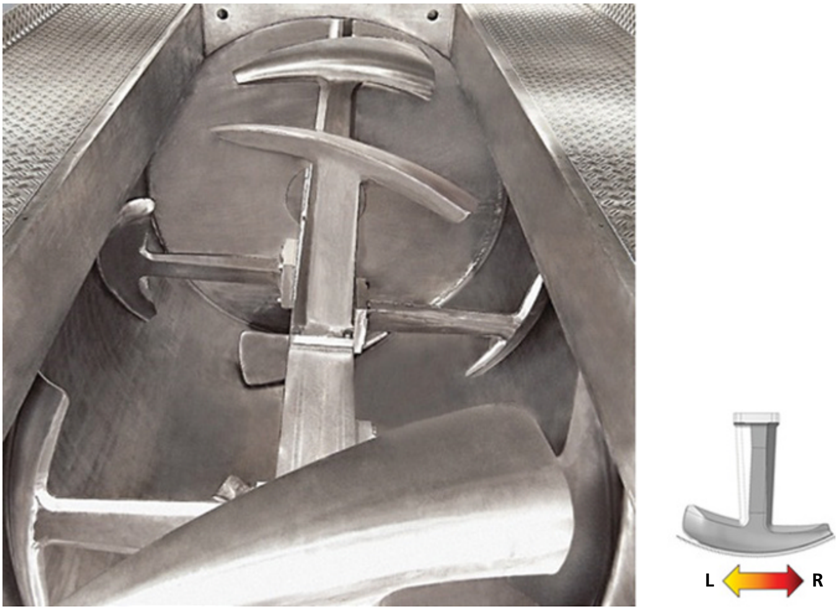

Figure 10.12 Conching paddle of Frisse-ELK conche. Source: Reproduced with permission of Bühler AG, Switzerland.

squeezed out from the surface of the particles and is also released by breaking down soft agglomerates. In order to maintain the motor current, the conche automatically reverses the direction of rotation at a preset value in order increase again the energy transfer into the mass. Subsequent liquefaction produces a homogenous and well-dispersed suspension. Process monitoring and control enable all the main objectives to be met (see Figure 10.13 and Chapter 24). These include de-agglomeration (through shearing and kneading), moisture (through aeration), fat release from the surface of some particles (e.g. milk powders) or due to the break-down of agglomerates in which fat was contained, surface coverage of particles with fats and emulsifiers/surfactants (through efficient liquefaction) and, finally, flavour redistribution (through shearing, mixing and good heat transfer).

The Frisse-ELK is constantly changing, for example:

1 Improved energy efficiency due to a direct drive without V-belts or planetary gear unit;
2 Product feeding via an inlet slide gate to ensure hygienic product feed;
3 Building the vessel in mild steel material to ensure good heat transfer;
4 Equipping the front and rear walls of the vessel with a double jacket for water cooling and heating to ensure optimal heat transfer.

This conche comes in a range of sizes from1500 to 12 000 kg and with a drive power from 55 to 315 kW, depending on the size.

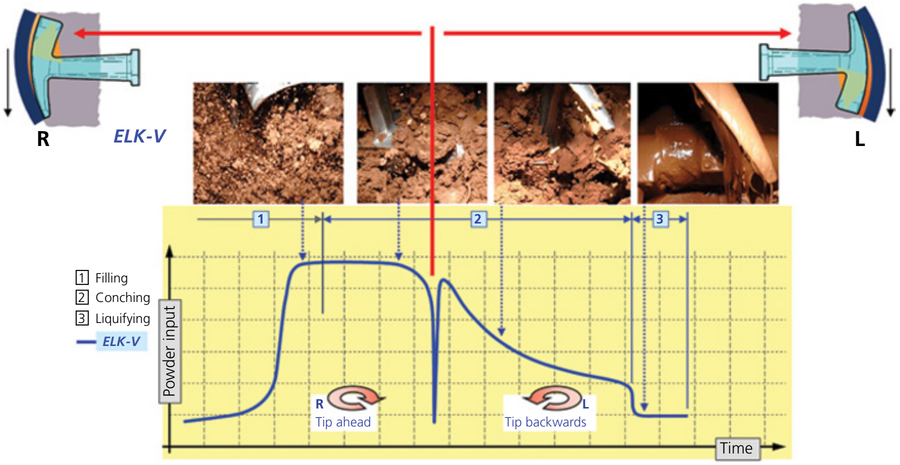

Figure 10.13 Process monitoring of Frisse-ELK conche. Source: Reproduced with permission of Bühler AG, Switzerland.

The TRIQUENCE® (Lipp Mischtechnik GmbH) is a different type of single shaft conche. It has a high-shear mixing whilst maintaining the required mass temperature. It is considered to have very good drying, reaction and dispersing efficiencies (Figure 10.14). The TRIQUENCE® can be used in two main modes: (i) as a standard conching unit whenever flavour development is needed (up to 5 h conching time) or (ii) as a liquefier whenever no significant flavour development is required (e.g. compound coatings). This mixing step then only takes 15–20 min. Different sizes are available from 5000 to 12 000 kg.

10.4.7 Two shaft conches

The Homega Conche (Carle and Montanari-OPM) is a classic example of a two shaft conche design (Figure 10.15). It has a capacity between 4000 and 10 000 kg and, depending upon the batch size, the installed power is from 92 to 150 kW. The authors have no direct experience of this technology, but it is claimed to give a high yield with improved rheological and organoleptic properties. In the process zone, shearing forces are applied against the wall of the vessel but also in between the conching paddles due to the overlapping shearing zone. An additional feature is the discharge mechanism where the two compartments in the vessel have separate outlets and, consequently, the emptying time of the mass is significantly reduced.

Alternatively, Petzholdt-Heidenauer (part of Hamburg Dresdner Maschinenfabriken GmbH) have designed the so-called HBC conche. Their catalogue includes different batch sizes (3000–12 000 kg) powered by two speed controlled drive motors (37–75 kW depending upon the batch size). A pneumatically operated louvre vent increases flexibility and enhances the flavour volatile removal. Typically, the conching cycle for a 3000 kg/h line with a 6000 kg conche is: (i) filling

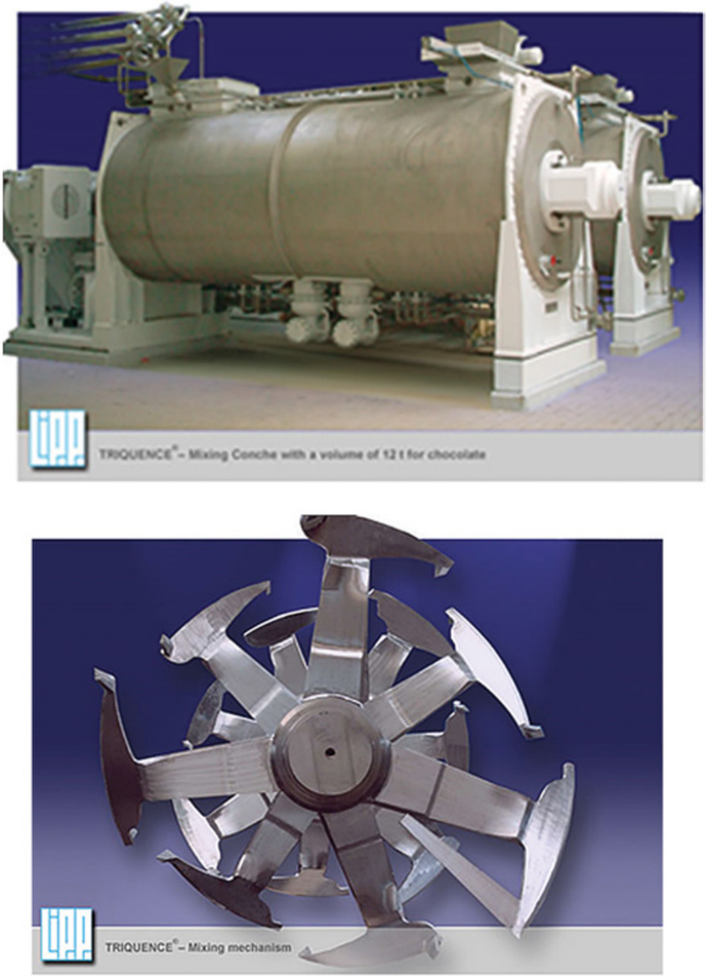

Figure 10.14 TRIQUENCE® single shaft mixing conche and its conching tool design (Lipp Mischtechnik GmbH).

Figure 10.15 Conching paddles and mass consistency in dry and liquid phases inside HOMEGA conche. Source: Reproduced with permission of Carle and Montanari-OPM.

time approx. 2 h, (ii) actual conching approx. 5 h and (iii) discharging approx. 30 min. In this process, the power input and time taken depends upon the liquid fat and emulsifier/surfactant additions.

BSA Schneider-Industrie and Vetriebs GmbH manufacture the TNCE 99 twin-shaft conche (Figure 10.16). This has been designed to pass the chocolate mass through an intensive dry conching phase to enhance the physical and chemical properties of the end-product. The high shear paddles were designed to give shorter conching times.

Thouet (Royal Duyvis Wiener Company) manufacture the Type DRC2 two shaft conches. The Type DRC2 carries out dry conching at slow and high speeds using a powerful motor with two large conching rotors, each with six conching elements fixed firmly to the shafts (Figure 10.17). The conching elements are specially profiled and arranged on the side wall of the vessel. Scrapers are mounted on the sides of the conching rotors at a fixed distance from both front and back walls of the conche vessel. This intensive process results in a relatively short conching time of approximately 5–6 h. Furthermore, this conche is fitted with specially designed tools or paddles that make it possible to run without, or at very low levels of, pre-added fat. Consequently, a very dry consistency is formed that significantly reduces the moisture and at the same time

Figure 10.16 Conche vessel of twin-shaft TNCE 99 (BSA Schneider-Industrie and Vetriebs GmbH).

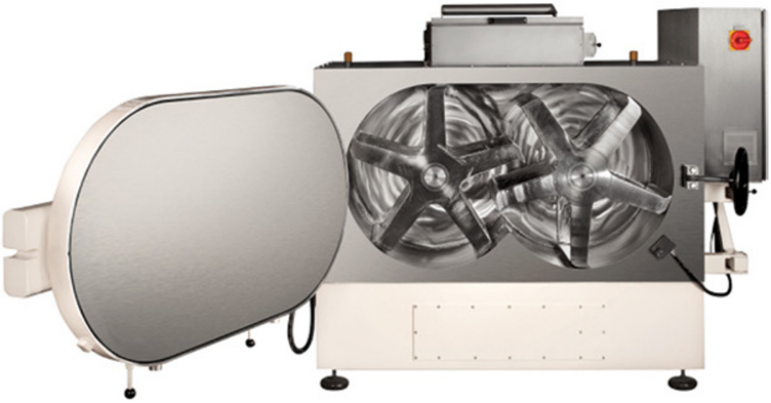

Figure 10.17 Laboratory type DRC2 conche (Thouet, part of Royal Duyvis Wiener Company). Source: Reproduced with permission of Royal Duyvis Wiener Company.

forces volatiles and undesired aromas to be removed. The motion of the two large conching rotors overlaps in the centre of the conche vessel giving very good mixing. The two conching elements are driven by a common gear box or by two geared motors (depending on the size of the conche). The discharge of the conche is situated at the deepest point of the vessel (two outlets) and the openings are closed by two special piston valves. Finally the louvres in the venting hood of the conche vessel can be turned by 90° using pneumatically operated drives. This machine comes in different batch sizes (from 3000 up to 12 000 kg) and the main drive power is between 90 and 250 kW, depending upon the loading.

In general, a twin-shaft design uses continuous movement of the chocolate mass to give a good aeration and drying efficiency. The moisture drops significantly and the unwanted volatile aromatic components are removed, provided that the conche is well ventilated with low relative humidity air. Together with de-agglomeration the process can produce low viscosity chocolate masses. Moreover contemporary conche design enables rotors to automatically slow down and avoid motor overload. At the same time the mass consistency or structure is maintained by the use of motors of multiple or continuously variable speeds. In the past, the risk of overload was managed by an experienced operator carefully adding fat or lecithin. This action often gave a high viscosity or high fat end-product due to moisture entrapment, inefficient de-agglomeration and incomplete phase transitions of amorphous structures and so on. As noted in Section 10.3, it is very important to maintain a given power intake/input over a long time. Once the initial power peak has started to decrease, servo-controlled machines increase the speed of rotation of the mixing shafts in order to obtain a constant power intake. This is aided by reversing the direction of movement of the rotors in combination with a novel paddle design.

10.4.8 Three shaft conches

One of the most widely used triple shaft conches is the Frisse-DUEC (Bühler AG; Figure 10.18). The abbreviation DUEC stands for Double-Overthrown Conche (Doppel-Ueberschlag Conche) whereas another variant is the so-called DUEC-G (Double-Overthrown Conche with synchronous gearing; Doppel-Ueberschlag Conche mit Gleichlaufgetriebe). The key difference between the two is the rotor tip speed. A higher tip speed reduces conching time and gives potential fat savings, due to optimal fat release producing better flow properties (viscosity and yield value, structural viscosity, viscosity at low and high shearing).

Both machines are based on three parallel rotors that run simultaneously and in opposed directions inside a triple vessel/trough. Specially designed conching tools perform mixing, aeration and shearing. The shearing effect is very efficient as it takes place both against the wall vessel and also within the meshing rotor tools. Intensive aeration and drying takes place as a result of an action similar to a gear pump (see Chapter 12) combined with a high power drive motor. Air is drawn into one shearing zone, forced through the mass and ejected in the other shearing zone. Due to this extensive shearing (impact on viscosity) and good aeration of the mass (impact on flavour), a substantial reduction of the actual conching time is possible.

The DRC-3 conche from Thouet (member of the Royal Duyvis Wiener Company) has a modified triple shaft design (Figure 10.19). Primarily, it is a

Figure 10.18 Conching paddles inside Frisse-DUEC conche. Source: Reproduced with permission of Bühler AG, Switzerland.

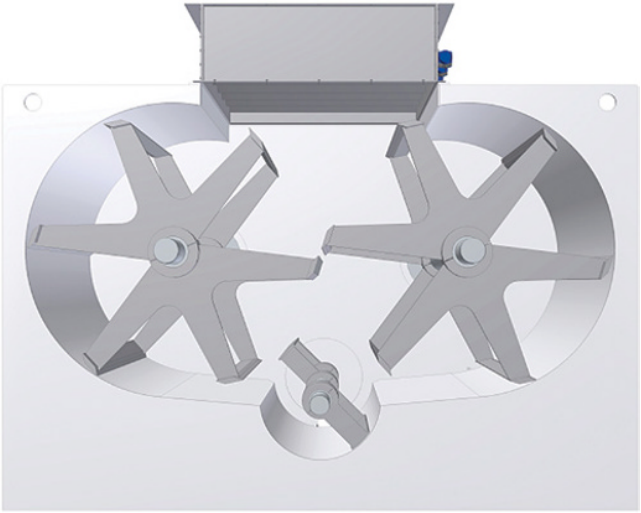

Figure 10.19 DRC-3 conche paddles (Thouet, part of Royal Duyvis Wiener Company). Source: Reproduced with permission of Royal Duyvis Wiener Company.

two-shaft machine with an additional third shaft on the bottom of the vessel. This moves the mass from the left to the right side and subsequently prevents the build-up of mass on one side.

10.4.9 Continuous conches

Petzholdt-Heidenauer (part of Hamburg Dresdner Maschinenfabriken GmbH) produces a continuous conche that can be used for both chocolate and compound masses. The principle involves using an intensive heat exchanger for a short processing time, thereby giving a low overall energy consumption (Figure 10.20).

During the process, high specific energy density is applied to a large surface area of the chocolate mass ensuring a constant and uniform treatment of the individual particles in a short time. This gives the degassing, deacidification and dehumidification that are responsible for the final rheology and flavour development. The external treatment is directly linked to flavour development by chemical reactions between amino acids and reducing sugars (Maillard reaction, see Chapter 8). In addition structural changes, important factors with respect to the final rheology, take place, such as de-agglomeration and wetting of particles with fat and emulsifiers. The most important processing parameters are: the process temperatures, the pre-charge of fat and/or emulsifiers (lecithin), the speed of the shaft of the pasting column, the addition of fat and/or emulsifiers in the pasting column or elsewhere and the gap adjustment of the wings and the baffles inside the pasting column (standard gap approx. 7 mm; range 6–13 mm). Different capacities are available

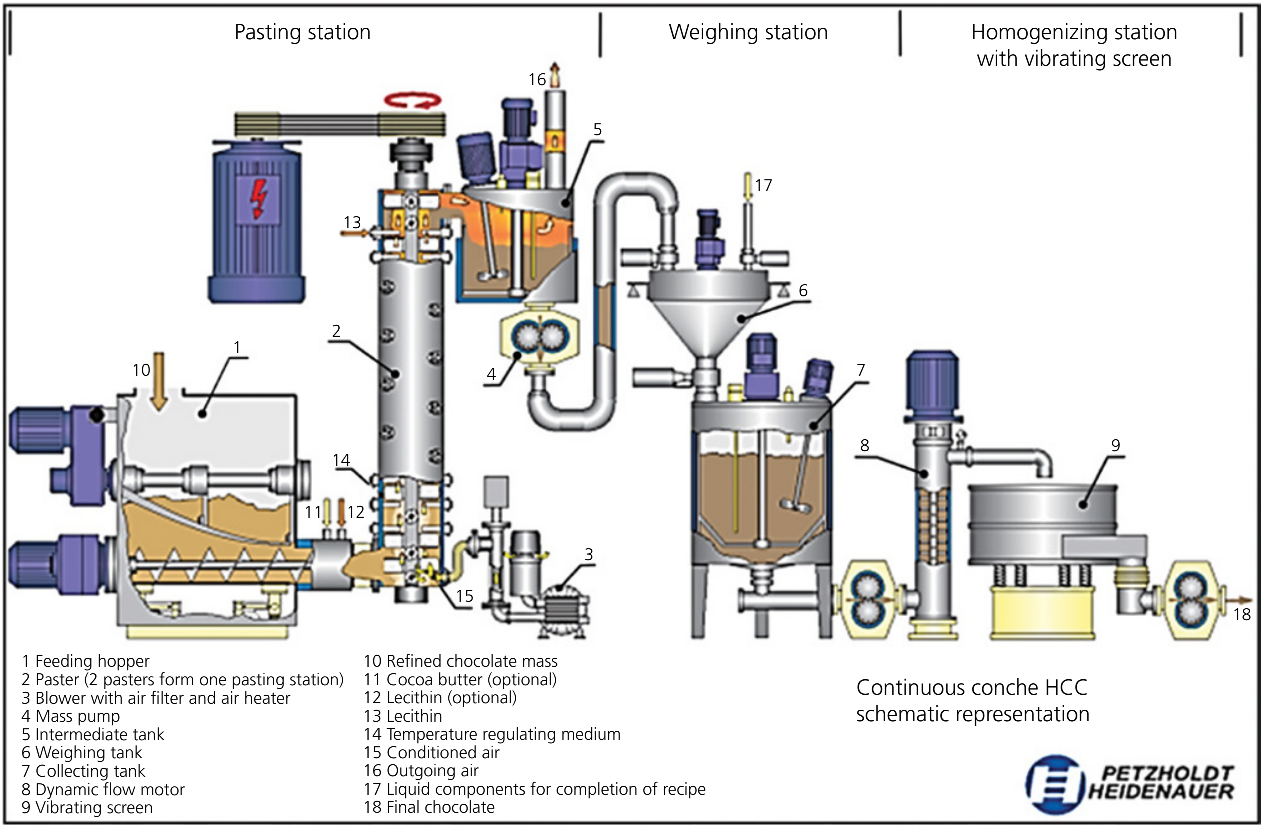

Figure 10.20 HCC continuous conche process scheme (Petzholdt-Heidenauer, part of Hamburg Dresdner Maschinenfabriken GmbH). Source: Reproduced with permisssion of Hamburg Dresdner Maschinenfabriken GmbH.

(HCC75 up to 1000 kg/h, HCC125 up to 2000 kg/h, HCC 250 up to 4000 kg/h, HCC 375 up to 5000 kg/h, HCC500 up to 6500 kg/h).

The Continuous Liquid Conche (CLC) was recently developed by Royal Duyvis Wiener Group to improve mass viscosity, yield, dehumidifying and degassing (Figure 10.21) Thermal degasification and mechanical shearing of thinly layered mass is carried out in the reactor. The product enters the reactor via a shear stress device on the top and is distributed over the reactor wall in a film. This film is constantly sheared by the rotating rotor and kept at a constant thickness. The mass moves continuously downwards towards the outlet. Due to the large surface area and thin film thickness of the mass, a very intensive short duration process can be used. Preheated air is directed onto the film using a range of outlet nozzles that are, in turn, fed through the rotor (the temperature of this fresh micro-filtered hot air is pre-selectable). Finally, the mass is discharged from the bottom of the reactor.

10.4.10 Add-on solutions to the conching process

Several concepts have been developed focused on either further improving the flow properties (through high shearing elements) or on fine-tuning the flavour profile of the end product. As an example, the REFLECTOR® Inline Mixer (Lipp Mischtechnik GmbH) is used as an additional dispersing stage that combines a

Figure 10.21 Continuous liquid conche CLC. Source: Reproduced with permission of Royal Duyvis Wiener Company.

Figure 10.22 Reflector® inline mixer (Lipp Mischtechnik GmbH).

continuous intensive mixer with a rotor/stator head and pump. The centrifugal acceleration induced by the rotor blades causes particle circulation in the shear zone. Large and heavy particles tend to move into the outer area where the shear force is the greatest. In the shear zones the rotor blades with their toothed ends intermesh with the toothed rings of the stator (Figure 10.22). The reflecting faces of the active elements cause constant changes in direction within a closely confined area, splitting up the product flow, breaking up agglomerates, dispersing and homogenising the product.

Fine-tuning of the flavour profile can be carried out by the Taste-Changer concept developed by Royal Duyvis Wiener. It is based on a combination of shear stress and an efficient film evaporator. Basically, hot, dry air jets are brought into contact with pumpable mass causing moisture, volatile components and off-flavour to be extracted from the matrix.

10.4.11 Combined grinding and conching

In the above sections, various conche concepts have been illustrated that operate in either a batch or continuous mode. Traditional chocolate manufacture is based upon conching a mixture of particles which have been pre-ground either by roll refining or by other means such as air classifier mills, jet mills and so on (see Chapter 9). In the roll refining approach, raw materials are dispersed into a fat matrix prior to refining. Usually the fat content is somewhere between 22 and 30%. In the dry grinding approach, ingredients of low fat content (<10%, optimum <1%) are milled either individually, or as a blend, with or without classification.

Machinery suppliers have also pursued alternative approaches based upon a pre-treatment of the mixture at a relatively low overall fat content. The objectives are mainly the reduction of the moisture content, the removal of undesired volatile components and the redistribution of key aromatic components (see Chapter 8) that will eventually contribute to the flavour profile of the final product. It is clear that this pre-treatment phase adapts some elements of the traditional conching process, although the structural mass changes are not necessarily present (since treatment occurs at low fat level). Often this pre-treatment step is referred to as dry conching, powder conching, light conching and so on. In an alternative approach, this conching-like step is combined with simultaneous coarse grinding step. At the end of this pre-treatment phase, addition of fats and/or lecithin takes place in a liquefaction phase, often at a fat level close to that of the end product. The process is completed by grinding the matrix, often in a bead mill.

CHOCOEASY® (Netzsch), developed in 2003, was one of the first processes for chocolate mass which combined dry conching with refining in a bead mill. Other versions such as RUMBA® have now been developed to satisfy industrial needs for larger capacities up to 6000 kg batches. The original CHOCOEASY® process also contained a specially designed universal mill (type CONDUX) for the pre-grinding of granulated sugar and/or milk powders. Today due to the efficiency of the low fat dry conching it is possible to start the process in the conche with crystal sugar without pre-grinding. A horizontally arranged, U-shaped conche version of the CHOCOEASY® concept is used to perform the low fat dry conching process in which dry ingredients are mixed together with some of the liquid components. Providing a large specific surface area and an intensive contact between the raw materials, the flavour development and reduction of the moisture is more effective. Moreover, an intensive hot air supply forces undesirable aromatic components and acids to be "discharged" from the matrix. The dry conching phase is followed by a further liquefaction and grinding step using a horizontal bead mill (Netzsch-type LME), with an integrated separation system to allow high throughput rates at a constant temperature without the ball mill blocking due to bead compression.

RUMBA® Basic is one of the latest developments by Netzsch that offers higher batch capacity (6000 kg). It comprises of the Netzsch U-Conch, a horizontal agitator bead mill (LME) and a process tank. This concept is used for real chocolate and premium compound applications (Figure 10.23).

The SmartChoc™ Plus (Bühler AG) operates using similar principles (Figure 10.24). It has a drying process phase, the so-called light conching, and a bead mill technology in a horizontal execution (Cenomic™ bead mill). Thus the process consists of a conche-like vessel, a bead mill and a mixer vessel. The process begins with the dosing of all dry ingredients together with just some of the liquid components in order to maintain a relatively dry consistency. The light conching phase occurs inside a single shaft conche, the ELK™-Light with specially designed conching tools, following the principle of Frisse-ELK conche shearing elements. Rotation in a clockwise direction (tip ahead) causes fluidising and mixing. On the other hand a counterclockwise rotation produces kneading

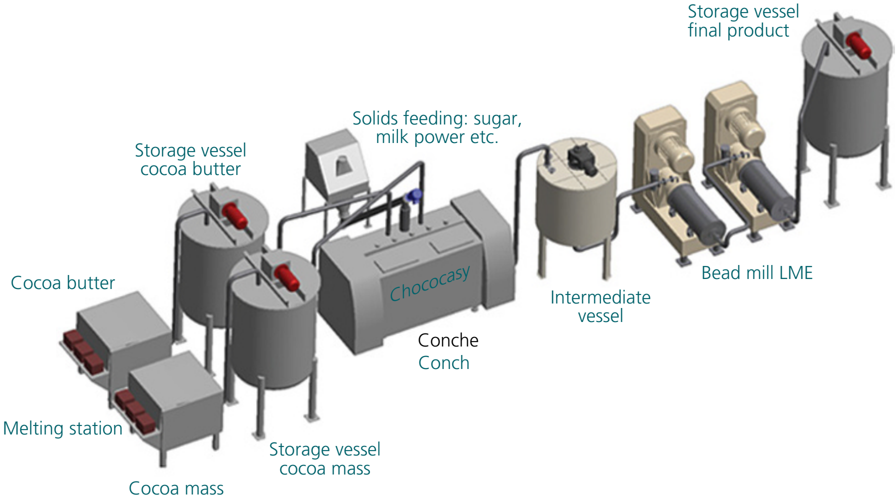

Figure 10.23 Rumba® process scheme (Netzsch).

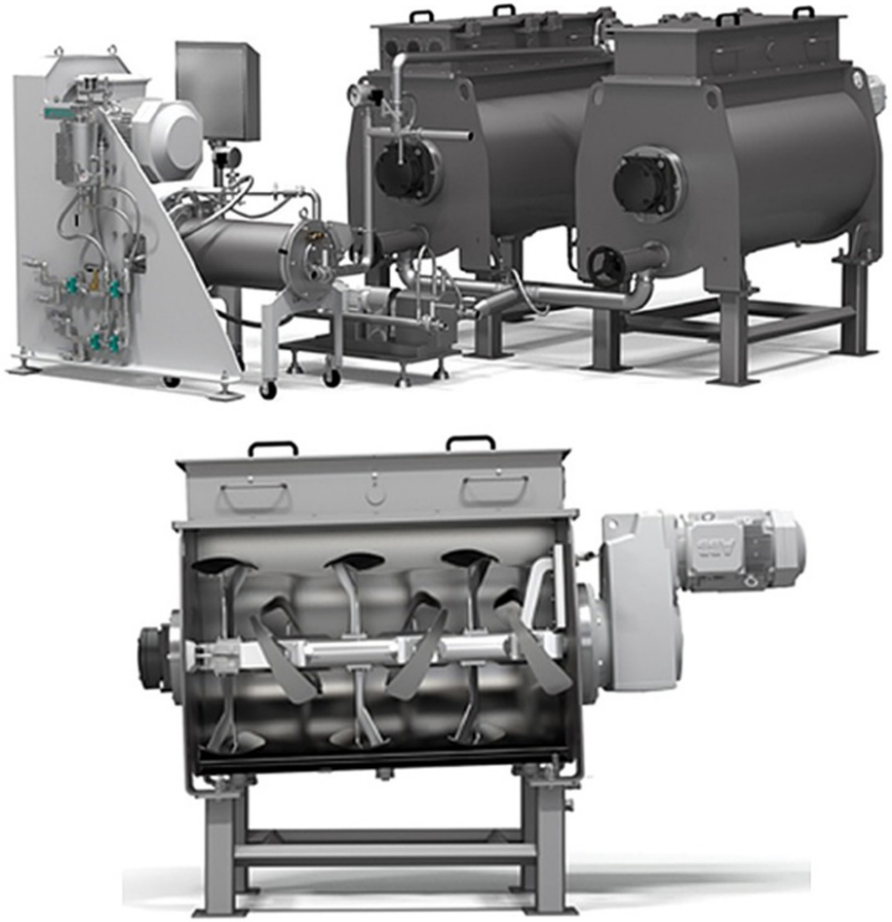

Figure 10.24 Smartchoc® PLUS and the ELK™-Light conche. Source: Reproduced with permission of Bühler AG, Switzerland.

and shearing actions ensuring fat release from the surface of the particles (e.g. milk powders) and eventually particle wetting. Moreover, the fat matrix will be enriched with aromatic components that eventually will be transferred and coat the sugar particle surfaces.

The ELK-Light Conche air heating unit can reduce acidity, moisture and final chocolate viscosity. The process is completed by liquefication and bead milling in an horizontal manner (Cenomic™); which has a high grinding efficiency due to EcoMizer™ conveying discs and centrifugal cage.

The ECO²-Choc concept (Lipp Mischtechnik GmbH) combines a dry conching phase with a coarse grinding step inside a conche vessel (Figure 10.25). Both steps finish prior to the final fine grinding which usually takes place in a ball mill. The coarse grinding occurs within integrated vortex chambers that reduce the size of crystalline sugar down to 300 μm.

At the same time milk powders are dried by heating and aeration. Dry conching is performed with some addition of liquid components such as fat but in particular with cocoa mass in order to strip-off the unwanted volatiles. A liquefaction phase follows to bring the mass to a suitable consistency for pumping. The next step is a two-stage ball mill with the options of an inline scraper cooler and the addition of liquid components in between the ball milling units. Last but not least, the high shearing mixer Reflector®, can be also included after the second ball mill in order to further de-agglomerate the particles and fine-tune the overall particle size distribution. The whole process is ended with addition of the final lecithin portion in order to further optimise the rheology of the end product (Figure 10.26).

A completely different concept is the so-called Refiner Conche that has been developed and manufactured by several companies (Royal Duyvis Wiener Company, Lloveras, MacIntyre and so on) and in which grinding and conching

Figure 10.25 ECO²-Choc conche vessel with integrated grinding areas (Lipp Mischtechnik GmbH).

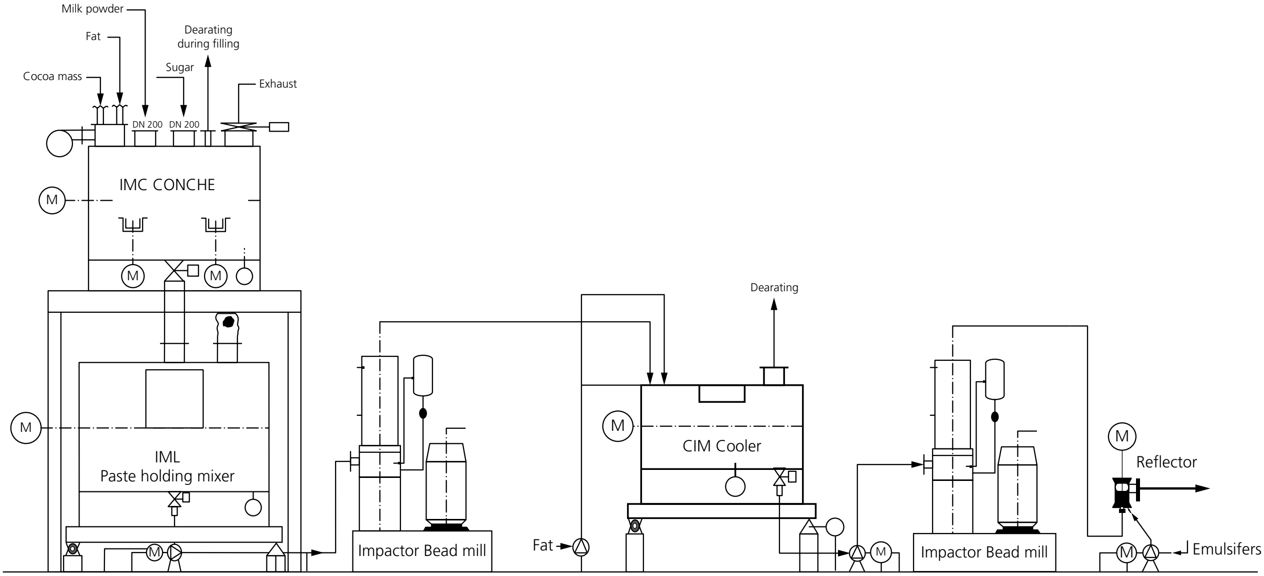

Figure 10.26 ECO²-Choc process flow (Lipp Mischtechnik GmbH).

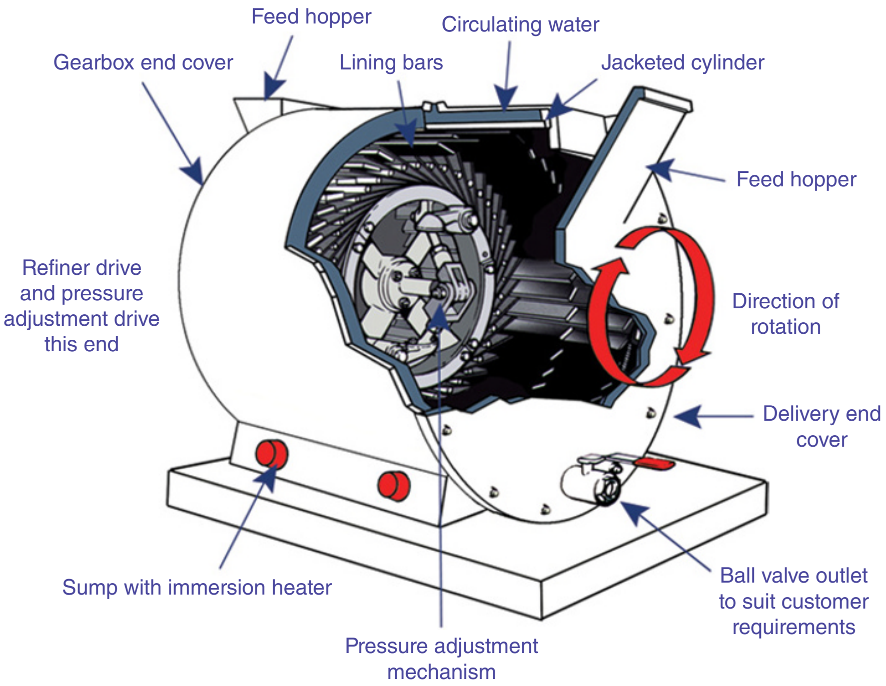

Figure 10.27 Inner part illustration of Refiner conche vessel (MacIntyre Chocolate Systems, part of Hamburg Dresdner Maschinenfabriken GmbH). Source: Reproduced with permission of Hamburg Dresdner Maschinenfabriken GmbH.

take place simultaneously inside a single machine. Typically, the Refiner Conche consists of a horizontal cylindrical vessel with a ribbed inner wall. A shaft with paddles and scraper blades runs through the centre of the vessel and the grinding takes place as pressure is applied between the blades and the ribs (Figure 10.27). Ingredients are sheared between the blades and the wall, while the applied pressure is monitored and increased with time until the target particle size is reached. Throughout the grinding phase, a temperature profile is also applied in order to aid moisture reduction, reduction of undesirable volatile components and flavour development. A drawback of such a machine is the relatively long processing time.

Companies, such as Royal Duyvis Wiener Company, have decreased the long processing time by combining the Refiner Conche with bead mills and/or add-ons like Taste-Changers. Here the Refiner Conche is used as a pregrinder, the bead mill as a fine grinder and the Taste-Changer as the means to further optimise rheology and the flavour profile (Figure 10.28).

Figure 10.28 Uniroto. Source: Reproduced with permission of Royal Duyvis Wiener Company.

Conclusion

As has been illustrated, there is a very wide variety of conches available to the chocolate manufacturer. There is, of course, no perfect all-purpose conche, so what criteria should be used when choosing a new machine?

The most important parameter is the ability to produce the required chocolate flavour and each design of conche tends to remove the volatile components in a different way. Strangely the same type of conche, in different factories, has been known to produce different flavours using the same recipe. This flavour matching may not be important if a new product is being launched, but it is critical for an established brand. Very often trials are carried out on small- or pilot-scale equipment. This can give very different results and unfortunately there are no robust rules for scaling to full-size production machines. The only certain way is to evaluate a full-size test machine on site. Where it is necessary to match a current process, a useful guideline is to try to maintain a similar temperature profile (time vs temperature curve).

Another important factor is the viscosity of the product. This will be related to the degree of shearing through the mixing elements. Powerful motors are required to produce a high shear rate. Although these use more energy per unit time, they frequently reduce conching time, which may result in an equivalent energy use per tonne of chocolate. High shearing systems also rapidly heat the product, so an efficient temperature control system is needed on the conche.

The space available for a conche may be the limiting factor. In this instance, a continuous system may be preferable to a batch one.

The type of chocolates to be manufactured, is another consideration. Some manufacturers make very large amounts of a single recipe, whereas others may only need a few tonnes, before changing it. The former is likely to use relatively large conches and the latter prefer concepts such as Refiner Conche or ball mill applications in combination to "conching" schemes.

The size of the conche to purchase is another factor. Small conches may be better for frequent recipe changes but are relatively expensive in terms of capital cost. Large volume conches, although cheaper to purchase, have the disadvantage that they frequently have long filling and emptying times, during which no processing is taking place. In addition, in general only a small proportion of the chocolate within the conche is being mixed at any one time.

In conclusion, just as there are many different chocolates, so there are many different conching requirements and a wide variety of machine designs to try to meet these needs.

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CHAPTER 11

Chocolate flow properties

Bettina Wolf

11.1 Introduction

The flow properties of molten chocolate are important for two reasons. First, if the chocolate's viscosity is incorrect then a poor quality product will be made, which may have to be sold cheaply as a mis-shape or perhaps have to be reworked (Chapter 17). For example if the viscosity is too low, the weight of chocolate on an enrober-coated sweet will be too low. When it is too high, "feet" may form (Figure 11.1) or bubbles not come out of a moulded tablet.

The viscosity also affects the consumer's eating experience of chocolate during its complex oral processing (Carvalho-da-Silva *et al.*, 2011, 2013). While it is easily conceivable that the mouthfeel is affected by chocolate viscosity, it may not be so obvious that the flavour of a chocolate in the mouth is also affected by it. The reason for this is that the mouth contains a lot of different flavour receptors, each capable of detecting a single type of flavour. As the chocolate melts it comes into contact with these receptors. The perceived taste depends upon the order and rate of contact, which is related to the viscosity and the rate of melt. This can be demonstrated by placing part of a chocolate in the refrigerator and the remainder in a warm room. If the two are eaten consecutively, then they appear to have very different flavours.

The flow behaviour of chocolate is very complicated because the viscosity is not a single value and is what is known technically as non-Newtonian. This means that, if we measure its viscosity, it will vary depending how fast the chocolate is flowing. In some ways it resembles non-drip paint, which is very thick when stationary in the tin but becomes very thin when it is brushed onto a surface. This will be discussed further in Section 11.2.

What is important is that we measure chocolate viscosity at a similar rate of movement to that at which it is used. When the product is being deposited into a mould, this is very fast, but when chocolate is running down the side of a coated sweet it is doing so very slowly. It is therefore important to measure the viscosity at more than one flow rate. The results can be presented as several

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Figure 11.1 Chocolate with “foot” due to incorrect viscosity. Reproduced from Beckett (2008).

single point measurements or by combining these using mathematical models to produce flow parameters, such as the yield value and plastic viscosity. The Casson model used to be the most frequently used within the confectionery industry and this will be explained, together with some of its limitations, in Section 11.3. The development of unified measurement protocols and ways of reporting flow properties of chocolate have been recommended by Servais *et al.* (2004). In addition a more advanced model was developed by Windhab (see Section 11.3).

Single point measurement systems do exist and these will be described, together with their limitations, in Section 11.4.

Rotational viscometers have become the industry standard and these are described in Section 11.5. However, the chocolate viscosity is altered by how it is treated and also by how the measurement is carried out (see Section 11.8).

The chocolate viscosity can be incorrect for a variety of reasons and it is important to determine the actual cause of a quality failure, so that it can be corrected. Section 11.9 reviews the factors that affect the flow properties of chocolate.

11.2 Non-Newtonian flow

Chocolate is a composite material of solid particles within a fat matrix, composed largely of cocoa butter, which will melt when the temperature is increased to around body temperature. Liquid chocolate is in fact a suspension. Without the solid particles being present, the liquid cocoa butter would have a single viscosity at whatever flow rate it was measured, that is it is Newtonian. Figure 11.2 shows two surfaces of area A separated by a gap of h where the lower plate is resting and the upper plate moves at velocity v as a result of pulling this plate at force F.

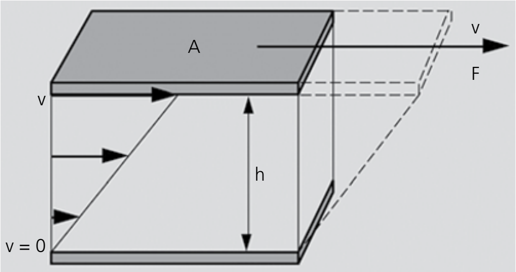


Figure 11.2 Two-plane model illustrating shear deformation. v = Velocity, A = surface area of plane, F = force and h = distance between planes. *Source*: Mezger (2006). Reproduced with permission of Vincentz Network.

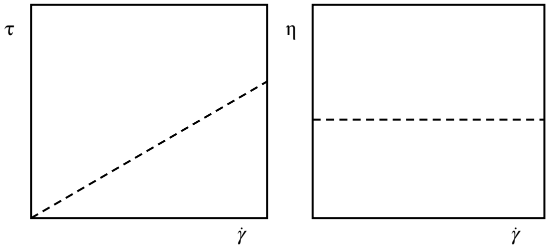


Figure 11.3 Shear stress – shear rate and apparent viscosity – shear rate relationship for Newtonian fluids.

A liquid confined between the two planes will deform as indicated by a linear velocity profile. The velocity gradient across the gap will be v/h and represents the rate at which the liquid is being sheared. This ratio is known as the shear rate, represented by $\dot{\gamma}$, and its SI unit is the reciprocal second (s^{-1}).

The ratio F/A represents the shear stress τ and its SI unit is the pascal (Pa). The force or shear stress required to move the upper plate to impart a desired shear rate is related to the resistance to deformation of the liquid, or the viscosity η:

$$\eta = \tau / \dot{\gamma} \tag{11.1}$$

At any particular shear rate the value of η is known as the apparent viscosity and is normally measured in pascal seconds (Pa.s). For cocoa butter the force that is applied relates directly to the rate at which it moves, so the apparent viscosity is the same at all shear rates (Figure 11.3). This case is referred to as Newtonian behaviour.

In chocolate this is more complex due to the presence of a high proportion of solid particles. This is illustrated schematically for two flow rates in Figure 11.4. At rest or at zero shear the particles are randomly arranged forming a network preventing flow. The continuous phase of cocoa butter is trapped within this network. The apparent viscosity is relatively high. With the onset of flow upon increasing shear, particles will start moving in flow direction and elongated particles align in flow direction. The trapped liquid is liberated and layer formation as indicated in Figure 11.4 is likely to occur. This structure provides less resistance to flow and with increasing shear rate lower viscosities are measured until

Figure 11.4 Schematic diagram of particles within a suspension at rest and during flow.

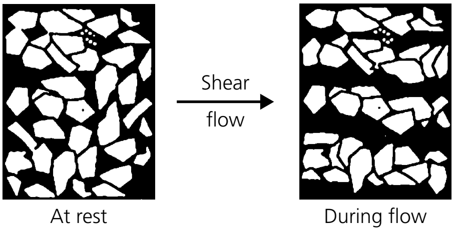
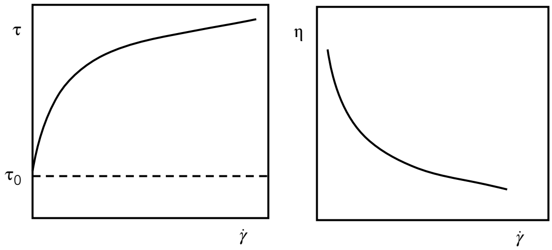


Figure 11.5 Shear stress – shear rate and apparent viscosity – shear rate relationship for shear thinning materials.



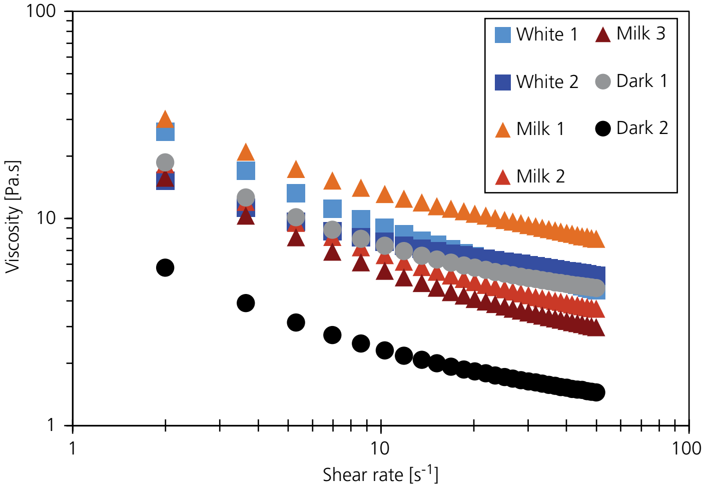


Figure 11.6 Flow measurements on a variety of liquid chocolates.

the flow induced structure has reached a pseudo equilibrium. The material behaviour is referred to as shear thinning. The corresponding plots of shear stress and apparent viscosity against shear rate are shown in Figure 11.5.

The shear stress at which the flow starts τ_o is often referred to as the yield value and is particularly important for enrobing or dipping chocolates, where the movement is slow and hence there is a low shear rate (Figure 11.5).

Figure 11.6 illustrates the apparent viscosity of commercial molten chocolates analysed in the shear rate range of 5–50 s^{-1} at a temperature of 40 °C. This shows that the viscosity decreases significantly with increasing shear rate and therefore the shear rate applied for analysis must relate to factors such as the processing conditions. Usually the shear rate is very high during depositing, but low for the removal of bubbles from a mould. This means that, when the viscosity of a chocolate is specified, more than one figure is normally needed.

11.3 Presentation of viscosity measurements

Presenting the viscosity of a chocolate as a curve, such as is shown in Figure 11.6, is not very helpful when trying to specify a chocolate from a supplier or to determine whether it has been giving production problems. Provided that the measuring technique is carefully controlled and the same shear rates are applied, the apparent viscosity can be used. The International Office of Cocoa, Chocolate and Sugar Confectionery recommend that the apparent viscosity should be reported in at least five points, so as to cover the low, medium and high shear rate ranges (OICCC, 2000). In practice most chocolates can be characterised by two measurements, one at about 5 s^{-1} for low flow situations and to approximate to the yield value and a second one between 10 and 20 s^{-1} for higher flow rates.

An alternative method of expressing the viscosity is to fit a mathematical equation to the flow curve for the liquid chocolate. There are a large number of these of varying complexity (Windhab, 1995), but the Casson model is the most widely used within the chocolate industry. Several variations of the model exist, some taking into account the configuration of the viscometer measuring system being used. The basic equation is:

$$\sqrt{\tau} = K_0 + K_1\sqrt{\dot{\gamma}} \tag{11.2}$$

K_0 and K_1 are constants which depend upon the viscosity of the chocolate being measured. This equation can be expressed in graphical form as is shown in Figure 11.7 and shows that, when there is a shear stress (τ) less than or equal to K_0 applied, no movement is taking place. This value is known as the Casson yield value ($\tau_c\alpha$). The gradient of the line, K_1, is equal to $\sqrt{\tau}/\sqrt{\dot{\gamma}}$, which using Equation 11.1 shows it to be the square root of the viscosity. The value of the slope of the line squared K_1^2 is known as the Casson plastic viscosity ($\eta_c\alpha$) which characterises the faster flow properties of the chocolate.

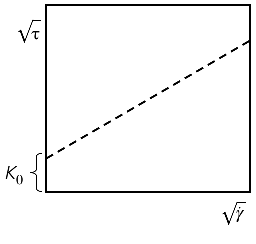


Figure 11.7 Viscosity plot for a Casson liquid.

The Casson equation therefore provides two figures that can be used in production to describe a chocolate and it does indeed provide useful information when the measurements are made on a single viscometer. Where several laboratories are involved in measuring the same chocolate, for example when it is transported between two factories, then the apparent viscosity should be used, as measured at agreed shear rates (Beckett, 2001). The reasons why the Casson model is unreliable for this purpose was illustrated when the same chocolates were measured in 32 laboratories in eight countries (Aeschlimann and Beckett, 2000). These showed that, for shear rates greater than 5 s^{-1}, the apparent viscosity could be measured between laboratories with a reproducibility with a coefficient of variation of less than 8%. (The repeatability within a single laboratory was better than 2%.) Using the same data in the Casson equation, the Casson yield value was found to vary between 3 and 23 Pa and the Casson plastic viscosity from 2 to 4 Pa.s. This covers the range for most useable chocolates, whereas measurements to be of use to the manufacturer need to be accurate to better than 20%. There were several reasons for this. One related to the fact that there are several different Casson models being used in the industry. It also makes a difference whether the data is fitted to the model in the linear or square root form. Many viscometers automatically calculate the Casson parameters without saying how this is done.

Another challenge is that very few chocolates have a flow curve that fits the square root (power 0.5) relationship of the Casson model, indeed many flow according to a 0.6 power (Chevalley, 1991). The Casson yield value is obtained by predicting outside the range of measurement and so very large errors may arise often rendering the values unusable.

11.4 Single point flow measurement

A single point measurement can provide information about part of the flow curve and, if this is the critical one for the process, this may be all that is needed. If the measurement is outside of specification then corrective action is necessary. Even if the corrected value appears what it should be, this does not mean to say that the chocolate will process correctly. Figure 11.8a shows the measurements obtained for two chocolates by a higher shear rate measuring instrument (flow cup, Figure 11.8b) plotted against a low shear rate measuring one (ball fall) over a period of several days. As can be seen for chocolate 1, the ball fall had a big range indicating large fluctuation in yield value, whereas the flow cup was relatively stable. If only the ball fall had been used the chocolate would probably have been modified, but this would not have been the case for the flow cup. The reverse situation occurred for chocolate 2.

The instruments used are relatively inexpensive and are still occasionally used in the industry, for example the flow cup and falling-ball viscometer

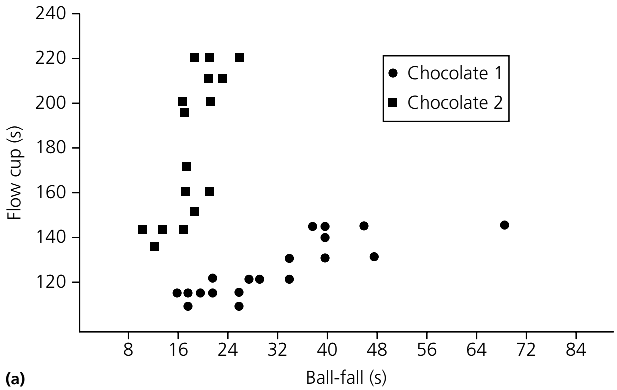
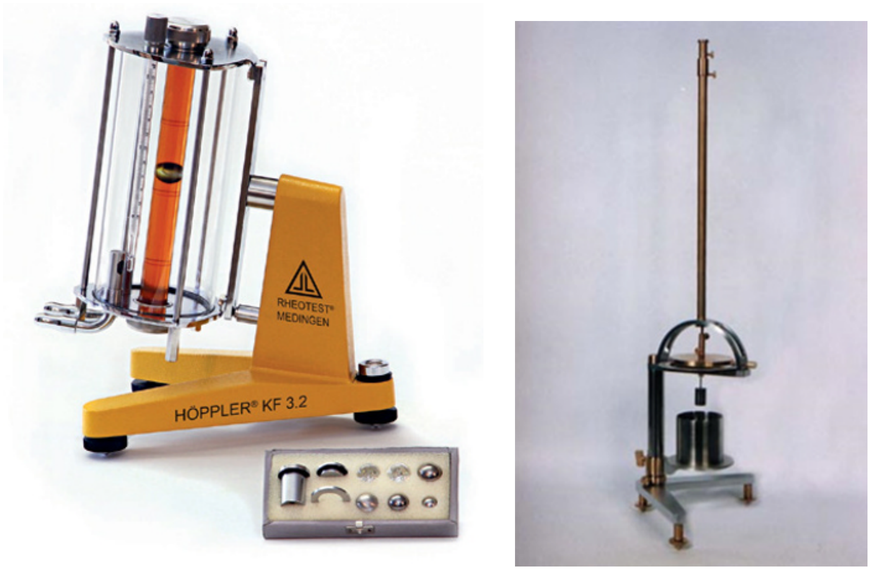


Figure 11.8 (a) Flow-cup and ball-fall measurements for two chocolates. (b) Flow cup.

(Figure 11.9a), the Gardner mobilometer as well as rotational devices. The reader is referred to earlier editions of this book (Beckett, 2009) or other textbooks (Mezger, 2006) for details of the former, whereas single point rotational devices have been included in this edition. The reason is that these rotational devices are often the standard instrument in many factories, in particular for measuring the viscosity of chocolate compounds. Their main disadvantage compared to multi-speed rotational viscometers or rheometers is that their data tends not to be comparable between laboratories and the results depend very much on how the device was used and the sample handled.

11.4.1 Gallenkamp torsion viscometer

Figure 11.9b shows the Gallenkamp torsion viscometer. It consists of a torsion wire, suspended at the top and with a bob at the bottom. Approximately halfway up the wire is a pointer set at right angles to the wire. The bob is placed in the chocolate and the pointer turned so as to twist the wire through 360°. Upon



(a) (b)

Figure 11.9 (a) Falling ball viscometer (google image labelled for re-use). (b) Gallenkamp viscometer (www.ejpayne.com).

release the pointer swings back beyond its original zero position. The amount of the over-swing relates to the viscosity of the chocolate, being small for thick chocolates and very much larger for thinner ones. Care must be taken to ensure that the instrument is operated in a vertical position.

11.4.2 MacMichael viscometer

This device is somewhat similar to the Gallenkamp torsion viscometer. In 1949 it was adopted by the United States chocolate industry as the standard instrument for measuring the viscosity of chocolate for bulk commercial use. The specifications for its use for chocolate requires a 26 gauge wire and a bob with a 2 cm (0.8 in) diameter cylinder that is immersed into the sample to a depth of 3 cm (1.2 in) in a 7 cm (2.8 in) diameter cup. The cup with chocolate is turned at a rate of 15 rpm. The product temperature must be adjusted separately – usually to 38 °C (100.5 °F). The viscosity of the chocolate causes the wire to twist, which is measured via a circular scale on the spindle that holds the wire.

The scale is 0 to 300 (not 360) and the amount of twist is referred to as °M (degrees MacMichael). It can be converted to an apparent viscosity of centipoise (equivalent to mPa.s), but it rarely is. The design of the MacMichael makes the 26 gauge wire highly vulnerable to bending, which then renders the measurement unreliable. Furthermore, the torsion constants of the 26 gauge wires vary over a range of 20%. The geometry of the bob and cup and the low rotational speed means that the shear rate of the MacMichael is low and is thus highly influenced by the yield value.

During the 1980s the United States industry replaced the instrument with the rotational Brookfield viscometer. It can duplicate the MacMichael measurement, avoiding many of its short-comings and in addition can measure the Casson yield value and plastic viscosity.

11.5 Rotational viscometers

In order to plot a flow curve it is necessary to measure the rate a chocolate moves under a predetermined stress, or to move it at a given rate and measure the force required to do so. Both types of instrument exist, and these are referred to as stress- or rate-controlled rheometers respectively. A rheometer is a more sophisticated device which can perform simple rotational tests as well as oscillatory measurements (see Section 11.7). Devices located in quality control and new product development laboratories are often simpler viscometers.

Three principle types of measurement geometries exist for rotational viscometers: cup and bob, cone and plate and parallel plate, see Figure 11.10. There are advantages and disadvantages to all three types of geometry and the reader is referred to rheology textbooks (e.g. Mezger, 2006; Goodwin and Hughes, 2008).

The most important factor when analysing the viscous behaviour of chocolate is the size of the suspended particles. Chocolate is usually manufactured with a maximum particle size of around 30 μm (Chapter 9), although the particles may aggregate to form larger pieces. For rheological analysis it is desirable that the gap size of the measuring head should be at least 10 times larger than the maximum particle size in the sample to avoid measurement artefacts. An exception is the cone-and-plate geometry where the tip of the cone is truncated by around 50–100 μm, depending on manufacturer giving the size of gap “a” indicated in Figure 11.10b. A gap size for the parallel plate geometry may be chosen large enough compared to the maximum particle size; however, the shear rate in the centre of the geometry is zero while it is maximal at the outer edge of the plate, which may be a source of particle migration within the gap. Settling of particles can also be of concern as it may create a layered sample structure, effectively decreasing the gap size and, in an extreme case, only the liquid phase will contribute to the instrument signal. The measurement is then meaningless as it is calculated assuming uniformity across the pre-set gap height. Settling of particles can be important although it is less of an issue in the cup and bob geometry, also referred to as concentric cylinder geometry.

The temperature of the chocolate sample must be kept constant and uniform. Control tends to be more reliable for the cup and bob geometry compared to parallel plates, where the upper plate is usually exposed to the laboratory environment. Although some modern rheometers feature temperature-controlled covers for the upper plate, this is rarely the case for equipment found in quality control laboratories.

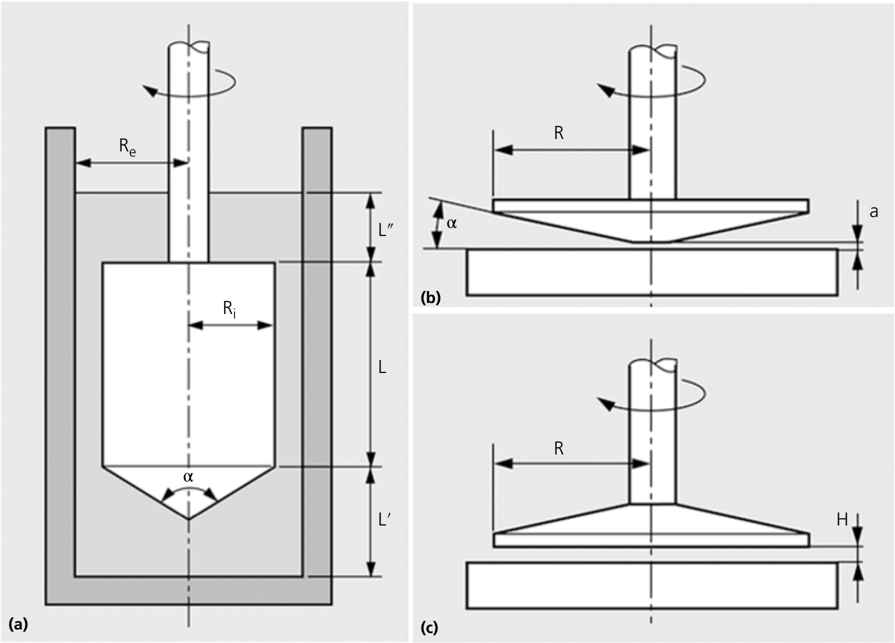


Figure 11.10 Geometries for rotational viscometers: (a) cup and bob, (b) cone and plate, (c) parallel plate. Reproduced with permission from Mezger (2006).

Figure 11.11 Bob types for concentric cylinder viscometers.

When using concentric cylinders, chocolate is poured into a temperature-controlled cup and a bob immersed in it. There are two types of bob in common use, as illustrated in Figure 11.11. As the bob turns there is a situation like Figure 11.2, with a constant distance between two parallel surfaces that are moving at different rates. The apparent viscosity is then directly related to

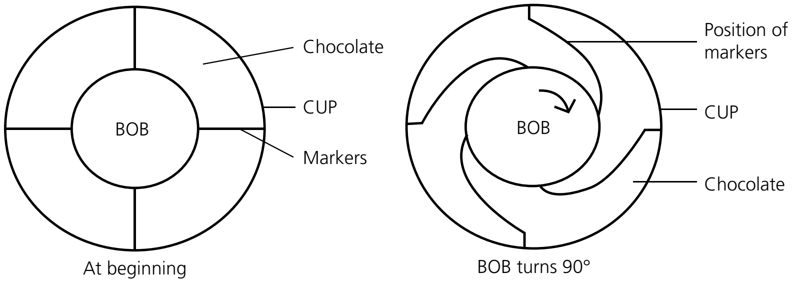


Figure 11.12 Flow in a concentric cylinder gap.

the force trying to stop the bob moving at a given speed. At the base of the bob the flow of the chocolate is different and difficult to calculate. The bobs shown have therefore been designed to minimise this end effect.

It is also important that the chocolate moves uniformly in the gap between the bob and cup. If the gap between the two is too wide this will not be the case, as only the chocolate near the moving bob will be affected, see Figure 11.12. The distance into the chocolate being moved will also depend upon how fast it is turning and upon the viscosity of the chocolate itself. The faster it turns the more of the chocolate within the gap is moved. This means that the lower shear rate (speed) readings are too low. Similarly a thinner chocolate may be measured across the full gap, but a very thick one for only half of it, which makes the thick one appear to be thinner than it actually is. For this reason it is recommended (ICA, 2000) that the ratio of the bob diameter to the cup should be greater than 0.65. There are viscometers available which do not have the outer cup and often have a spindle with a narrow cylinder (sometimes coneshaped). For the above reason they cannot be used to give precise viscosity measurements, especially at low shear rates or over a wide range of viscosities. Their use should be limited to determining whether samples lie within a particular range, which has previously been determined using the viscometer concerned. However, Joye (2003) has published shear rate and viscosity correction factors for a Casson fluid in cylinder geometries. The narrow gap type and a cylinder in a semi-infinite medium such as a spindle rotating within the sample (e.g. Brookfield) are included and the results compared to literature data as well as cone and plate data. For the reasons mentioned above the agreement with cone and plate is not very good at low shear rates.

In the most widely used instruments the internal coaxial bob rotates, with the shear rate being fixed by a drive motor and the shear stress measured by means of a torsion spring connected to the rotating bob. A cross-section of a concentric cylinder gap, including the velocity profile, is illustrated in Figure 11.12 for the case of the narrow gap arrangement. In this arrangement the velocity profile is nearly linear across the gap akin to the two plane model (Figure 11.2).

The narrow gap situation is defined by a maximum ratio of the outer cylinder radius (R_i) to the inner cylinder radius (R_e) of 1.0847 which is often quoted as:

$$\left(R_i/R_e\right)^2 = 0.85 \tag{11.3}$$

The analysis of wide gap situations is more complex and may not be available in the software of commercial equipment if the supplier does not specifically offer large gap geometries. Details of the requirements for the dimensions of a concentric cylinder geometry can be found in rheology textbooks, for example Mezger (2006).

11.6 Vibrational viscometers

During chocolate manufacture, processes involving shaking or vibrating of the product are frequently encountered (Chapter 14) to aid the removal of air bubbles or to level the chocolate in moulds. An overview on the effect of vibration on chocolate has been written by Vavreck (2004). Vibrating a Brookfield viscometer at 50 Hz with an amplitude of 0.12 mm has been shown to remove the yield stress. Other sources quoted by Vavreck showed that the apparent viscosity (at a slow shear rate of 1 s^{-1}) decreased with increasing amplitude of vibration and he postulated that the yield value had disappeared. This was confirmed on both milk and dark chocolate. Here the effect of frequency was found to be more important than amplitude. It was possible to obtain chocolate with a Newtonian flow by vibrating it at 50 Hz and an amplitude of 0.1 mm (0.004 in). The effect was reversible however and the chocolate regained its previous viscosity as soon as the vibration stopped. As an alternative to rotating devices with superimposed vibration, Vavreck described an efflux vibratory viscometer (Figure 11.13) and reported that for milk chocolate that the efflux flow rate was almost linearly correlated to the peak vibration acceleration (Vavreck, 2004). This type of measurement can be used to optimise the operation of shaking machines.

11.7 Oscillatory rheometers

Oscillatory rheology presents an alternative method to unidirectional continuous shear rheology for measuring yield stress of structured materials such as chocolate. It has been reported to differentiate between chocolates that were not different when using the Casson model (De Graef *et al.*, 2011). In this method, the torque or the strain oscillate periodically and the corresponding changing strain or torque response is detected. The phase shift between torque and strain provides information on the flow behaviour of the sample. In the case of fully elastic behaviour the phase shift is zero, while it is 90° for totally viscous samples.

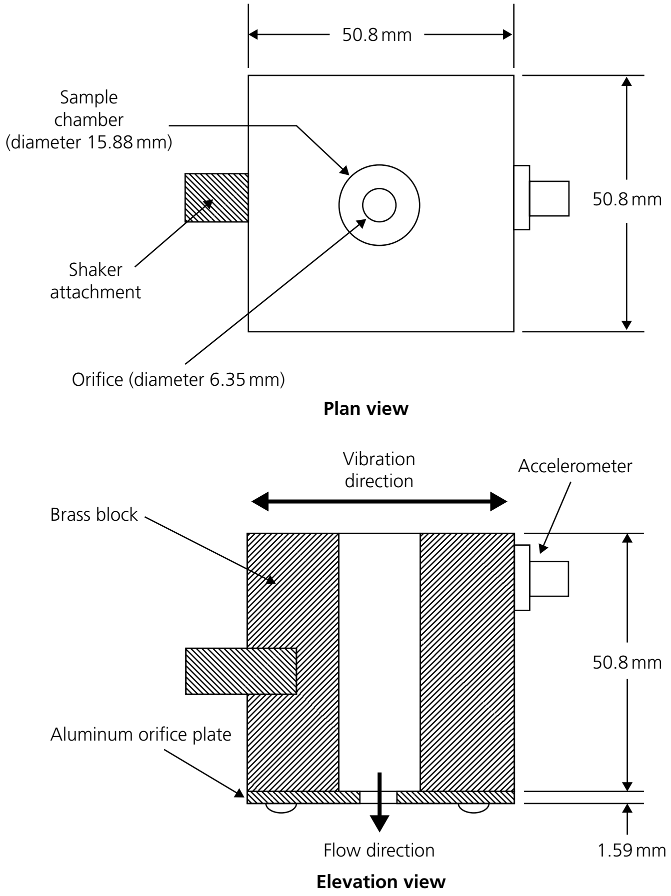


Figure 11.13 Vavreck's efflux vibratory viscometer (Vavreck, 2004; reproduced with permission).

Materials showing phase shifts between 0° and 90° are referred to as viscoelastic. Results of oscillatory rheology tests are often reported as the storage modulus (G′) and the loss modulus (G″), which represent the elastic behaviour and the viscous behaviour respectively of the test material. The reader is referred to rheology textbooks for a detailed introduction to oscillatory rheology (e.g. Mezger, 2006; Goodwin and Hughes, 2008; Rao, 2014).

11.8 Sample preparation and measurement procedures

11.8.1 Sample preparation

The sample being tested must be representative of the chocolate being used. Liquid chocolate should be stirred thoroughly before the sample is obtained and, where possible, it should not be taken from the top of storage tanks, as some separation of fat may have taken place.

The viscosity measurement on chocolate should be made at exactly 40 °C (104 °F). The viscosity changes by between 1 and 4% per °C, depending upon the recipe and the shear rate with the bigger effect being at the higher shear rates. The reason for choosing this temperature is that, at temperatures below about 35 °C (94 °F), crystallisation begins to occur, which makes the viscosity unstable. Above about 45 °C (125 °F) protein reactions within the milk can cause thickening to occur, especially at low shear rates. Dark chocolate is also affected, especially if there is no lecithin present (Chevalley, 1999).

When a sample is taken directly from a conche and provided the temperature has not fallen below 35 °C (94 °F), the measurement may be taken as soon as the sample temperature has reached 40 °C (104 °F). All other samples, whether they are liquid or solid chocolate, must be heated to remove all the fat crystals. Any moisture will thicken the chocolate, so this should be done in dry conditions and never over a water bath. If the chocolate is solid it should be divided into lumps rather than grated and melted in a sealed container in an incubator or oven. The liquid chocolate should be brought to 50 °C (122 °F) and then cooled again to 40 °C (104 °F). A 100 g (3.5 oz) sample of chocolate was found to take 75 min in an oven at 52 °C (126 °F) to reach this temperature (Aeschlimann and Beckett, 2000). Prolonged storage of milk chocolates should be avoided as thickening occurs with time. This is even more likely to happen for white chocolates, which should be stored at a lower temperature. Ideally milk chocolate should not be kept in the liquid state for more than 2–3 h before the measurement is taken. Where the measurement is not going to take place for an extended time, then it is preferable to store a sample in solid form and re-liquefy it, rather than keep it in the liquid state.

11.8.2 Checking the viscometer

If the bob has become scratched or bent it should be replaced. The calibration should also be checked at regular intervals with calibration oil, whose apparent viscosity in the mid-shear rate range is similar to that of the chocolates being tested.

The viscometer cup and bob should be washed and thoroughly dried between samples, as any residual moisture will affect the results.

As noted earlier, temperature has a big effect on the viscosity. The temperature of the fluid being used to heat the cup is often measured elsewhere in the circuit. The actual temperature should be determined by placing chocolate in the cup and measuring its temperature with a calibrated thermometer.

11.8.3 Preconditioning

When the sample is placed in the cup it is unlikely to be at the correct temperature throughout. Chocolate is a poor conductor of heat, so some mixing by stirring with the bob is required. If this is done too vigorously the chocolate will become thinner (chocolate is shear-thinning or thixotropic when it is stirred – see Section 11.2). The chocolate should therefore be stirred at a low shear rate until the shear stress reading becomes stable; and it has also been proposed that the chocolate is being kept at rest for about 30 s before the actual measurement is taken. The method presently recommenced by the International Confectionary Association (ICA, 2000) uses a pre-shear period at 5 s^{-1} to be applied until the viscosity reading is stable at $\leq 2\%$.

11.8.4 Shear rate range

Although in theory the lower the shear rate the better the determination of the yield value, viscosity readings of chocolate at low shear rates tend to be highly irreproducible due to the complex structure of this system. Inter-laboratory trials have shown that 5 s^{-1} can produce repeatable measurements on most viscometers. The highest shear rate will depend upon the thickness of the chocolate and the scale range. It is not advisable to exceed 80% of the full scale reading. Viscometers should be able to provide readings up to about 50 s^{-1} on a standard enrobing or moulding chocolate. This shear rate corresponds to the maximum value recommended in the ICA method (ICA, 2000).

11.8.5 Holding time at the maximum shear rate

Measurements of shear stress can then be taken over a range of shear rates. The increase in rate can be continuous or carried out as a series of steps. After a period at the maximum shear, the measurements are repeated as the shear rate is reduced again. At the maximum shear rate, the shear stress will slowly decrease due to the thixotropic nature of chocolate. It is impractical to wait for a long time in the middle of the measurement until this decrease has stopped. The final measurement therefore depends upon the time the viscometer remains at this shear rate. It is therefore necessary to standardise this when carrying out comparative measurements. Normally this should be of the order of 1 min (ICA, 2000).

11.8.6 Hysteresis

If the shear stress is plotted against the shear rate for both ascending and descending curves, it is often found that the descending values are lower at a particular shear rate for most of the curve. The difference between the two is known as hysteresis and is a measure of how well the chocolate has been processed. A poorly mixed or conched chocolate will have a big difference between the two curves. In this case the chocolate is being further processed by the shear within the viscometer itself.

11.8.7 Overall measurement time

The overall measurement time will also affect the final result (Aeschlimann and Beckett, 2000) and so needs to be standardised. The ICA standard method (ICA, 2000) recommends an overall time of 7 min, comprising of 3 min of ascending shear rate, 1 min at maximum shear rate, followed by 3 min of descending shear rate.

11.9 Factors affecting the flow properties of chocolate

A major reason for being able to measure the viscosity of chocolate is to be able to correct it when production difficulties occur. Some may relate to the yield value rather than the plastic viscosity and vice versa. In order to correct it, it is therefore important to know which factors affect the flow property concerned. Some of these factors are therefore described in the following sections.

11.9.1 Fat content

It is useful to consider the microstructure of chocolate in order to understand how it flows. This is illustrated schematically in Figure 11.14. It is the liquid fat (both cocoa butter and milk fat) that enables the chocolate to flow. In weight terms it constitutes about one-third of the chocolate, but in volume terms (because fat has a lower density) it is almost one-half. As the fat content increases the distance between the solid particles increases so the viscosity drops. Some of the fat is bound by and within the particles (see Chapters 3 and 5) and so does not aid the flow. If a chocolate is too thick, the further grinding of the cocoa liquor or the use of an alternative milk powder source should be considered.

It is the free fat that enables the chocolate to flow and if the total fat content is low (e.g. about 25%) then the proportional increase in free fat content of an extra 1% of cocoa butter is going to be a lot greater than for one with 35% fat content. This means that the effect on viscosity of additional cocoa butter is much greater at lower fat contents and becomes very small indeed above 35%, as illustrated in Figure 11.15 (Chevalley, 1999). The yield value arises mainly from the inter-particle interactions and is less affected than the viscosity value by the addition of fat. Where the yield value is incorrect, other such factors should be investigated.

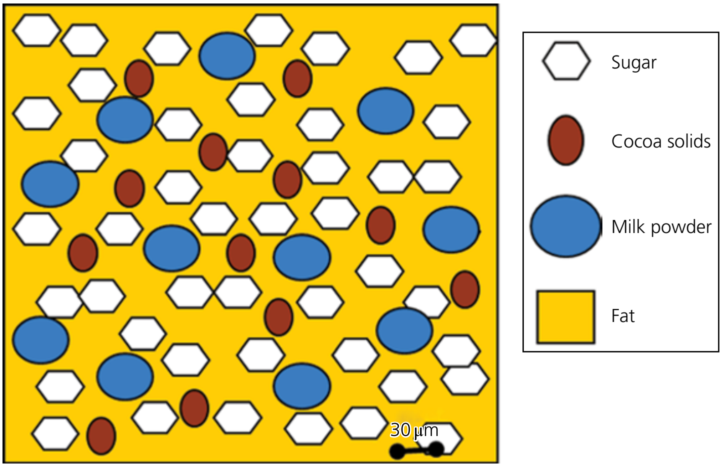


Figure 11.14 Schematic representation of the solid particles and fat within a milk chocolate.

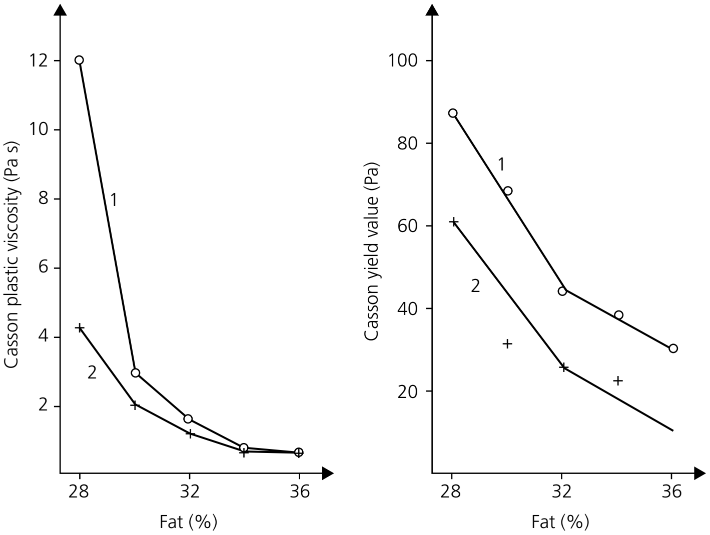


Figure 11.15 Influence of fat content on the Casson viscosity parameters in two milk chocolates with 0.25% lecithin: (1) fine chocolate with 5.7% particles > 20 μm, (2) coarse chocolate with 16% particles > 20 μm (Chevalley, 1999).

All the factors tend to be interrelated. In Figure 11.15 it can be seen that the magnitude of the effect of adding extra fat depends upon the particle size.

11.9.2 Particle size distribution

It is necessary to grind all the sugar and other solid particles below about 30 μm to avoid the chocolate tasting gritty. Granulated sugar has a diameter of about 1 mm (0.04 in) so must be broken many times during the chocolate production. Each time it is broken new surfaces are created, which have to be coated with fat (Figure 11.14), so in general the finer the chocolate the higher the viscosity. Particle size, like viscosity, is not a single parameter but a distribution, which can be measured for example using laser light scattering devices (Chapter 24). This type of instrument is able to show the distribution from sub-micron to above a millimetre. The percentage of larger particles is required to determine the textural roughness of the chocolate. Another parameter that the instrument calculates is the specific surface area, which relates to the surface area of solid particles which must be coated with fat.

As the chocolate is ground finer, there are more particles to interact so the yield value is increased. In practice the effect upon the yield value is much greater than for the plastic viscosity (Figure 11.16; Chevalley, 1999). The yield value normally correlates with the measured specific surface area. This is not the case for the Casson plastic viscosity, however, where at very large particle sizes the plastic viscosity can indeed increase again. This may be due to increasing amounts of bound fat or to how the solid particles pack themselves together.

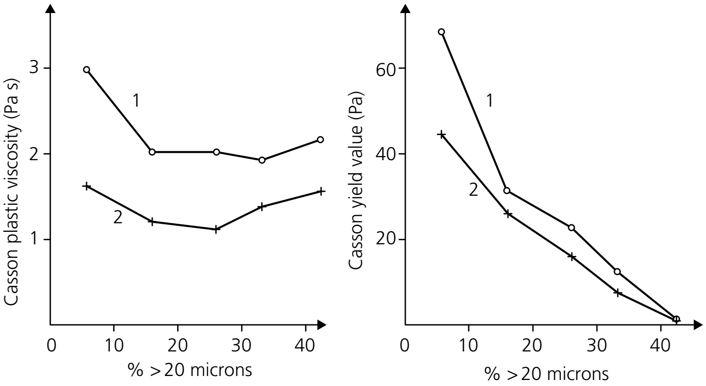
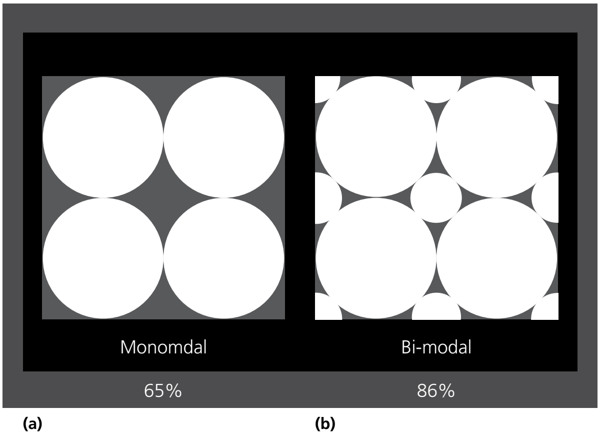


Figure 11.16 Influence of particle fineness on the Casson viscosity parameters in two milk chocolates with 0.25% lecithin: (1) 30% fat, (2) 32% fat (Chevalley, 1999).

Figure 11.17 Illustration of the packing of spheres that are: (a) all the same size, (b) two different sizes.



If spherical particles all of a similar size are packed together, a lot of space will remain between them, which must be filled with fat or smaller particles (Figure 11.17). In the extreme of having a lot of larger particles or chocolates with very few very fine ones, further grinding will reduce the viscosity. This is however very unusual.

Where an industrial chocolate is found to have a very high yield value, but the plastic viscosity is correct or only slightly high, then the particle size should be investigated as it is possible that the grinding procedure is producing an excessive proportion of fine particles. A high yield value can be counteracted by the use of a surface active agent.

11.9.3 Surface active agents (emulsifiers)

Although it is necessary to coat sugar particles with fat, this is not always easy as the sugar surface is lipophobic, that is it tries to repel the fat. To smoothly combine sugar and fat and thus enable the mass to flow, surface active agents, normally

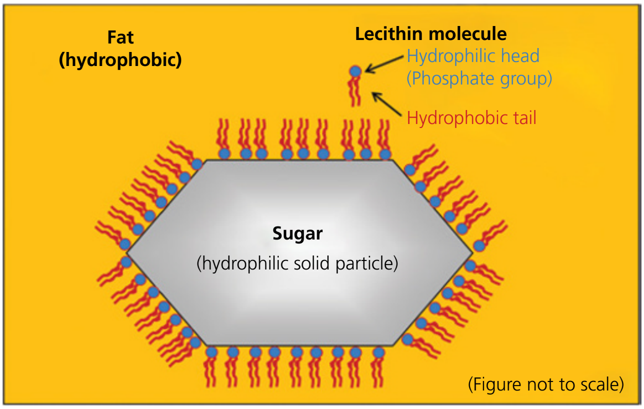


Figure 11.18 Schematic diagram of lecithin molecules around a sugar particle.

known as emulsifiers, are added to the formulation. These amphiphilic molecules adsorb with their hydrophilic (water liking) part onto the sugar surface and the lipophilic (fat-liking) end reaches into the fat separating individual sugar particles (see Figure 11.18). This prevents the formation of sugar aggregates with entrapped fat that is then not available to contribute to the flow properties. Emulsifiers may act on the other particulate ingredients in chocolate although they are understood to predominantly adsorb onto the sugar. The most common emulsifier is lecithin, which has been used in chocolate since 1930. It is naturally occurring, often produced from soya. Soya lecithin aids the flow properties to such an extent that, for additions of up to about 0.3%, it has an effect equivalent to 10 times this weight of cocoa butter. As with cocoa butter additions, the higher the viscosity, the more effective is the addition of the emulsifier (see Figure 11.19). Unlike cocoa butter however, further additions of lecithin can cause the yield value to increase. This may be due to lecithin particles attaching themselves to each other and forming new particles called micelles, or due to the lipophilic ends attaching themselves to the lipophilic ends of a second layer of lecithin and reducing its effectiveness. The point at which this occurs depends upon the surface area of the solid particles being coated. A fine chocolate with high sugar content can therefore tolerate a higher lecithin level than a coarse one or one with lower sugar content. In addition it will depend upon the type of lecithin used.

What is termed lecithin is in fact a mixture of phospholipids, glycolipids, triglycerides, carbohydrates, some water, sterols and free fatty acids. The phospholipids are the predominant amphiphilic compounds and lecithin can vary in the amount and composition of phospholipid present. To optimise industrial chocolate flow, it may be beneficial to use a standardised fractionated lecithin (van Nieuwenhuyzen and Tomas, 2008). The phosphatidylcholine part of lecithin has been shown to be particularly effective in reducing the plastic viscosity of some dark chocolates (van Nieuwenhuyzen, 1997), whereas other fractions are less effective than standard lecithin in reducing the yield value.

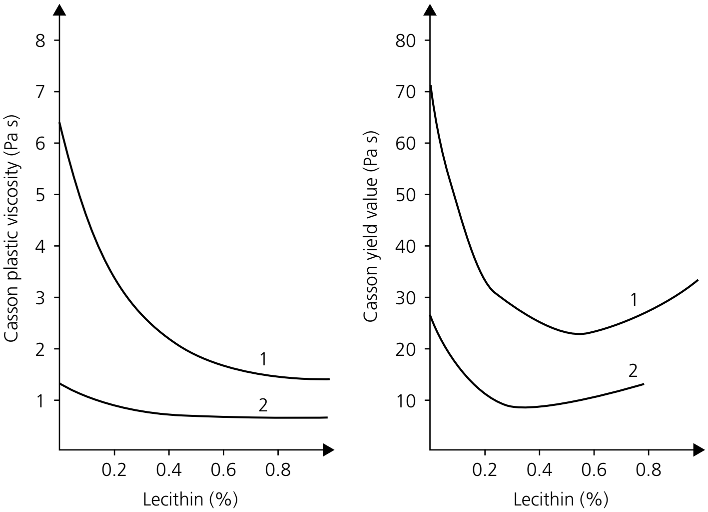


Figure 11.19 Influence of soya lecithin addition on the Casson viscosity parameters in two dark chocolates: (1) 33.5% fat, 1.1% moisture; (2) 39.5% fat, 0.8% moisture. Source: Finke (1965). Reproduced with permission of Springer.

An investigation into the impact of the individual phospholipids and binary mixtures on the rheology behaviour of a chocolate model (sugar in oil suspensions at 0.31 solid volume fraction) has shown that, at low concentration, binary mixtures are more efficient in reducing yield stress than the individual phospholipids (Arnold *et al.*, 2014). The authors also assessed the adhesive interactions between sugar surfaces using atomic force microscopy and correlated these with the rheology of the suspensions.

In addition to lecithin, other surface-active agents have been developed for chocolate. One of the most widely used is the synthetic lecithin YN. It is obtained from partially hardened rapeseed oil after glycerolysis, phosphorylation and neutralisation. YN is more consistent in composition than soya lecithin; its flavour is bland and neutral; its efficiency is said to be greater than that of soya lecithin and, at levels above 0.3%, no thickening occurs. When compared with soya lecithin, YN can sometimes have a stronger effect on $\tau_c\alpha$ than on $\eta_c\alpha$ (see Table 11.1). Concern about genetically modified soya has led to increased interest in YN and lecithin produced from other crops such as sunflower.

Another widely used emulsifier is polyglycerol polyricinoleate (PGPR), sometimes known as Admul-WOL. PGPR has the ability to strongly reduce or even cancel the yield value of chocolate (Table 11.1). This useful property is exploited by the confectioner in such applications as the moulding of Easter egg shells and also for correcting the viscosity of a chocolate that has too many fine particles, or indeed if too much lecithin has been added. A combination of lecithin and PGPR can in fact produce good flow properties, especially in low-fat chocolates. It is possible to purchase this combination as a mixture.

Table 11.1 Flow characteristics of plain chocolate with added emulsifiers at 50 °C. *Source*: Harris (1968). Reproduced by permission of the Society of Chemical Industry.

Addition	Casson plastic viscosity (Pa s)	Casson yield value (Pa)
0.3% soya lecithin	0.6	9.2
0.3% YN	1.03	3.0
0.3% sucrose dipalmitate	0.9	16.6
0.3% PGPR	3.25	2.5
0.8% PGPR	2.0	0

Other emulsifiers include citrem, sorbitan tristearate, sucrose esters and calcium-stearoyl lactoyl lactate. Citrem (citric acid ester) has the properties of the lecithin/PGPR combination, whereas sorbitan tristearate is an emulsifier which is used to reduce bloom formation in vegetable fat chocolates rather than to control viscosity.

Emulsifiers sometimes affect the tempering of chocolate, which in turn affects the flow properties of the tempered chocolate (Dhonsi and Stapley, 2006; Radujko *et al.*, 2011; Hartel 2013). The effect of the emulsifier on chocolate flow is normally evaluated on un-tempered chocolate, as in Figure 11.19, but it is useful to check the results on tempered chocolate. It should also be noted that over-tempering thickens chocolate and can cause a low viscosity chocolate to become unusable.

The stage in the process at which the emulsifier is added is a very important factor, for example lecithin added towards the end of conching reduces viscosity by a greater amount than when exactly the same amount is added at the start. The reason for this is that, as the action of lecithin is a surface effect, if it is added to the mass too early, some of it may (by prolonged mixing and grinding) be absorbed into the cocoa particle, thus reducing its efficiency (Weyland, 2008). It is also known that exposure to relatively high temperatures for long times reduces lecithin performance. In addition it can reduce the work input provided by the conche.

11.9.4 Conching

In addition to the time of addition of the fat and emulsifier, the time and intensity of the conching have a big effect on the final chocolate viscosity. The longer a chocolate is conched normally the thinner a chocolate becomes. However with increased time the lowering of viscosity becomes less significant or economic. The intensity governs the rate at which the solid particles are coated with fat. This is normally governed by the conche design but can be helped by changing the amount of material in a conche and the time and order in which the fats and emulsifiers are added. A low intensity conche will never produce as thin a chocolate as a high intensity one however long it is operated. As noted earlier

(Section 11.8), poor conching results in big differences between the up and down measurements of a viscometer. Further details concerning the effect of conching parameters on chocolate viscosity are given in Chapter 10.

In addition to coating particles, conching also removes moisture from the chocolate mass, which also has a big effect on viscosity.

11.9.5 Moisture

If a small percentage of moisture is added to chocolate it will become very thick. Indeed if as little as 0.3% extra moisture is left within the chocolate, it will be necessary to add another 1% of cocoa butter to restore the viscosity to what it should have been. This is probably in part due to water on the surface of the sugar particles, sticking them together and impeding the flow. Where lecithin is also present this is less likely to happen and indeed chocolates containing this emulsifier can have more water present and yet retain their correct flow properties. However, lecithin can have a negative effect during conching as its hydrophilic properties will reduce the amount of water evaporating from the mass.

Below the 1% level, however, most of the moisture is bound into the ingredients, for example as water of crystallisation in lactose, and so has little effect on the flow properties.

11.10 Advanced methods to characterise chocolate flow behaviour

Advanced methods to characterise the viscosity behaviour of chocolate include nuclear magnetic resonance (NMR) and ultrasound. These methods are not designed for routine laboratory analysis but have research and trouble-shooting applications.

Gotz *et al.* (2005) applied NMR T1 and T2 relaxation time measurements to chocolate model suspensions composed of fat blended with different emulsifiers, sucrose and skimmed milk powder. T2 was found to be more sensitive to the addition of solid material than T1. Only a small impact of emulsifier on the relaxation times was noted. The relaxation times were reported to correlate with zero shear and infinite shear viscosity determined with rotational and capillary rheometry.

Ouriev *et al.* (2003) described an industrial non-invasive trial which measured ultrasound velocity profiles and pressure differences (UVP-PD) in an untempered chocolate. The velocity profiles were fitted to a power law model and wall shear stress calculated from the pressure difference measurement. Good agreement was obtained with laboratory viscosity data and the UVP-PD method was also able to generate information on processing behaviour that could not be obtained by other techniques.

Conclusions

The flow properties of chocolate are very complex. However, an understanding of both flow property measurement and the factors affecting the flow can greatly help trouble-shooting and plant optimisation.

It is always important to measure the flow properties of chocolate under conditions that are as close as possible to those under which it is being processed. Where faults occur, corrective action should be taken according to the flow parameter that is incorrect, for example add PGPR for a high apparent viscosity at a low shear rate (Casson yield value), or cocoa butter for a high reading at a high shear rate (Casson plastic viscosity).

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CHAPTER 12

Bulk chocolate handling

John H. Walker

12.1 Introduction

The output from chocolate manufacturing plants has continued to increase and this, coupled with a demand for higher rates of productivity, has resulted in the transport of ingredients and finished masse becoming more important. Wheeled tanks and the transport of solid blocks of material have often been replaced by the use of pumps and heated pipework. Within large confectionery factories the flow rate of chocolate in the pipelines can be as high as 10 t/h and the distance which it is transported is often 200 m (600 ft) or even more. It is important, therefore, that the pump and pipe system is designed to meet the expected duty. Liquid chocolate is a non-Newtonian fluid and this means that both the yield value and the plastic viscosity and operating temperature (see Chapter 11) must be considered when specifying the chocolate delivery system.

There are many different types of pump that can be used to transport chocolate, each with its own advantages and disadvantages. In addition, there are numerous applications for pumps, ranging from the metering cocoa liquor to pumping tempered chocolate, which means that many different types of pump are employed in a single manufacturing plant. The purchase cost of the pump may also influence the choice, however it should be remembered that the incorrect choice could lead to considerable problems.

12.2 Viscosity and viscometry

12.2.1 What is viscosity?

It is easy to tell the difference between a thin and thick chocolate, but difficult to quantify viscosity in a meaningful way except by using specialised instruments. It is important to understand the influence of the chocolate viscosity since a high viscosity chocolate requires more power to pump than a low viscosity one. Knowing its rheological behaviour therefore, is essential

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

when designing pumping and piping systems. When specifying pump requirements to a supplier, it is always necessary to quote the expected viscosity and temperature variations, together with the flow rate and pressure limitations for sensitive ingredients or vulnerable equipment such as tempering machines.

Viscosity is the measure of the internal friction of a chocolate. This friction becomes apparent when a layer of chocolate is made to move in relation to another layer. The greater the friction, the greater the amount of force required causing this movement, which is call "shear". Shearing occurs whenever the chocolate is physically moved or distributed, as in mixing, pumping, stirring, depositing and so on. Highly viscous chocolate, therefore, requires more force to move than less viscous chocolate.

Isaac Newton defined viscosity by considering the model shown in Figure 12.1. Two parallel planes of fluid of equal area "A" are separated by a distance "dx" and are moving in the same direction at different velocities "V1" and "V2". Newton assumed that the force (F) required to maintain this difference in speed was proportional to the difference in speed through the liquid, or the velocity gradient at the part of liquid under consideration.

The velocity gradient, (V2–V1)/dx, is a measure of the change in speed at which the intermediate layers move with respect to each other. It describes the shearing the liquid experiences and is thus called the "shear rate" and is often symbolised as "D".

Its unit of measure is the reciprocal second "(centimetre per second) per centimetre" (or, more simply, s^{-1}).

The term F/A indicates the force per unit area required to produce the shearing action and is known as the shear stress (τ).

Newton stated that the coefficient of viscosity remained the same at varying flow rates, but this only applies to Newtonian fluids at a fixed temperature. Using these simplified terms, viscosity (η) may then be defined mathematically by this formula:

Viscosity $= \eta = \tau/\mathrm{D} =$ shear stress/shear rate

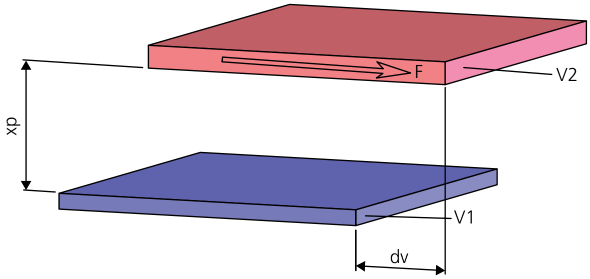


Figure 12.1 Diagram illustrating shear.

For confectionery products the units of viscosity are usually: centipoise, poise or Pascal seconds.

If η is a constant and does not vary with changing values of D, then the fluid is Newtonian. A Newtonian liquid is therefore one for which the graph of shear stress plotted against the rate of shear is a straight line, for example glucose syrup. For such materials the pump supplier only needs one viscosity figure at the temperature of use. *Note*: viscosity can vary a lot with temperature, so it may be necessary to carry out several measurements.

A non-Newtonian fluid is defined as one in which the relationship of shear stress/rate of shear is not a constant, as is shown in Figure 12.2. In other words when the shear rate is varied, the shear stress does not vary in the same proportion. The viscosity of such fluids will therefore change as the shear (flow) rate is varied. The measured viscosity at any particular shear rate is known as the "apparent viscosity" at that shear rate. The value of the shear rate should always be quoted. When providing the viscosity specification to a plant designer, measurements should be obtained at both a high and a low shear rate. The type of viscometer that is used can also affect the measurement obtained (see Chapter 11).

12.2.2 Laminar and turbulent flow

The flow of a fluid down a pipe may be either laminar or turbulent. In laminar (streamline) flow, the molecules within fluid follow well defined paths, which may converge or diverge, but their motion is in the general direction of the bulk flow. The viscosity is dependent upon temperature but largely independent of pressure and surface roughness.

If the shear rate becomes very high however, the movement of the molecules within the fluid becomes more random and some molecules can even move in the opposite direction to that in which they are being pumped and the flow becomes turbulent. This should never be allowed to happen within a chocolate pipeline as it can cause damage to the system. The shear stress down a pipe is proportional to its diameter, so larger pipes should be installed if any turbulence occurs. In addition, since many of the chocolate pumps and pipeline fittings available are only suitable for working pressures of 10 bar maximum, it is advisable to size the pipeline to be big enough to operate below this limit.

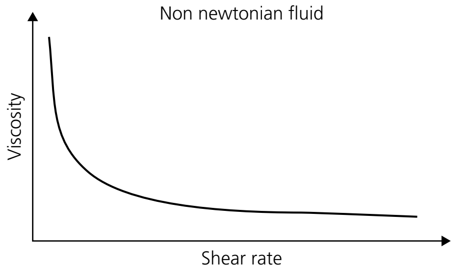


Figure 12.2 Diagram illustrating non-Newtonian flow.

12.3 Pump sizes

12.3.1 Power

The power requirement for the pump has to take into account the work required to make the chocolate flow and other frictional inefficiencies, such as those arising from gearboxes, belt drives and the internal friction of the pump bearings and seals. These vary greatly between the different types of pumps that are used.

Never size a pump using the viscosity of chocolate measured for standard operating conditions. Allowances must be made for start-up conditions, particularly after shutdown periods such as weekends and holidays. If the chocolate is not constantly moved in the pipeline or storage tank, sedimentation of the solid particles within the chocolate may occur. This can result in an increase in the system pressure or even blocking of the pump.

12.3.2 Speed

The speed at which the pump operates should be as low as possible without causing the pump to "slip" excessively. Slip is chocolate leaking from the pressure outlet to the inlet due to the internal clearances within the pump. Some chocolates are shear sensitive and can have their viscosity changed by over shearing by the pump. Excessive speeds can also produce heat which may result in caramelisation of the chocolate, which in turn may eventually lead to the pump seizing. The life of the pump and the seal can also be extended by operating the pump at low speed.

Many chocolate pumps are built to a special configuration using large internal clearances between the fixed and rotating parts within the pump and are designed to minimise the damage caused by frictional heat to the chocolate whilst at the same time maintaining operational efficiency.

12.4 General criteria for choosing a pump

All pumps must have a means of keeping the chocolate warm when they are not in operation. This is usually achieved by the means of a hot water jacket or saddle built into the pump.

When choosing a pump for the transport of chocolate or chocolate ingredients the following criteria should be considered.

- The quantity of chocolate the pump it is required to deliver;
- The pressure the pump will need to overcome (pressure drop in pipeline);
- The accuracy to which the pump will need to operate (e.g. metering cocoa mass);
- The type of seal arrangement (e.g. gland packing, lip seal);
- The operating control of and shear action of the pump (heating caused by excessive shear may cause caramelisation);

- The length of time the pump will be required to operate without stopping (e.g. ring main where the pump operates 24 h for 7 days every week), or intermittent batch operation such as discharging a conche;
- If inclusions are to included in the chocolate the pump will be required to accommodate this;
- The material in contact with the chocolate: cast iron pumps are normally satisfactory, but stainless steel may also be used.

12.5 Types of pump

There any many different types of pump used in the manufacture of chocolate, but most fall into the following categories:
- Gear pumps;
- Sliding vane pumps;
- Lobe and rotary piston pumps;
- Screw pumps;
- Progressive cavity (mono) pumps;
- Pawl pumps;
- Positive displacement piston and diaphragm.

12.5.1 Gear pumps

Internal gear pumps are suitable for use with high viscosity chocolates. In addition they provide a non-pulsating flow and are self- priming. Because they have only two moving parts they are reliable, simple to operate and easy to maintain (Figure 12.3). By reversing the drive motor the pump can operate in either direction. This facility is particularly useful to drain a tempering machine prior to a change of chocolate.

There are several types of gear pumps, but the most common types found in the confectionery industry are the simple spur gear pump and the internal gear pump. The spur gear pump has two meshing gears that revolve in opposite

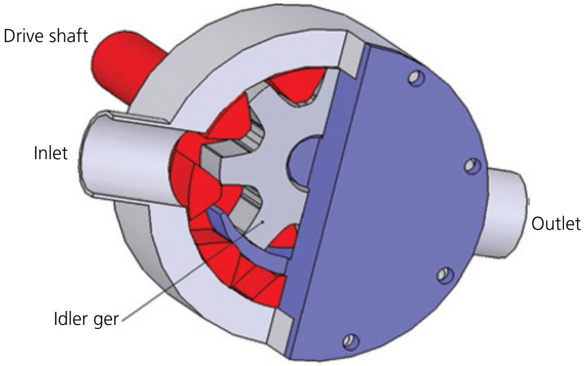


Figure 12.3 Internal gear pump.

directions and has a very small clearance between the gear and the body of the pump. The chocolate, that fills the cavity between two successive gear teeth, must follow the rotation of the gear. When the gear teeth mesh together, the space between the teeth is closed and the entrapped chocolate is pushed out. As the gears revolve and the teeth disengage, the space on the low pressure side of the pump is created, trapping new quantities of chocolate.

12.5.2 Sliding vane pump

In a sliding vane pump the eccentric (off-centre) rotor incorporates sets of sliding vanes, which mechanically displace the fluid (Figure 12.4). Internal clearances although small, are required in this type of pump and therefore they cannot be truly classified as positive displacement pumps since slippage will occur. By design this system of displacement creates a pulsation in the discharge flow from the pump. However these pumps can handle solids entrained in the chocolate.

These pumps are less suitable for applications that involve very high throughputs, high viscosity, or large pressure drops, for example pumping over long distances.

12.5.3 Lobe and rotary piston pumps

Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the pump body (Figure 12.5). However in this case the lobes are prevented from making contact with each other by timing gears located in the external gearbox.

Rotary lobe pumps can handle large inclusions with minimal damage and a gentle pumping action minimises product degradation. They are usually made from stainless steel and therefore can be cleaned with water. When the rotors have a covering of chocolate then the air gaps around them become "sealed". This improves the efficiency of the pump to self-prime.

A lobe pump should not normally be used to move white chocolate, since severe caramelisation of the chocolate can occur in the area of the lobe lock nut

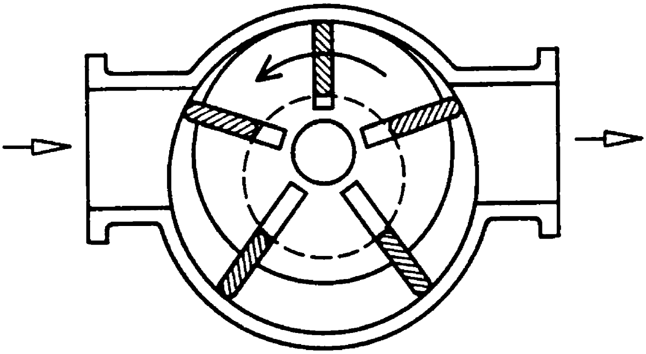


Figure 12.4 Mode of operation of a vane pump.

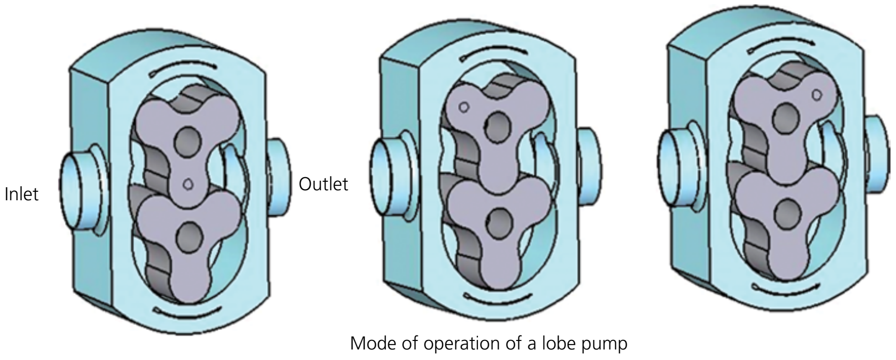


Figure 12.5 Mode of operation of a lobe pump.

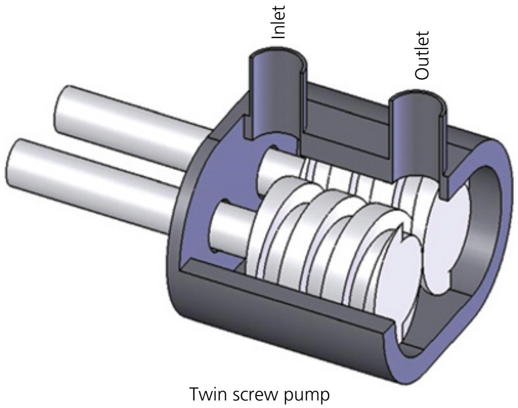


Figure 12.6 Illustration of twin screw pump.

housing. (The front plate of the pump is recessed to fit around the locknut, and it is in this recess where chocolate can become heat-damaged.)

12.5.4 Screw pump

Screw pumps have been used for many years in the conveyance of bulk chocolate. They normally have two or three rotors. A twin-screw system is illustrated in Figure 12.6. As the twin screw systems is driven by a set of gears, situated in the gearbox, there is no contact between the two pumping screws. These pumps can operate equally well when driven in reverse and at low speed offer a gentle pumping action, together with a uniform flow with little pulsation or turbulence. They are available either manufactured from cast iron or stainless steel. Some designs can cope with inclusions in the product of up to 5 mm (0.2 in).

The three rotor design comprises of a central rotor, which is connected to the drive motor and two idling satellite rotors which are driven by this central rotor. The rotors are encased in a closely fitting steel housing. The rotors are free to mesh together (there are no external timing gears). This therefore consists of a sealed chamber through which the chocolate is conveyed. When the centre rotor is turned by the drive shaft these sealed chambers receive the chocolate to be pumped at the suction side of the pump and convey the medium in a uniform (non-pulsating) flow to the discharge port.

12.5.5 Pawl pumps

This type of pump is frequently used as a circulation pump in chocolate enrobers or to pump tempered chocolate. A gentle action is achieved by having a high conveying volume within the pump but operating at a very low speed. The central rotor is shaped so that two swept volumes of material are present within the pump. As the rotor turns, the material is pushed round the pump until it comes up against a scraper blade (Figure 12.7). This is forced against the rotor by a spring, which diverts the flow to the outlet and prevents the chocolate from re-circulating back in to the suction area.

These pumps are suitable for medium pressure applications with or without inclusions such as nuts and raisins.

12.5.6 Progressive cavity pump

The progressive cavity pump, often referred to by the specific makers name such as Moyno, has a single helical rotor rolling eccentrically in a double thread helix of twice the pitch length. When the rotor turns it forms a series of sealed cavities, 180° apart, these progress from suction to discharge as the single helix rotates. As one cavity diminishes, the opposing cavity is increasing at

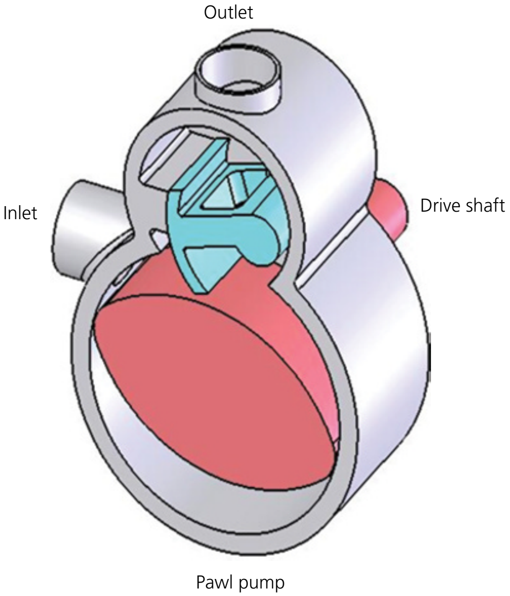


Figure 12.7 Operating principle of a pawl pump.

exactly the same rate: so the sum of the two is constant. This results in a pulsation-free flow which may contain particulate matter. The rotor is usually manufactured from hardened stainless steel and the stator from natural or synthetic rubber.

During continuous operation in a large-scale chocolate plant, wear of the stator may become a problem. This type of pump is versatile in small scale or pilot plants and it has been successfully used for metering applications. By increasing the length of the rotor–stator assembly it is possible to produce pumps for system pressures in excess of 30 bar.

12.5.7 Positive displacement piston and diaphragm pumps

The construction of this type of pump is illustrated in Figure 12.8. As the piston draws back, the lower valve lifts and liquid is pulled into the space created. On the return stroke, the lower valve is closed and the upper valve is opened, releasing the product in to the pipeline. By adjusting the rotational speed of the drive or the amount of eccentricity of the drive wheel, an accurate quantity of liquid can be displaced. This accuracy enables this type of pump to be used as a metering pump for cocoa mass and butter. In these cases the quantity of material to be moved is relatively small and the viscosity is low. However care should be taken when choosing this type of pump liquids that contain solid particulates such as nuts, which can catch in the valves.

Diaphragm pumps use positive displacement to move liquids. They are similar in construction to the piston pump, but are designed with a diaphragm that seals the pumping chamber from the piston. This eliminates the problem of sealing the reciprocating piston, minimising the possibility of leakage. The diaphragm is moved by means of a mechanical linkage, compressed air or a food grade liquid. Diaphragm pumps will stall if the outlet pressure becomes too great. They can also be used to pump chocolate with solid inclusions.

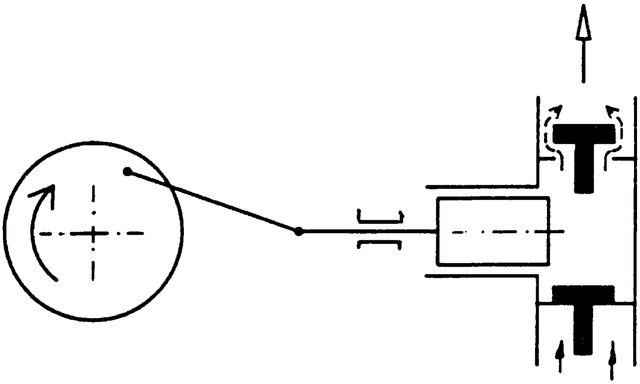


Figure 12.8 Positive displacement reciprocating plunger pump.

12.6 Pipeline pigging

Pipeline pigging was developed in the United States to clear the debris in crude oil pipelines. They are now widely used to clear pipelines carrying chocolate. The term “pig” comes from when the device was first used to clear a pipe carrying a product with poor lubrication properties. The lack of a lubricant caused the projectile to squeal like a pig.

A pig acts like a free-moving piston inside the pipeline, sealing against the inside wall with a number of elements, and is propelled along the pipe by either compressed air or by other product. The compressed air used should be filtered to meet all hygiene requirements. The pig pushes any residual product from the pipe and via an open valve into a receiving tank. This technique allows a single pipe to be used to sequentially carry many batches of products with fast change-over times and without the lengthy process of disassembling the pipeline for cleaning. A diagram illustrating a pigging system is shown in Figure 12.9.

The pig should be manufactured from the correct grade of food compatible plastic such as polyurethane or neoprene; any swelling or change in colour of the pig could be caused by the absorption of fat or the leaching out of plasticisers into the chocolate.

Pigs generally need specially designed launching and receiving vessels and valves to introduce them into the pipe work. The pipeline should be designed in such a way as to not have any obstructions that may impede the movement of

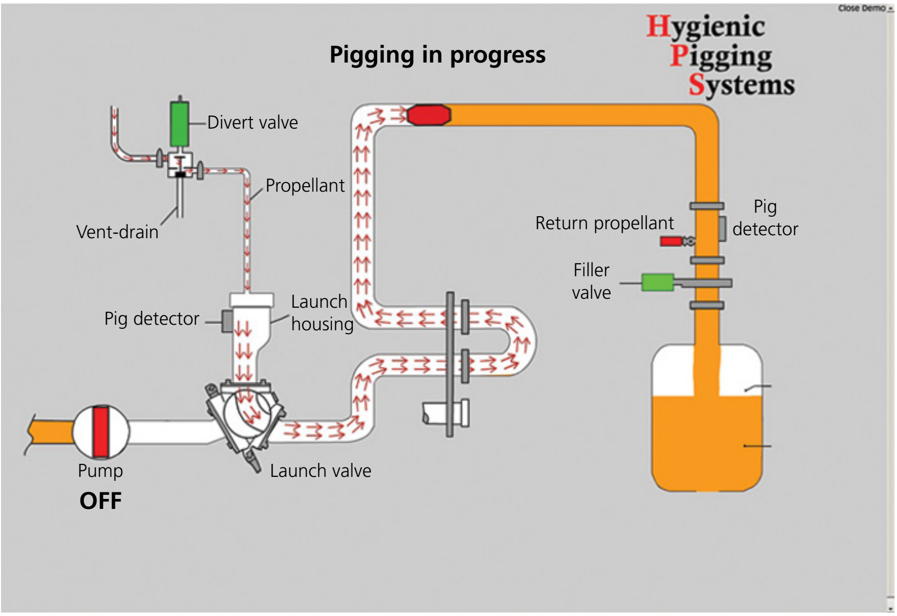


Figure 12.9 Diagram of pigging system.

the pig along the pipeline. All “T” junctions and “Y” type fittings may have to have rails or bars welded across the openings to guide the pig past them. All in-line valves must be of the full port design with a 100% pipe size opening.

12.7 Storage of liquid chocolate

Liquid milk chocolate should be stored at 40–45 °C (103–110 °F) and white chocolate from 38–40 °C (100–103 °F). In all cases however, care should be taken to ensure that the temperature of the chocolate is uniform throughout. Hot or cold areas can give rise to several problems and it is for this reason that the storage tank is constructed with a water-heated jacket. As in pipelines temperature control is important. At low temperatures the chocolate becomes viscous, making it difficult to stir and pump. There is also the possibility that if the chocolate becomes too viscous the stirring mechanism may be damaged.

The liquid chocolate in any tank or vessel requires agitation and a slow-moving low shear stirrer must be mounted on to the top of the vessel. Failure to do so results in fat separation from the chocolate. In extreme cases the sediment can cause damage to the pump and will prevent the flow of chocolate out of the tank. The rotational speed of the tank stirrer depends upon the diameter of the tank and the quantity of chocolate being stored. Recipes and manufacturing process also play an important part: some chocolates become thinner while others thicken. If the stirrer speed is insufficient a puddle of fat will appear on top of the chocolate.

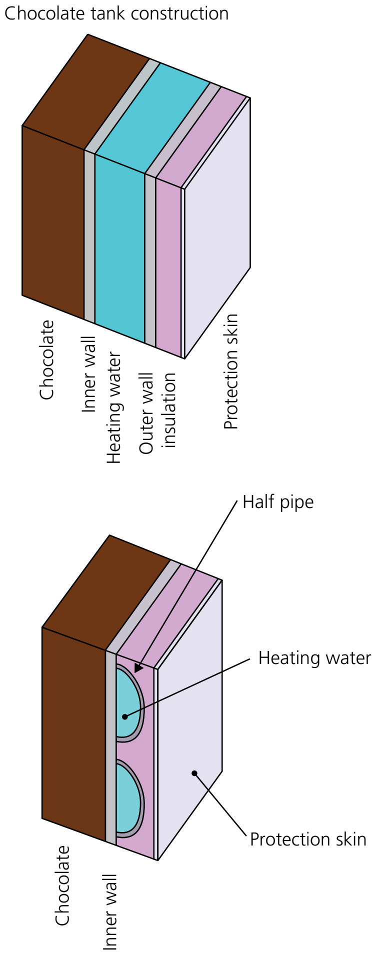
The above recommendations also apply to the bulk transportation of chocolate in road tankers. These are sometimes heated or have localised heaters, resulting in hot spots.

Chocolate that is shaken in unstirred tanks during transportation is also more likely to separate and have a fat layer on top. Some further mixing may therefore be required at the receiving factory.

The equilibrium relative humidity of most chocolate at 40 °C (103 °F) is about 30%. This means that, if the relative humidity in the area where the chocolate is being stored is above 30%, the chocolate will pick up moisture and this will increase the viscosity of the chocolate. Many tanks, especially those with built-in sieves are open to the atmosphere, therefore it is important to control the humidity of the room where the storage tank is sited, to avoid moisture pick-up. It is recommended that liquid chocolate should have the minimum storage time possible.

Tanks manufactured from mild or stainless steel are used for the storage of chocolate and these can be constructed with a double skin jacket, a dimple jacket or a half-pipe jacket (see Figure 12.10). The tank should be insulated to conserve energy and to eliminate any cold spots. The water jacket of the tank, together with any associated jacketed pipe work, should be periodically examined for corrosion.

Figure 12.10 Illustration of sections through the walls of chocolate storage tanks.



It is important to remember that, if the equipment that maintains the temperature of the chocolate in the tank should fail, the chocolate will eventually solidify and the stirrer motor will be overloaded. Not only could this condition result in damage to the tank stirrer, its gearbox and motor it would also require that the tank is emptied by manual labour. If chocolate is allowed to solidify in a tank the heating systems generally do not have sufficient power to re-melt the chocolate. It is recommended that monitoring devices are fitted to the heating systems to warn the operating staff when a breakdown occurs.

12.8 Jacketed pipe work

Jacketed pipe (Figure 12.11) can be manufactured from either mild steel or stainless steel. If mild steel is used the pipe will be joined with flanges and gaskets. For stainless steel pipes hygienic unions can be used, these are available

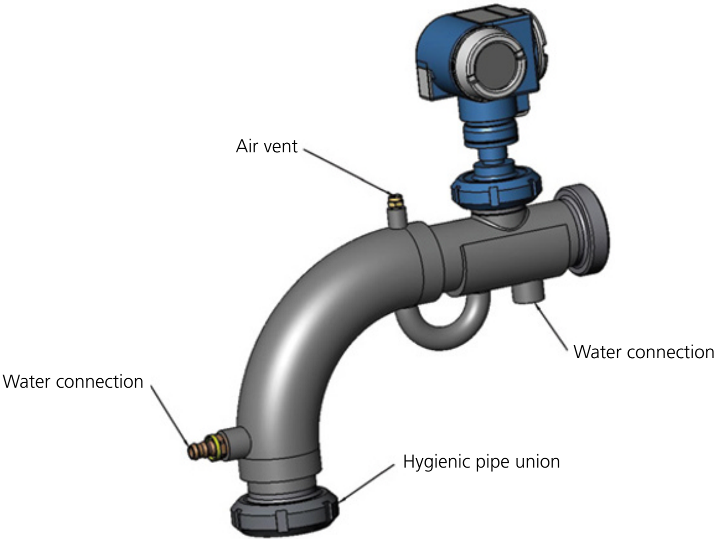


Figure 12.11 Illustration of section of lagged pipeline with pressure transmitter.

to the maximum size of 100 mm (4 in) and for most types the generally accepted maximum pressure rating is 10 bar. Wherever possible an over-pressure protection device should be fitted in to the pipework, preferably just after the pump. This can be either a conventional spring operated valve or a pressure transducer interlocked with the stop circuit of the pump. If a spring device is fitted, it must be kept at the same temperature as the other pipe in the system, the the discharge pipe from the valve must also be kept warm.

For stainless steel jacketed pipe it is recommended that type 316 stainless steel is used throughout and good manufacturing practices should be used at all times during the welding process. On completion both the jacket and the internal pipe should be pressure tested.

12.8.1 Corrosion of stainless steel

The corrosion resistance of stainless steel is greatest when a layer of oxide film is formed on its surface. If the oxide film is damaged or destroyed the stainless steel becomes much less resistant to corrosion. Care must be taken when welding and fabricating not to contaminate the stainless steel with particles of carbon steel and procedures must be in place to restore any damaged areas.

Any anti-corrosion water treatment should not impair the heat transfer function of the water and ideally contain a biocide. The treatment chemicals must be compatible with all the metals used in the system and be of a food grade quality.

Solid particles, sludge and fouling organisms should not be allowed to settle in the bottom of jacketed pipe work and tanks, since this contributes to the corrosion process.

12.9 Valves

A wide range of valves is used in the distribution of chocolate and their design should be suitable for hygienic applications. Not all valves are suitable for all applications and careful consideration should be given to installing the correct valve. If a pigging system is to be used then the valve must not obstruct the travel of the pig. To prevent cold sections around the valve, the valve should have a hot water jacket or be electrically trace heated. The valve must be selected to be compatible with the operating pressure of the system. Valves should be installed to avoid dead-legs.

12.9.1 Plug cock valve

The plug cock valve (Figure 12.12) is widely used in the food industry and can be used as a simple on/off device, as a diverter valve or to throttle the flow. The design of this valve does not lend itself easily for remote operation, cannot be cleaned in place and it is difficult to add a water jacket.

12.9.2 Butterfly valve

The butterfly valve (Figure 12.13) is a simple on/off device and two or more can be used to divert flow. It can be manually operated or it can be fitted with a powered actuator to assist automation. Because of its slim design it is often unnecessary to provide a heating jacket.

12.9.3 Ball valve

The ball valve is similar in principle to the plug cock valve except that the plug is replaced by a sphere. Ball valves provide on/off control with the minimal pressure drop. They can be manually operated or powered by an actuator, and are suitable to be operated at high pressures.

Figure 12.12 Three-way plug cock valve.

Figure 12.13 Butterfly valve (shown in open position).

The construction of a standard ball valve does lend its self to be easily dismantled for cleaning. Chocolate will become trapped between the ball and the housing and this could result in product contamination during subsequent process operations. If a ball valve is to be used then it is essential to choose a valve designed to comply with hygienic conditions.

12.10 Contamination removal

12.10.1 Magnets

The equipment used to manufacture chocolate is, more often than not, made from carbon steel of various grades. Wear of these machines can contaminate the chocolate with small amounts of ferrous material. Magnet traps, fitted into the pipeline have been used to successfully remove ferrous contamination. The magnets are encapsulated in stainless steel and form a matrix of fingers that the chocolate flows around. The magnets are fixed into a water-jacketed housing and they need to be regularly removed for cleaning. Failure to clean the magnets will result in them becoming inefficient and contaminating metal could drop off. Usually the magnetic trap can only be installed in pipelines that operate below 5 bar and so they are often installed in the feed to a tempering machine.

12.10.2 Sieving

It must be remembered that magnets cannot remove stainless steel and aluminium contamination. These and other hard particles can be removed by sieving. The position of the sieve may need careful consideration. It is normally recommended that a sieve is installed prior to the feed tank to chocolate tempering machines. The aperture size of the sieve will be dependent upon the quality of the chocolate; an aperture size of 40 μm is often used.

Conclusions

Pumps and pipelines are among the least glamorous parts of chocolate manufacture. They are however extremely important and need to be chosen and designed correctly. If done well they can run without trouble for many years. An incorrect decision can result in large losses of production and even product recalls.

Acknowledgements

The author would like to thank Mike Leadbeater for his time and expertise during the revision of this chapter; his contribution is greatly appreciated.

CHAPTER 13

Tempering

Erich J. Windhab

13.1 Introduction

Chocolate tempering is a process in which chocolate masse is thermally treated to produce a small fraction of homogeneously dispersed, highly stable fat crystals of the correct type and size. These crystals then seed the masse and grow to form a micro-homogeneous solid fat crystal network during the cooling stage following moulding or coating/enrobing.

The important effects of tempering the liquid chocolate masse are:

1. Adjustment of the yield value and viscosity for moulding, coating or enrobing (Chapters 11, 12, 14 and 24);
2. Long-term stability of the chocolate flow properties under moulding, coating or enrobing conditions;

and also results in the final solidified product having:

3. Good surface gloss and colour;
4. Good snap;
5. Smooth and fast melting;
6. Good heat stability.

When considering the strong impact of tempering on these very important quality characteristics, there is an obvious need to quantitatively understand the effect of the tempering process on: (i) the fat crystal structure, (ii) the chocolate itself and (iii) the relationship between the two. The temper-related properties are determined by the fat micro-structure, which can be tailored by the tempering process.

From a fundamental research point of view, it is important to understand and characterise both the process–structure and the structure–property relationships.

Major *processing aspects* that have to be considered are:

1. The fat/chocolate masse pre-heating;
2. The thermal and mechanical (flow) history of the chocolate masse in the tempering device;

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett, Mark S. Fowler and Gregory R. Ziegler.

3 The post treatment of the tempered chocolate masse in pumps, moulding devices, coating devices/enrobers;
4 The cooling and solidification process;
5 Post tempering and storage temperature conditions;
6 The factory environmental conditions.

Tempering-related *structural aspects* are:

1 The fat crystal fraction;
2 The fat crystal size distribution;
3 The fat crystal polymorph distribution (the relative amount of each type of crystal present);
4 The fat crystal network density (total amount of crystal) and its homogeneity;
5 The crystallisation kinetics (how fast the fat will set);
6 The polymorph transformation kinetics (how fast one type of crystal changes into another);
7 The migration kinetics of liquid components through the fat crystal/particle network (how fast the liquid fat components move through the solid network formed by the fat crystals and the other solid components).

13.2 Physics of cocoa butter crystallisation

Chemically fats are triglycerides with three fatty acids connected to a glycerine molecule. Most fat systems form crystals with several different polymorph (same chemical composition different molecular arrangement) structures. For fats containing only a small number of triglycerides like cocoa butter (with SOS, POP, SOP triglycerides; S denoting stearic acid, P palmitic acid and O oleic acid) up to six different polymorphs have been identified (γ, α, β_{III}, β_{IV}, β_{V}, β_{VI}, see also Chapter 7). Different crystal types are formed depending upon the steric (ability to fit together because of shape) or energetic compatibility of the molecules, the temperature/temperature gradients they are submitted to and for how long this takes place. The higher the temperature and the longer the crystal formation time, the denser and more perfect molecular ordering occurs (i.e. the individual molecules can pack more closely together, giving a higher crystal density). This is demonstrated in Figure 13.1 and Table 13.1.

Different forms of nomenclature for the polymorphs are shown in Table 13.1. Within the chocolate industry and the scientific community it is accepted that the β_V cocoa butter crystal polymorph is the most preferable in chocolate with respect to giving the best overall surface gloss, colour, hardness/snap, smooth melting and shelf life (heat shock) characteristics.

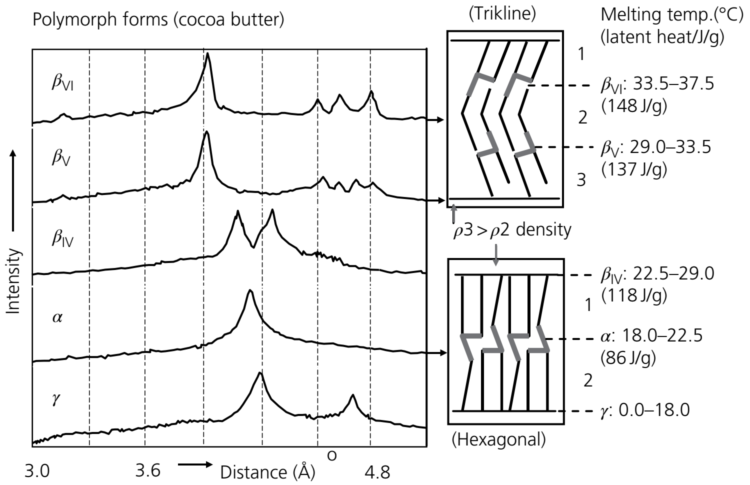


Figure 13.1 Cocoa butter polymorph characteristics.

Table 13.1 Melting temperatures/melting temperature ranges of cocoa butter polymorphs (°C, with °F in brackets).

Vaek (1951)	**Duck (1963)**	**Wille and Lutton (1966)**	**Lovegren *et al.* (1976)**	**Dimick *et al.* (1987)**	**Windhab and Zeng (1998)**
				From onset to peak maximum	Melting range
γ 18.0 (64)	γ 18.0 (64)	I 17.3 (63)	VI 13 (55)	13.1 (55) to 17.6 (63.5)	γ 13.0–18.0 (55–64)
α 23.5 (74)	α 23.5 (74)	II 23.3 (74)	V 20 (68)	17.6 (63.5) to 19.9 (68)	α 18.0–22.5 (64–72)
		III 25.5 (78)	IV 23 (73)	22.4 (72) to 24.5 (76)	III 22.5–27.0 (72–81)
β″ 28.0 (82)	β″ 28.0 (82)	IV 27.5 (81.5)	III 25 (77)	26.4 (79) to 27.9 (82)	β_{IV} 27.0–29.0 (81–84)
β 34.4 (94)	β′ 33.0 (91)	V 33.8 (92)	II 30 (86)	30.7 (87) to 34.4 (94)	β_{V} 29.0–33.5 (84–92)
	β 34.4 (94)	VI 36.3 (97)	I 33.5 (92)	33.8 (93) to 34.1 (93.5)	β_{VI} 33.5–37.5 (92–99.5)

13.3 Chocolate tempering technology

Chocolate and similar coatings are produced according to many different recipe formulations (see Chapter 20), but all contain a mixture of finely milled solids (cocoa, sugar, milk crumb or powder) suspended and well dispersed in cocoa butter with or without milk and substitute fats, which at normal processing temperatures is the liquid carrying medium.

For conventional tempering machines, it has been reported that 2-4% of the fat solidifies during tempering according to the type of temperer and hence an increase in viscosity can be seen, because there is now significantly less liquid fat present. As a general rule for such tempering machines, the viscosity increases by a factor of about two from the incoming chocolate to that leaving the tempering unit, although this may be greater if cooling conditions are exceeded. 1.5–3Pas (Casson plastic viscosity) has been reported to be a typical increase (Windhab *et al.*, 1991).

New tempering processes, like seed tempering, produce very finely dispersed cocoa butter seed crystals contained in a cocoa butter melt. Such suspensions contain about 10–20% of solid fat and, if 0.2–1.0% of this is added to untempered chocolate (equivalent to 0.02–0.15% of solid crystals), it still guarantees a good temper and gives excellent product characteristics (Windhab and Zeng, 1998). Work on conventional chocolate tempering with improved analytical instrumentation, such as nuclear magnetic resonance spectroscopy (NMR) and differential scanning calorimetry (DSC), has also demonstrated that there can be less than 1% of fat in crystallised form after "good" tempering (Padar and Windhab, 2007).

Due to the fact that tempered chocolate is not in a thermodynamic equilibrium, another factor, time, has a crucial influence on the temper state or quality. Time and temperature are the key parameters and of paramount importance when designing tempering systems.

In chocolate tempering literature the need for maturation of fat crystals after tempering and before moulding or enrobing is frequently emphasised. This was related to the fact that the tempering time in many conventional tempering processes was insufficient, particularly for chocolate systems with formulation-related slow crystallisation kinetics, such as those containing a high level of butter fat. For such systems it was found that some residence time under temperature controlled conditions was required (e.g. in the connecting pipe between tempering machine and enrober) in order to keep a satisfactory temper during enrobing or moulding, particularly if slightly increased temperatures were applied. This so-called maturation of the fat crystals is essentially post-tempering, which is needed because of insufficient capacity or mixing power of the tempering device being used.

Incomplete, or bad tempering, results in unstable crystal growth (α or β_{IV} polymorphs instead of β_V) and, as a consequence, results in poor solidification, contraction and setting characteristics, as well as differences in colour and even whitish surface spots or a streaky grey-white finish known as "fat bloom" (see also Chapter 7). Chocolate prior to coating or moulding, therefore, must be tempered to contain sufficient stable fat crystal nuclei of the β_V type in order to generate more than about 90% of β_V in the resulting product. In optimum conventional tempering processes all the seed generated within the chocolate masse is in the β_V form after tempering.

Newer seeding techniques however use seed crystals consisting of 30-95% β_{VI} polymorphs in addition to the β_V, leading to optimum tempered chocolates and high quality finished products (Windhab and Zeng, 1997). Beside the total seed fat crystal fraction, the polymorph distribution of the seed crystals is of major importance, particularly for an optimised process with the fastest possible solidification-crystallisation kinetics obtained under the lowest possible cooling temperature conditions, whilst avoiding the formation of unstable polymorphic forms. In conventionally tempered chocolate systems the fat crystal size distribution cannot be properly analysed. Mean crystal diameters are occasionally found by microscopic techniques to be in the range between 10–30 microns, depending on the volumetric mechanical power or energy input in the tempering machine. For the seeding based tempering techniques using seed crystal suspensions, optical analysis of the mean fat crystal size can be easily carried out and provides seed crystal mean sizes in the range of about 2–5 microns. For a constant total crystal fraction, smaller crystals lead to an improved temper, accelerated crystallisation kinetics during cooling and eventually an increased structure density in the final product.

For conventionally well tempered chocolate systems the temper (= tempering degree) is related to crystal fraction and crystal size distribution of the β_V crystal polymorphs. As demonstrated in Figure 13.1 and Table 13.1, the melting temperature range of cocoa butter in the β_V form is about 29–31.5 °C (84–89 °F) Following conventional chocolate processing in the temperature range of 30–31 °C (86–88 °F) subsequent to tempering (e.g. coating/enrobing, depositing or moulding) the temper of the chocolate will be affected by a temperature fluctuations as small as ±0.5–1 °C (1–2 °F) occurring in the process. As a consequence conventional tempering has to produce a well developed temper (eventually even slightly over-tempered) equivalent to a crystal mass volume fraction of up to 1%, or even more, in order keep sufficient seeding crystals throughout the post tempering processing. The temperature to which a chocolate can be raised for a certain time, without losing the good degree of temper correlates with the amount of crystal seed present in a particular chocolate.

From this it can be shown that if β_{VI} polymorphs with a melting temperature range of 34–37.5 °C (93–100 °F) can be produced in the tempered masse, they are not significantly affected by subsequent processing, so long as the temperature does not exceed about 33.5 °C (92 °F) that is 2.5–3 °C (5–6 °F) above the typical processing temperature (Windhab and Zeng; 1998 and Bolliger *et al.*,1998).

13.4 Measurement of temper and its related characteristics

How do we know if chocolate is correctly tempered and ready to be used? There are four basic analytical methods which indicate the degree of temper: (i) temper curve measurements using a calorimetric tempermeter, ii) heat flux curve or melting enthalpy measurements by DSC, (iii) solid fat content (SFC) measurements by NMR or (iv) temperature-dependent flow curve measurements by thermorheometry (see also Chapter 24).

13.4.1 Tempermeters

Figure 13.2 illustrates schematic details of a *tempermeter*, which consists of a cooling block (Peltier element) to hold a constant temperature (isothermal cooling) of 0–10 °C (32–50 °F), the sample tube made from highly conducting aluminium or copper, a probe shroud and insulator and a thermistor/thermocouple probe, plus a recorder or computer to store and plot the temperature versus cooling time data. An optimum cooling temperature depends on the geometry, heat capacity and heat conductivity of sample and sample cup. Using 25 ml aluminium tubes/cups an optimum of 8 °C (46 °F) was found for a large number of chocolates and fillings. Different types of cooling curves are illustrated in Figure 13.3.

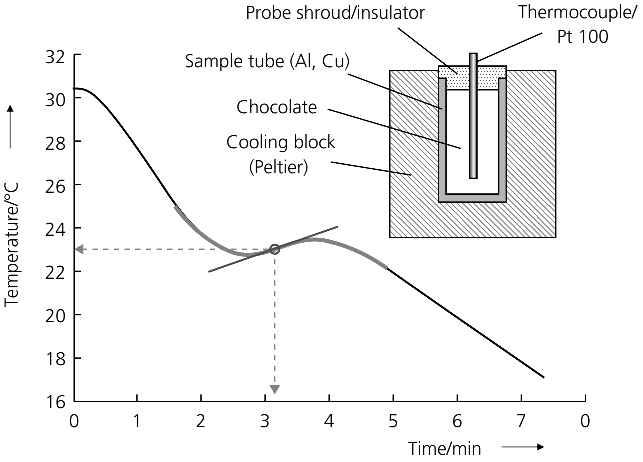


Figure 13.2 Schematic diagram of tempermeter.

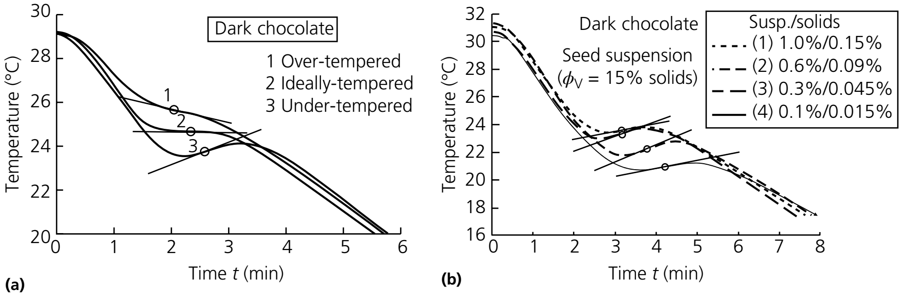


Figure 13.3 Selection of typical temper curves. (a) Conventionally tempered; (b) seed tempered.

ln Figure 13.3a it can be seen that the chocolate sample cools with about a constant gradient for a period of time, then levels off producing different tangent slopes at the inflection point, depending on the degree of temper. This is due to crystal growth, with the latent heat being released and thus generating sufficient heat to retard cooling. The sample is in a semi-solid state at this time. Once most of the latent heat has been liberated, cooling continues until complete solidification occurs. Graph 1 in Figure 13.3a shows an over-tempered sample which cools slowly with a negative tangent slope in the inflection point. Graph 2 in Figure 13.3a shows a well tempered sample according to conventional tempering, which cools faster than the previous sample 1 and shows a horizontal slope of the inflection point tangent indicating a slightly delayed, but more pronounced increase in crystallisation heat release. Graph 3 represents an under-tempered chocolate sample, which first cools quickly due to the lack of crystals generating crystallisation heat, but followed by a further delayed and more intensive release of crystallisation heat leading to some reheating and a related positive slope of the inflection point tangent. Setting for sample 3 takes place over a longer period of time.

Beside fat composition the rate of crystallisation and setting are also influenced by a number of additional factors such as the type and amount of emulsifier used. This can be investigated using the tempermeter cooling curve.

The tempermeter cooling curve serves only as a guide, because it varies according to the type of tempering process, that is depending on residence time, temperature and mechanical treatment. Figure 13.3b demonstrates temper curves for β_{VI}-seed tempered dark chocolates, which indicate that good temper curve shapes are process-specific. According to the conventional scale for the degree of temper, all seed tempered samples from lowest to highest crystal seed suspension fractions of 0.1–1.0%, (equivalent to about 0.02 to 0.2% of solid crystal mass in the chocolate) would be classified as under-tempered if originating from a conventional tempering process. However product quality was demonstrated to be optimum if ≥0.3%wt of seeding crystal suspension (equals ≥0.06% crystal mass, related to total masse) were added.

Figure 13.4 shows the inflection point tangent slope values (m_{IP}) as a function of the inflection point temperature (T_{IP}). This relationship can be interpreted as crystallisation intensity (m_{IP}) as a function of supercooling (T_{IP}) of the fat melt. The fewer crystal nuclei present in the tempered masse, the greater the supercooling before massive crystallisation will start and lead to an increased m_{IP}. Below a certain critical supercooling temperature, T*, crystallisation kinetics is expected to slow down due to a dominating increase of viscosity, which greatly reduces the diffusion controlled mechanisms. From Figure 13.4 one such T* value is shown in the range of about 22 °C (72 °F). Furthermore it has to be expected that an increased fraction of less stable polymorph crystal nuclei forming during supercooling within the tempermeter will also accelerate the release of heat of crystallisation and thus increase m_{IP}. This effect is also seen for the conventionally crystallised samples. It is expected that the major reason why

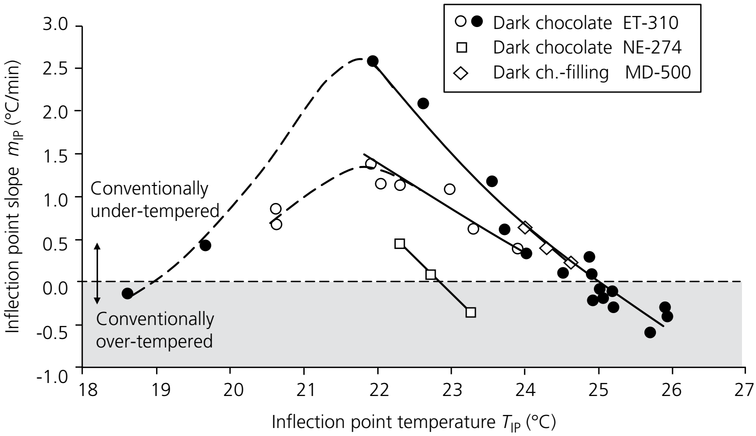


Figure 13.4 Relationship between the tangent of the slope in temper curve at the inflection point (m_{IP}) and the inflection point temperature (T_{IP}). Open symbols: seed tempered; closed symbols: conventionally tempered.

these conventionally tempered samples form a larger fraction of unstable polymorph crystals during supercooling than the seed tempered ones is because they contain more bigger crystals, and hence larger volumes of fat containing no seed crystals at all.

In addition the function $T_{IP}(m_{IP})$ will vary according to the chocolate recipe (milk or plain), types of cocoa butter or other fats present and any emulsifiers that are used.

When comparing conventional tempering machines using the same recipe chocolate, a higher T_{IP} value can be taken as an indicator for more stable crystals being present. Both the shape of the curve and the temperature of the inflection point should be recorded when taking cooling curve measurements and this is done by most of the commercial tempermeter instruments (see Chapter 24).

13.4.2 Differential scanning calorimetry

Differential scanning calorimetry (DSC) measures phase transition heat during cooling (crystallisation) or heating (melting) with controlled temperature/time gradient applied to a small sample volume (in order to provide near homogenous temperature conditions; see also Chapter 24). The so-called direct DSC method developed by Breitschuh and Windhab (1998) makes it possible to measure the crystal fraction and the polymorph distribution within a tempered chocolate masse. This method involves sampling in DSC aluminium pans for short sampling times (≤60 s), under isothermal conditions [e.g. $T \approx 28$ °C (82 °F) for a standard milk chocolate standard: 30 °C (86 °F), dark chocolate] and with a constant sample weight (≈5 mg). If these requirements are met, reproducible measurements of the seed crystal nuclei generated in the tempered chocolate system can be obtained.

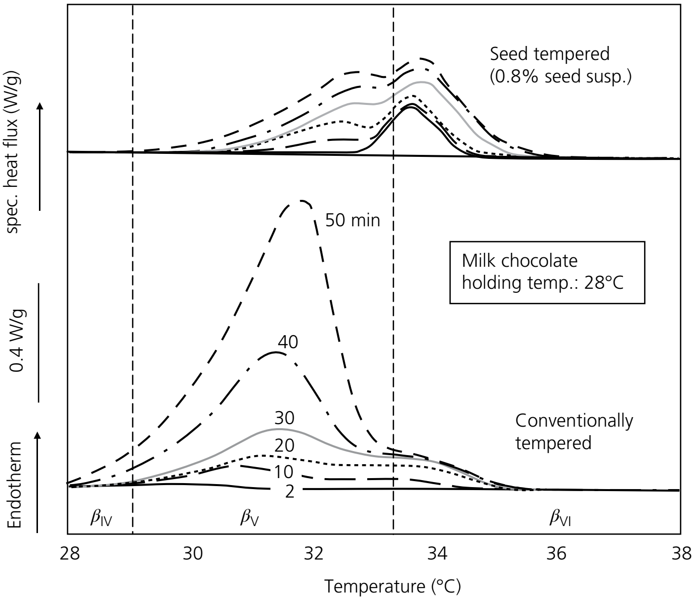


Figure 13.5 DSC measurements. Melting curves measured by the DSC direct method according to Breitschuh and Windhab (1998) for milk chocolate held at 28 °C (82 °F) under constant moderate stirring for different residence times.

Figure 13.5 shows DSC measurements for differently tempered (conventional and seed-tempered) milk chocolate held at 28 °C (82 °F) for different mean residence times. This simulates processing conditions for chocolate masses, for example being kept in the depositor of a moulding or enrobing machine. The different starting conditions for the conventionally and seed-tempered chocolate masses enable their respective total crystal fraction and polymorph distribution to be calculated. The development of the crystalline component is also shown as a function of residence time at 28 °C (82 °F; Figure 13.5). For the conventionally tempered milk chocolate there is a significantly faster increase in total crystal fraction with time and a clear dominance of the β_V polymorph, whereas the β_{VI}-seeded system increases in β_V and β_{VI} fraction in a more balanced manner, but with a clearly lower total crystal fraction.

13.4.3 Thermorheometry

Thermorheometry is a complementary technique for temper evaluation with the advantage of dynamic measuring conditions, which can be adjusted to come close to the conditions within a tempering machine. In general, the (apparent) viscosity is measured as a function of time for constant (apparent) shear rate. After distinct residence times under constant shear (e.g. at $1\,s^{-1}$) shear rate sweeps preferably between 0.1 and $100\,s^{-1}$ are carried out. Flow functions $\tau(\gamma)$ for a milk chocolate masse shear treated at a shear rate of $1\,s^{-1}$ for 3000 s (50 min)

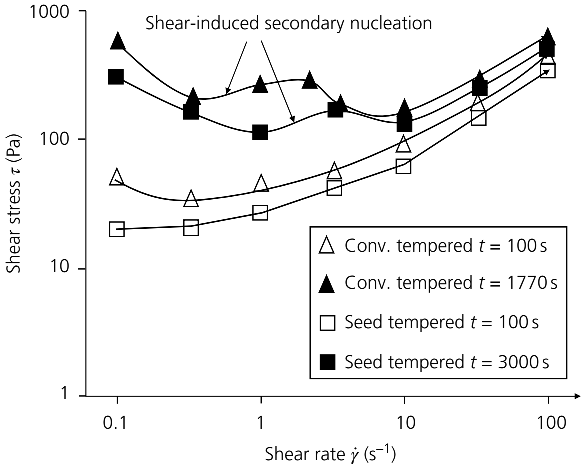


Figure 13.6 Thermorheometry measurements. Transient development of flow functions (shear rate range: 0.1–100 s^{-1}) for conventionally and seed tempered milk chocolate under holding conditions [temperature: 28 °C (82 °F); shear rate: 1 s^{-1}]. Rheometer: Paar/Physica UM 300 with concentric cylinder geometry.

at 28 °C (82 °F) are shown in Figure 13.6 for two different tempering processes: conventionally shear-tempered in an AMK 50 (Aasted Mikroverk ApS,) tempering unit (conv.) and seed tempered using a Seed Master *Cryst Mix* (Bühler AG; seed).

13.4.4 Nuclear magnetic resonance

Nuclear magnetic resonance (NMR) spectroscopy measures the proton spin relaxation, which in chocolate systems provides a signal correlating with the solid fat fraction and can consequently be used for the solid fat content measurements (SFC; see also Chapter 24). To obtain sufficient accuracy at solid fractions ≤1%, (relevant for tempered chocolates) requires optimised temperature adjustment of the NMR magnet as well as a defined sampling routine, such as is described for direct SFC measurements by Breitschuh and Windhab (1998). Figure 13.7 demonstrates the SFC of a milk chocolate masse as a function of holding time at 28 °C (82 °F) over a time period of about 370 s. This simulates again solidification behaviour under processing conditions, for example in the depositor of a moulding or enrobing plant. As can be seen in Figure 13.7, an equilibrium solid fat content of about 25% is reached after about 350 s.

13.5 Tempering processes

There are several ways to temper chocolate, known as “hand”, “batch” or “continuous” processes. This section is primarily concerned with continuous machinery relevant for industrial chocolate production, although the principles involved are applicable for all methods.

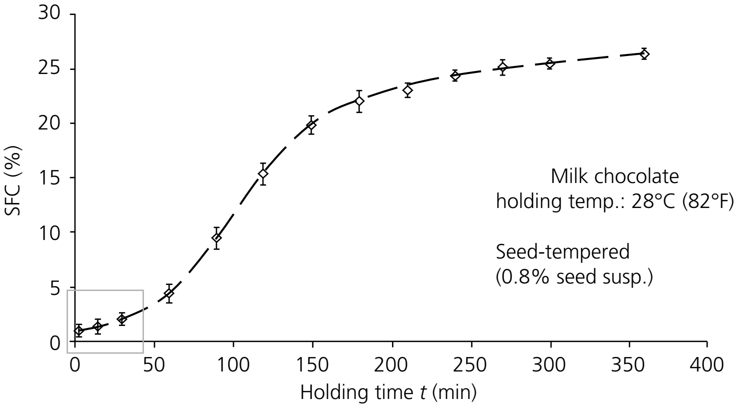


Figure 13.7 NMR measurements. Increase of solid fat content (SFC) in seed tempered (0.8 % cocoa butter seed suspension containing 15% solid seed crystals) milk chocolate during holding at 28 °C (82 °F) and stirring at1 s^{-1}.

13.5.1 The principle of conventional continuous chocolate "stir/shear-tempering"

Conventional stir/shear-tempering is carried out in a continuous flow through stirred vessel systems, generally divided into three temperature zones: (I) precooling, (II) cooling and (III) reheating. The chocolate passes in the order I to III and with the stirring elements normally designed in such a way that shear gaps are formed between stators connected to the vessel walls and rotating sections attached to a central shaft, as shown schematically in Figure 13.8. The higher shear rates are mainly applied in the shear gaps between the rotor and stator elements or between the rotor and the inner vessel wall. In addition wall-scraping blades may be added onto the rotating stirrer parts. The residence time distribution of the chocolate within the temperer is planned to be as narrow as possible (all the chocolate spends approximately the same time within the machine).

There is a wide range of different tempering devices commercially available with widespread combinations of shear rate, temperature and residence time distributions.

The following sections discuss the most relevant factors (i.e. temperature, shear and time) and how they influence tempering quality in conventional stir-/shear-temperers.

13.5.2 Impact of temperature/temperature control

Controlled tempering generally assumes that the continuous chocolate in-feed to the temperer is completely free of fat crystals. However this chocolate is typically at about 45 °C (113 °F), and may even be lower for energy conservation reasons [e.g. 41–42 °C (106–108 °F)]. At this temperature there are a number of high-melting triglycerides contained in cocoa butter, as minor fractions that are still

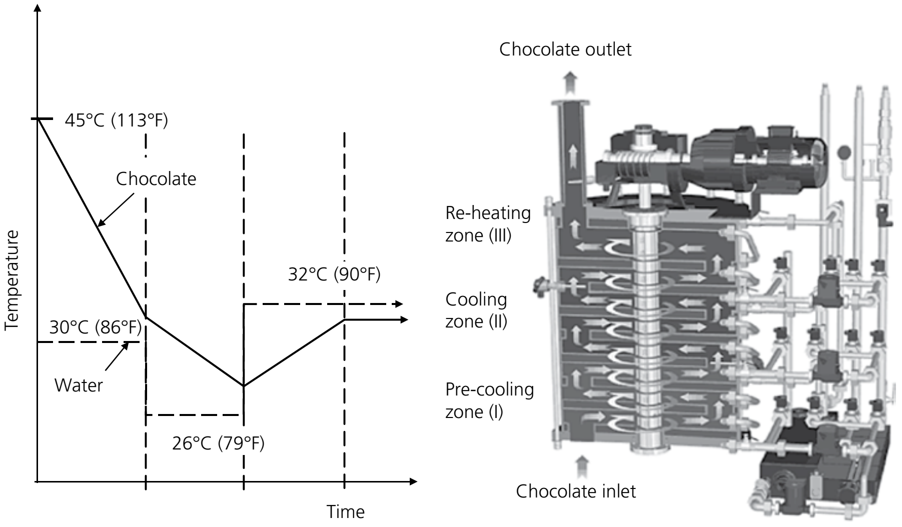


Figure 13.8 Characteristic temperature versus time plot during conventional tempering treatment and schematic drawing of a continuous stir-/shear-tempering device.

solid. The amount depends upon the source of the cocoa butter and this means that the nucleation potential may differ between different chocolate masses.

The major goal of tempering is to gently cool the warm chocolate through a multi-stage tempering machine, gradually reducing the temperature to "strike seed" and initiate the first stages of nucleation and crystal growth.

Primary nucleation is performed at cooled walls (or shearing elements) in the cooling section of the tempering machine from which fat crystals are scraped off and mixed into the chocolate suspension, where secondary nucleation takes place. This is mostly due to fat crystals/fat crystal agglomerates being broken down between the solid particles (sugar, cocoa and milk powder particles) in the fat-based suspension. The cooling wall temperature determines the type of fat crystal formed at the wall. At temperatures below 22 °C (72 °F) in the cooling section, these are mainly unstable α, whereas between 22 and 27 °C (72 and 81 °F) unstable β_{III}/β_{IV} polymorph nuclei are formed as well as a small fraction of the stable β_V polymorph. During mixing into the chocolate masse the unstable polymorphs get gradually transformed into the β_V type due to the applied shear stresses and the temperature increase in the subsequent reheating section. The reheating happens gradually via the heat exchange at the wall of the tempering device and in addition by the latent heat released from the fat that is crystallising.

In some systems there is a subsequent holding (retention) stage within or after the tempering machine with associated temperature and mixing control. This is a crystal "maturation" step, in which the fat crystal nuclei polymorph and size distributions develop further by crystal growth and ongoing polymorph transition from unstable forms to the stable β_V form towards an equilibrium, which is almost never reached – often the temper is very far from optimum. Some "maturation" may also occur, but generally in an uncontrolled manner, within subsequent moulding, enrobing or coating process steps. In the case of a new type of seed crystallisation process (see Section 13.6.3 and Chapter 15) such maturation produces between 30 and 95% of β_V to β_{VI} within a pure cocoa butter fraction or within a mixed fat fraction containing a minimum of about 10% of cocoa butter. This crystal suspension is subsequently used for seeding the bulk of the chocolate. When added and homogeneously mixed into the non-tempered chocolate a well controlled "matured" degree of temper is achieved.

13.5.3 Impact of shear

Since the 1980s, many authors have demonstrated that higher shear in tempering equipment is a "prime" consideration for producing high nucleation rates, with more stable crystals at higher temperatures than normal (Ziegleder, 1985; Windhab, 1986; Windhab *et al.*, 1991; Zeng and Windhab, 1999; Windhab and Zeng, 2000). From empirical tempering experience, it was found that there is a difference between what is described as optimised tempering in a low residence time temperer (4–6 min) and a fully matured stabilised tempered chocolate (12 min to 2 h) and that claims that a fully matured chocolate, milk or plain, can be obtained from a low residence time (<6 min) temperer merely by shear rate and water temperature are simply incorrect.

Now we are able to interpret or revise such statements based on improved insight into the crystallisation mechanisms and the process–structure relationships taking place during tempering: The tempering degree of a chocolate masse depends on the *structure parameters*: (i) crystal fraction, (ii) crystal size distribution and (iii) crystal polymorph distribution. In addition (iv), the viscosity of the pre-crystallised suspension system has to be taken into account, because it is desirable to reach an optimum tempering degree with the lowest possible increase in viscosity. The following relationships can be used in order to get the lowest viscosity increase compared with the non-tempered state: The lower the solids crystal fraction, the smaller size of the crystals is required and/or the more the crystal polymorph distribution has to be shifted to the stable β_V. The *process parameters* providing adjustment to get such an optimum include a lower residence time and lower wall cooling temperature for higher and more homogeneous shear. Figure 13.9 demonstrates qualitative "optimum spaces" for the structure $[S(\psi,\xi_{50},\varphi_V)]_{OPT}$ and the process $[P(\gamma,t,\upsilon_K)]_{OPT}$ parameters to be quantitatively correlated for each specific fat/fat-mixture system. Figure 13.10 illustrates the relationships between the fat crystal structure characteristics, related physical characteristics of a chocolate system, resulting processing characteristics and the final product quality properties.

A good temper, as measured by conventional tempermeters (e.g. Sollich-, Tricor-, Systech-Analytics tempermeters) can be generated by a crystal nuclei fraction of less than 0.5–1.0% of the total cocoa butter fat with more than about

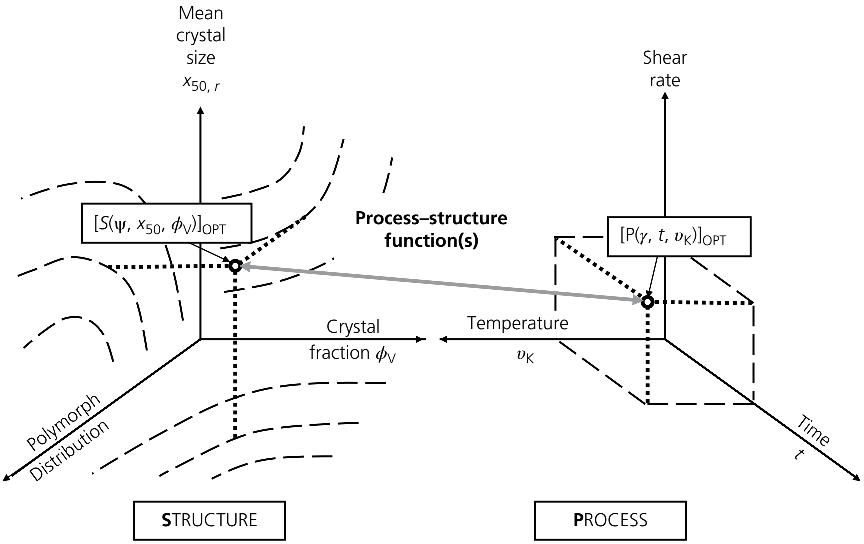


Figure 13.9 Process–structure relationship: correlation between qualitative “optimum spaces” for the structure $[S(\psi,\xi_{50},\varphi_V)]_{OPT}$ and the process $[P(\gamma,t,\upsilon_K)]_{OPT}$ ($\psi,\xi_{50},\varphi\varsigma r$, ξ_{50} mean diameter/size, φ_V volume fraction, γ shear rate, t time, υ_K cooling temperature).

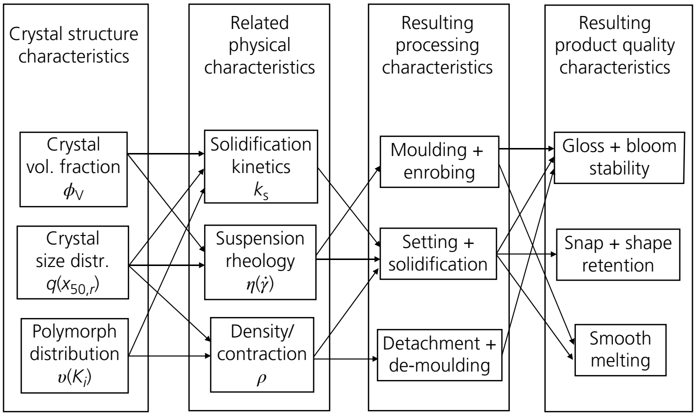


Figure 13.10 Relationships between: (i) fat crystal structure characteristics, (ii) related physical characteristics of a chocolate system, (iii) resulting processing characteristics and (iv) the final product quality properties for a system with a given fat/triacylglycerol (trigyceride) composition.

75% of β_V polymorph crystal nuclei produced under higher homogeneous shear crystallisation conditions ($\geq 750\,s^{-1}$) within a residence time period of as short as <60 s and cooling wall temperatures between 5 and 15 °C (41 and 59 °F; Windhab and Zeng, 2000).

However, as was stated earlier, a temper state reached under conventional tempering conditions will generally not be completely stable if typical temperature fluctuations of ±0.5–1 °C (1–2 °F) occur during further processing treatment of the tempered chocolate masse. This is certainly due to the fact that the typical temperature range for tempered chocolate processing is about equal to the outlet temperature of the tempering unit, which also lies in the melting temperature range of the β_V cocoa butter crystal nuclei [29.0–33.5 °C (84–92 °F) and which in the case with about 10% added milk fat (milk chocolate) reduces due to mixed crystallisation to about 26–30.5 °C (79–87 °F)].

Shear rates affect mixing and heat exchange rates in a tempering machine. There are limits to the amount of shear that can be applied to chocolate in the tempering phases. Too much shear will produce heat, too little, poor mixing and poor heat exchange.

From experience, local maximum shear rates acting in tempering machines vary from about 500 to 12000 s^{-1}. However it has to be noted that the highest shear rate values are in general only applied in a very small part of the flow gaps. Thus an average shear rate can be significantly (up to two orders of magnitude) smaller. Typical maximum shear rates in tempering equipment are given in Table 13.2.

The maximum shear rates are usually measured at the outer periphery, where the clearance gap between the heat exchanger wall and the rotor or scraper flight can be accessed. The highest shear rates given in Table 13.2 relate to the narrowest gaps between scrapers/stirring elements and the cooled wall. In the case of a rotating disc or scraper arm the radial dependency of the shear rate has to be considered, and the apparent shear rate can then be calculated by dividing the local circumferential velocity by the respective shear gap width. For more precise calculation the viscosity dependant local velocity field has to be known. High shear crystallisers with narrow concentric cylinder shear gaps as are used in the generation of seeding suspensions apply highest average shear rates in the range of 1000–3000 s^{-1}. This value is however very constant throughout the machine.

In order to avoid confusion in shear rates quoted by manufacturers, it is necessary to look at the different mixing/scraping tools and calculate the local ratio between tool-velocity and respective gap width. From this it can be seen

Table 13.2 Approximate maximum local shear rates in tempering machines.

Type of tempering device	Maximum shear rate range (s^{-1})	Examples of producers of tempering devices[1]
Kettle type scraped	500–12 000	
Screw type	500–3000	Hosokawa Kreuter
Stacked plate multi-zone	3000– 6000	Aastedt, Sollich
Stacked plate multi-chambered	4000–8500	APV

[1] The producers of tempering machines mentioned here are only examples; a more complete list of manufacturers is given in the Appendix of this chapter.

that many manufacturers of tempering machines give maximum shear rates, which may act only in a small volume, thus being not representative. Some tempering machines also contain undesirable features such as:

1. Intermittent and variable shearing/mixing flow;
2. Some chocolate can bypass the shear going directly from the inlet to outlet of the machine.

This type of feature means that different parts of the chocolate is treated to different amounts of shear for different times, so that it is impossible for the bulk of the masse to be homogenous at the microscopical scale.

The relatively high fluid viscosities of chocolate masses lead to low Reynolds (Re) numbers (denoting the ratio of inertia to viscous forces). Consequently flow in tempering devices is generally laminar. The fat crystal primary nucleation starts at the cooled walls, where there is the strongest cooling. Crystal growth normally takes place along the temperature gradient direction, thus forming dendritic (needle-like) crystals, which are scraped off or detached by flow shear stresses and mixed into the chocolate masse. In a tempering machine the action of shearing/mixing scrapes these needle-like crystals from the walls and breaks them up to form more seed. The higher the acting shear, the more efficient the process becomes. As this secondary nucleation action is continuous, this results in the formation of many more crystals and increases the crystal growth rate provided that the heat exchange and cooling temperatures are able to remove both the mechanical heat input and that generated by fat crystallising.

Following the first phase of striking seed, which generally consists of a semi-stable form (mostly α-type), a transition occurs when semi-stable crystals re-crystallise into a more stable mature form (mostly an α–β_V transformation). During this transition, further latent heat is generated. This transition is an important indicator for degree and efficiency of the tempering process. From the kinetics of latent heat generation the confectionery engineer can derive information for process optimisation (see Section 13.4.1). The shear rate or mixing action in a tempering machine is a function of the type of machine and the speed/design of the mixing elements. If the tempering machine is of the screw type, then the shear rate range along the mixing elements is narrowly distributed, with the first in first out principle being nearly fully effective as the chocolate passes down the screw and back-mixing is negligible.

If however the tempering machine is of the stacked plate design, then the shear rate distributions are intermittent and vary from the centre to the peripheral parts of the machine. If the machine has a rotary Archimedes disc (see Figure 13.16 in Section 13.6.2) mixing element, then there is continuous increase of the shear rates applied to the chocolate masse from the centre to the periphery during progression through the machine. The “contact” time at the higher shear rate at the periphery is only a few seconds during the tempering cycle.

A kettle-type tempering device can be considered to be a stirred vessel reactor in which complete re-mixing can be achieved, depending on the number and type of scraping/stirring elements and the throughput rate. This principle requires in general a long residence time to reach a homogeneously tempered state of the chocolate and this is seldom applied in practice.

13.5.4 Importance of residence time distribution

For conventional tempering it has been shown to be important to ensure the chocolate contains only the highest-melting crystal polymorphs. For typical tempering times the most stable cocoa butter polymorphs are the β_V, although some fraction of β_{VI} is possible for the longest tempering times. It was shown by Nelson (1999) that the mean residence times in conventional tempering required to ensure good product quality characteristics from moulding and enrobing processes are:

1 10–12 min for moulding plants;
2 20–360 min for enrobing.

The reasons for these differences between moulding plant and enrober plant requirements were described as follows: The *moulding plant* generally needs less fluidity and can make up for a higher viscosity by more intensive shaking and cooling systems. *Enrobers* should have the highest practical coating temperature that can be obtained from the tempering machine and from the enrober tank (to give the minimum viscosity; see Chapter 14). This requires a high maturity of the fat crystals, that is a long residence time. Defects easily show up in enrobed pieces and are less visible in a "moulding plant" where the product takes its shape and some gloss from the mould.

If a "matured" (e.g. long enough tempered) chocolate masse is produced by conventional tempering, then it is possible to raise the temperature in further processing without losing any crystals. As the temperature rises the viscosity falls, making it easier to coat the centre of a product. This means that, for any fat content, the thinnest chocolate is obtained at the highest temperature, which in turn requires a long tempering period. These temperature differences can be as much as going from 31–32 °C (88–90 °F) to 34-35 °C (93–95 °F) for dark chocolate with full maturation. In this case a substantial content of the β_{VI} polymorph has to be assumed. Specific operating conditions and product advantages have been reported for products coated with the "fully matured" seed tempered chocolate coating (Windhab and Zeng, 2002). From experience for optimum conventionally tempered chocolates with low viscosity the following aspects have been reported (Nelson, 1999):

1 Good decorative markings, especially on chocolates of high milk fat content that require extra time during tempering.
2 When bloom-resistant additives such as sorbitan tristearate and polysorbate 60 are used in a coating, time is essential to introduce stable nuclei in sufficient quantities to ensure a high coating temperature.

3 The improved flow at the higher temperature gives better weight control.

4 A "mature" chocolate with stable nuclei is not easily affected by adverse conditions, such as a high ambient temperature and varying centre temperatures.

5 A large masse of "well seeded" chocolate is held at a high temperature but, being under the melting point of the stable nuclei and being well agitated, remains very stable over long periods of time.

6 The high-temperature coating contains only stable crystals and, with correct cooling, good colour and gloss characteristics will be found.

7 Better shape, for example good bases, are a byproduct of the thinner chocolate produced.

8 A harder, more heat-resistant chocolate is produced, which gives a longer shelf life.

9 Better contraction is obtained in moulding plants.

10 The better hardness and heat resistance results in fewer finger-marks during packing, or fewer wrapping machine problems and down time.

13.5.5 "Recipe factors" influencing tempering quality

Chocolate recipes have changed over recent years particularly with respect substitute fats, viscosity-reducing agents and other additives. Changing the recipe can have an effect on the tempering procedure required, as ingredients may affect the crystal type, shape and rate of formation. For example milk chocolate has a proportion of animal fat (butter), which contains a wide spectrum of low-melting triglycerides. When mixed with cocoa butter this gives a type of "eutectic effect" due to mixed crystals or co-crystallisation. This is useful on one hand (bloom-resistant) and detrimental on the other (lower melting point, softer, slower in tempering and set in a cooler). Mixed or co-crystallisation of cocoa butter with milk fat lowers the melting point of the mixture and hence the temperature to "strike seed". Therefore in conventional tempering more time is necessary to create mature crystal growth (see Chapter 7).

A group of additives generally influencing the crystallisation behaviour of the fat phase are the emulsifiers used in chocolate manufacturing. According to their molecular nature, emulsifiers interact with the surfaces of solid particles as well as with fat crystal interfaces, thus slowing down crystallisation kinetics. This normally means that residence time under crystallisation conditions must be increased.

13.6 Types of tempering machine

13.6.1 Chocolate tempering kettles

Kettle tempering has been used in batch form for very many years, but is no longer seen in modern large-scale chocolate manufacture, although it is sometimes used by small confectioners. However due to its exemplary role, the stirred vessel type of reactor with its pronounced back-mixing properties is still of interest for comparison with other temperers. When it has good wall-scraping and radial/axial mixing rotor/stator elements, it is an almost-ideal homogenising crystalliser, although a rather long residence time is required.

The kettle is basically a stirred tank whose temperature can be controlled within the appropriate range. It is even possible to adapt kettles to work continuously, by metering chocolates in at the base and overflowing out at the top or vice versa. Additional control can be gained by feeding into a second kettle, once again in at the top and metering the chocolate out at the base. The "time period" is determined by the volume of the kettles and the volume flow rate. It can have major advantages over some other types of temperer, probably the most important being the maturity "time period", which can be from one to two hours, resulting in a high temperature usage chocolate. Further advantages are as follows:

1. Simplicity of all mechanical parts.
2. A simple, easily maintained agitator.
3. Bearings are mounted outside the product contact area, hence do not have the wear or contamination problems associated with pressurised systems.
4. There is no pressure in the equipment and thus no seals are required (they are, however, advisable in order to retain the lubrication oil).
5. Kettles are easy to drain and clean (and can be seen to be clean), which is a prime consideration when changing different colours of chocolate or non-compatible coatings.
6. Particulate ingredients can be added (nuts, raisins, crystals of sugar) at a suitable point, provided the exit pump is slow-running with a large swept volume designed for particulate matter (see Chapter 12; in fact chocolate kettle tempering embodies most of the criteria needed for high quality tempering).

Major disadvantages are a longer start-up time and a greater floor space requirement, when compared with vertical tempering machines. The trend for modern continuous tempering machines during the past two decades has gone towards speeding up crystallisation kinetics by applying higher shear rates and also slightly lower cooling temperatures in order to achieve higher throughput rates. Consequently there tend to be shorter residence times. It is certainly a challenge to the manufacturers of tempering machines to try to match the good mixing homogeneity and "maturation" capability achievable in kettle type units and this has not always been met with some designs of temperers.

13.6.2 Types of continuous industrial tempering machines

This section describes examples of some of the different types of tempering machines that are available (Nelson, 1999). Some older forms of temperers are included to show how different developments have taken place. It is not intended to give a complete market overview of existing tempering machines.

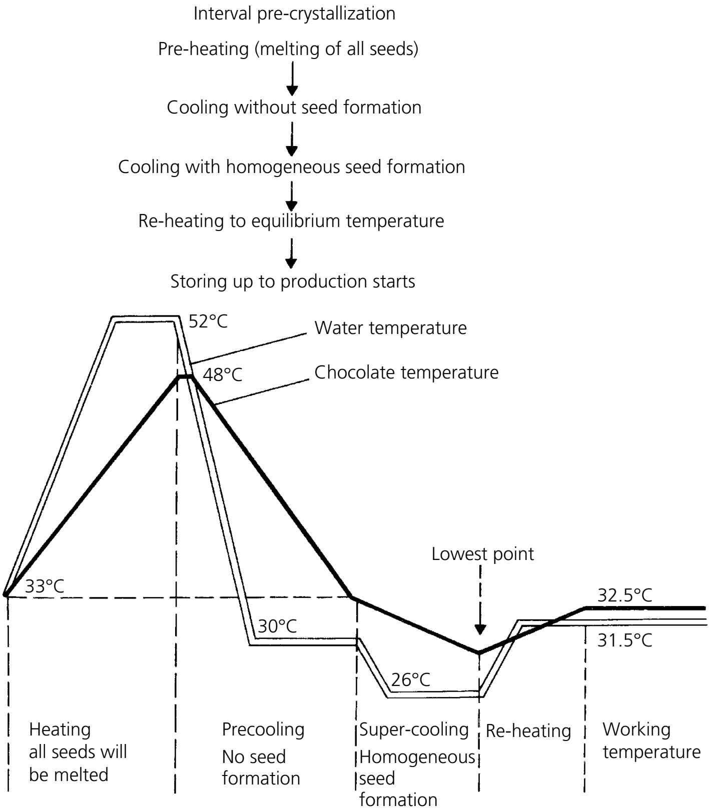


Figure 13.11 Kreuter interval pre-crystallisation procedure.

Hosokawa Kreuter: It is interesting to consider an early temperer of Hosokawa Kreuter, because it probably has the longest theoretical "residence time period" for the chocolate of any commercial machine. This is the Kreuter Interval Pre-crystallisation procedure, which is illustrated in Figure 13.11. The Interval design consists of a "batch" stock tank of chocolate that is first pre-cooled and then super-cooled until seed formation takes place. An outboard pump recirculates the chocolate, further enhancing the mixing from top to bottom in the tank. In addition a stirrer creates light mixing to give good heat exchange at the vessel walls, for both cooling and heating to take place. Once the machine strikes seed in the super-cooling period, temperatures have to be raised gradually over a period of time. This time period induces mature crystal growth. Up to this point, this is the mode of operation of most tempering kettles. In these, however, too long a retention time will result in over-temper. Hosokawa Kreuter on the other hand have made use of the fact that there is a higher temperature that will prevent further solidification and still retain maximum fluidity from the resulting stable mature chocolate (equilibrium). This is possible since the batch system allows for time to create crystal growth. All this sounds too good to be true and there is of course a trade-off between advantages and disadvantages.

The advantages are:

1. It is possible, with a designed time period, to create the optimum maturity in the chocolate.
2. This in turn produces a high-temperature coating giving good handling characteristics and long shelf life; fat may possibly be removed from the recipe due to lower viscosity.
3. It is suitable for all types of chocolate.
4. Since no more crystal growth can take place at the control temperature, a state of equilibrium exists.
5. Energy savings are claimed, since there is no need to reheat and de-temper excess chocolate feeds that many other systems demand; the user plant takes only what it requires and no return piping is necessary.
6. Prepared tempered chocolate can be stored ready for immediate use, thus reducing start-up times.

The disadvantages of this system are:

1. The system relies on keeping the seeded chocolate at the pre-determined control temperature to within very close limits; this could affect the readiness for usage.
2. As this is a batch system, a large storage tank would be necessary to suit the high usage rate of a wide enrober plant - one day's usage may require a 16 t tank, or several smaller tanks, which could create space problems.

Hosokawa Kreuter nowadays preferably provides the "K procedure", a screw tempering device. This is a short-residence time machine with what is claimed to be a fast-revolving screw capable of working at high pressures and generating high shear. The high pressures may be due to the remote location of the tempering machine from the user plant, viscous chocolate or both. This type of machine falls into the short residence time period category. The application of screws gives a narrow residence time distribution of the tempered chocolate. Combined with the locally applied high shear rates this provides short process time and conventionally well tempered chocolate.

Aasted: The Aasted tempering device is a vertical unit, consisting of a stack of interchangeable heat exchange plates scraped continuously to give efficient cooling and mixing. Because the heat exchange plates/discs have a chamber-like space, each one has a retention zone in its own right, and once stacked together they have a sufficient "time period" to temper the complete range of chocolate recipes. It has a range of zonal temperature controls to enable it to match the requirements of a wide range of recipes. Such is the range of capacities and models available that any change in flow rate can be matched to the required adjustment to the retention time (Figure 13.12). This tempering device is well suited for moulding plants or enrobers and takes up minimal floor space.

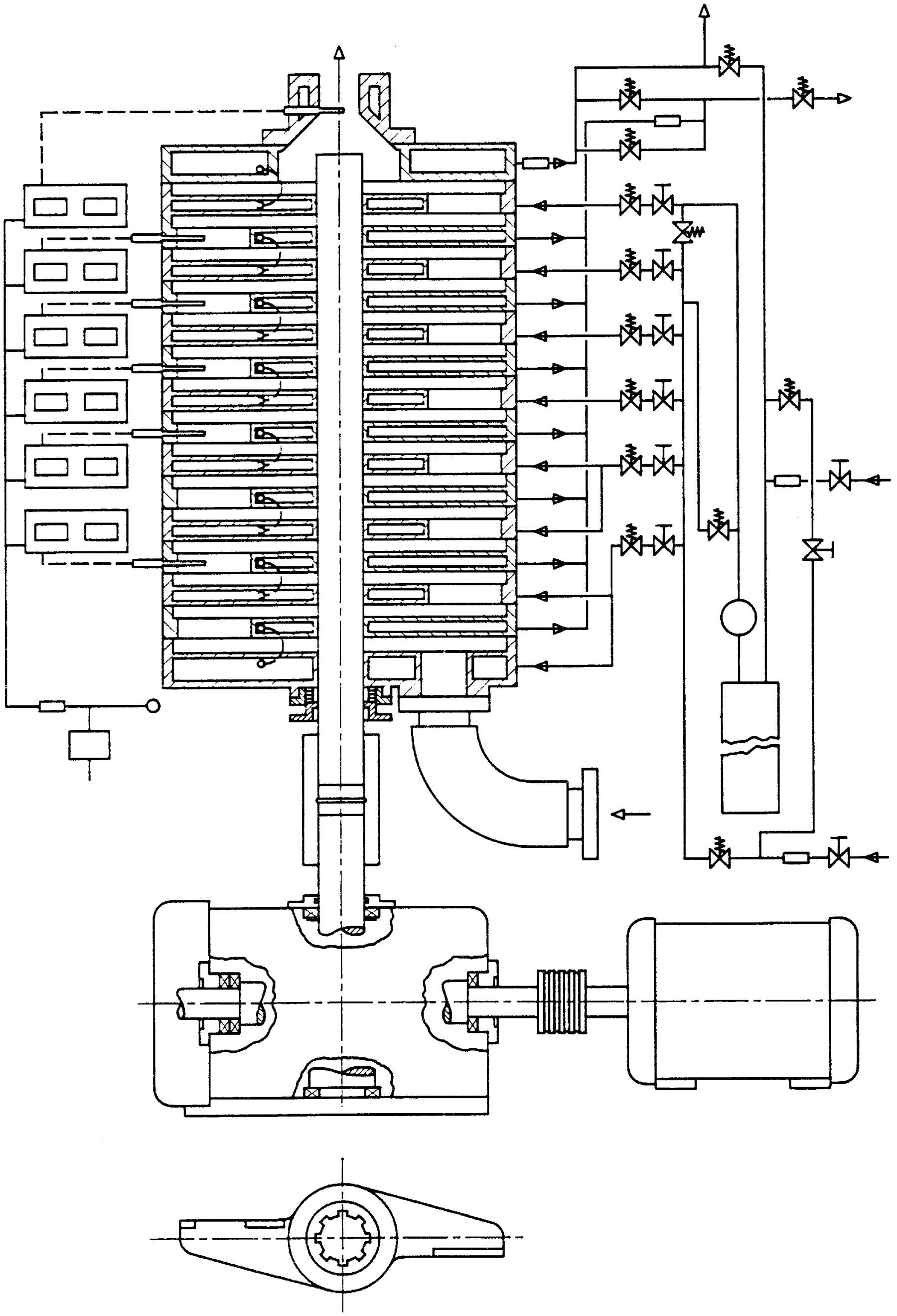


Figure 13.12 The Aasted temperer.

The Aasted temperer operates in the following manner. Chocolate is gently metered through the machine. Aasted, recognising the fact that inadvertent accidents can happen, have fitted a heat-jacketed relief valve to protect the pump and temperer from high-pressure damage (pumps can break down at 14 bar; 200 psi). The chocolate rises up through the control zones, of which there are three in current models, although older ones may have more. The cooling controls in the first zone strikes seed and initiates crystal growth, allowing the remaining zones to be adjusted to give the best conditions. The chocolate leaves the temperer, after being reheated to the user required temperature.

Sollich: Sollich are the company who have probably made the most ingenious varieties of tempering machines, ranging from very short residence times, through to present-day systems. These include single-stream, double-stream and multi-stream systems. "Streams" are blends of previously seeded masse, or may represent the new untempered feed into the tempering worm. Sollich have manufactured a range of combined temperer/enrobers (see Chapter 14). Their separate or outboard temperers include the Solltemper MST-V and the current popular MSV Turbo.

With the Solltemper MST-V (Figure 13.13) Sollich have developed a plate type heat exchanger for tempering chocolate, which claims to have more residence time, "microcrystalline growth" and thermo-cyclic conditioning, through the use of special scrapers. For this machine a residence time of 5 min is needed to create seed (Figure 13.8). This temperer has proved to combine well with enrobing machines to produce a good temper. The enrobing temperature is, however, lower than could be achieved with a longer residence time in the enrober tank.

In the MST-V temperer, metered chocolate is fed in the base of the machine and rises through heat-exchange plate elements, which are divided to create three cooling zones and which have spring-loaded scraper blades in order to provide efficient heat exchange. The required "strike seed" temperatures occur in the later stages of the cooling cycle. A further zone reheats as necessary and extends the residence time period. The chocolate now passes through to the user plant. It is also claimed that water at 16.6 °C (62 °F) can be used effectively as the cooling medium.

This model has been largely superseded by the Sollich tempering machine designated the MSV Turbo. This machine has a stacked plate design like the MST-V. Major changes have taken place however in the method of scraping the cooling plates and water circulating systems. The previous spring loaded scrapers have been replaced by a semi-scroll cruciform design (Figure 13.14). Water cooling and circulation is now improved and is continuous. This is achieved by a circulating pump passing water through redesigned cooling or heating zones. A modulating control valve system for precise temperature control admits heating or cooling water. An automatic capacity control system adjusts the cooling surface area as required, when variations of flow rate or incoming chocolate temperature occur. This ensures an almost uniform degree of temper at all times.

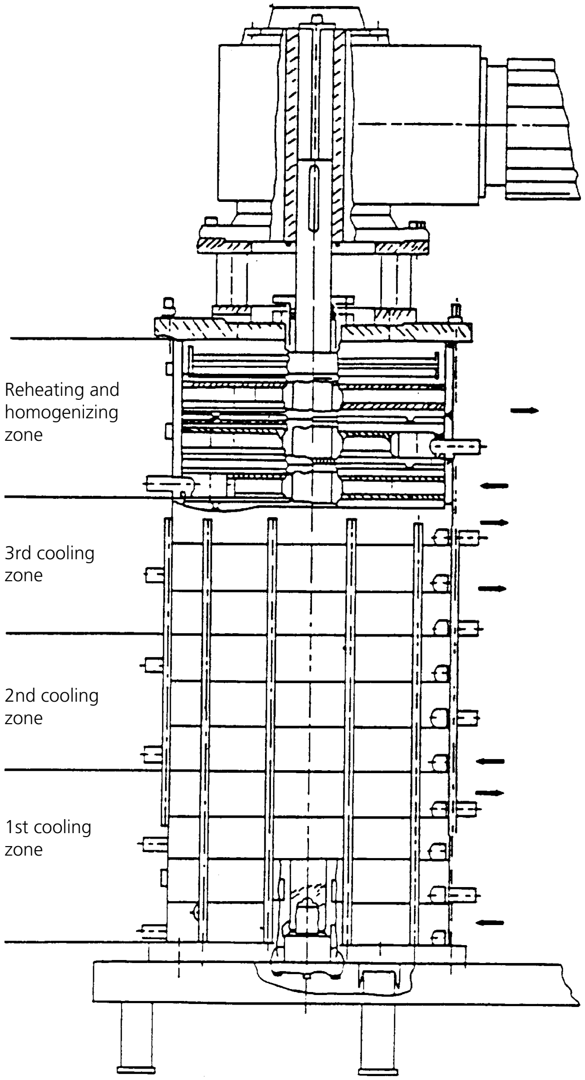


Figure 13.13 The Sollich Solltemper MST-V.

Carle and Montanari: A wide range of tempering machines have been produced. These started with the "Tan" worm screw types, followed by the "BETA" stacked plate type temperer and a very novel design, the "τ" ("Tau") intensive shear machine (Figure 13.15) which was introduced in 1996.

This machine was designed to be opened like a clam shell. The intention of the designers was not only to allow easy clean out, but also to follow the theories related to relatively high shear tempering. The *"τ" Tempering Machine, as* can be seen in Figure 13.15, is made up of two circular bodies, both of which present a corrugated surface, forming a series of concentric round chambers. The profile of

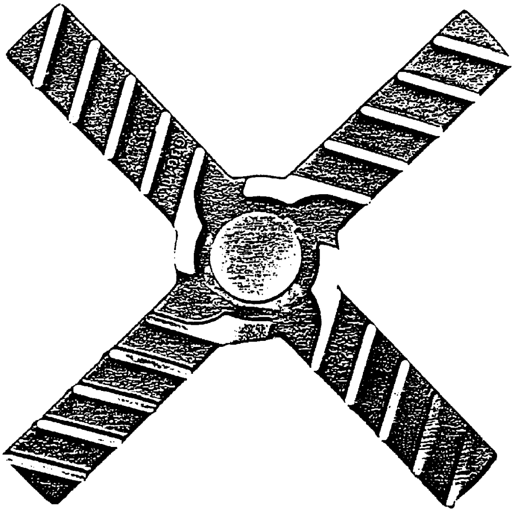


Figure 13.14 Sollich cruciform scraper (MSV Turbo Temperer).

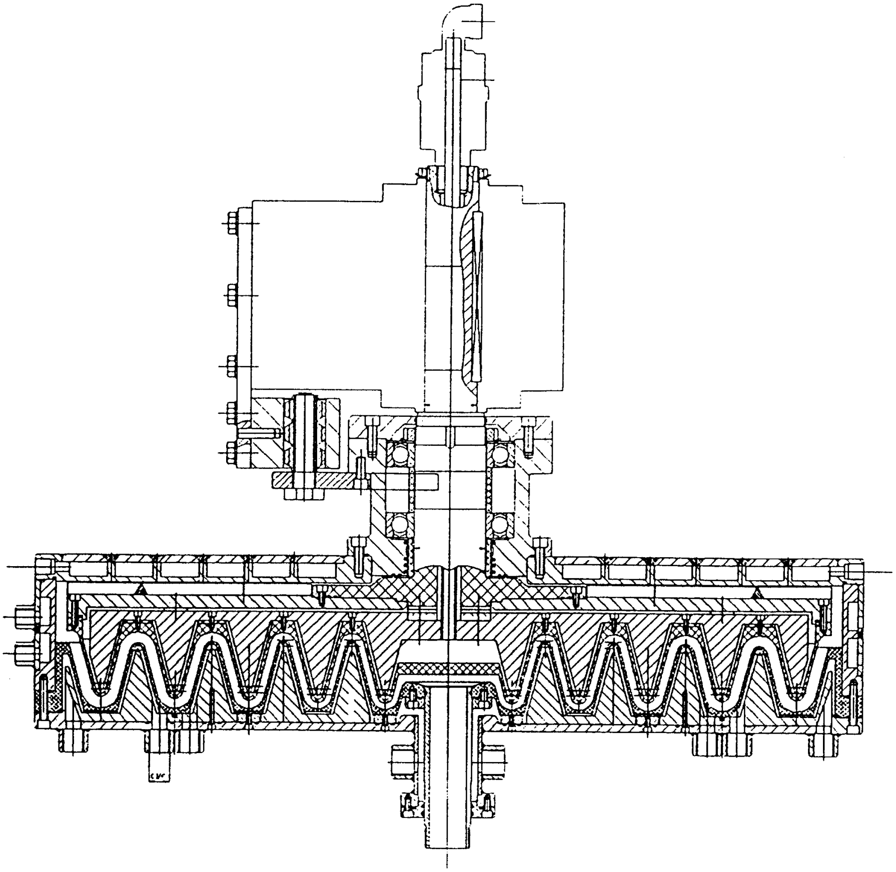


Figure 13.15 Section of a "τ" tempering system. Reproduced with permission of Carle and Montanari-OPM.

the two bodies is such that, in the final arrangement of the system, there is an interpenetration of the crests of one element's corrugated surface into the chambers of the opposite facing element. In this way a product passage gap is created in the space left between these two bodies.

One of the two bodies rotates (rotor), whilst the other is fixed (stator). Both elements contain cavity walls for the passage of the cooling medium and temperature controlled fluids. This cooling/heating fluid system has been designed so as to give two areas of different controlled temperature in the stator, each having 50% of the heat exchange surface. A further independently controlled temperature zone exists in the rotor element, with a further zone positioned in the core of the tempering elements. The key advantages of this machine are:

1. A large surface area in a relatively small space.
2. The formation of a passage/gap for the product, which is of constant dimension and controllable at every point. This applies a homogenous and continuous shearing action, whereas in conventional tempering systems this effect is limited only to the areas of close proximity between the mixers and the heat exchange walls.
3. The possibility of getting into the inside of the machine by simply uncoupling the tempering elements. This is made possible by the fact the machine consists of only two tempering elements within a housing, thus forming a unit which is easy to open.
4. The rotor is driven by a variable speed drive.

The product flows from the centre of the system to the periphery so that, as the cooling area increases with distance from the centre, so too does the volume available to contain the chocolate. This means that the system is not very sensitive to the increase in viscosity of the product during tempering and as a result only very low pressures are present within the machine. In addition, the relative speed between the rotor and stator increases with the distance from the centre. This results in an increasing shear rate and hence a higher shearing stress being applied to the product as its viscosity also increases. This means that the maximum shear stress is applied to the cooled product, where it is able to increase the rate of crystallisation and encourage the formation of stable β_V polymorph crystals.

Carle and Montanari produce other temperers including a four-section vertical temperer based on scraped heat exchangers.

APV Baker: (No longer produced, but of interest due to its novel features.) In the late 1950s Baker Perkins were licensed to produce their own version of the Sollich built-in tempering techniques. These were designed into enrobers as integral units. Early designs had the problems associated with low residence time systems. Baker Perkins solved these problems in the mid1960s by using a large enrober seed bed with a variable retention time of 15–60 min. This was shown to be enough time, together with efficient agitation, to create the most stable high-temperature coatings. In this machine the principle of seed maturation has been applied to the tempering machine itself, rather than just to

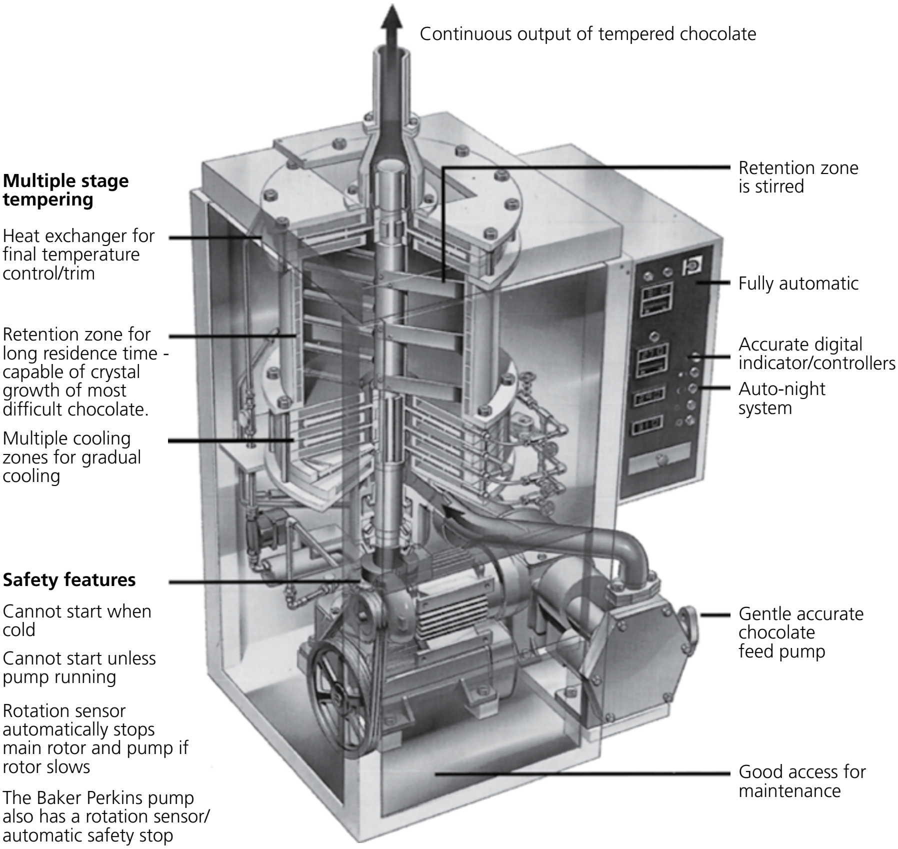


Figure 13.16 The Baker Perkins 105 TU tempering machine (Baker Perkins BCS Ltd).

a holding tank or the enrober. This led to the development of the Baker Perkins 105 TU ACS tempering machine (Figure 13.16) with a "real" retention zone, located approximately midway through the temperer. Advantageous features of this model were:

1 High-pressure chocolate metering pump.
2 Safety features on start-up.
3 High shear rate Archimedes cooling discs ($8500\,s^{-1}$).
4 Water plates with high velocity turbulent flow.
5 Transition maturation mixing zone giving significant improvement in final crystal hardness (timed residence mixing zone).
6 High shear rate Archimedes control discs controlling temperature to user point.
7 Chocolate zonal temperature control is by autotune electronic instruments operating chilled water-modulating valves, effectively holding temperatures to 0.1 °C.
8 Where the de-seeded chocolate temperature is unreliable, extra preheating plates or cooling plates are available on a modular machine.

9 Savings in fat (cocoa butter) were documented to take place because of the higher temperature of the chocolate at use.

The operation of the APV Baker tempering machine was as follows (Figure 13.16). A high-pressure metering pump took de-seeded chocolate from bulk storage and metered it into the first zone of the tempering machine. This zone was filled with Archimedes mixing discs mixing and spreading chocolate in a prescribed continuous path from the centre of the machine to the outside and back again. At the same time the chocolate progressed upwards through the machine due to the pumping action of the discs. During the passage through this first zone, sensors regulated the chocolate temperature. At the end of the first zone, at approximately 27 °C (81 °F), chocolate seeding was initiated, giving rise to very fast and fine crystal growth. If this state was allowed to proceed solidification would result.

On entering the second zone the transition from the unstable crystalline states to the β_V form took place and a natural temperature rise of 2 °C (3.6 °F) was observed. This “transition” is not seen in other machinery and is the early stage of maturing to the more stable crystal form. As the chocolate, now being rewarmed, progressed within the second zone it was intensively mixed. This shear, together with the time element, provided the necessary maturation conditions required to produce a more highly tempered chocolate. This zone had a retention time of 12–20 min, depending upon flow rate.

The next part of the machine was a disc-type heat exchanger which was capable of precisely controlling the exit temperature. This machine could handle the most difficult eutectics as well as, of course, the easier recipes. The ACS temperer filled the dual role of feeding enrober plants or moulding systems. As mentioned earlier, this machine recognised the *latent heat temperature rise* in the retention zone by sensor probes, and could be pre-set to attain a pre-determined cooling curve. Although highly tempered, this chocolate exhibited a higher melting point and a lower viscosity, with the temper cooling curve showing a higher than normal (temperature) inflection point.

13.6.3 Continuous industrial seed-tempering

13.6.3.1 Summary of the principles

In conventional tempering, the crystal seeding is performed by scraping seed crystals from a cooled wall. Whereas these needle-like seed crystals are in a semi-stable polymorph form (mostly α-form), a new methodology has been developed in the past ten years of seeding by continuously adding pure, fully matured β_{VI} or $\beta_V+\beta_{VI}$ cocoa butter seed crystals in concentrated suspension into temperature controlled, untempered chocolate. Currently commercial industrial temperers based on this principle (Seed Master tempering machines) are manufactured by Bühler AG of Switzerland.

Control of crystallisation processes by seeding is used commercially to make many different products, for example sugars (Kleinert, 1980), vitamins, drugs

(Bollinger *et al.*, 1998) and fine chemicals (Cebula *et al.*, 1991). The idea of seeding chocolates with well defined crystals has also been reported in a number of scientific and patent applications either based on specific cocoa butter crystals (e.g. Windhab and Zeng, 1998;, Bollinger *et al.*, 1998; Pate, 1983; Dieffenbacher, 1986) and a system based on BOB (1,3-behenoyl, 2-oleoylglycerol) seeding, which is used in Japan, but is not legal in most other countries. Such seed crystals are added to the chocolate in crystal powder form, or by the confectioner's "artisan methodology" (Chapter 18) of adding small amounts of solid chocolate pieces/powders into an untempered chocolate melt. The use of the former seeding concepts for continuous industrial chocolate manufacture was not significantly implemented, since they did not have the consistency or robustness to fulfil one or more of the following required aspects:

1. Good control of the tempering state with respect to resulting polymorph distribution;
2. Stable active seed crystal fraction and seed crystal size distribution;
3. Homogeneity of seed distribution;
4. Thermal stability of the seed
5. A method of handling continuous seed powder dosing and homogeneously mixing it into a chocolate stream.

Many of these problems are overcome by adding the seed (containing a majority of β_{VI} crystals) in a concentrated suspension within liquid cocoa butter. The seed crystal suspension containing cocoa butter crystals is continuously added to the pre-cooled chocolate stream in quantities from 0.2 to 1.0% and homogeneously mixed using a specially designed static mixer system. The cocoa butter seed crystal concentration in the seed suspension is fixed between 15 and 25%wt with a β_{VI} fraction between 50 and 95%. This gives the possibility to pre-crystallise and further process the chocolate at temperatures of at least 3–4 °C (5–7 °F) higher than in conventional tempering technology (depending the fat matrix of the confectionery product), leading to an improved processability during moulding and enrobing. Other advantages include improved fat bloom stability, accelerated solidification, ability to crystallise mixtures of vegetable fats and cocoa butter down to only 10% of cocoa butter fraction and diminishing the crystallisation-inhibiting effects of added milk fat or other fats without reducing their positive contribution to support anti-bloom.

These advantages are based on the fact that stable cocoa butter crystals are externally generated and introduced into the various chocolate and chocolate like systems in suspended form with:

1. Controlled polymorph distribution (preferably with a fixed β_{VI} fraction in the range 50–95%);
2. Controlled seed crystal size/size distribution (adjusted by the degree of shear treatment and residence time in the seed crystal suspension processing within a mean crystal size range of about 2–10 microns);

3 A controlled fraction of active seed crystals (0.02–0.15% crystals is equivalent to 0.2–1.0% suspension per total chocolate masse) by precise dosing and micro-homogeneous mixing of the seed crystal suspension into the chocolate.

Consequently a large number of nuclei controlled with respect to these three aspects is present in the seed tempered chocolate, providing the basis to form a dense and finely structured fat crystal network with fast solidification kinetics.

It has been found that the triclinic crystalline structure of the β_{VI} seed crystals makes the chocolate solidify in the triclinic β_V state, if the cooling and solidification kinetics is faster than that of a $\beta_V \rightarrow \beta_{VI}$ polymorph transformation (Mehrle *et al.*, 2007). This condition can easily be fulfilled, because in the chocolate the $\beta_V \rightarrow \beta_{VI}$ transformation may take from about 30 min to several hours, even at an elevated temperatures of 32–33 °C (90–91 °F).Typical industrial cooling conditions [10 °C (40 °F) for 20 min] produce an insignificant amount of additional β_{VI} crystal fraction. This is what is needed, however, because the β_V solidification provides the desirable smooth texture and melting, and avoids a waxy mouthfeel that is commonly associated with the β_{VI} state.

13.6.3.2 Industrial seeding process

These principles have been applied by Bühler AG in its industrial-scale SeedMaster Compact®.

This essentially consists of two stages. One part produces the so-called cocoa butter crystal suspension (CBCS), whereas the other is related to the chocolate masse stream, the dosing unit of the CBCS into the chocolate matrix and, finally, the mixing element to ensure homogenous outcome. The core process is the production of the CBCS and it takes place in a shear crystalliser which is divided into two cooling zones that are necessary for the nucleation, growth and transformation of the stable crystal modifications (Figure 13.17). In practice, low temperatures are applied in the first zone [15–18 °C (58–64 °F)] in order to initiate nucleation and growth of crystals. The second zone is critical for the transformation and stabilisation of the final cocoa butter crystal suspension. Usually the temperature of this particular zone lies somewhere between 20 and 28 °C (68–82 °F). The cocoa butter is circulated through the shear crystalliser and on average it takes about 30–50 min for the CBCS to stabilise in the right crystal form and concentration. This CBCS usually consists of 15–20% of the stable crystals.

As soon as the CBCS is stable, the seeding process is started. The chocolate stream is cooled down in heat exchange plates to temperatures that do not initiate crystallisation [approx. 30 °C (86 °F)]. An accurate dosing pump adds an exact amount of CBCS into the chocolate masse whilst specially designed static mixer elements ensure homogenous mixing (Figure 13.18).

The quality of the CBCS is critical for the performance of the end product and a specially designed measuring tube in the shear crystalliser circuit gives online monitoring and regulates the process (Figure 13.19).

Figure 13.17 Shear Crystallizer in the interior of SeedMaster Compact®. Reproduced with permission of Bühler AG, Switzerland.

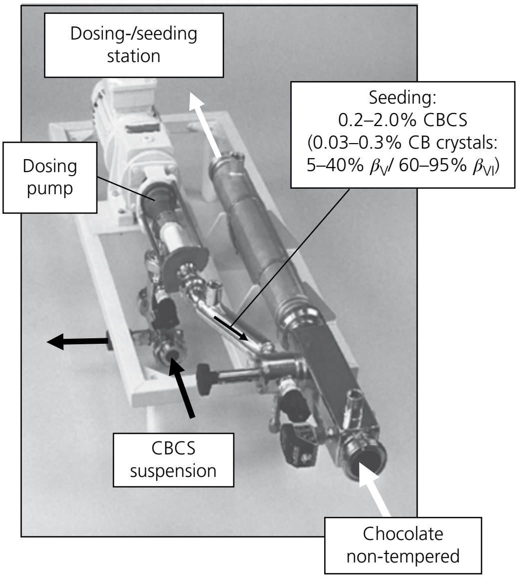


Figure 13.18 Seeding station for dosing/mixing of CBCS into an untempered chocolate stream. Reproduced with permission of Bühler AG, Switzerland.

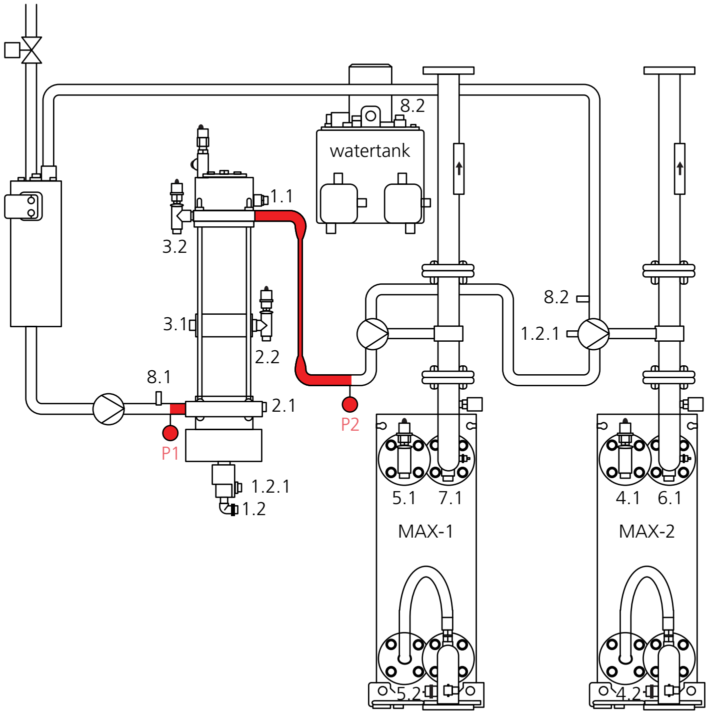


Figure 13.19 Measuring points for determining the differential pressure in the crystalliser circuit. Reproduced with permission of Bühler AG, Switzerland.

The pressure differential is measured to provide information on viscosity (a 20% crystal content the CBCS has a mayonnaise-like structure in comparison to molten cocoa butter and consequently significantly different flow properties). This can be correlated with the crystal content of the CBCS. In addition deviations out of a given range of differential pressure will immediately trigger action by the process controller and the temperature on the second zone of the crystalliser will be adjusted in order to maintain the differential pressure within the subjected range feature (a self-corrective action by the system itself).

The CBCS is dosed at a volumetric rate of 0.2–0.5% into the pre-cooled chocolate masse. This means that only 0.04–0.1% crystals are being incorporated into the chocolate matrix (assuming 20% solid fat content of the CBCS). Static mixer elements are used to ensure homogeneous mixing of the two liquid streams, CBCS and chocolate (Figure 13.20).

This mixer consists of different elements and sections (pre-mixing and main mixing parts). In addition there is a bypass section which ejects masses with different flow properties (e.g. high viscosity → high pressure in the system → activation of bypass).

Another critical factor is the temperature at which mixing takes place between the CBCS and the chocolate masse. This seeding temperature is strongly

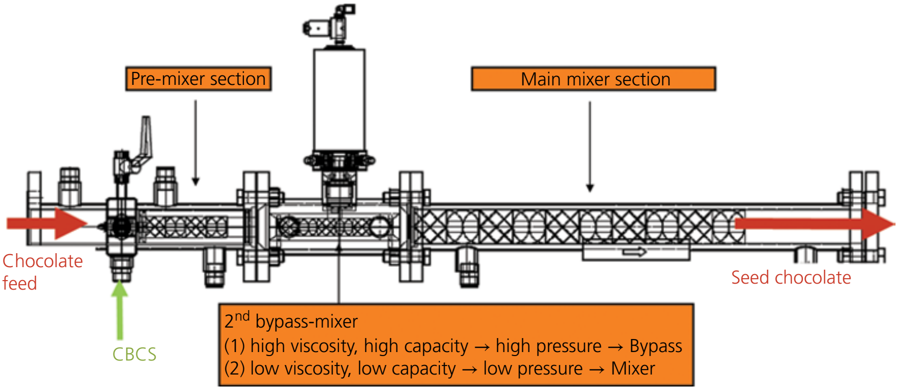


Figure 13.20 Illustration of static mixer elements. Reproduced with permission of Bühler AG, Switzerland.

$$\text{Seeding temp.} \propto \frac{\text{CB}_{(\text{pure added})} + \text{CB}_{(\text{contribution of cocoa mass})}\,(+\text{CBE})}{\text{Total fat in the chocolate matrix}} \times 100\%$$

Figure 13.21 Seeding temperature determination. Reproduced with permission of Bühler AG, Switzerland.

dependent on the fat matrix composition of the chocolate recipe. The "foreign" fat matrix (other than cocoa butter) in the chocolate composition, such as milk fat, nut oils, alternative fats and so on reduces significantly the crystallisation temperature of cocoa butter. On the other hand, cocoa butter equivalents are regarded as cocoa butter fractions due to their similar composition and chemical structure. Thus, the seeding temperature is decreased with the decreasing ratio of cocoa butter to the total fat in a given mass matrix (Figure 13.21).

This means that dark masses are seeded at higher temperatures than milk chocolate ones, whereas for confectionery fillings such as nougat even lower seeding temperatures are required, as illustrated in Figure 13.22.

13.7 Properties of CBCS tempered chocolate

13.7.1 Pre-crystallised liquid state

The influence of chocolate temperature on the measured temper for constant amount of added seed crystal suspension is illustrated in Figure 13.23 for a dark chocolate. In this particular example, dark chocolate is seeded constantly with 0.3% CBCS, and the seeding temperature was increased from 30 to 33 °C (86 to 91 °F). Due to the CBCS having the right form of crystals and concentration level, the degree of temper (expressed by tempering index) remains constant and only drops significantly at the extreme of 33 °C (91 °F; seeding temperature).

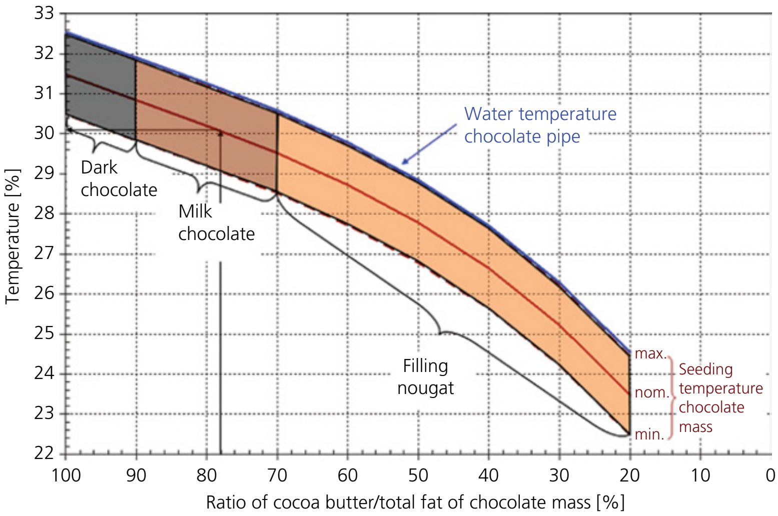


Figure 13.22 Seeding temperature and its dependence on the fat matrix. Reproduced with permission of Bühler AG, Switzerland.

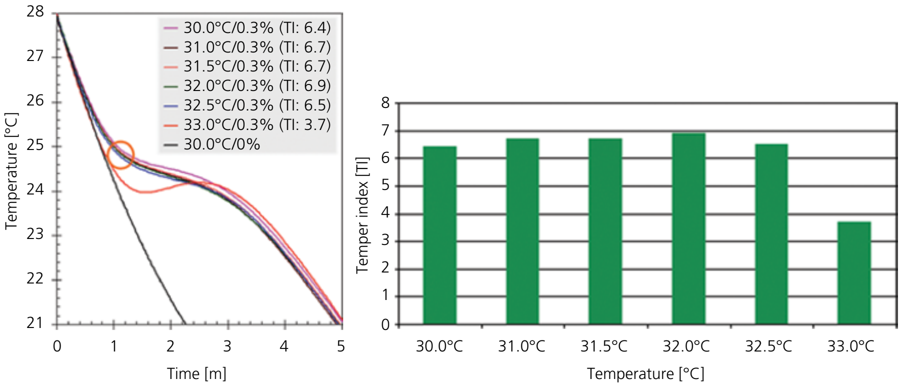


Figure 13.23 Tempering curves for seeded dark chocolate treated at different temperatures. Reproduced with permission of Bühler AG, Switzerland.

In another example, a dark chocolate matrix is seeded with different levels of CBCS (0.2–0.5%), whilst the seeding temperature remains constant at 32 °C (89 °F; Figure 13.24). This time the tempering index changes from a well tempered state (seeding at 0.2%) to an over-tempered one (above 0.3%).

The robustness of the seeding process is demonstrated in Figure 13.25. Here, a dark chocolate of 50% total fat (cocoa content at 65%) was seeded constantly at 0.5% level, with a seeding temperature of 31.5 °C (88 °F).The tempering index remained constant over a 42 h production run.

Milk chocolate behaves the same as all the above dark examples. The seeding process therefore gives the opportunity to deposit and mould or enrobe at

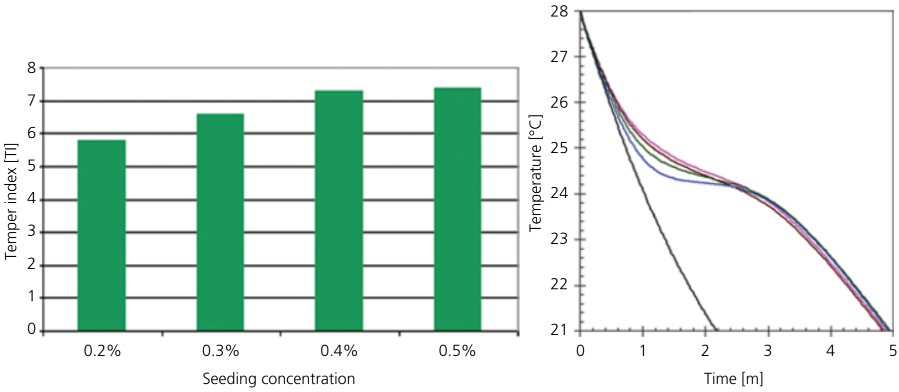


Figure 13.24 Tempering curves of dark chocolate at different levels of CBCS. Reproduced with permission of Bühler AG, Switzerland.

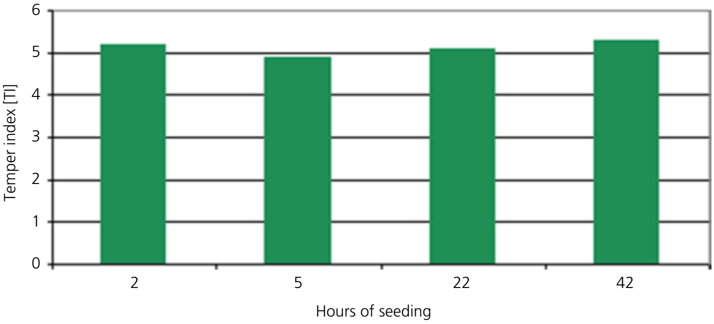


Figure 13.25 Tempering index measurements of seeded dark chocolate over 42 h production. Reproduced with permission of Bühler AG, Switzerland.

significantly higher temperatures than was possible for conventionally tempered chocolates. This greatly affects the flow properties of the chocolate, because chocolate viscosity reduces significantly as the temperature increases. This lower viscosity often produces better coating and weight control, particularly during enrobing. Alternatively lower fat chocolates can be used, yet maintaining the same flow properties.

13.7.2 Semi-solid and solid state

The speed of setting of moulded chocolate during cooling depends on the fraction of seed crystals and their size distribution. Although conventionally tempered chocolates contain more solid fat (0.5–1%, compared to about 0.02–0.3% for seed tempered) and would therefore be expected to set faster, normally the effect of the more finely dispersed seed crystals (seed tempered 3–7 microns, conventionally tempered estimated at >15–20 microns) overcomes this and the seed tempered chocolate sets faster.

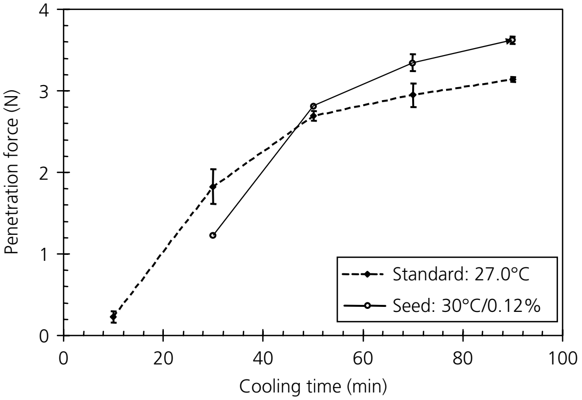


Figure 13.26 Effect of the type of tempering on the snap/hardness of milk chocolate as measured by needle penetrometry (Zeng, 2000) – during cooling (12 °C, 54 °F).

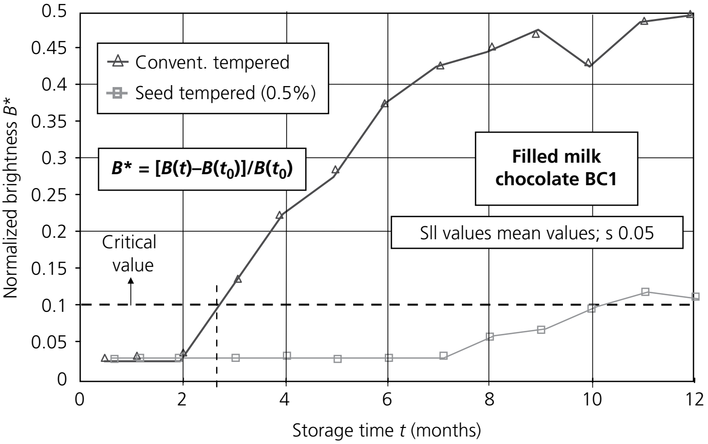


Figure 13.27 Effect of the type of tempering on the surface gloss of a filled milk chocolate product; surface brightness measurements by LAB-colormeter (Zeng, 2000) – brightness versus storage time (19 °C; 66 °F).

The improved size distribution of the seed crystals also explains the characteristic increase of hardness and improved "snap" for seed-tempered products (Figure 13.26) and their significantly improved bloom stability. The latter is particularly pronounced in the case of filled products for which both the filling and the coating have been seed-tempered (Figure 13.27). Here the liquid fats in the centre (e.g. trioleins) find it harder to diffuse through the more dense, structured fat phase produced by the seed tempering.

A tendency for increased final contraction (density) for seed-tempered systems particularly when cooled more rapidly, is assumed to indicate the overall solidification in the stable β_V polymorph form, compared with 10–20% of less

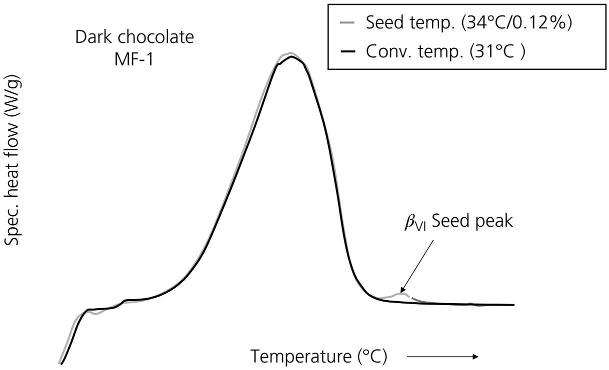


Figure 13.28 Melting behaviour of conventionally and seed-tempered dark chocolate as measured by DSC.

dense β_{III} or β_{IV} polymorphs forming in conventionally tempered chocolates. However, it might also be due to a systematic difference in micro-dispersed gas between the two types of tempering.

Research on long-term storage trials with seed tempered chocolates of different fat composition indicates that the local inclusion of finely dispersed β_{VI} crystals improves stability of the chocolate system against further $\beta_V \rightarrow \beta_{VI}$ transformation, which could cause the undesirable structure effects known (but not yet clearly understood) as the non-controlled β_{VI} bloom (Van Mechelen, 2006a, b) with visible re-crystallised β_{VI} crystals.

In Section 13.6.3 it was explained how the seed contained a high proportion of β_{VI} crystals and yet the chocolate was almost entirely β_V because of the relatively slow transformation to β_{VI}.From Figure 13.28 it can be seen that both conventionally and seed tempered dark chocolate samples show a very similar type of melting behaviour, which is typically dominated by β_V crystals. For the seed-tempered chocolate, a small peak at 36 °C (92 °F) can still be seen, which is the melting peak of the β_{VI} seed crystals. The fact that the chocolate solidifies largely in the β_V state explains why the sensorial perception – no waxy mouthfeel as would be expected for β_{VI} crystals – of the seed-tempered chocolate is practically equivalent to the conventionally tempered chocolate.

13.7.3 Industrial process layouts

The first SeedMaster Compact® machines were able to handle one (single version) or two (twin version) chocolate process streams with a single shear crystalliser. For example, the twin version can feed two different moulding lines (Figure 13.29) or two different depositor heads on the same moulding line.

In more complex cases such as the moulding lines for filled products, one SeedMaster Compact® unit is able to handle the seeding of the chocolate masse for the shell making and bottoming, whereas the second stream may be dedicated

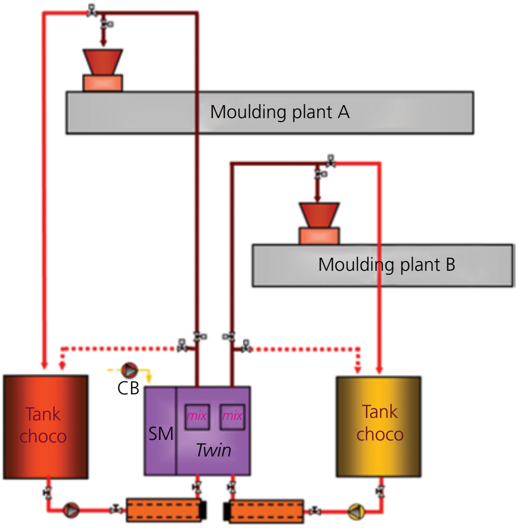


Figure 13.29 Process layout for SeedMaster Compact® twin version in two moulding lines. Reproduced with permission of Bühler AG, Switzerland.

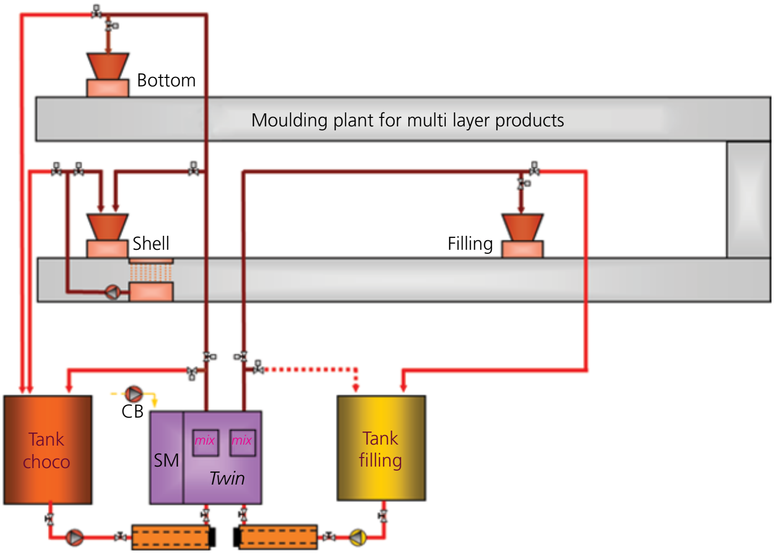


Figure 13.30 Process layout for SeedMaster Compact® twin version for filled products. Reproduced with permission of Bühler AG, Switzerland.

to the confectionery filling (Figure 13.30).This concept is strongly dependent on the size of the moulding line, length of pipings, distance to depositors and so on. Often the combination of a single with a twin SeedMaster Compact® unit is applied to provide even greater flexibility.

The Seedmaster Compact® Triple and Quattro versions are also commercially available. The Quattro model has four different chocolate process streams seeded by a single crystalliser unit.

13.8 Other methods of tempering

There is a variety of other tempering methods and machines found, particularly in patent literature. Many are of historical interest and no longer relevant for modern industrial production of chocolates and it is not possible to mention them all here. Some types of these "historical" tempering systems described by Beckett (1995) are listed below:

1. *Cooling drum.* Multiple or single layouts condition chocolate before it is trickle-fed to the enrobers.
2. *Drip feeding of untempered chocolate*, where the material already in the enrober tank seeds new incoming chocolate.
3. *Screw-type tempering machines*, some horizontal, some vertical with different screw geometries and arrangements.
4. *Lehmann Multi-Roller* for cooling and tempering highly viscous paste systems and delivering it into suitable trays at the end of the machine.
5. *Bauermeister pressure tempering*, a high-efficiency, scraped cylindrical, horizontally disposed, heat exchanger, fitted with an adjustable relief valve at the exit to maintain a cylinder pressure of between 1.7 and 10.5 bar.
6. *Thermocyclic/cyclothermic tempering* with four or five subsequent cooling–heating steps to stepwise generate highly stable seed, but long residence time and large volume equipment are required.

Conclusion

There are many types of tempering machines available to the chocolate manufacturer, each having its own advantages and disadvantages. To obtain good processing and a high-quality product however requires accurate control of the mechanical and thermal history of the fat crystals generated in the chocolate. This can in principle be done by precisely adjusting the temperature, shear rate and residence time. This requires homogeneous shear flow fields, good heat transfer and frequent detachment of material from wall boundary layers. In addition, an understanding of the processing and final product from the molecular via the macroscopic/micro-crystalline to the macro-disperse level is very helpful in optimising the tempering process, particularly with respect to raw material variations, new product developments/optimisations and process scaling. It is expected that new analytical methodologies, such as those based on x-ray and neutron scattering, as well as on improved in-line instrumentation to monitor the chocolate's rheological and calorimetric characteristics, will be the key drivers for ongoing and future improvements in the tempering of confectionery.

Acknowledgements

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Appendix: Machinery manufacturers

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Carle and Montanari-OPM S.P.A., Via Trebbia 22, 20089 Rozzano, Milan, Italy.
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Hacos N.V., Oostmalle, Belgium.
Hosokawa Kreuter Gmbh, Essener Strasse 104, D-22419, Hamburg, Germany.
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CHAPTER 14

Moulding, enrobing and cooling chocolate products

Michael P. Gray, revised and updated by Ángel Máñez-Cortell

14.1 Introduction

Previous chapters have discussed the manufacture of liquid chocolate, its ingredients and how to handle and temper it. This chapter deals with ways of forming chocolate into a finished product ready for wrapping.

There are two principal ways of doing this. The first is to form the final shape using a mould into which tempered chocolate is poured. This can be a simple dosing operation if making solid tablets, or can include forming a shell of chocolate and adding various fillings to create a more interesting eating experience. Enrobing is the other method and uses a pre-formed centre over which chocolate is poured to produce a coating. The thickness and form of the coat are controlled by using a chocolate masse with the correct viscosity and by blowing off any excess masse using air and then vibration.

Moulding gives a more obvious gloss to the finished product, whilst enrobing can cope with complex shapes and gives a soft and pleasing finish to the article.

In both cases, subsequent cooling is required to prepare the sweets for immediate wrapping. If chocolate is used as the coating, then good temper (see Chapter 13) is a necessary prerequisite, though if a vegetable fat-based compound coating is used, this may not be necessary (see Chapter 19).

14.2 Moulding

14.2.1 Background

Moulding chocolate has been used to make sweets since the nineteenth century. Initially it was carried out entirely by hand but, over the intervening years, automation has gradually taken over. Early moulding lines still required a lot of people to move the moulds from one stage to the next and to carry out operations such as inversion of moulds, topping up depositor hoppers and

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

even scraping off excess chocolate from the moulds. Further automation was gradually introduced until, during the last quarter of the twentieth century, advances in electronics and automation techniques allowed the number of operators to be reduced to one per plant and sometimes even one between two plants.

At the same time, the metal moulds which were originally used have been replaced by plastic, normally polycarbonate ones, resulting in a significant reduction in noise in the production areas. The easier handling of these lighter moulds has allowed the introduction of automatic mould changers, both for complete changes of moulds and for the removal of individual moulds, which have undemoulded items left in them. Polycarbonate moulds are also more flexible, so they can be twisted to aid demoulding.

Plant speeds have increased from just a few moulds per minute (mpm) to around 70 mpm for solid items, and plant widths from 275 mm to 1800 mm (12–75 in) are now available with capacities of up to 10 000 kg/h (22 046 lb/h). This has all meant that outputs have steadily increased, whereas labour requirements have fallen. In general, reliability has also improved, though some of the earlier automated lines in particular continue to give problems unless heavily modified.

In recent years, although there has been no real "quantum leap" in moulding technology, manufacturers are constantly tweaking their designs to improve the efficiency of the processes. These improvements include easier cleaning and attention to hygiene: (i) construction methods using solid supports to eliminate hollow bodies, (ii) components being installed with a clearance to the floor to allow easy inspection and cleaning underneath and (iii) electric cables being routed away from dirty areas or made easily accessible for cleaning. Wood and plastic cladding have been replaced by clear polycarbonate so that all the components are visible, and leaks and spills can be seen and eliminated. Other improvements are in the areas of flexibility and use of modular lines that can be combined into any configuration to fulfil the requirements of customers and produce different product ranges, upgrades of software and use of wireless mobile control panels to provide more flexibility, quicker changeover to new products with equipment easier to modify and, with increasing emphasis, improving the energy efficiency and sustainability of the processes. One example of this is the reduction of the weight of moving parts by using lighter materials and clever constructions. This has an impact on the energy load and size of the electric motors, leading to lower power consumption.

14.2.2 Loose and fixed mould plants

Fixed mould plants are those with moulds attached to continuous motion conveyors, usually chains, and are well suited to large production volumes. They can reach speeds of more than 70 mpm when moulding solid chocolate and approximately 40 mpm when producing filled articles. Intermittent motion and crowding (pushing the moulds together to prevent chocolate falling underneath during depositing) are possible for short sections, generally by using hydraulic mechanisms to slacken the drive chains. Fixed mould lines are usually arranged vertically with the return leg from the demoulding to the mould heater being above or below the depositing leg to minimise the area they occupy.

Loose mould plants have a higher degree of flexibility in terms of the variety of products that can be made on one plant (sometimes simultaneously) and in their ability to change from one product to another rapidly. They are linear and modular, and can easily be adapted to users' requirements. The moulds are moved by a variety of chains and conveyors and can switch rapidly from continuous motion to intermittent and vice versa, as required. Modern technology, in particular the servo motor, allows each section to be independently controlled electronically and has revived interest in loose mould plants, as they now have the potential to operate at much higher speeds than lines using older technologies. Conventionally, lines have had one or possibly two central motors with lengthy shafts being used to drive the individual components.

14.2.2.1 Plant layout

Simple loose mould lines are usually laid out in a square, though a figure of eight (8) layout is often adopted to allow sections not being used to be bypassed for cleaning or changeover, or just to save wear and energy. More complex layouts with parallel legs or star shapes around a central cooling zone can be found on ultra-flexible plants used to make a wide variety of assortments (Aasted, 2014). These lines can be built and expanded upwards, crosswise or lengthwise to adapt to the existing production facility. The various components may be independent or combined according to the age and design purpose of the plant. A typical layout of a loose mould line capable of manufacturing filled chocolate bars is shown in Figure 14.1. A picture of the turning point on such a line is shown in Figure 14.2.

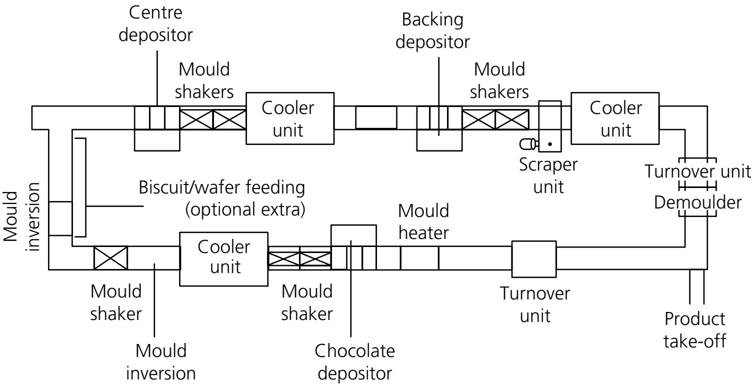

Figure 14.1 Layout of loose mould moulding plant.

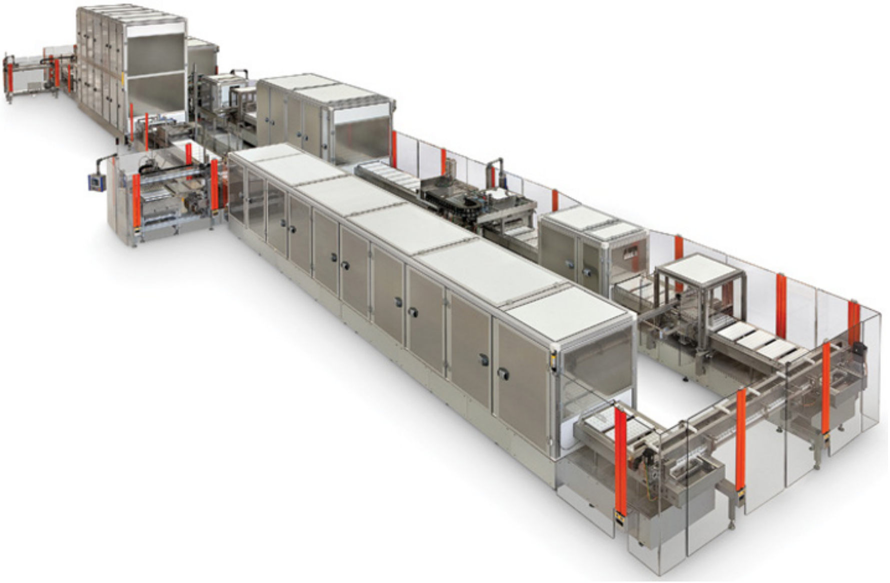

Figure 14.2 Picture showing turning points on loose mould moulding plant. Reproduced with permission of Carle and Montanari-OPM.

Fixed-mould lines require the same components, generally in the same sequence, as those of the loose mould line. Large capacity lines are usually laid out in a straight line. Smaller or older lines are sometimes also laid out in the form of a square, but normally the return leg will also be above or below the depositor leg.

The necessary components are:

- Mould conditioning.
- Depositing:
  - There can be several depositors according to the number of products made.
- Shelling forming and cooling[1]:
  - The cooler can be vertical or horizontal, and continuous or intermittent in operation.
- Centre filling/placing and cooling[1]:
  - There may be several depositors, often used simultaneously to produce all the components of an assortment at the same time. Or there may be placing modules if it is a solid centre such as a wafer or a biscuit.
- Backing off[1]:
  - Can be flood, deposited or sprayed according to the type of centre.
- Main cooler.
- Demoulding.

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[1] These sections are not required for the manufacture of solid tablets.

14.2.2.2 Pre-requisites

Other chapters in the book cover temperers and tempering (see Chapter 13), chocolate recipes (see Chapter 20) and the handling of masses before they reach the moulding line (see Chapter 12). It is imperative that the chocolate is well-tempered before reaching the depositors and that its temperature is as high as possible to maximise fluidity. The level of surfactants such as lecithin and PGPR in the chocolate must have been optimised for moulding and the viscosity must not only be suitable for the purpose, but also be consistent. Without these requirements being met, it is impossible to produce consistent glossy items of the correct weight and shape. Such defects will not only result in poor visual appearance and sensory attributes, but may well lead to problems in the wrapping area, where wedge or banana shaped items will slow down or jam wrapping machines, especially at high operating speeds.

14.2.3 Mould conditioning

If tempered chocolate is put into moulds that are not at approximately the same temperature (ideally ±1 °C; 2 °F) problems will arise:

- If the moulds are too warm, de-tempering can occur resulting in product sticking in the impressions following demoulding, poor gloss and bloom.
- If they are too cold, poor gloss and sticking in the mould can result. The flow of chocolate in the mould can also be affected and can result in markings on the finished product as well as an increased number of air bubbles.

Moulds returning from the main cooler are usually at around 12–15 °C (54–60 °F) and so must be re-heated. If they have just been introduced to the plant, or there has been a long stoppage, they are likely to be at room temperature and will require less heating. The conditioner will take some time to adapt to these changes, and there will usually be a gap in production as a result.

Mould heating may be direct or indirect. Indirect systems use air heated by steam coils or electric heaters which is blown across the mould surface. This has the advantage of giving a precise and even control of mould temperature. However, the disadvantages include higher capital cost and greater space requirement, the need for a longer heating zone (and consequently more moulds in the circuit) and a higher energy requirement. The air is diverted during stoppage periods to prevent overheating.

Direct systems use a radiant heat source, usually an electric heater mounted above the moulds and shining down onto their top surface. Advantages include energy efficiency (as it only acts on the mould surface), simplicity and a shorter conditioning time, which in turn leads to fewer moulds in the circuit. Disadvantages are that the temperature is never completely even and it is difficult to get heat into the bottom of a deep mould cavity. The reflectors are normally moved through 180° during a stoppage to reflect the heat away from the moulds.

An optical pyrometer, infra-red (IR) thermometer or a conventional one with a contact probe can be used to check that the temperature is even across

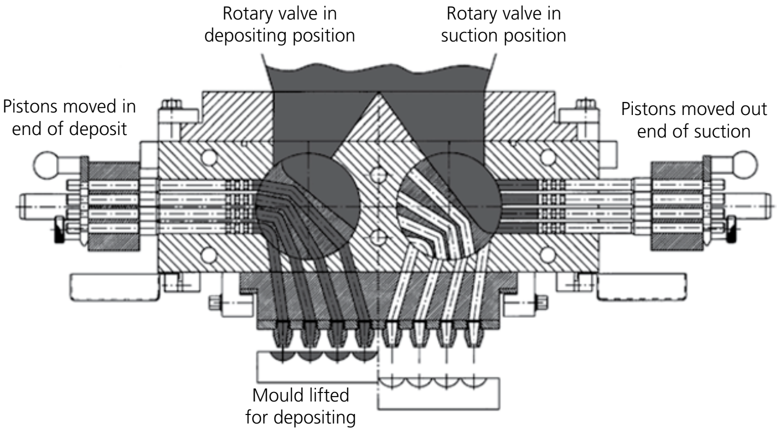

Figure 14.3 Typical piston depositor. Reproduced with permission of Bühler AG, Switzerland.

the moulds – usually an IR thermometer is fitted above the line, but this measures at only one point across the mould. With mould heating being so important it is also recommended to install a sensor before depositing with the function to stop the depositor if the mould temperature is not in the desired range.

14.2.4 Depositors

There are several types of depositor, which will vary depending upon its age, manufacturer and purpose. Piston depositors (Figure 14.3), of which there are many different models, are the most accurate. Their layout can be either linear or rotary. In a modern piston depositor all its motions are accurately controlled by servo drives, which monitor feedback signals from the electric motors and continually adjust any deviation from the expected behaviour of speed, position and torque. The diameter of the pistons and the duration of the stroke determine the volume that can be handled by the depositor. Various different solutions have had to be found to ensure that all the different pistons provide an even distribution of chocolate in every mould cavity all the way across the plant, with the degree of success depending on the manufacturer and on the product. Checking the weight variation across a moulding line should be part of each new product start-up.

Rotary gear depositors (Figure 14.4), which tend to be more compact and somewhat cheaper, are used for tasks requiring less accuracy such as shelling and biscuit applications.

The depositor has three basic components: (i) a jacketed hopper, usually stirred slowly to distribute the mass evenly and minimise variations in temper and temperature, (ii) the piston block, where the mass is metered by being drawn in to the bore and then in the next part of the cycle pushed out into (iii) the depositor plate. It is this complex and heavy device that directs the chocolate into the various cavities in the mould. The depositor plate is interchangeable to

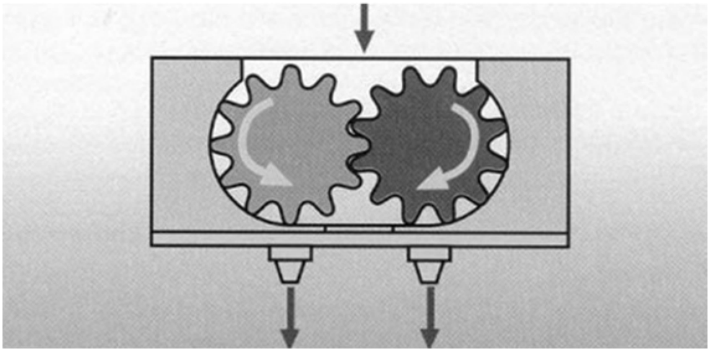

Figure 14.4 Typical gear depositor. Reproduced with permission of Bühler AG, Switzerland.

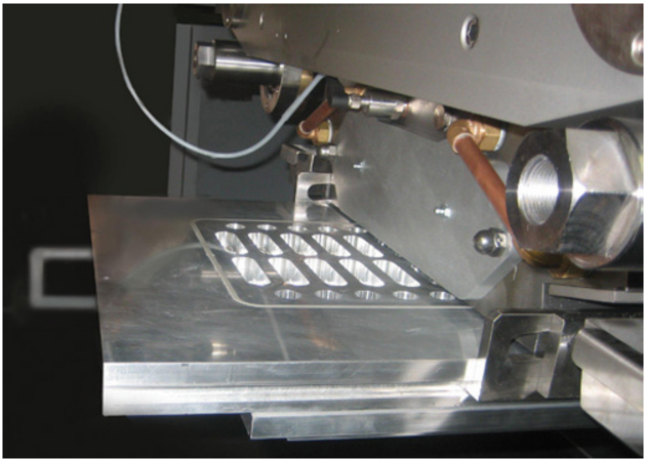

Figure 14.5 Typical depositor plate. Source: Aasted. Reproduced with permission of Aasted Denmark.

adapt the depositor to the layout of the various moulds used on a plant. More than one piston can be used for each cavity, if the product being made is large. The plates on wide plants may have more than 100 nozzles and frequently there are two rows of depositors per plant filling alternate moulds to enable higher operating speeds. The pressure applied to the plate can be as much as 18 bar (260 psi), which is why it has such a massive construction (Figure 14.5).

On some plants, the moulds are lifted up so that they are closer to the depositor and then rapidly dropped back to their normal height: this is done to break any tails that might form when depositing stringy materials such as caramel. There is also the possibility of lifting or lowering the depositor head instead of the moulds, which has basically the same effect. The whole depositor may also move backwards and forward at the same speed as the moulds, or may swing whilst depositing. This is done to allow more accurate positioning of the material being put into the cavities. Other typical parameters that can be adjusted to optimize the deposit are the depositing speed and suck-back (pistons are slightly pulled back at the end of a deposit cycle to create a suction effect that helps in avoiding tailing and dripping of chocolate outside the mould cavities).

Many modern depositors can be slid away from the line to allow cleaning, whilst the line itself is still running, resulting in a significant reduction in downtime during changeovers. Other improvements are the development of quick-changeover kits where not only the depositor plates are easily interchangeable, but also the whole piston block can be easily and quickly replaced with spare units that have the required special size pistons (Roncato, 2011).

14.2.5 Adding inclusions

Depending on the type of product, the depositing plate can be designed for spot depositing (also called point depositing) or ribbon depositing. In spot depositing, small-diameter nozzles are generally fitted to a depositor plate for dosing liquids, whether it is chocolate or a product centre. There can be one nozzle or multiple nozzles per cavity depending on the size of the cavity. However, this approach does not work when there are inclusions, such as nut pieces or crispies (cereals) mixed into the liquid masse. In this case ribbon depositing is the preferred choice where instead of nozzles the depositor plate has long narrow openings that cover almost the width of the cavity. The openings must be large enough to let two inclusions travel through side by side. If the inclusion is 3 mm (0.1 in) long then the outlet needs to be at least 6–8 mm (0.25–0.3 in) diameter. With such a large opening dripping can occur, so a shut-off knife or valve is usually fitted to the underside of the depositor plate to physically close the outlet after depositing is completed.

Figure 14.6 shows a typical worm conveyor/mixer for inclusions, which can be mounted on a swivel to allow for cleaning whilst the plant continues to run.

Figure 14.6 Screw mixer conveyor system. Source: Aasted. Reproduced with permission of Aasted Denmark.

Alternatively double hopper systems make it possible to change very easily between different types of inclusions. There are in fact many machines that can be used to add nuts and fruit accurately. With all of them however accurate weighing, good temperature control and homogeneous mixing mean better weight control. Adding inclusions to the chocolate in a mixer before pumping to the depositor hopper gives a more homogeneous result and allows better deposit and weight control.

Defects from incorrectly adding inclusions include:

- Grey marks over inclusions: due to poor temper or inclusions being too warm.
- Badly shaped bars: inclusions should ideally be near to the temperature of the chocolate, and should at least be stored in a warm room for several hours before use.
- Poor weight control: non-homogeneous mixing either of inclusions with chocolate or, if using more than one inclusion, of the inclusions themselves.

14.2.6 Removal of air bubbles

Air bubbles can spoil the appearance of a chocolate tablet and in extreme circumstances may give rise to weight variations. They can be minimised by choosing the correct mould temperature prior to depositing. Some mould designs will inherently trap bubbles, and this must be addressed during their design.

It is important to begin vibrating to remove trapped air bubbles as quickly as possible after the chocolate is deposited into the moulds. Most vibrators act vertically; the mould is pushed a set distance (amplitude) at a given frequency by an eccentric cam or an air cylinder. Ideally both the frequency and amplitude should be adjustable. Particular attention should be paid to one-shot deposited products or products with inclusions, as excessive vertical vibration could push the centre or inclusion towards the bottom of the piece.

Horizontal vibration can be used to spread a small amount of chocolate over a large distance in a thin piece. Orbital shaking is a special application used to ensure even coverage of a chocolate shell during traditional shelling method, once the mould has been inverted.

Vibrating times should be a minimum of 30 s and are ideally 55–60 s. The moulds must make sufficient contact with the shaker rails to allow effective transfer of energy between the two: if they are not well restrained, they will bounce and little energy will transfer.

14.2.7 Shell forming

In the traditional method of forming a shell, that will later be filled and backed off, the mould cavities are filled almost to the top, the moulds are vibrated to remove air bubbles and are then inverted. The inverted moulds are vibrated immediately to drain out all but a thin shell of chocolate. The drained chocolate is pumped back to the feed tank to undergo the de-tempering, tempering and depositing cycle again. The viscosity of the masse must be controlled so as to make this the controlling step. Too low and the chocolate will run out irrespective of the shaker setting, too high and the shell will be thick, uneven and too heavy. The moulds are then returned upright, cooled, the centre is added and a back or seal is applied as required.

If a biscuit or similar item is to be placed in the shell, the chocolate may be left uncooled to make good contact and to prevent the formation of air pockets between the chocolate and the inserted item.

Other methods of shell forming are described in Section 14.2.15.

14.2.8 Centre filling

Centre filling is crucial to the quality of the finished item. Overdosing leads to leaking sweets and can contaminate the backing-off chocolate. Under-filling gives a poor eat due to a thick back and not enough centre. If the filling is too warm it can de-temper the shell, leaving a grey colouration, possibly leading to bloom, as well as sticking in the mould. If the centre is too cold it will not flow uniformly to form a flat surface. This leads to poor sweet backs, possible leaking sweets and contamination of the backing-off chocolate. Air bubbles can also be trapped around a cold (viscous) centre giving weight control problems.

The centre may cost more (nut pastes, ganaches) or less (fondants, frappés, caramels) than the chocolate, so incorrect filling can be expensive. If the centre is less expensive the correct proportions must still be maintained for quality reasons.

The centre may be more (fondant, caramel, syrups) or less (whipped or fat-based crèmes) dense than the chocolate, or almost the same (pralines, gianduja). It is important to be aware of the effect of each of the filling masses used on a line.

There are contraction differences between fat- and fondant-based centres. Generally, fondants will contract less than fat-based centres. This can cause problems in shell moulding since pressure may build up in the centre during cooling resulting in cracks in the chocolate and possibly leakage of water-based centres.

If the centre is a solid piece, it must be correctly positioned inside the shell so that it is completely coated with chocolate during the backing off. Exposed centres such as wafers and biscuits may have a shorter shelf life because of moisture pick up and changes in texture.

14.2.9 Backing off

There are several ways to put a back on a product. Ideally a separate temperer is used to supply the backing-off chocolate, to avoid contamination from any returns (e.g. some of the centre material may be scraped into this chocolate), to avoid pumping the tempered mass a long distance and also to allow a lower degree of temper or a slightly higher fat content, which will make producing a flat back easier. If the backs are uneven, problems can appear downstream, particularly in high-speed wrapping machines where good contact between the back of the sweet and the conveyor belts is essential for consistent acceleration.

14.2.9.1 Flood backing off

This is the cheapest method (Figure 14.7), as there is no need to meter the chocolate. Weight control depends on viscosity and scraper efficiency. Soft centres can be pushed out of the shell and contaminate the chocolate and it is difficult to avoid incorporating air bubbles. A static knife across the mould is used to control the flood, with a second one to clean the moulds and improve accuracy. It is essential to use the correct material for the blades and not to apply excess pressure.

14.2.9.2 Deposited backing off

This is more expensive to install than the flood system (Figure 14.8). An accurate volume is applied, but the chocolate viscosity needs to be low enough to enable the chocolate to spread into the corners during the brief period of vibration. Cold centres can be difficult to cover. Mould surfaces usually need cleaning to spread the chocolate properly and to remove any excess; this is usually done with a licking roll or scrapers running at right angles to the plant.

14.2.9.3 Sprayed backing off

Spraying the back onto a sweet is an expensive and potentially messy way of adding a back, but it is good for very liquid centres such as liqueurs and is sometimes used to form a first thin untempered coating before being followed by a flood or deposited back. The chocolate viscosity must be low, and extra fat normally has to be added. The mould surface in between the cavities will need cleaning as it is not possible to direct the spray only onto the sweet.

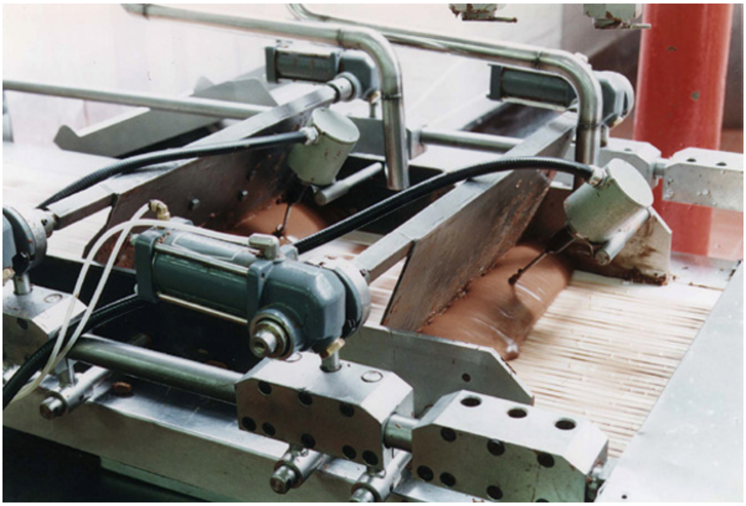

Figure 14.7 Picture/diagram of flood backing off.

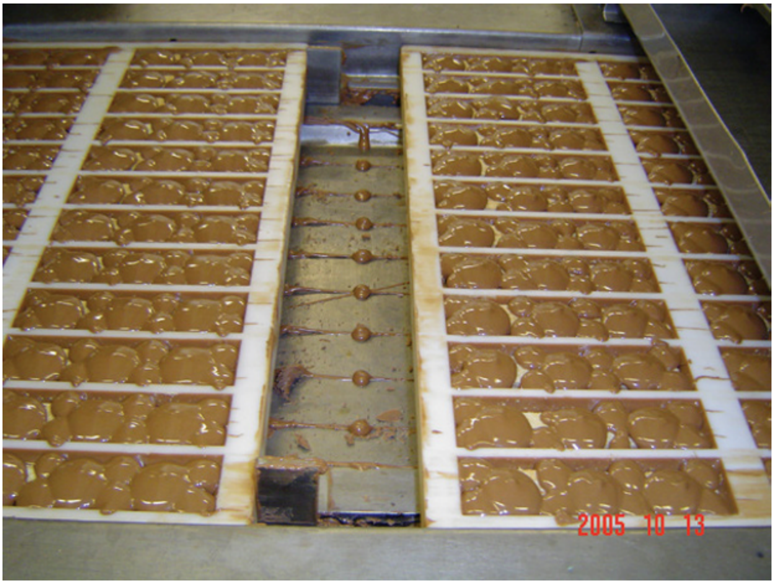

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Figure 14.8 Deposit backing off. Chocolate deposited onto back of shell moulded bar with light coloured filling, prior to being shaken.

14.2.10 Cooling

When cooling and then crystallising any fat-containing product, heat has to be removed from two sources (Cruickshank, 2005):

- *Specific heat* has to be removed to cool it.
- *Latent heat* is given out when the fat crystallises and, as can be seen below, this is the more significant of the two, when solidifying chocolate.

Specific heat of fat	2.0 J/g°C
Latent heat of crystallization of fat	157 J/g
Specific heat of milk chocolate	1.6 J/g°C
Latent heat of crystallization of milk chocolate	44 J/g

(See "Useful Physical Constants", at the end of this book).

To cool 1 g of fat from 28 to 12 °C (from 82 to 54 °F) requires the removal of 32 J (specific heat of 2 J/g °C over a temperature drop of 16 °C), whilst 157 J will need to be removed due to crystallisation (latent heat of 157 J/g). Conduction or contact cooling is the most efficient because of the intimate contact with the product. Forced convection is the next most efficient form of cooling for enrobed products since the top and sides of the product are in the air stream. This is analogous to "wind chill" and high-velocity air aids cooling. Radiation, the third method of heat extraction removes a much smaller amount of heat.

The need to crystallise fat as small crystals in Form V limits the rate of cooling that can be applied. Low cooling temperatures or short cooling times, give less stable polymorphs such as Form IV and can result in a lack of stability and poor contraction (see Chapters 7 and 13). Some recipe factors such as the proportion of butterfat and the presence and type of vegetable fat (where legally allowed) will affect the maximum allowable cooling rate. These ingredients both have the potential to reduce the crystallisation rate of Form V, and therefore longer cooling times will be required. Other factors that must be considered during cooling are the rate of heat conduction (i.e. large chocolate bars will need longer cooling times), and the level of temper in the chocolate which will have an effect on contraction.

14.2.10.1 Intense cooling

Intense cooling is sometimes necessary when depositing a hot centre, for example a caramel, at 55–60 °C (131–140 °F) into a chocolate shell. An intense shell cooler will prevent the centre from melting or de-tempering the chocolate. Typically the shell is cooled to 10 °C (50 °F) prior to depositing the centre. Cooling continues immediately after depositing to ensure that the chocolate remains undamaged.

14.2.10.2 Cooler zoning

Older coolers tend not to be zoned, having one source of cold air that has to be directed in such a way as to optimise cooling, whereas the more modern ones usually have at least three temperature zones:

Zone 1 – Specific heat removal with temperature settings of 12–15 °C (54–59 °F), and typically about 5 min residence.

Zone 2 –Most of the latent heat is removed. It tends to be released suddenly as crystallisation sets in. Typical temperatures are between 7 and 10 °C (45 and 50 °F) for 10–20 min. Although, if tunnel length and throughput permit, a temperature of 10 °C (50 °F) is to be preferred for better quality crystallisation. Very large tablets can require up to 30 min cooling.

Zone 3 – The product is warmed to just above the dew point of the packing room prior to exiting. The dew point is the temperature at which moisture begins to condense from the surrounding air and this would damage the chocolate surface and cause marks or sugar bloom. (Sugar bloom has an appearance similar to fat bloom, but is actually sugar crystals on the surface. Unlike fat bloom it does not melt under warm conditions.) The actual dew point can be measured using a wet and dry bulb thermometer in conjunction with a psychrometric chart. Times are typically the same as Zone 1 though temperatures may be slightly higher.

Dark or low butterfat milk chocolates can be cooled at temperatures 2–3 °C (3.5–5.5 °F) higher than those given above.

In a cooler, the air speed needs to be high enough to give a turbulent flow across the moulds, which is generally agreed to occur once it has reached 5 m/s (990 ft/min). Air should not blow directly onto the chocolate as it can cause ripples to form on the backs. Older coolers that use cold plates to cool and have low airflow require a much higher temperature differential and this can result in condensation inside the cooler, which could lead to sugar bloom and, in extreme cases, can cause moulds to start to grow on the chocolate surface. All coolers require some sort of periodic defrosting unless supplied with dehumidified air. Traditionally this has been done during shift changes or during a forced stop for the purpose. Some more modern units are equipped with hot-gas defrosting systems, which can defrost the coils without production being interrupted.

The position of the air temperature control probes in a cooler should also be checked. To give the correct value, they must be fully in the airflow they control and in a position that is not affected by outside conditions, that is adjacent hot rooms or strong sunlight. Older coolers and those moved around at various times are prone to suffer from this problem. Check where the cooling air is drawn from and ensure that it is not from a humid or hot zone, nor from a process area with strong aromas as these can taint the products.

14.2.10.3 Cooler layouts

Single-level coolers with a residence time of 15–20 min are adequate for most enrobed products (see Section 14.3.12), but would be impracticably long for larger moulded products which require much longer cooling times. This has led to multi-level designs which are used in most moulding and shell plants (Figure 14.9). The multi-level (or multi-tier) coolers are designed where moulds enter from one side and in groups are raised to the top of the tower and then lowered to the bottom on the other side towards the exit. The different temperature zones in the cooler are maintained by having several chillers with separate control and by controlling the airflow with a variety of guides, baffles and so on.

All tiered coolers require turning points or star wheels to guide the moulds and keep them upright as they are conveyed into the next layer. Such mechanisms are frequently a cause of jams and so need to be regularly cleaned and carefully maintained.

Other multi-tier cooler designs are in the form of a spiral (Knobel, 2014). These allow the use of loose moulds with no attachments and are claimed to provide a jam-free transportation and better temperature control for the individual moulds, since every single mould travels exactly the same path.

14.2.10.4 Cooling of compound coatings

Non-cocoa butter-based systems can be cooled at faster cooling rates because their polymorphism is less complex. Here the constraint is to avoid cooling into a glassy amorphous state or having water condensation at the exit of the tunnel (see Chapter 19). Lauric coatings require shock cooling in the tunnel with very low entry and middle zone temperatures, typically about 6–8 °C (43–46 °F). This ensures that small crystals are produced to enhance the gloss of the coating and to provide sufficient contraction for easy demoulding. Advice for non-lauric coatings varies, with some recommendations being to shock cool as in lauric

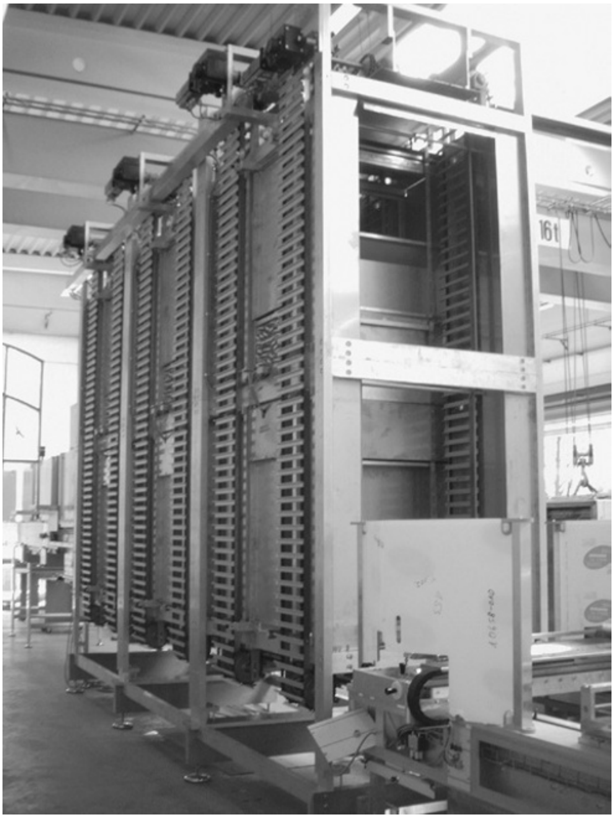


Figure 14.9 Multi-tier cooler.

coatings and others being to follow the more gentle type of cooling given to chocolate. Talbot (2009) recommends temperatures in between that of chocolate and lauric coatings (an entry temperature of about 12 °C (54 °F) and a middle zone of about 8–10 °C (46–50 °F) to provide a good compromise between crystallisation speed and good gloss.

14.2.11 Demoulding

If tempering and cooling have been optimised, then demoulding is a minor part of the process, with good quality product cleanly leaving moulds that are returned to the start of the process. As any user can testify, life is not always that simple!

A small amount of force is normally needed to part the product from the mould and this is usually supplied by a hammer, possibly aided by a mechanism that twists the moulds. The product is demoulded onto either plaques or a belt, depending on subsequent packing arrangements. Detectors are available to identify moulds containing sticking sweets (see Figure 14.10).

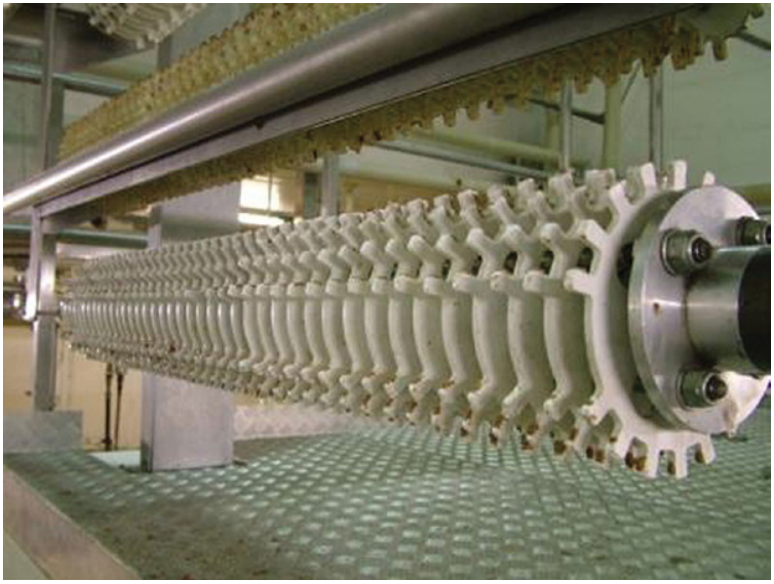


Figure 14.10 Sticker detector.

14.2.12 Troubleshooting demoulding problems

Poor demoulding should be tackled at once, as stickers can go back round the plant and cause further trouble. Check all the plant operations that might affect contraction in a sequential manner confirming that each is working within its defined limits. The following hints can help troubleshooting.

14.2.12.1 Twister and hammer

Incorrect setting or functioning of the twister and/or hammer at the end of the cooler can cause poor demoulding. Using hammers on the back of the mould at a high setting can shorten the mould life. Hammers can be replaced in some cases by vibrators which are quieter and use less energy (can be timed to coincide with a filled mould being present in the demould area).

14.2.12.2 Static

The product can be held in place by electrostatic charge, which is more of a problem with light or small units than moulded bars. A static discharge device can help in releasing the chocolate from the mould.

14.2.12.3 Mould condition

Mould surfaces will roughen with use and washing, particularly if the products being moulded contain abrasive inclusions or centres such as wafer or grated hard boiled sugar. A lip can also form at the edge of the cavities if a scraper or knife is of the wrong material or if too much pressure is being applied.

14.2.12.4 Proportions

Very thin shells can result in less contraction, making good temper and optimised cooling essential to give good demoulding. Poor mixing with other ingredients can also result in increased sticking (see Section 14.2.5).

14.2.12.5 Contraction

As cocoa butter crystallises, its volume decreases slightly, resulting in contraction of items made using it. The presence of butterfat, or other soft fats or oils (e.g. nut oils) will reduce contraction.

To obtain good release from the mould, the degree of contraction needs to be maximised. This requires the degree of temper, the mould conditioning temperature and the rate of cooling to be optimised. Not enough cooling as well as excessive cooling will both result in improper crystallisation and insufficient contraction. Compounds made using vegetable fats rely much more on contraction mainly due to cooling, but the choice of the correct fat system will affect release. Lauric fat systems, for example, require very sharp initial cooling to get sufficient contraction to release.

Typical values for contraction of chocolate:

Milk	0.3%
Dark	0.8%
Compound fats	<0.6%

For filled items, under-tempering will result in more contraction and give better de-moulding. Better flow from under-tempered masse (lower viscosity) helps distribution within the mould and will result in a more uniform wall thickness. Too warm centre in a filled item can also de-temper the chocolate coating and affect contraction.

14.2.12.6 Humidity

Another cause of poor demoulding may be residual wetness due to either improper drying after washing or condensation that collects in cavities. The relative humidity (RH) during mould conditioning has a subsequent effect on the demoulding step (Keijbets *et al.*, 2010). The adhesion of the chocolate to the mould increases initially with increasing RH. At approximately 25% RH the adhesion force stabilises to a constant plateau until about 50% RH. Above 50% RH the adhesion force decreases sharply, but the high humidity present at the mould–chocolate interface can have a detrimental effect on the gloss of the chocolate (i.e. may dissolve some of the sugar crystals and give rise to sugar bloom). Therefore, minimum surface adhesion (best demoulding) and maximum chocolate quality (best gloss) is achieved at <25% RH. In an industrial environment, however, such conditions may be difficult to achieve and it will depend on the particular circumstances of each line. The pragmatic approach is to achieve as much control over the process as possible to minimise deterioration in product quality. High humidity is generally accepted to cause product deterioration consequently the recommendation is that the moulds be conditioned under controlled environmental conditions (i.e. as low as practically possible RH).

14.2.12.7 Mould material

The properties of the mould surface have a significant influence on how the chocolate solidifies and how it separates from the mould during demoulding (Keijbets *et al.*, 2009). The surface energy of the material, determined using a classic contact angle approach, has an effect on the adhesion of the chocolate to the mould. Materials with low surface energy (<30 mN m^{-1}) such as polycarbonate, teflon or stainless steel have been proven to provide the cleanest demoulding and are the best materials available nowadays for chocolate mould fabrication.

14.2.13 In-line storage systems

Unless there is a considerable excess of wrapping capacity over moulding output, a flexible store or buffer can be used to avoid costly and potentially damaging traying-off of excess product during wrapping machine stops and then having to hand feed them again. These were traditionally paternoster type with product being pushed onto trays that move up and down a series of stacks until reaching the exit, but other formats are now available. A bypass is normally provided for use when the wrapping machines can handle the full line output.

Such systems (e.g. Figure 14.11) can also be used to allow a moulding line to run more shifts than the wrapping line but, however they are used, there is a possibility of the store hiding inefficiencies in the moulding line performance that line personnel must be aware of.

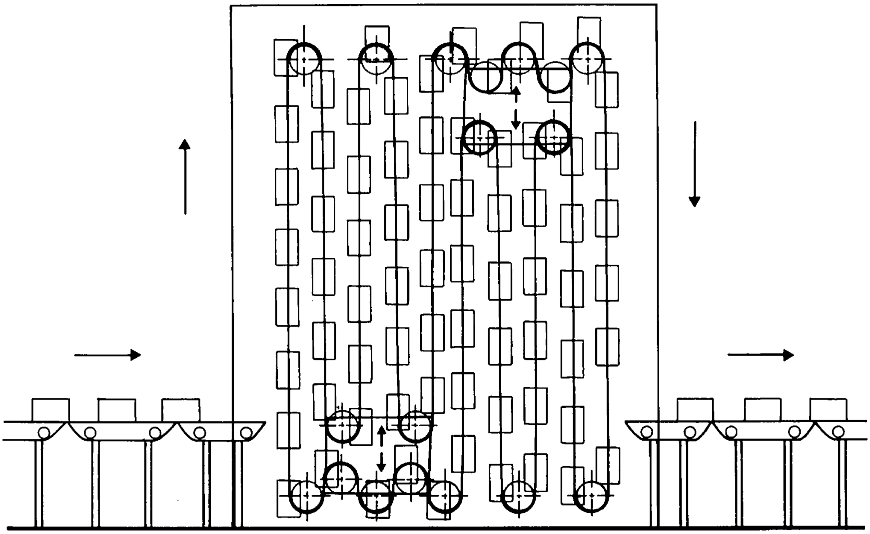


Figure 14.11 Schematic diagram of a flexible storage system.

14.2.14 Keeping moulds clean and changeovers

It is far more efficient to keep the moulds clean, rather than resort to scrapers or rollers to clean them up. Factors such as correct depositor timing to avoid depositing outside the impressions, making full use of any suck-back fitted to the depositor and avoiding drips from the depositor by good maintenance and using the correct nozzle diameter (the wider the nozzle is the more likely it is to drip) can all help.

If dirtying of the moulds cannot be avoided, then a suitable combination of licking rollers (Figure 14.12), surface scrapers and edge scrapers can help avoid build-ups that shorten runs and cause contamination.

Changeovers will always be a part of running many lines, so it is essential that their efficiency is improved as well as minimising their number. It is imperative that each line has its own Standard Operating Practice written and available locally. Analysis of downtime for changeover, against stock levels from longer runs, should be carried out to ensure that the most cost effective options are chosen. "Single Minute Exchange of Dies" is a useful tool: its aim being to systematically reduce the time lost in production for machine changeovers and set-ups.

14.2.15 Other methods for shelling forming

The traditional method of shell moulding was described in Section 14.2.7. Several other methods are available however.

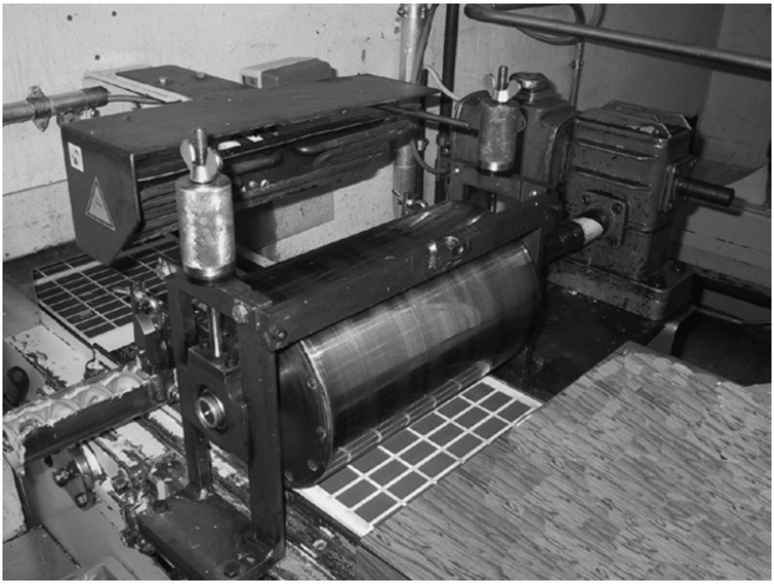


Figure 14.12 Licking roller.

14.2.15.1 Book moulding

Initially similar to conventional shelling, but once the shell has been formed the two matching halves of the mould are pressed together like a book so that they seal, forming a hollow (or centre filled) shell. A shallow but continuous and even lip is needed to provide chocolate for the seal. Conventionally the lip is formed after shelling, whilst still inverted, by an extra shaking stage. The mould is re-inverted and the lip is reheated by infrared heaters before closing the book to form a seal. Closing can be done by turning one half of the mould pair through 180° whilst held in a frame, or on a loose mould plant by moving both moulds through 90° to the vertical. A plastic clip or a magnet holds the halves together.

14.2.15.2 "One shot" or "Single shot" moulding

This is described in detail in Chapter 15 and is a method of depositing both shell and centre simultaneously.

14.2.15.3 Spinning

The liquid chocolate mass is placed inside one half of the mould, which is then closed and spun on two axes and can also be vibrated for de-aeration of the mass. Once the chocolate has set and contracted the mould is opened and the item taken out. Different coloured chocolates can be added to certain portions of the mould to give the item an attractive appearance (e.g. Santa Claus' beard in white on a milk chocolate). The hollow articles can also be filled with surprise toys or other solid or liquid fillings. To insert the toys or objects the moulds are opened quickly after spinning. At this point the chocolate is not liquid and remains stuck to the mould wall, but it is not completely hardened. After filling with the surprise toys, the mould is closed again and brought into the cooling tunnel.

There are several suppliers that can offer fully or semi-automated moulding plants for the production of hollow figures. They differ mainly in the type of spinning machine and rotation pattern, and the type of mould used, that is separate mould halves with centring pins, hinged book moulds or exchangeable mould sheets supported by magnet containing frames (Gebhart, 2013).

14.2.15.4 Cold forming

This is described in detail in Chapter 15, but in the context of this chapter, it is a way of making very accurate shells wherein an exact amount of liquid chocolate is put into a cavity, and a plunger at around –20 °C (–4 °F) applies pressure to distribute and set the mass. This is very good in forming a lip for book moulding. It can also be added to a conventional tablet moulding line to enable it to make filled products.

14.2.15.5 Drop moulding

This is a specialised plant for making chocolate pieces such as buttons or chips for cookies. Depositing is done directly onto a cooled belt (see Figure 14.13). Such plant can also be used to make easily melted chips for the distribution of industrial chocolate masses.

14.2.15.6 Dragee moulding

A plant for making shaped chocolate pieces, such as lentils for sugar coating, was originally developed by Erikson in the 1940s and is shown in Figure 14.14. Liquid tempered chocolate is poured between the two rolls, which are maintained

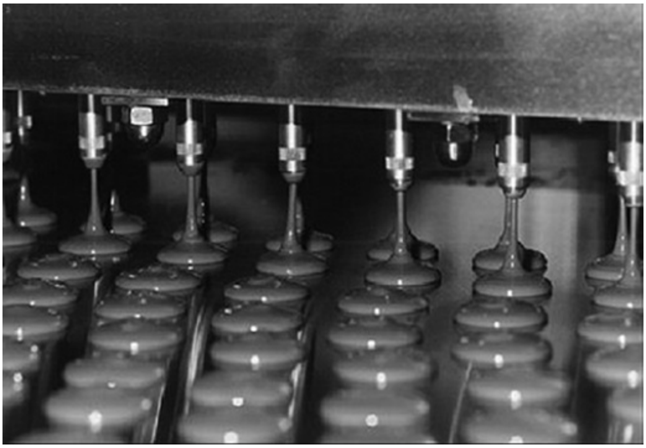


Figure 14.13 Picture of drop moulding production plant.

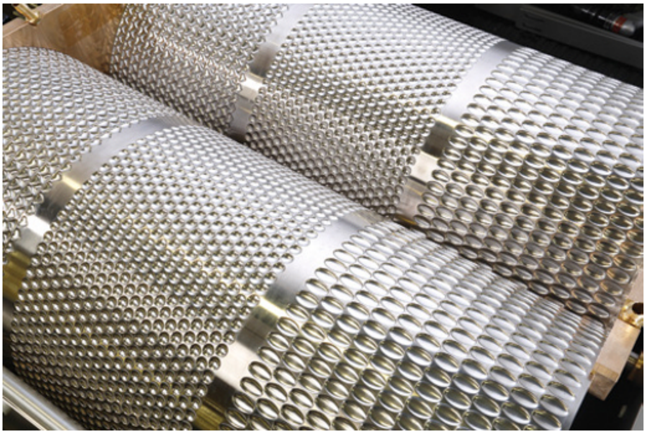


Figure 14.14 Picture of dragee moulding plant. Source: Aasted. Reproduced with permission of Aasted Denmark.

below freezing point. A web containing the lentils comes out below the rollers. This web is then broken after cooling, to release the individual pieces. The remaining web crumbs can then be melted and reworked.

14.2.16 Troubleshooting moulded product faults

14.2.16.1 Weight variability

If there are significant weight variations between the shells of moulded articles it is helpful to build a “map” by weighing individual shells from 10 consecutive moulds. If there is a pattern within each mould or between moulds, there are several possible causes:

- Incorrectly adjusted shakers.
- Temperature variations across the mould, possibly from the conditioning zone.
- Temper or temperature variations across the depositor hopper.
- Poor mould restraint due to broken or worn lugs on the mould (see Section 14.2.17).
- If using book moulds, the clips that hold the mould into the frame are not properly adjusted.

14.2.16.2 Cracking of hollow figures

For hollow figures, solidification and shrinkage may result in stress cracks due to too much contraction. A higher pre-crystallisation level (6–7 on a Sollich temper meter) should be used, and the moulds and the beginning of the cooling line should be run warmer.

14.2.16.3 Visual defects

Tablets with missing corners or holes (from air bubbles):

- Viscosity of the masse too high,
- Insufficient vibration,
- Ambient or mould temperature too low,
- Over-tempered,
- Inclusion level too high,
- Wrong deposit type – ideally need ribbon deposit for inclusions.

Curved bars:

- Incorrect temper,
- Cooling too rapid,
- Inclusions or centre expanding or contracting more than the chocolate,
- Poor design of bar with plinth (base) too thick.

Grey areas and spots:

- Local de-tempering due to incorrect mould or inclusion temperature, poor tempering or mixing in of un-tempered masse,
- Water stains or fatty specks on the surface of the mould due to inadequate mould washing,

Pale curvy lines:

- Poor temper,

Rub marks on bar sides:

- Incorrect setting of demould belt height or speed, or hammer/mould twist not set correctly,
- Demould not quite good enough, causing tablets to partially release,
- Such marks can also often be caused by the wrapping machines.

14.2.16.4 Breakage at demould

Breakage at demould can occur due to poor mould design, for example when the product sticks to the mould due to sharp corners, or there is too much flat, non-engraved surface.

A shelled tablet with chunks or cubes, having a base or plinth that is too thin compared to its height, will break when dropping out of the mould. On a typical 10 mm (0.4 in) deep 100 g (3.5 oz) tablet, the plinth should be at least 5 mm (0.2 in) thick. A bar with an odd number of cubes is less likely to break. If a thinner plinth is needed, adding reinforcing ribs of chocolate between the cubes will help. The base and the cubes of such a tablet should have radii of 0.75–1.0 mm (0.03–0.04 in) to get even contraction. Sharp radii will cause the shell to have thin areas and result in leakage of the central ingredients or breakage. Very large deep tablets (e.g. 300 g) can bend and even break in the mould due to contraction of the plinth if it is too thick.

14.2.16.5 Formation of meniscus

Feathering is a thin rim of chocolate or meniscus around the edge of the bottom of a chocolate product (Figure 14.15). It can be caused by the mould being too deep, or by shaking a solid product too much. Some additional depth is necessary to avoid spillage, but there should be no more than 0.5 mm (0.02 in) in a small piece (less than 50 g (1.8 oz)] or 1 mm (0.04 in) in a bigger item. When a meniscus occurs and breaks off during demoulding or wrapping, chocolate

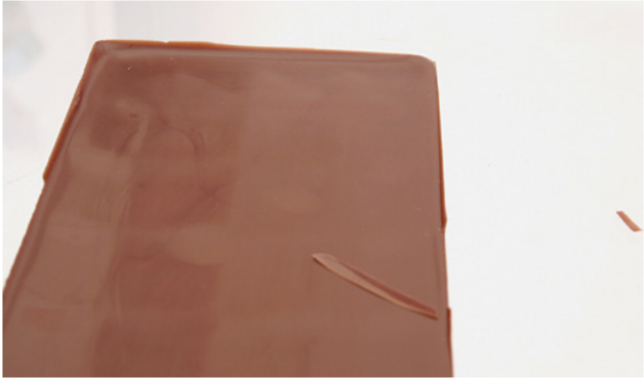


Figure 14.15 Picture of meniscus on a chocolate bar, showing a piece broken off.

particles can dirty the wrapping machine or spoil the surface of the product. According to the Agathon company, this problem can sometimes be reduced by using an ionising (anti-static) device.

14.2.17 Mould design, care and innovations

14.2.17.1 Mould design

Any reputable mould manufacturer will give advice on the basics of mould design. It is vital to follow such guidance to ensure good demoulding, with gloss and minimum of marks due to uneven cooling or sticking. Mould life will also be dependent on good design and a efficient injection moulding process.

The following points are examples of the details that must be designed in to any successful mould (Harbecke, 2005).

- Impression tapers must be large enough to allow the product to be released from the mould, 8–10° is the minimum. Sharp angles should be avoided, or air bubbles will remain in the cavities giving poor appearance and demoulding. External radii should be about 1.5 mm (0.06 in).
- Engravings give a sweet a unique appearance and identify it. They also assist demoulding, as they enlarge the surface of the item and help contraction. They will reduce cool spots and demould marks. Engravings should be about 0.18 mm (0.007 in) deep and well-rounded with a taper of 15–20°.
- Engraving lines can be incorporated in the side walls of a flat thin item to avoid a vacuum forming and holding the product in the mould.
- For a typical 100 g (3.5 oz) bar, the base or raft should be at least 5 mm (0.2 in) thick compared to the total height of the bar of approximately 12 mm (0.5 in). If a thinner base is desired, there should be reinforcing ribs of chocolate, preferably around the outside of the bar between the cubes.
- Radii on the back of the mould are important. Any notched or non- rounded area will soon result in breakage of the plastic mould itself. For those which undergo rough treatment, radii of 0.5–1.0 mm (0.02–0.4 in) should be specified to avoid early breakage.
- Flexibility is important. Should you make use of the natural property of the plastic material which is flexibility, or have a rigid mould leading to a longer life because of its frequent abuse on shaker tables? It is a balance between having a more rigid mould that could last longer and a flexible one that will cope with the stress imparted by the demould twister and the hammers. The shaking of a rigid mould is more even as vibration energy is transmitted rather than absorbed as in a flexible one. Ribs add strength and rigidity to the primary walls of a mould. They are thin wall protrusions that extend perpendicularly from a wall or under surface of the mould. They can be both length and crosswise, as a continuation of the cavity sidewalls, or diagonal when top rigidity is required. The ribs are good channels for distribution of the polycarbonate in the injection moulding tool. They also act as connecting points between the outside frames and help keep the mould straight on the line.

14.2.17.2 Mould construction and care

Most chocolate moulds are nowadays made with polycarbonate (PC) or derivatives of polycarbonates. Commercial grade PC is an amorphous, engineering thermoplastic which is based on bisphenol A (BPA) and has an aromatic structure. It is the aromatic constituents that provide PC with its excellent physical properties (broad temperature usage, high glass transition temperature, high toughness and rigidity). Polyesters such as PC are hygroscopic and will absorb moisture from its surroundings. A chemical reaction between PC and water causes a reduction in molecular weight, therefore reducing the mechanical properties significantly. In order to retain the engineering properties of PC, moisture content during PC processing must be maintained below 0.01%.

Polycarbonate obtained in granular form is used for manufacturing chocolate moulds using the injection moulding process. Prior to injection moulding, the PC granules need to be pre-dried at about 120 °C (248 °F) for around 2–4 h. During the injection process the temperature of the material should be at 280–300 °C (536–572 °F). Moisture uptake continues for 24 h after moulding, from which point the moulds are dimensionally stable. Polycarbonate is a naturally clear polymer. A colourant is added to the PC at very low weight percentage, 0.1–0.2%, to make any broken pieces visible and look less like glass if broken pieces should get into a product. The level of colourants added should be as low as possible since they can potentially weaken the PC structure. There is not normally any premium payable for colour addition. Several modified PCs have also been tested, thus the option exists to choose a material that is more resistant to certain processes such as extreme exposure to cold or hammering.

The distribution of the injection points (gates) for the PC when making the mould will have a direct impact on its strength. The optimal flow length of a typical PC will be about 280 mm (11 in; Harbecke, 2005). Any flow length higher than this could result in the formation of stress points and early aging of the mould. Large moulds will require more gates and therefore will be more expensive to manufacture.

Broken moulds should be examined and the reason for breakage logged. Action must be taken to find and eliminate the cause of any trend that is established, that is several moulds showing similar damage. Up to 1% breakage shortly after first use and mainly attributed to manufacturing defects is normal: above that amount, the causes should be investigated. Avoid excessive hammering of the moulds, that is solve problems of poor demoulding. Twisting during demould shortens mould life and should be adjusted to an effective minimum.

Mould breakage can be a significant source of foreign bodies in a product and, for standard PC moulds, there are no satisfactory means of detection or removal.

Common causes of breakage due to mechanical stress are:

- Poorly aligned turn points,
- Plant components moving out of alignment and touching the moulds,

- Badly adjusted or damaged scrapers,
- Stickers being hammered out with metal or sharp objects.

Other causes of breakage could be due to a combination of moisture, chemicals, temperature and mechanical stresses. Too high a temperature during mould washing for example can weaken the mould structure. Also, a defective injection moulding process where optimum conditions were not followed could accelerate the stress cracking process.

Continuing to use cracked moulds is a false economy: they can distort under the backing-off knife and cause bad backs and over-weights, and they are likely to cause jams at turn-points by breaking or becoming distorted.

Moulds should be stored face to face, not just stacked, to avoid scuffing and scratching the upper surface.

14.2.17.3 Mould washing

The importance of mould washing is often overlooked until problems arise. These can often be water spots that transfer to the product or fatty specks that leave micro-pits in the product: both a sign of inadequate washing. There are five main factors in mould washing (Stuart, 2011):

1. *Water quality* Water needs to be soft. Hard water can cause deposits due to dissolved salts being left on mould surfaces after drying. Treatment options for hard water include softening and deionisation. Deionised water is best used for final rinse water in order to prevent the deposition of any residue on the mould. Reverse osmosis water can also be used as the final rinse water.
2. *Time* In a mould washer the conveyer speed and length of each zone defines the time element. The speed can be adjusted based on the type of mould (and residue) that is run. A shallow mould with a sugary residue might be able to be run at a faster speed than a large intricate PC chocolate mould with fats.
3. *Temperature* The optimal temperature is defined by the detergent specifications and the limits of the material being washed. The maximum recommended washing temperature for PC moulds is 60 °C (140 °F). Above this, moisture will be absorbed and weaken the moulds.
4. *Detergents* Detergents have mainly surfactants that help wet and penetrate the surface of the mould. They may also contain other additives to add alkalinity or acidity, defoamers and even enzymes to perform specific actions. Concentration and type of detergent is best defined by the detergent supplier after testing sample soiled moulds.

   Detergents must be neutral (pH ~ 7) to avoid chemical attack and it is most important that the product be specifically made to clean polycarbonate. Rinsing may be done at temperatures of up to 75 °C (167 °F) if the residence time is only seconds. A rinse aid should be used to help drying and prevent spots on the moulds. There are several types of rinse aids. The type needed depends on the quality of the water and the types of detergents and defoamers used.

5 *Mechanical force* Mechanical force is provided by the use of strategically aimed nozzles that direct the water to all surfaces and both sides of the mould. Powerful water pumps are required for this. Water is the central figure as it allows the transfer of mechanical force to aid lifting the soil, it applies the detergent and is the medium providing the necessary temperature for the process.

Typical mould washers have the same basic functions but may differ in design. A summary of the main washer zones and recommended conditions for washing and drying moulds is given in Table 14.1.

Solid chocolate must be removed from the moulds before washing, both to avoid contaminating the detergent solution and to prevent discharge of contaminated effluent which will be expensive to treat. There is a double cost saving, for lost chocolate and for effluent charges.

14.2.17.4 Mould innovations

Moulds made with BPA-free materials are available as a response to the escalating debate on the potential effect and exposure of this chemical on infants and children. These new materials offer the advantage of being BPA-free but may also compromise some of the key properties of the PC they replace (broad temperature usage, toughness, rigidity, gloss imparted on product, etc.). At the present time BPA-free moulds are still a rarity in the confectionery industry. Nevertheless, as the plastic industry improves the functionality of these new materials, they are likely to become more widely adopted.

Metal detectable moulds offer a solution for the removal of foreign bodies caused by mould breakage. The thermoplastic composition of these moulds includes a metal detectable agent in combination with PC or other more complex thermoplastic polymers. The metal detectable agent can be any ferrous or non-ferrous material having good magnetic permeability and/or good electrical conductivity. The amount of metal detectable material that can be incorporated in the mould is limited as it may potentially weaken the polycarbonate structure. Typically pieces of broken mould <5 mm will not be detected as there is not enough metal in the mould structure. Increasing the amount of metal in the

Table 14.1 Recommended washing conditions for polycarbonate moulds.

Wash type	Recommended temperature [°C (°F)]	Water type	Contact time (s)	Detergent
Pre-wash (heavily soiled moulds)	60 (140)	Soft	10+	None
Main wash	60 (140) maximum	Soft	15+	Detergent
Re-circulating rinse	60 (140) maximum	Soft	10+	None
Final rinse	60 (140) maximum	Deionised or reverse osmosis treated	Minimal	Rinse aid
Blowing off-air drying	105 (220)	—	As required	—

mould to improve the detection level is not an option as it weakens the mould and increases the risk of breakage.

Electronic chips have been sealed into moulds for various purposes:

- Measuring the hours the moulds have run,
- Counting the times the moulds have been washed,
- Signalling to the depositor the amount of chocolate to be deposited in each cavity when the next mould is different and requires more or less chocolate.

14.3 Enrobing

14.3.1 Background

Until the early l900s chocolates were coated by hand, or by automated batch techniques copying hand-dipping methods. The traditional hand-dipping of chocolate, with batch tempering, results in an attractive finish that is difficult to copy. The first enrober is credited to Magniez (1901) and was produced by A. Savy Jeanjean et Cie. This machine, the “Standard Enrober”, was also supplied by the agents Baker Perkins and manufactured by the National Equipment Co. of America. Such was the advanced nature of the machine that many were sold throughout the world, and it became the basis for all future designs of enrober with the principles little changed to this day. The Savy enrober had many features, which are lacking on present-day enrobers, though often for reasons of simplicity. For example, all of the many rollers were driven and scraped, the blower to remove excess chocolate was of a turbo layout, the rotor in the blower being the same width as the belt and a sideways driven movement of the delivery belt produced zigzag decorative markings from a piping system.

Whilst the basic components of an enrober have not changed significantly over the years, the methods used to control their operation and the degree of precision possible have changed significantly, accompanied by a modest increase in throughput. Manufacturers are continually improving the hygiene aspects of their designs and the techniques to reduce chocolate build up inside the enrober, a common problem with this technology. Energy saving is now given serious attention by the end users, thus more efficient motors and better hood designs for temperature control are being developed (Bean, 2009).

Enrobers are provided for the smallest producer to the largest and there is a wide variety of different designs to meet all requirements. Belt widths from 125 to 2600 mm (5 to 110 in) are available and the variety of accessories that can be added both before and after the enrober is vast and increasing.

Many modern enrobers have two or more curtains, either from one hopper or two. As long as all the coats of chocolate are added whilst liquid, they will blend together as one.

However, double enrobing required two separate enrobers with a cooler in between them. This gives a discontinuity in the coating, which provides a better

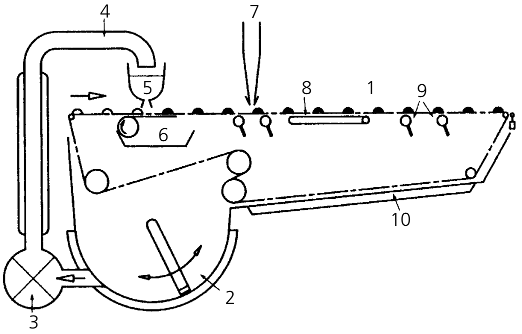


Figure 14.16 Components of an enrober (Sollich, Germany): 1. wire grid conveyor belt, 2. reservoir tank, 3. chocolate pump, 4. riser tank, 5. top flow pan, 6. bottoming trough, 7. air nozzle, 8. grid shaker frame, 9. licking rolls, 10. heated extension trough.

moisture or fat migration barrier. It also allows the second coat to bridge any discontinuities in the first, and gives the possibility of using different materials in the two layers, either having different colours, or different barrier properties.

14.3.2 Basic layout of an enrober

The sweets entering the enrober are transferred from a plastic feed belt onto a wire mesh belt and pass under one or more curtains of chocolate (Figure 14.16). There is a plate or a trough fitted with a roller underneath the belt to ensure controllable coating of the underside of the sweet. The excess masse from the curtain falls through the wire mesh belt into a sump, and is recirculated. Part of the masse is diverted through a de-temperer and is then re-tempered: blending of the freshly tempered and recirculated streams controls the overall level of temper in the enrober.

After the curtain, excess chocolate is forced off the product by an air blower and a licking roller is used to control the amount of masse left on the underside of the sweet. There is normally a vibrator after the blower to remove excess chocolate and to improve the appearance of the sweet; Finally there should be a de-tailing roller between the end of the wire belt and the start of the cooler belt.

14.3.3 Enrobers with inbuilt temperers

Until the 1980s, enrobers generally had a built-in temperer and indeed many units still incorporate such a device today, though usually only those with a lower throughput (Figure 14.17). The main advantages are compactness, lower capital cost plus simple and rapid installation.

Tempering and de-tempering are done by worm screws which tend to have a limited throughput and are more difficult to zone and control accurately than conventional modern high-shear temperers. Generally enrobers with internal temperers use a ratio of between 1:6 and 1:8 fresh to recirculated masse.

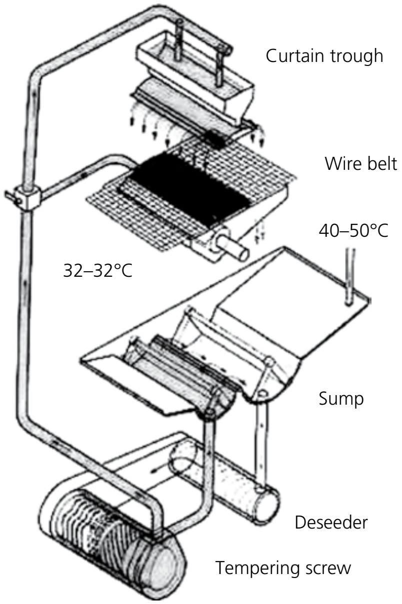


Figure 14.17 Enrober with inbuilt temperer. Source: Sollich. Reproduced with permission of Sollich Germany.

A mass temperature of 45 °C (123 °F) is required for de-tempering, but as the cylinder surrounding the de-tempering worm and the worm itself wear, the rate of heat transfer reduces and de-tempering becomes more difficult. Typically in a Sollich unit, the cylinder and worm each have a nominal diameter of 198 mm (8 in) with a tolerance measured at the centrepoint of +0.15 to +0.2 mm (0.006–0.008 in) for the cylinder and –0.15 to –0.2 mm (–0.006 to –0.008 in) for the worm: the gap is thus 0.3–0.4 mm (0.012–0.016 in). If this gap reaches 1 mm (0.04 in), replacement is necessary.

14.3.4 Enrobers with external temperers

In these machines the chocolate supply from the temperer is pumped directly into the sump, where it mixes with the masse already there and with returns from the curtain (Figure 14.18). It is then pumped up to the curtain trough, generally mixed at a ratio of between 1:4 and 1:6 with recirculated mass. To control the temper in the sump, a proportion of the masse is returned via a de-seeder to the temperer feed tank. A sieve should be included in the circuit so that any broken pieces of the product centre can be eliminated. Such small pieces can otherwise build up inside the enrober, leading to a discontinuous curtain and to poor visual quality of the coating.

14.3.5 Chocolate recirculation

An amount of 1 kg/h (2.2 lb/h) of chocolate is needed per 1 mm (0.04 in) belt width for one curtain, 1.5 kg (3.3 lb/h) for double curtains. The contents of the enrober should be exchanged every 6–10 min to avoid build-up, to keep a

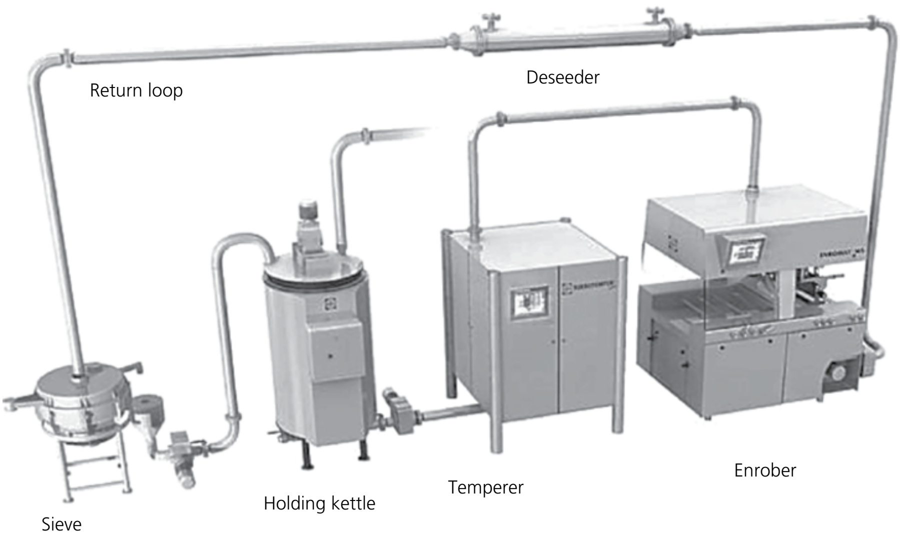


Figure 14.18 Pipe circuit for an enrober with an external temperer. Source: Sollich. Reproduced with permission of Sollich Germany.

constant temper, to avoid air bubbles in the curtain and to reduce changes in colour and density due to air incorporation. Since a 1000 mm (40 in) wide enrober has an internal capacity of about 150 kg (330 lb), changing the contents every 10 min will necessitate a feed of 1000 kg/h (2200 lb/h).

The recirculation pump is a pawl type (Chapter 12), chosen for gentle handling and minimal temperature increase. It also has good suction characteristics and will handle nuts and so on, without much breakage.

For modern Sollich enrobers running on milk chocolate, the recommended water temperature for the sump is ~0.5 °C (1 °F) lower than the required masse circulation temperature, as some heat is added by the recirculation pump. Recommended water temperature for the table is 3 °C (5.5 °F) above the water temperature of the sump. For best operation, ambient temperatures of 24–27 °C (75–81 °F) are considered the optimum for the enrobing area. The temperature inside the enrober hood should be 24–30 °C (75–86 °F); lower temperatures will only cause a build of chocolate on the internal surfaces. The temperature of the item to be coated should be in the range 22–24 °C (72–75 °F); a higher initial temperature needs a longer cooling time.

When enrobers are dedicated to compounds that do not require tempering the handling system can be much simpler. The temperature of the masse, water jackets and enrober hood area will all need to be adjusted to the quality and crystallisation properties of the fat used. A fast setting fat such as a lauric fat needs operating temperatures inside the hood as high as 40–45 °C (104–113 °F) to prevent build up.

14.3.6 Temper

Tempering has been discussed in Chapter 13, but it is possible that a degree of temper is required for the optimum coating performance, which does not conform to the "good" temper value.

- A slight over-temper can be used if there is a limited cooling tunnel length and quicker solidification of the chocolate is needed. The disadvantage of this is a less fluid masse and so a thicker coating.
- A slight under-temper gives a more fluid chocolate, which can result in a more uniform coat.

Both the gloss and the shelf life of the finished product should be checked when making these changes.

14.3.7 Product centre

Preparation of the centre for enrobing is equally important to tempering the chocolate (Koch, 2011). Assuming the centre material (wafer, rope or slab) has been sized and shaped, the individual pieces must be brought to a temperature compatible with tempered chocolate. For most applications and in a normal climate controlled environment, ambient temperature (22–24 °C; 72–75 °F) is a good guideline for optimal gloss and bloom stability. Depending on the chocolate specification, centres can also be introduced at temperatures up to 27 °C (81 °F). Too warm centres may cause poorly tempered chocolate and excessive feet (see Section 14.3.14). Cold centres give a dull finish and may cause cracking in the coating after leaving the cooling tunnel. The arrangement of the centres on the belt before the enrober is important to cover each piece completely and prevent "doubles". Typically they are fed in straight rows with a separation that will vary with the shape and size of the piece and the speed of the line. A good guideline for optimal coating is to separate the pieces by about twice the height of the piece itself.

The structure of the centre dictates the enrobing technique and whether one enrobing station or multiple stations are necessary. Soft products require extra care on the bottoming and often a pre-bottomer is required to achieve a good result (see Section 14.3.8). Light products are also a challenge to ensure complete coverage of all surfaces. Starch moulded pieces or wafer pieces must be clean of dust since chocolate behaves somehow like "Sellotape" and will not stick to a dusty surface. Oily surfaces will not coat easily either, while loose nut pieces, coconut shreds or crumbs can be washed off the centres and cause problems with tempering or viscosity of the chocolate.

The quality and quantity of fat used in the centre also needs consideration especially in relation to fat migration and fat bloom.

14.3.8 Enrober components

Whether fitted with a temperer inboard or externally, enrobers have the same basic components (Schremmer, 1988).

14.3.8.1 The curtain

There are two main methods of controlling the feed rate to get a continuous curtain:

- A trough with an adjustable slot in the bottom,
- A trough with a rotating roller(s) to control feed rate.

In either case, there should be a feed pipe into the trough about every 250 mm (10 in) across the unit, to equalise the holding time of the chocolate across the curtain. Tempered chocolate changes very quickly when not stirred and if there is only one feed, it takes longer to reach the outside edges of the trough, where it will contain larger crystals and less liquid fat and so be more viscous.

The metal discharge plate on the underside of the curtain trough can usually be tilted at various angles. If it is in an approximately horizontal position, there will be two curtains and, if it is angled, one curtain is produced.

The position of the curtain trough can be adjusted horizontally and vertically, with the first curtain normally being about 20 mm (0.8 in) before the start of the bottoming bath. If the curtain is more than 2 0mm (0.8 in) above the product centre, it can be wavy and may cause air to be included. The adjusting plate(s) at the sides of the curtain trough must be set by hand to give a constant level in the curtain.

A roller produces a more even and more easily controlled curtain, but is more expensive. Most older enrobers, as well as many new ones, use the simpler adjustable slot to form the curtain, generally with perfectly satisfactory results. The necessary criteria include a uniform, thick curtain across the complete machine width, even with relatively viscous chocolate.

Most of the air bubbles present in the chocolate can be burst using a thin chocolate layer (approx. 1 mm; 0.05 in), A still smaller trough slit (0.5 mm; 0.02 in) will show even better results; however, it may be necessary to sieve the chocolate to prevent blocking such a narrow aperture.

14.3.8.2 The bottomer

Chocolate from the curtain flows into the bottoming tank; this may be a simple plate, or it may be fitted with a bottoming roller, which transports the masse upwards. This roller rotates in the opposite direction to the belt. The sides of the bottoming tank each have an opening which acts as an overflow into the sump. The depth of the bath is controlled by the speed of the bottoming roller and is normally 6–10 mm (0.25–0.4 in). If it is set too high the chocolate can roll or overflow over the front of the scraper (see Figure 14.19). Light product centres then do not run freely into the bottoming bath and create a blockage. If the chocolate level in the bottoming bath is too high, the rotary valve on the chocolate feed pipe can be opened. It serves as bypass and directs part of the chocolate directly back into the sump. Controlling the chocolate level in the bottoming bath by means of partially opening and closing the discharge flap is not recommended, as the chocolate then runs through the wire belt and air bubbles can be incorporated.

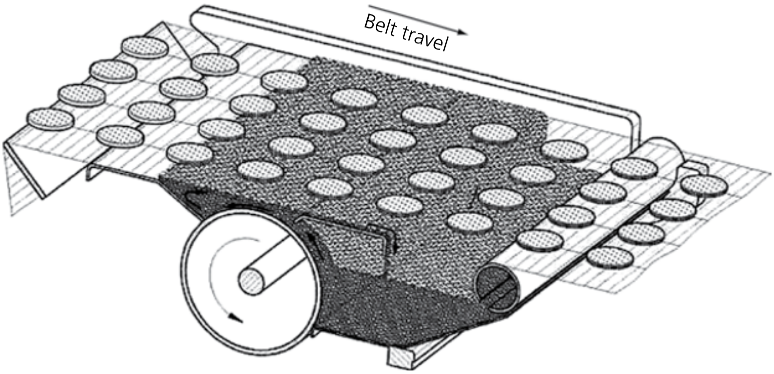


Figure 14.19 Schematic diagram of a chocolate bottomer. Source: Sollich. Reproduced with permission of Sollich Germany.

To form a bottom without the curtain, the chocolate valve lever must be moved to the "bottom coating" position. All of the chocolate supplied by the pawl pump is then directed to the bottoming tank.

A "pre-bottomer" is sometimes used to ensure that the base of the item is correctly coated, this being a standalone unit that as the name implies, adds only a bottom. It is effectively an enrober without a curtain, and is followed by a cooling table allowing 2–3 min to set the base so that it transfers to the wire belt of the enrober. If it is shorter, it will need to run so cold that condensation can be a serious problem. A hold-down device (see Figure 14.20 in Section 14.3.8.9) will be needed to control lightweight items. They are not often included in a line, but can help to put a good base on a difficult product.

14.3.8.3 The blower

Blowing reduces the coating thickness mainly on the upper face of the article; it can also leave a distinctive fine wavy appearance that improves the visual character of the product. The blowing effect is regulated mainly by adjusting the amount of air, though the height of the blower mouth can be adjusted, with a gap of 15–20 mm (0.6–0.8 in) between articles and the blower mouth piece being usual. The blower discharge lip can also be moved. A lip air temperature of 30–33 °C (86–92 °F) with a tilt of about 10° against the belt direction is generally best.

A second blower may be necessary if the remaining chocolate on the product needs to be reduced further, or when the surface is very uneven as in the case of a wafer product.

As the blower air circulates within the cabinet it may become too warm and a slide on the upper part of the coater can be opened to suck in air. For a constant and accurate blower output, the discharge lip must be cleaned once a week and the turbine once a year. Blowers are calibrated during manufacture to give an even flow all the way across the belt; with the calibration record usually being kept by the manufacturer.

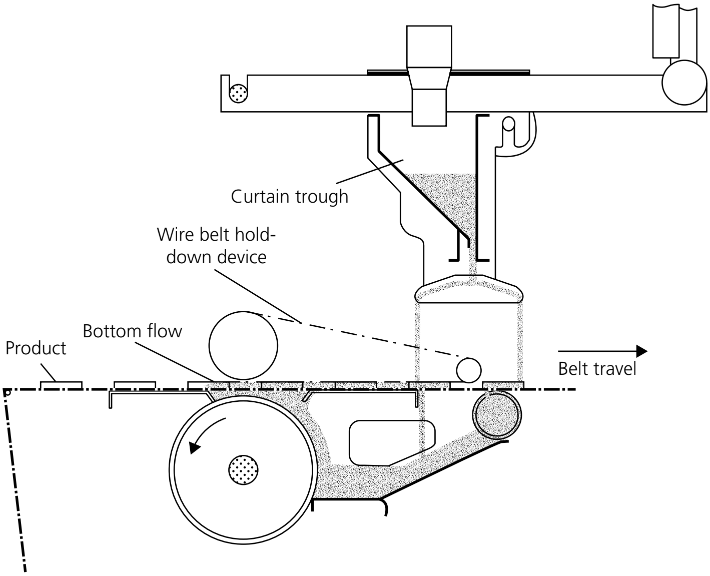


Figure 14.20 Schematic diagram of enrober hold-down device. Source: Sollich. Reproduced with permission of Sollich Germany.

14.3.8.4 The shaker

The shaker also helps to remove excess coating, but it is most effective at slimming down the side coverage. The standard shaking grid consists of three or four crossbars under the wire belt and a mechanical movement of the grid to shake the products travelling on the wire belt. The effect of shaking can be regulated by adjusting the amplitude and frequency of the shaker. The greater the yield value of the coating the more energy it takes to shake it off. Starting to shake while the chocolate is still flowing due to the blower can make the shaker even more effective in overcoming the yield value. Shaking smoothens out the ripples left by the blower which could limit its use if ripples are desired on the product. Sometimes the shaker must be also turned down to avoid having the pieces move sideways on the belt and stick to each other.

14.3.8.5 The wire belt

The rod network wire belt is at the heart of an enrobing system and was perhaps the principal invention that led to the success of the first enrobers. Both its construction and installation require care and accuracy, if it is to have a good service life. The belt tension should be set so that it is carried perfectly in the drive sprockets, with the teeth in true alignment. Any oscillations or unevenness that might cause excessive belt wear should be avoided or at least minimised. The arrangement of the product centres on the belt is important to avoid grid marks on the bottom of the sweet. Ideally they should be aligned away from the links in the enrober grid.

14.3.8.6 The sump

The wire belt draws chocolate falling into the sump down to the bottom, where it can mix with freshly tempered masse.

14.3.8.7 Rollers

A licking roller is fitted under the wire belt both to remove excess chocolate from the underside of the product returning it to the coater tank and to help clean and support the belt.

An additional bottom scraping device can be fitted to remove more chocolate from the underside of the article. Three or four rollers are normally installed and the sweets pass over them just after leaving the curtain. The rollers usually turn in the same direction as the wire belt. Although depending on the structure and softness of the centre there is the option too of running them in different directions to achieve best results. The rollers rotate at varying speeds and are all fitted with a heated scraper. The speed is usually two to three times the speed of the belt and a unit with variable speed control is the better choice. The rollers are normally about 20 mm (0.8 in) in diameter and their number may vary according to the size of the items being enrobed. They can also be grooved such that the joints of the wire belt sit in the grooving and enable the cross wires of the belt to sit directly on the rollers. This reduces the gap between the product bottom and the roller allowing maximum chocolate removal. The licking rollers are most frequently used to remove excess chocolate when coating biscuits.

14.3.8.8 De-tailing

The de-tailing roller removes excess chocolate that would otherwise cause a tail to appear at the end of articles as they transfer from the enrober wire belt to the cooling tunnel belt. It is a roller of about 3 mm (0.1 in) in diameter mounted on a heated block which supports roller and provides a scraping action to keep it clean. The heating of the block maintains chocolate fluidity and prevents build up. The roller is held by clips in the block and needs to be absolutely straight! The clips and the scraper block can wear, and both need to be in good condition.

The best effect is achieved with the following settings:

1. Minimum spacing between the de-tailing roller and the cooling tunnel transportation conveyor. The tunnel belt should be adjustable in height and proximity to the wire belt to facilitate smooth transfers. The speeds of these two belts must be almost the same with any difference being due to optimise the transfer.
2. A gap between article bottom and de-tailing roller of about 2 mm (0.1 in).
3. The de-tailing roller should normally run in the opposite direction to the product, except for small items when it turns in the same direction as the belt: Failure to do this may result in pieces being retarded by the de-tailer, leading to a lot of rework.

4 The speed of the roller needs to be high (1000 rpm or more) to "wind up" the string of excess chocolate that naturally follows the product onto the cooling belt. A unit with individual drive and variable speed is therefore the better choice.

Very small items or those with arched bottoms can turn over when transferring from the wire belt to the cooling tunnel belt. To avoid this, the de-tailing device can be lowered and the nose bar of the cooling tunnel belt can be set lower and closer to the wire belt.

14.3.8.9 Hold-down devices

A holding-down grid enables half or shoulder coating, also called dipping or masking, to be carried out (Figure 14.20). It can also be used to completely dip articles into the bottoming bath chocolate without interfering with the curtain. By adjusting the bottomer, an upwards flow of chocolate between the wire belt and the holding-down device can be achieved, so that even articles with a very uneven and porous surface and overhanging pieces are completely covered with the chocolate. This process leads to a more complete coating for difficult articles than would be possible with only the curtain and bottoming bath system. The holding-down grid is installed between the bottoming tank and the curtain trough, though it can be extended forwards to prevent small articles moving around on the belt.

Biscuits may be coated top and bottom or only underneath. There are feed systems available to turn them over at the exit from the enrober (Figure 14.21), as well as the hold-down devices to control them whilst being coated.

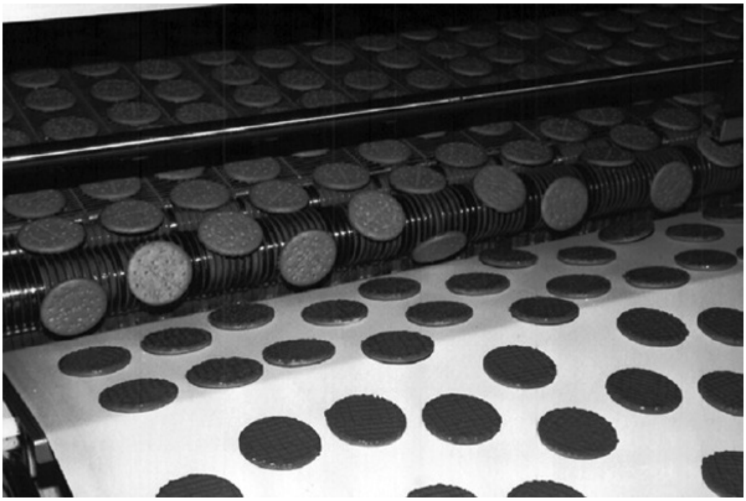


Figure 14.21 Picture of biscuit turn over device. Source: Sollich. Reproduced with permission of Sollich Germany.

Figure 14.22 Picture showing extendable belt running through the first enrober (in white) which is bypassed. Source: Sollich. Reproduced with permission of Sollich Germany.

14.3.9 Changeovers

Enrobers designed for rapid changeover are also available, some of which are on wheels, and push in and out of the line as required with rotary joints on all feed lines. Changeover time is around 10 min.

An alternative is two enrobers in line, one after the other, with an extendable belt that allows the product to be run through one of the enrobers and so avoiding contamination of either product or enrober (Figure 14.22).

Enrobers are manufactured that are suitable for wet cleaning, which can be useful when changing between incompatible masses or those containing difficult to remove flavours (or allergens).

14.3.10 Avoidance of air bubbles

Generally bubbles are not a major problem on enrobed items, as the coating is fluid enough for them to be displaced or burst by the blower. However with thicker masses or some more difficult products, bubbles can be a problem and action may be needed to minimise them. Certain basic precautions should be taken anyway, even if bubbles are not an obvious problem.

Each feed pipe to the curtain trough should have its outlet under the chocolate surface to avoid incorporating air. The correct rate of replacement of masse in the enrober by freshly tempered masse will also help prevent the build-up of bubbles due to recirculation. Holding tanks should be filled under the product surface, or using an angled pipe end which directs the flow down the wall of the tank. The tempered feed to the enrober should either have an extended feed pipe terminating under the surface or have a “cup” under the pipe end to eliminate air incorporation. Opportunities for the chocolate to fall any distance inside the enrober should also be eliminated.

14.3.11 Avoidance of chocolate build-up inside an enrober

One of the major reasons for having to stop and clean or reheat an enrober is a build-up of chocolate on the internal surfaces that can increase the temper and, hence, the viscosity of the mass and can also endanger the belt.

Some simple precautions will help:

- Always keep the cabinet windows closed.
- Cooling water must be >10°C (50°F), use a higher volume if necessary.

Further modifications can be made to reduce chocolate build up:

- Side heating can be retrofitted using the 45 °C (113 °F) water circuit to supply it. Three shift heating packages are also available, consisting of wire heaters for the nose rollers at infeed and discharge, plus cross members and the bottoming pan.
- The square structural beams can also be trace heated by buying exchange units with a suitable groove.
- An agitator in the feed trough can also help prevent build-up.

14.3.12 Downstream processes

In addition to the details below, please consult Schremmer (1988).

14.3.12.1 Engrossment

It may be necessary to add a layer of particulates onto the centre either after enrobing, or between two coatings. Cereals, nuts, kibbled high boiled candies and "hundreds and thousands" are typical of the kind of addition that is made.

The article to be coated is conveyed with its coating still soft onto a layer of the engrossing material. More is dropped onto the bars via a curtain to ensure an overall coating. The bars pass on to a wire mesh belt that allows excess pieces to fall through and be recycled. Finally, they will usually go through a second enrober to receive a protective second coating before passing into the cooler.

14.3.12.2 Decorating

A wide variety of patterns can be applied, using the same or different colour chocolates; and then, by using a comb, these patterns can be dragged and modified. A decorator (Figure 14.23) may be placed immediately after the enrober; or alternatively, further down the line to let the wet coating masse partially set and so be less messy. A combination of applied decorations and combs can be used to produce distinctive patterns even with the same colour chocolate.

The most common units are made either by Sollich (Decormatic) or by Woody Stringer in the USA. The original Stringer, first produced in 1956, was capable of making zigzag decorations in thick or thin patterns on candies and baked goods. Over the years, various features were added beginning with a single loop attachment for producing circles, ovals and slanted zigzags. Later, the double loop attachment was developed, allowing the decorator to produce more complex designs, such as the figure of eight (8), tree bark and cross-hatching. Heaters were added to ensure an even temperature across all the nozzles. The Stringer can be custom-designed to produce zigzag, single-loop, double-loop and cross-hatching designs. Likewise, the Decormatic is a very versatile unit capable of applying many designs.

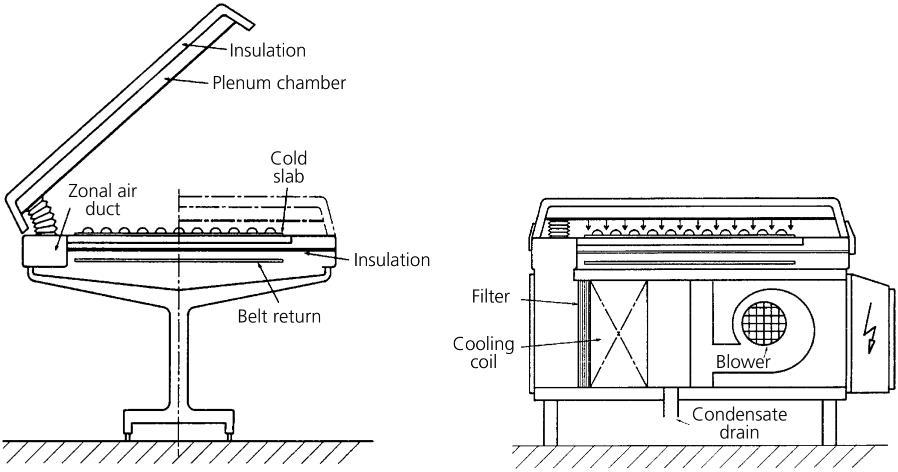
Figure 14.23 Picture of decorating machine. Source: Sollich. Reproduced with permission of Sollich Germany.

Both units require a small local temperer, if the decoration uses a different chocolate masse to the coating.

14.3.13 Cooling

The cooler normally occupies around two thirds of the linear space of the enrober installation. Two types of single level cooler are shown in Figures 14.24 and 14.25. These are the Gainsborough cooler and the Sollich contact radiation cooler seen after most enrobers. Modern Sollich coolers are designed as modular systems of sections, each 3 m in length, which can be individually regulated for air speed and temperature (Sollich, 2014). In a Sollich cooler, cold air enters the product space from the cooling unit via a duct and there is a brief initial cooling by convection. Air flaps in the covers divert cold air to the space above the conveyor where plates above the product are cooled, leading to radiation cooling which is gentler than convection. At the end of the first tunnel air returns to the conditioner via the space below the conveyor so that products in that area are cooled from the bottom (contact cooling). In the second section, cooling is by convection with air flowing with the product and warming up. Again it returns to the cooler below the conveyor (Figure 14.26). High-performance single level coolers operate not only with radiation and convection cooling from above, but can also include cold water contact cooling from below with a water-jacketed slab under the belt.

As with coolers used for moulded products, both latent heat and heat of crystallisation need to be removed. Without the plastic mould to insulate part of the product, cooling times tend to be shorter for enrobers, especially if the cooler belt runs on a cold table.



(a) (b)

Figure 14.24 Sections through the Gainsborough cooler at (a) the centre and (b) the blower.

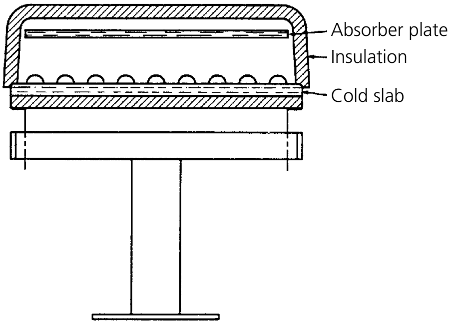


Figure 14.25 Section through a Sollich cooler section. Source: Sollich. Reproduced with permission of Sollich Germany.

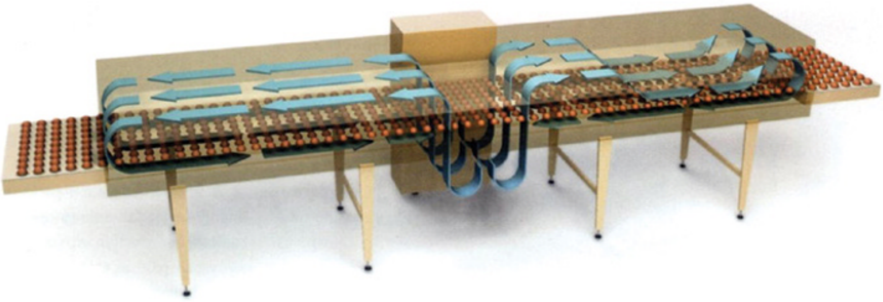


Figure 14.26 Typical airflow in a Sollich cooler (product flows from left to right). Source: Sollich. Reproduced with permission of Sollich Germany.

A higher temperature and longer cooling time are more favourable than a lower temperature and short cooling time. Milk or white chocolate requires a longer cooling time than dark due to higher milk fat contents and consequent lower solidification temperatures.

The air temperature will depend on the recipe and cooler length and zoning, but for milk chocolate should ideally be 14–18 °C (57–64 °F) at the inlet, 10–12 °C (50–54 °F) in the centre section and 12–16 °C (54–61 °F) at the outlet. Lauric compounds especially need more aggressive initial cooling at 6–8 °C (43–46 °F), with a gentler second stage preventing any problems with the dew point. For non-lauric coatings the recommended temperatures are in between that of chocolate and lauric coatings, that is 8–12 °C (46–54 °F; Talbot, 2009).

14.3.13.1 Suggested cooling times

The minimum total cooling time required depends on the coating composition and thickness (Sollich, 2014). Below are some guidelines for the different chocolate masses:

Dark chocolate	4–6 min
Milk chocolate	6–9 min
Milk chocolate with high milk fat, nut oil or softer CBE	9–12 min
Lauric coating	2–3 min
Non Lauric coating	4–6 min

14.3.14 Troubleshooting enrobed product faults

Below is an overview of potential problems with enrobing and their possible causes (Webb, 1996). They are by no means all that there may be, and as anybody skilled in the art knows, an enrobing defect can often be the result of a combination of several causes.

Chocolate is not setting in the cooling tunnel:

- Poorly tempered product masse, not enough seed,
- Reheat stage of temperer too warm,
- Too much soft fat in the product masse (nut oil, soft CBE or milk fat),
- Cooling time too short or temperatures not set correctly,
- Enrober hood or blower air too warm.

Coating chocolate has a grey sheen and/or develops fat bloom:

- Untempered or over-tempered chocolate,
- Centres too cold or too warm,
- Enrober hood or blower air too high a temperature which de-tempers the chocolate,
- Shear heat from an overheating circulation pump de-tempers the chocolate,
- Cooling in tunnel too intensive, setting the chocolate in one of the unstable crystalline forms,
- Contamination of coating with incompatible fat,
- Incompatible fat in centre and fat migration,
- Pieces below dew point or RH too high in tunnel or wrap room (condensation leading to sugar bloom),

Incomplete coating:

- Chocolate viscosity too high,
- Overtempered masse, so too high viscosity,

- Dusty surface on centres,
- Excessively oily surface on centres.

Uneven weight distribution across the belt:

- Blower blocked or not positioned evenly,
- Curtain thickness or vibration is uneven.

"Foot" around the bottom edge:

- Too much coating on centre,
- Chocolate yield value too low,
- Licking roll or shaker incorrectly adjusted,
- Vibration of cooling belt.

Conclusions

Although the basic components of a moulding or enrobing plant have not changed significantly in recent years, manufacturers and also end users are continually introducing variations to improve their automation, hygiene, flexibility and efficiency.

The machines described in this chapter enable good quality chocolate goods to be made, often at high speed, and generally using very few operators. They are however equally capable of making large amounts of waste and rework. The difference lies in the skill and knowledge of this small workforce responsible for its installation, maintenance and operation, and in ensuring that this knowledge is passed on as the workforce is renewed.

Acknowledgements

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CHAPTER 15

Non-conventional machines and processes

Dave J. Peters

15.1 Introduction

It is almost impossible to put a clear line between conventional and non-conventional processes. Most companies modify “standard” layouts in some way to give themselves some advantage in their particular circumstances and, no doubt, some manufacturers will be surprised to see some of the processes included in this chapter described as “non-conventional” because they have been using them for many years. However, the vast majority of the world’s chocolate is produced on lines using pasters, pre-refiners, refiners and conches, with the chocolate then being mechanically tempered and transformed into chocolate confectionery by moulding, enrobing or panning. I have chosen to regard these as “conventional” processes and, from all the remaining “non-conventional” processes, selected the following for inclusion in this chapter:

- Ultrasonic processes;
- High shear tempering;
- High pressure tempering;
- Extrusion;
- “Single shot” depositing;
- Chocolate aeration;
- Cold forming;
- Paste conching.

15.2 Ultrasound

Nordenskjold and Holmquist (1946) proposed the use of ultrasound to conche chocolate or cocoa mass as early as the 1940s. The high-frequency forces were used to impart energy into the product and this was said to have the following effects:

1 Acceleration of some chemical reactions without changing the form of the reaction, for example the extraction of tannins from cocoa mass;

Beckett’s Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett, Mark S. Fowler and Gregory R. Ziegler.

2 Freeing of gases from the mass;
3 Formation of electrostatically charged oxygen and ozone, thus causing some oxidation;
4 Homogenisation of the ingredients.

It is now known that ultrasound can create free radicals, which promote oxidation and other reactions that may be beneficial to some types of chocolate but detrimental to others. For example it is said that, whereas oxidation may assist flavour development in plain chocolates, it may give rise to an unpleasant taste in milk chocolates. Initially, in fact, treatment with ultrasound was more successful with plain or bitter chocolate, where it was generally found to reduce conching time from about 72 to 36 h. Mosimann (1963) in particular developed it for use with all types of chocolate, so that it could be used as part of a manufacturing process which required no conching at all (Figure 15.1). He concluded that previous workers were using too long a treatment time (up to 120 s) and limited his processing period to a fraction of a second. Mosimann found that ultrasonics accentuated flavours, including undesirable ones, so it was necessary to ensure that the latter were not present in the feed material. In addition some de-aeration was needed for milk chocolates. For these, the exposure time was extremely critical, with longer times giving a deterioration of flavour and an increase in astringency. The ability of ultrasound to generate free radicals decreases with increasing frequency and therefore the frequency used is crucial: 800 kHz was found to heat the chocolate and give inferior results; and, although the most suitable

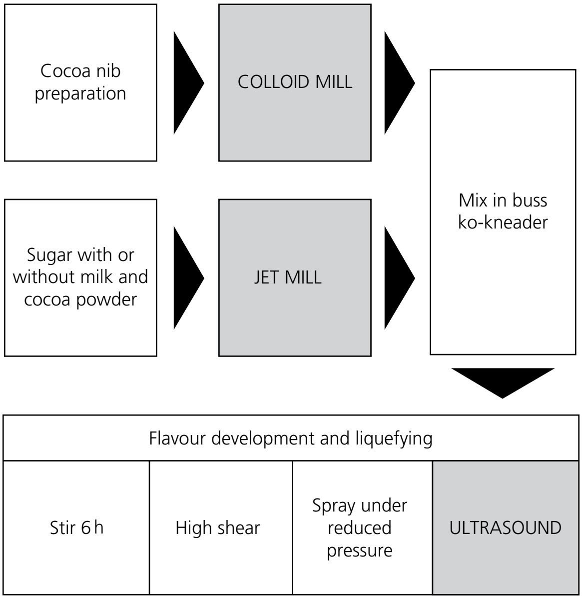

Figure 15.1 The Mosimann process for chocolate making.

frequency was found to vary with the chocolate recipe, it was normally in the region of 20 kHz.

Ultrasound has also been shown to improve the texture of the final product and make it less sticky in the mouth. This may be related to the fact that it aids the tempering of chocolate. Roberts at the Leatherhead Food RA in the United Kingdom used ultrasound in the 1980s to promote the formation of specific polymorphic forms, whose type depended upon the temperature used. He also found that tempering, particularly of plain chocolate, was improved. Milk recipes were less affected, probably because of the influence of the milk fat.

This has been subsequently developed by Kraft Jacobs Suchard R&D, Inc. (1997), who describe work in which ultrasound is applied in order to retard fat bloom in fat-based confectionery masses. The chocolate is cooled to a temperature of at least 3 °C below the melting point of the required crystalline state and pulses of ultrasound are then applied. The pulse lengths and intervals can vary over a wide range, but preferred values are said to be from 0.5 to 4 or 5 s. Similarly, although a wide range of ultrasound frequencies can be used, the range 20–100 kHz appears to be the most effective. The use of ultrasound is said to make the tempering process more robust and to give products with optimal contraction, gloss and snap.

Ultrasound can also be used to determine the amount of crystalline fat within chocolate at different temperatures, that is the solid fat index. Povey (1997) has shown that this can be done by cooling the fat or chocolate to 0 °C (32 °F) before grinding it into a powder which is smaller than the wavelength of sound. The powder is then dispersed in a mineral oil at a fraction of 20% w/w and the temperature increased to the range needed for the measurements. The amount of solid fat present can be calculated from the velocity of the ultrasound through this mixture. The use of ultrasound to measure chocolate temper online was unsuccessful however, as the signal from air bubbles within the chocolate was much greater than that from the crystallising fat (Anon., 2002).

15.3 High shear/low temperature crystalliser

High shear is considered to be of critical importance in rapidly tempering chocolate (see Chapter 13) and Ziegleder (1985) demonstrated that cocoa butter could be tempered in 30 s at very high shear rates. This is impractical in standard temperers because the heat generated cannot be removed and raises the temperature above the melting point of the fat. This is illustrated in Figure 15.2 (Windhab, 1995) which plots the crystal volume fraction of dark chocolate against the rotational speed of a crystalliser. This machine operates by shearing the fat as it is being cooled. Initially, as the speed is increased, more seed nuclei are able to spread throughout the sample. This eventually tempers it, enabling it to set quickly. The actual crystal content required to temper chocolate varies considerably from author to author but is probably in the range of 1–3%. Eventually the speed becomes so high that the energy generated by the crystalliser melts some of the crystals. Subsequent increases in speed further decrease the temper.

Windhab (1994) overcame the melting problem by maintaining the walls of his crystalliser (Figure 15.3) at a very low temperature [4 °C (35 °F)] and keeping the outlet temperature between 28 and 30 °C (82–86 °F) to prevent the machine from blocking. This was possible because the cocoa butter or chocolate was being pumped through the concentric cylinder shear gap in a way in which there was no possibility that there were any "dead spots" and because some heating was being provided due to the shearing. The actual shear energy was controlled by varying the speed of the inner cylinder within the range 600–1200 rpm. It was possible to obtain a stable temper by using in line temper/viscosity readings on the outlet from the crystalliser to control its speed of rotation. It would have been expected that, because of the low temperatures, unstable crystalline forms of cocoa butter would be produced. Windhab showed, however, that in his crystalliser the crystal type was related to the power input per unit volume of material. He was also able to show that the crystals produced contained a higher proportion of Form V crystals than a conventional temperer. He was therefore able to produce a very good temper with a residence time of about 10–15 s. This principle has been incorporated into a new tempering machine that is sold by the Bühler Company of Switzerland and is described in Chapter 13.

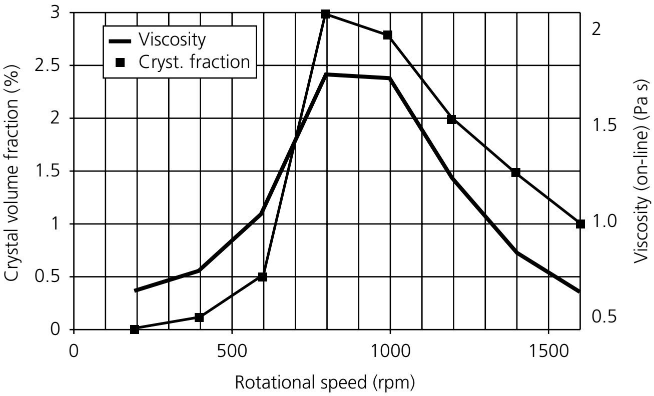

Figure 15.2 Pre-crystallisation of dark chocolate in a pilot plant crystalliser under constant cooling conditions (15 °C, 59 °F).

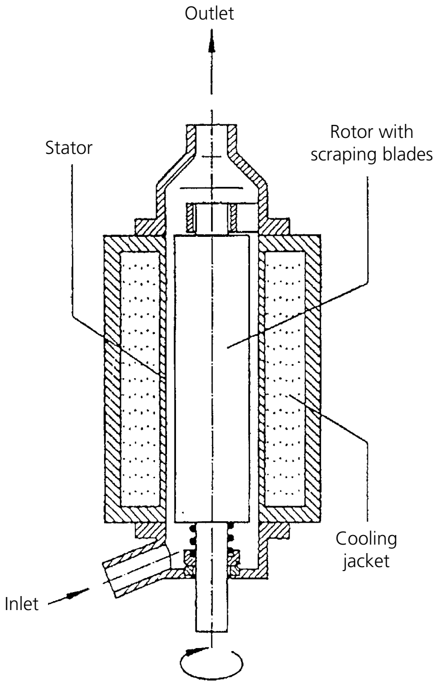

Figure 15.3 Principle of the continuous shear crystalliser. Source: Windhab (1994). Reproduced with permission of Springer.

15.4 High pressure temperer

A Bauermeister pressure tempering system has existed for many years operating at pressures of between 175 and 1000 kPa (25–150 psi) in combination with shearing and cooling. Trials in Japan, however, have shown that it is possible to temper pre-cooled chocolate by pressure alone (Yasuda *et al.*, 1992), but at much higher levels (about 150 MPa; 20 000 psi).

Very high pressure systems have been developed for the food industry in order to kill vegetative bacteria without the need for heat. Fruit colour and flavours are therefore better preserved and commercial machines are used to manufacture jams and preserves. This type of machine has been shown to be also able to act as a temperer.

The principle behind this process lies in the fact that the melting point of cocoa butter rises linearly with pressure (Figure 15.4; Yasuda *et al.*, 1992) according to the equation:

$$T = 0.14P + 26.6 \tag{15.1}$$

where T is the solidifying temperature (°C) and P the pressure (MPa). From this it can be calculated that applying a pressure of 150 MPa has an equivalent effect to lowering the temperature of the cocoa butter by 20 °C (36 °F). This means that, if this pressure is applied to liquid cocoa butter at 30 °C (86 °F), all the main different crystal types are formed. When the pressure is released

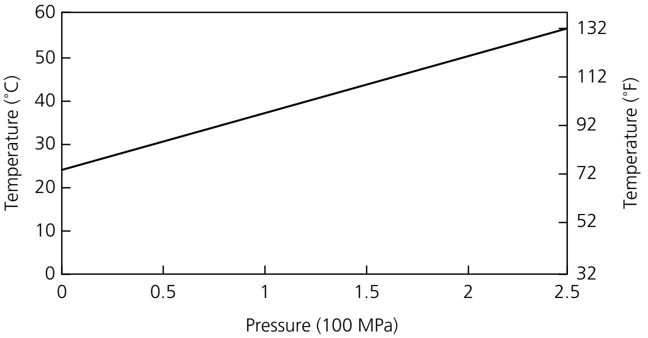

Figure 15.4 The effect of pressure on the melting point of cocoa butter (Yasuda *et al.*, 1992).

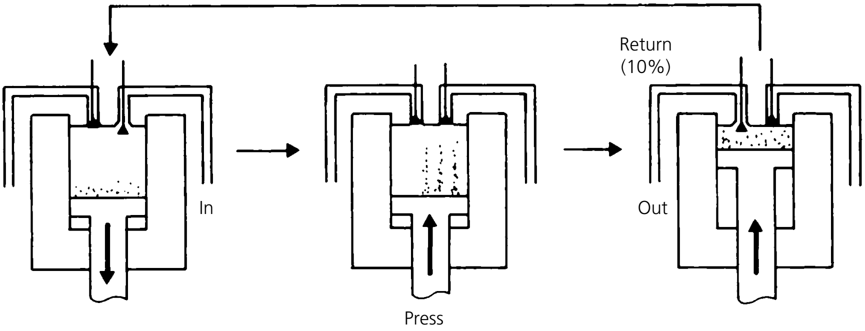

Figure 15.5 Diagram of prototype system for tempering chocolate using very high pressures (Yasuda *et al.*, 1992).

however, those unstable forms with lower melting points disappear leaving tempered chocolate. Experimentation showed that at least two pressure pulses are required with holding times of up to 5 min. This is obviously not suitable for industrial applications. Further trials indicated, however, that by returning 10% of the tempered chocolate to the feed system as seed crystals, a holding time was no longer required. A prototype continuous pressure temperer was therefore developed (Figure 15.5).

15.5 Extrusion

15.5.1 Types of extruders

Extruders are widely used in the food industry (Riaz *et al.*, 2007). They are excellent mixers, can give good heat transfer rates because of their high surface area to volume ratios and can handle high viscosity materials. The simplest form of extruder has a single screw conveying the material along a close-fitting, parallel or tapered barrel. Other machines have two interlocking screws which are either co-rotating or contra-rotating (Table 15.1 and Figure 15.6). These have the

Table 15.1 Comparative characteristics of co- and counter-rotating extruders.

Co-rotating extruders/screws	Counter-rotating extruders/screws
Mass transport by positive conveyance and drag	Positive conveyance acts like a "screw pump"
Longitudinally open flights leave open path from feed to discharge	Radially and longitudinally closed flights; screw flights form sealed chambers Limits mixing but quickly generates pressure Good transport of low viscosity material
Pressure generation depends upon the number and pitch of the reverse pitch elements and very much upon the die exit; the through "path" limits the upper pressure obtained	Pressure generation by the reduction of pitch length
Good mixer but less control over temperature and shear	Poorer mixer, but each small "pocket" of material can have a more precisely controlled temperature regime Within limits, temperature and shear can be controlled independently

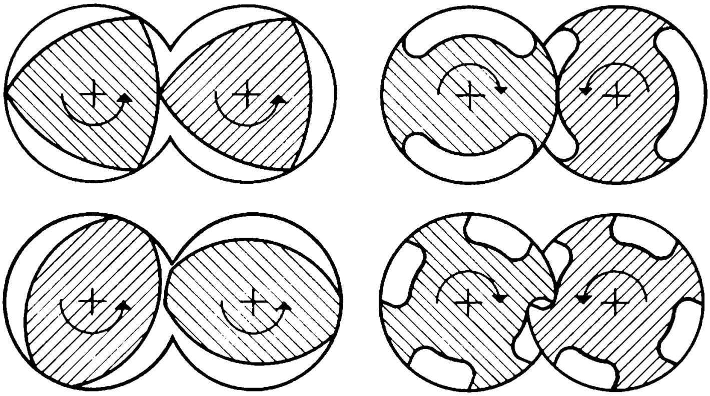

Figure 15.6 Examples of cross-sections of co-rotating and counter-rotating extruder elements.

advantage of being effectively self-cleaning. Still others have a "planetary" system in which a central screw drives a series of secondary screws running in grooves in the barrel.

The extruder screw profile will be configured to suit the processing conditions required. For example, the screw might provide sections of high shear to induce heating, sections with intense mixing shortly after the introduction of an ingredient or a low pressure section for removal of volatiles. Additional flexibility comes from the ability to add ingredients at almost any point along the barrel. Temperatures along the extruder barrel can also be controlled by having different cooling/heating regimes on each barrel section. Single and twin-screw extruders often have screws built from removable elements slotted onto a shaft making it easy to "tune" the screw profile to match the processing requirements and reducing operating costs since individual screw elements can be replaced in the event of wear rather than the entire screw.

In the chocolate industry, extruders have been used to treat cocoa mass, for flavour improvement (Section 15.5.2), as a liquefier to partially or fully replace the conche (Section 15.5.3) or to shape tempered chocolate to produce novel products (Section 15.5.4).

15.5.2 The extruder as a flavour modifier

The ability of an extruder to heat and de-gas liquids has led to its use in pasteurisation or flavour modification of cocoa mass or nibs. Traditionally this has been carried out by thin film or spray devices (Chapter 10). One system using an extruder, developed by Werner and Pfleiderer (Elsner, 1989), adds water or steam into the extruder, where the cocoa nibs are thoroughly wetted and slightly crushed. Pasteurisation is carried out by applying a high temperature over a short time. The steam de-gasses at the machine outlet, taking with it many other compounds, including some acidic ones, which are detrimental to chocolate flavour. The high humidity during the process also raises the water activity (equilibrium relative humidity) of the material, thereby increasing the probability of destroying *Salmonella* and other bacteria (Chapter 25).

In addition to treating cocoa mass to remove flavours and thereby shorten conching times, an extruder can also be used to treat the chocolate ingredients to produce a crumb type of flavour. As was described in Chapter 6, chocolate crumb was produced historically to give the milk needed for chocolate making a longer shelf life. Although this may now no longer be necessary, the cooked caramel flavour is preferred in some markets, for example the United Kingdom. The manufacture of crumb usually involves a vacuum drier and is relatively slow and expensive.

In the Continua crumb process (Anon., 1996; Figure 15.7) a crumb-like flavour can be produced in about 60 s. Sweetened condensed milk and/or milk powder, water and sugar are fed into a twin screw extruder together with cocoa mass. Here they are thoroughly mixed and heated to a temperature of 95–130 °C (203–266 °F) depending upon the desired final flavour. Towards the end of the process the mixture is reduced in temperature by applying a vacuum. At this stage the residual moisture is 1–3% and the mixture has a consistency which enables it to be pelletised. This granulate is then milled to a powder, which can be used as the main ingredient in a traditional chocolate making process. The milling will also reduce the moisture by up to a further 0.5%.

15.5.3 The extruder as a chocolate conche

In Chapter 10, the importance of high shear and temperature control in reducing chocolate viscosity during conching was emphasised. Extruders are ideally suited to such applications.

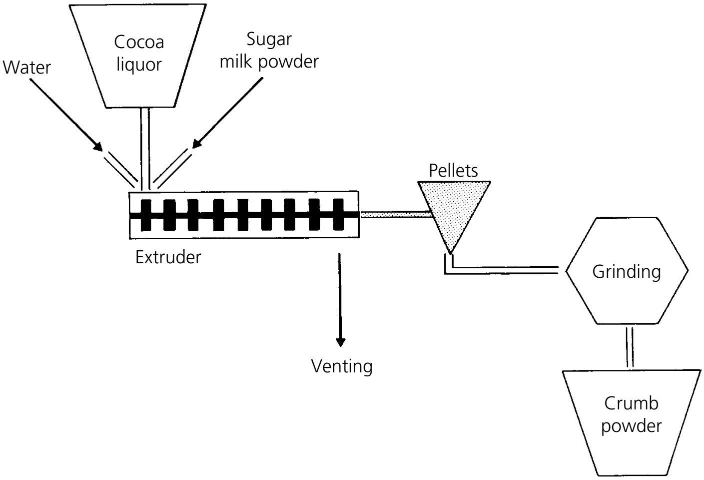

Figure 15.7 Chocolate crumb making process using an extruder (Anon., 1996).

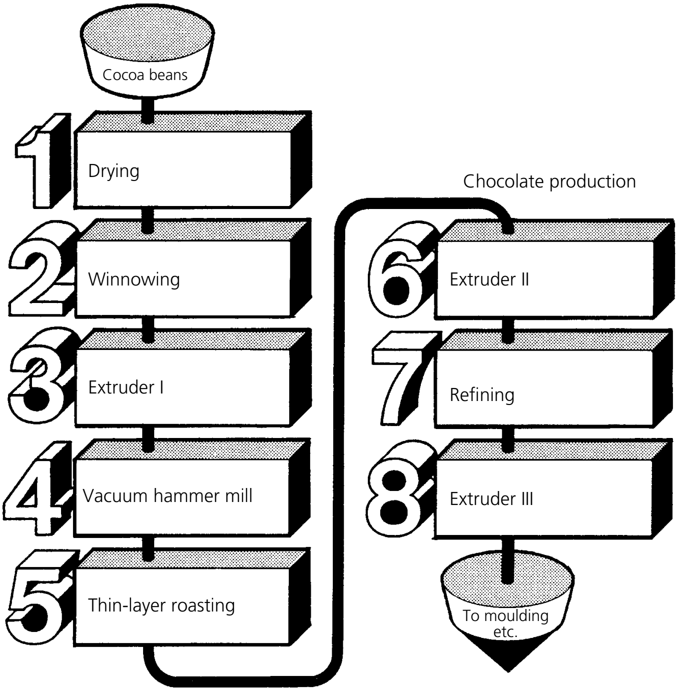

Figure 15.8 Werner and Pfleiderer system for chocolate manufacture.

One of the first descriptions of their being used for this purpose was as part of a novel chocolate process developed by Werner and Pfleiderer (1970). The total process used three extruders (Figure 15.8). The beans were dried and winnowed before being slightly crushed under high moisture conditions in the first extruder, as described above. The cocoa mass was then produced by grinding followed by thin-layer roasting. The second extruder was then used to mix in the other ingredients, apart from the emulsifier and some of the cocoa butter. It also completed the flavour development by heating and venting. A roll refiner then reduced the solid particles to the required size, before the chocolate was fed into the third extruder for the final additions and liquefying. The total process was reported to take 30 min and to be able to operate at between 300 and 3000 kg/h (660–6600 lb/h) and to produce a wide range of flavours.

Although described as a twin-screw, co-rotating, high-shear continuous mixer, the Readco Kurimoto continuous processor has many of the features of an extruder. The close clearances between the paddles and between the paddles and barrel walls provide the high shear for all the material present and thus very efficient liquefying. The movement of the shafts is essentially self-wiping so very little cleaning time is required. Units have been designed with hollow paddles and/or jacketed barrels to give a precise temperature control.

This type of machine has been used as an alternative to the conche in order to produce a relatively thin chocolate with a very short processing time. Ziegler and Aguilar (1995) and Aguilar *et al.* (1995) describe experiments in which two 5 cm (2 in) shaft processors were used in series to conche a milk powder-based milk chocolate. The first processor acted as a flavour developer, with the second being used as a liquefier, the final lecithin/cocoa butter additions being metered at half-way along the barrel (see Figure 15.9). In some experiments, an additional roll refiner was used between the two processors, or following conching. The latter was said by Niediek (1991) to be a method of producing some of the best quality chocolate.

The residence time in a Readco Kurimoto continuous processor was determined by the screw configuration, mass feed rate, discharge opening size and screw speed. Using the high shear system, only the feed rate was found to have a significant effect. For rates between 30–10 lbs/h (14–4.5 kg/h) the mean residence times were between 2 and 8 mins. Even with these short times the chocolate appeared to be fully liquefied. The temperature of the first processor

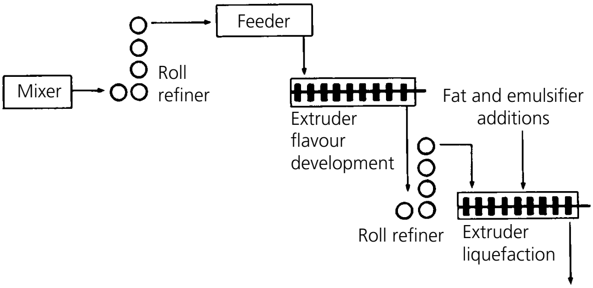

Figure 15.9 Continuous conching system using Readco Kurimoto Processor (Aguilar *et al.*, 1995).

was critical both for the flavour of the chocolate and its viscosity. The Casson yield value and the plastic viscosity (see Chapter 11) were much lower for a temperature of 70 °C (158 °F) than for 40 °C (104 °F). When an even higher temperature was used, however, the chocolate became gritty and post-processor refining was required.

The flavour of the chocolates produced was compared with that produced from the same roll refiner material, but which had been processed in a traditional batch conche for 24 hours at 60 °C (140 °F). The samples were found to be significantly different, but there was no significant preference for either. The chocolates were evaluated in terms of sweetness, caramel, milk and chocolate flavour. Of these, only caramel was found to be affected by the processing time and temperature. The chocolate processed at 90 °C (194 °F) was found to be most like the batch conched control chocolate. This chocolate was however gritty. This may have been due to the crystallisation of amorphous lactose as many milk powders contain a high proportion of lactose in the amorphous state. Crystallisation is both time- and temperature-related and Arvanitoyannis and Blanshard (1994) demonstrated that, in anhydrous mixtures with sucrose (i.e. as in chocolate), this transition would take place within minutes at temperatures of 90 °C (194 °F). This crystallisation, which would be expected to change the flavour and improve the flow properties, would also take place in a batch conche, but over a much longer period of time.

The Readco Kurimtoto continuous processor was therefore able to match many of the properties of a traditional conche. Its advantages were said to be:

1. Reduced conching time;
2. Faster product changeover and greater flexibility;
3. Increased production rates;
4. Reduced energy requirements;
5. Smaller floor space needed;
6. Less material in process;
7. Enclosed operation and improved cleanliness.

15.5.4 The extrusion of tubular shapes, ropes and nets

When chocolate is tempered part of the liquid fat solidifies, thus increasing the viscosity. The viscosity is, however, still low enough for the chocolate to be used for enrobing or moulding. As the chocolate is further cooled, more of the fat solidifies and it becomes paste-like. In other words it will deform under pressure, but will retain that shape once any force is removed. In this state it is possible to extrude the chocolate onto a mould or belt, where it is subsequently cooled in the traditional manner. The extrusion must of be done quickly whilst there is sufficient liquid fat present to enable it to deform in the extruder nozzle but before it has become solid.

Cadbury Schweppes (1981) applied this principle to produce net shaped or tubular products. The tempered chocolate is rapidly cooled, whilst continuously

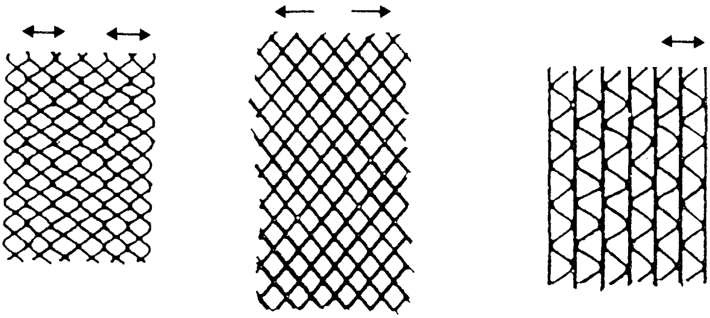

Figure 15.10 Selection of net designs produced by Cadbury (1981) extrusion technique.

being stirred, until it reaches a temperature where the chocolate becomes sufficiently viscous to extrude. Instead of extruding the chocolate through a hole, cooled net-forming dies can be used. The inner and/or outer parts of the die can be rotated or oscillated to give different patterns (see Figure 15.10). This net can be passed over a cooled mandrel to form it into a tube. If this mandrel is hollow, a filling material such as mallow, fondant, fudge or spread can be fed directly into the tube. The tube can be cut as it leaves the mandrel and is passed onto the take-away belt.

The major problem with this type of technology is that the processing conditions, in particular the temperature and the chocolate viscosity, must be very tightly controlled. If the extruded tube is too liquid the tube will collapse and become misshapen. Too thick a chocolate will not extrude properly and may have a rough surface or may crack upon bending.

Sollich GmbH and Co. has also developed a machine to extrude chocolate paste into a stick or rope (Hilker, 1996). The chocolate flow properties are influenced by the fineness of the chocolate and the recipe, but above all by the temperature which must be carefully controlled (see Chapter 11). Tempered chocolate is cooled between the pump and the extrusion nozzle, so that the chocolate rope, being discharged onto a transport belt, has a surface temperature of about 22 °C (72 °F). It is therefore sufficiently viscous to hold its shape but requires a short cooling period before it can be cut. This extruder can produce chocolate products containing solid ingredients with a diameter of up to 1 mm (0.04 in) and which have a smooth surface or have a twisted shape.

The Sollich stick-extruder has been further developed to produce a chocolate mesh. In this machine several extruding heads are located one after the other above a moving belt. The heads are moved backwards and forwards across the width of the belt. When the distance covered by one oscillation of the heads is the same as that of the movement of the transport belt itself, a diagonal pattern of thin chocolate strands is produced. This can then be repeated by a series of subsequent heads to produce a product with a woven-like appearance. The number of strands, together with their diameter, determines the height of the product. Increased visual impact can be made by extruding different coloured chocolate for the different levels. In addition textural contrast can be achieved by putting wafers, nuts or crispies between the chocolate layers.

As with the Cadbury process, the temperature and chocolate viscosity are critical. Here it is important that each strand be present and be of the same diameter. In order to do this every pipeline from the pump to the extruding head is the same length and temperature. One feed pump is connected to three nozzles, each of which produces five strings. The chocolate mesh is still too pasty to cut cleanly when it is deposited upon the belt but would be very brittle if it were left to solidify fully. An intermediate stage is provided by passing the product for about 4 min through a conditioning tunnel. After this the chocolate mesh is cut using a slitter and guillotine. Final separation and wrapping is carried out after a second cooling tunnel. This process gives very good weight control with individual pieces being within ±2% of each other. Production lines are available which can make product at the rate of 500 kg/h (1100 lb/h).

The above processes depend upon accurate temperature control and use a chocolate that is in a semi-liquid state. An alternative approach, based on processing in the plastics and ceramic industry, was described in Beckett *et al.* (1994). Trials, where the chocolate remained essentially solid throughout the process, were carried out on a laboratory scale. Solid chocolate buttons about 10 mm (0.4 in) in diameter and 3 mm (0.1 in) in thickness were fed into a Florin ram extruder (see Figure 15.11). The extruder and chocolate were at an ambient temperature of 23 °C (73 °F). The extruder initially compacted the chocolate before extruding it in the form of a rod or tube. The extruded chocolate had no detectable temperature rise, so the processing was essentially iso-thermal and was called "cold" extrusion. It was found that a continuous uniform extrudate could be obtained

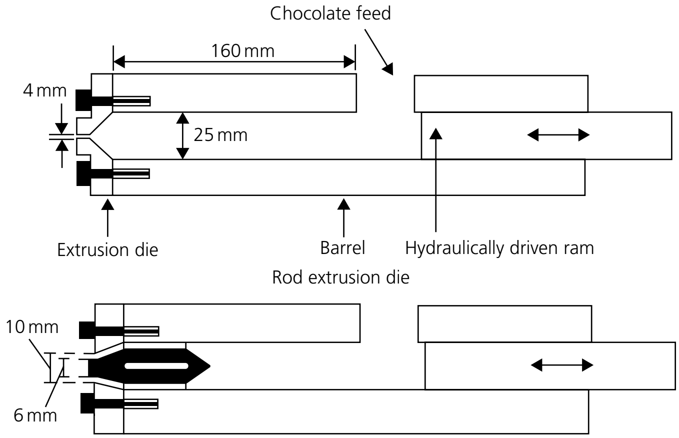

Figure 15.11 Schematic diagram of the "Florin" ram extruder when used to produce rods and tubes (Beckett *et al.*, 1994).

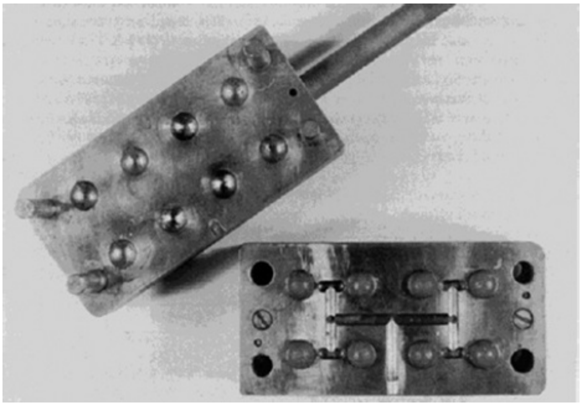

Figure 15.12 Photograph of injection mould used to make small balls (Beckett *et al*., 1994).

at temperatures above 18 °C (64 °F) up to just below the melting range of the chocolate (about 30 °C, 86 °F), and so accurate temperature control was no longer required.

The surprising property of the extruded chocolate was that it remained in a plastic condition for a significant amount of time, enabling it to be twisted or even tied into knots. The actual period of this plastic state was found to depend upon the type of chocolate, the extrusion conditions and the post-extrusion storage temperature. In general it took from 30 min to several hours for the chocolate to return to its previous brittle form.

Many plastic products are formed by injection moulding. Because of the plastic nature of the cold extruded chocolate, this type of process was investigated. A mould capable of producing eight 12 mm (0.5 in) diameter balls (Figure 15.12) was attached to the Florin ram extruder. Once again the trials were carried out at room temperature. Eight balls were consistently produced, but their surface quality was variable, ranging from matt to glossy. The entrance gate to the ball was only 200 μm (0.008 in), showing that chocolate can be extruded through a very narrow opening.

This process (Mackley, 1993) can be carried out using single and twin screw extruders in addition to the original ram type machine. With skilful process control, therefore, it is possible for liquid chocolate to be tempered, solidified and extruded in a single extrusion–processing step.

15.6 “Single shot” depositors

15.6.1 Background

A substantial proportion of the chocolate confectionery market consists of moulded filled sweets, that is a chocolate shell containing a contrasting centre which can be praline, sugar fondant, peanut butter and so on. The advantages of moulded products over enrobed ones (Chapter 14) are that they can be made in a much wider variety of shapes and that they have a higher gloss finish. The main disadvantage is the number of procedures required to produce a traditional shell moulded product, that is:

1. Mould warming;
2. Tempering of the chocolate;
3. Depositing the chocolate to fill the mould;
4. Shaking to remove air bubbles;
5. Cooling and inverting to remove the centre chocolate;
6. Vibrating to control shell thickness before inverting again;
7. Shell cooling;
8. Scraping to remove excess chocolate from mould;
9. Deposit the centre;
10. Vibrate and cool centre;
11. Re-heat the back of shell and the centre;
12. Deposit tempered chocolate to produce back (bottom) of sweet;
13. Scrape off excess chocolate;
14. Vibrate and cool;
15. Demould.

Although obviously complex, shell moulding works well and can be used with a wide variety of centres including whole nuts and cherries and the filling can be as much as 66% of the sweet.

Single-shot depositing is more limited in the types of centre that can be used, in that this must be in a form which can be pumped. In addition the centre is normally less than 50% of the sweet. It does however enable a very wide range of products to be made by a much shorter process. Cadbury Ltd. (now part of Mondelēz) in the United Kingdom has used the process for over 60 years, but it has only been available to the confectionery industry at large as ready manufactured plants since the 1970s (Jeffery, 1990).

15.6.2 Basic principle of single shot depositing

The basic principle behind this technique is illustrated in Figure 15.13. As can be seen, it relies upon carefully timed depositing through concentric cylindrical feeds and through a central nozzle. Tempered chocolate is fed through the outer ring and the centre is deposited down the inner tube.

The sequence starts with the chocolate being deposited through the outer nozzle hole. After a predetermined time the centre starts to flow, so that a ring of chocolate surrounding a rod of centre is being forced through the nozzle. Subsequently the centre stops and a plug of chocolate once again flows through the nozzle, to complete the sweet. Thus a chocolate “balloon” is formed containing the centre confectionery. This may be deposited on a belt to form a chocolate “kiss” (see Figure 15.14) or more usually falls into a mould, where it is vibrated to make the chocolate and centre conform to the required shape, which includes

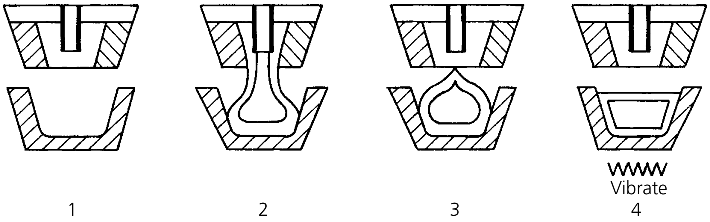

Figure 15.13 Schematic diagram of the principles of "single-shot" depositors.

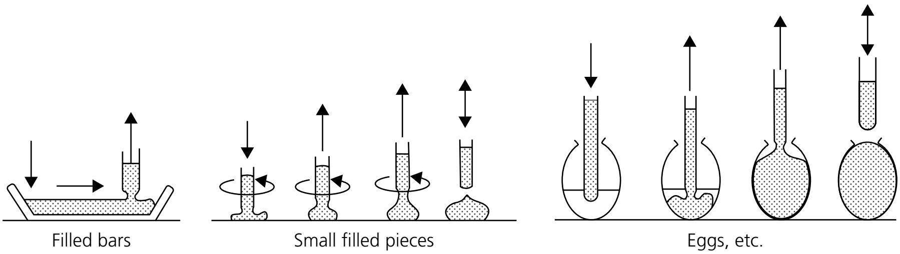

Figure 15.14 Illustration of some of the moulds used with "single-shot" depositors.

bars and egg shapes. The product is then cooled and demoulded ready for wrapping. Egg shaped products can be made by depositing into a book mould, that is one which consists of two moulds which are hinged at one edge (Chapter 14). The hinges open to release the product once the chocolate has set.

This process is obviously much quicker than the traditional process, with the whole product being formed in one depositing action, hence the name *single-shot*. Its big advantage is that it can greatly extend the range of products which can be produced on a standard moulding line at a low cost compared with a shell plant.

This principle was taken even further by Cadbury Ltd., who developed a triple-nozzle version to produced a double centre sweet, for example jam (jelly) inside fondant, surrounded by chocolate. The German company Winkler and Dünnebier has since produced a triple-shot machine for putting two centres into praline shells (Anon., 2005). The Awema company have taken this one stage further to produce a four-shot (Quadro) depositor. By using a mechanical nozzle plate and the specially designed hopper dividers, it is possible to produce products with two fillings in two component shells, as shown in Figure 15.15. The viscosity of the two fillings can be different.

15.6.3 Limitations of single shot depositing

15.6.3.1 Temperature of depositing

The process needs the temperature of the centre to be no higher than that of the enclosing tempered chocolate. If it is, the chocolate will detemper resulting in slow setting and poor contraction during manufacture and give a poor-textured, easily bloomed product. The actual temperature will depend upon the type of

Figure 15.15 Chocolate products with two components in the centre and shell (Awema A.G., Switzerland).

chocolate used, in particular its fat phase. In practice this is higher for dark chocolate at about 33–36 °C (91–97 °F) than for milk chocolate, which will be in the range 28–31 °C (82–88 °F). It is possible to have a temperature towards the top of this range by using a harder cocoa butter, for example one from Malaysia rather than one from Brazil. In milk chocolate the lower the proportion of dairy butter, the higher will be the tempered chocolate temperature, which then allows for a warmer centre material. Where it is possible to use vegetable fat in chocolate or for coatings, a high melting point cocoa butter equivalent fat (see Chapter 7; sometimes known as a cocoa butter improver) can be used to raise the operating temperature by a few degrees. Even this, however, is not enough for the process to be used to make hard toffee centres, as the toffee would require much higher temperatures to be able to flow at the correct rate through the central depositor. These sweets require a shell moulding or enrobing plant.

15.6.3.2 Matching viscosities of the chocolate and centre

The process operates best when the centre viscosity and density match as closely as possible those of the tempered chocolate, which surrounds it. The chocolate viscosity can be increased by lowering the temperature and/or increasing the temper. Typical Casson plastic viscosities lay in the range 10–80 Pa.s (100–800 Poise). Mechanically operated cam systems required very good viscosity matching, but programmable electronically controlled machines can tolerate bigger differences between the two (Watson, 1997).

15.6.3.3 Size of inclusions

The centre has to be forced through the inner depositing channel. Although it is normally possible to include small pieces, such as bits of nuts, the process cannot be used with whole nuts, cherries, raisins and so on. Even small pieces can cause the central channel to be blocked or break the outer chocolate "skin".

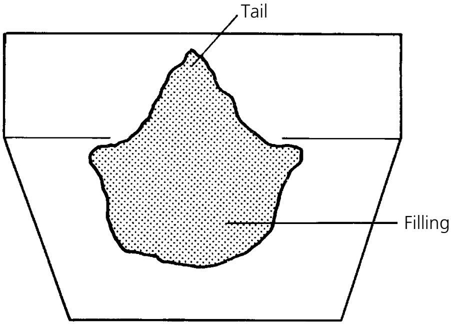

Figure 15.16 Diagram of "tailing" in a moulded product.

15.6.3.4 The ratio of centre to chocolate

Early single shot depositors had a centre that was about 40% of the product. This has been increased to 55% or more by the use of electronically controlled machines, and one manufacturer claims that products with 80% have been produced (Awema, 2007). The shape is also important with more spherical egg-shaped products having higher centre proportions than moulded tablet shapes (Figure 15.15).

15.6.3.5 "Tailing"

Of course this is also a problem with shell moulded products and occurs when the centre forms long "tails" or "strings" due to its elastic or gummy nature, which prevents flow from stopping cleanly when the depositor closes. These form a passage through the chocolate (Figure 15.16), which often results in the centre leaking out of the sweets. This is a major cause of rework with soft caramels, syrups and jellies.

15.6.4 Key control parameters

Jeffery (1990) gave the following parameters as being key to obtaining satisfactory results from a single shot system:

1. Accurate timing of both chocolate and centre deposits, which must be independent of each other;
2. Accurate control of depositor piston or pump speeds, independent of depositing rate, to control the velocity of the fluid through the nozzle;
3. Accurate valves to stop the depositors and obtain the material from the feed hoppers (often rotary valves are used);
4. A controlled "suck back" to minimise "tailing";
5. Temperature control of centre and chocolate to within ±0.1 °C (±0.4 °F);
6. Accurate weight control of both components;
7. Accurate location of the deposit in the mould. Otherwise the chocolate "skin" may distort, leading to weak spots;
8. Good design of nozzle assembly;

9 Correct temper and viscosity: both temper and viscosity need to be consistently well controlled (use of accurate viscometers and tempermeters strongly recommended);
10 Shakers should have a length, amplitude and frequency which is independent of the product throughput, so that the plant conditions can be optimised;
11 A cooling time of at least 40 min is normally required to avoid cracking of the chocolate;
12 The mould shape is particularly important with blocks or tablets, where cooling stresses on the product must be minimised to prevent cracking. An "egg" shape is almost ideal for this technique.

15.7 Aeration of chocolate

15.7.1 Types of aeration

Aerated chocolate has a lower density than normal chocolate, as some of the solid material and fat is replaced by a gas. This gives the consumer what appears to be a larger product at the same weight and usually a softer texture and melting sensation. It does not reduce the calorific value, as this is measured in calories per gram and is therefore the same whether or not there is air inside it.

There are four very different types of products that have been produced over the years (Jeffery, 1989). The most common is where the individual bubbles within the chocolate are clearly visible and have a mean diameter within the range of about 0.05–3.0 mm (0.002–0.1 in). The normal density of chocolate is 1.3 g/cm^3, but due to the presence of the bubbles aerated chocolate tablets are produced with densities of 0.4–0.8 g/cm^3. This can be produced under vacuum (Section 15.7.2) or by beating in gas under high pressure (Section 15.7.3). The first product on the market was Rowntree's Aero® in 1935, which is currently still manufactured by Nestlé. Most of these products are produced by first making a shell either by traditional shell moulding (Chapter 14) or by cold forming (Section 15.8). The aerated centre is then deposited and allowed to set, before further liquid chocolate is poured into the mould to give a smooth back.

It is possible to produce very fine bubbles, so that they are not clearly visible to the naked eye. This is sometimes known as micro-aeration and can produce densities as low as 0.7 g/cm^3. At these densities it produces a quicker melt and creamier texture. The main application is for moulded chocolate biscuits, where it is able to reduce the percentage by weight of chocolate on the final product.

Another type of aeration is where continuous tubes of air run within the chocolate. These can be produced by extruding semi-set or solid chocolate, as described in Section 15.5.4. An example of this type of product was marketed by Cadbury under the name of Spira®.

In normal chocolate the fat is the continuous phase which binds it all together, but certain aerated products are held together by the solid particles, in particular the sugar, forming a continuous skeleton. This also makes it possible to make very low fat products. The air bubbles are irregular and this type of product does not melt with heat like normal chocolate. It can however have a very low density (e.g. 0.2 g/cm^3) and it dissolves rapidly in the mouth, releasing a chocolate flavour. Two methods of manufacture have been described, both of which are based on evaporating water from chocolate ingredients (Section 15.7.4).

15.7.2 Vacuum aeration

When liquid chocolate is placed in a vacuum, it will rise into a foam. If this is then cooled and the fat allowed to set, it will retain its structure. Sometimes additional gas, usually carbon dioxide, is mixed into the chocolate before the vacuum is applied. The size and shape of the bubbles can be variable (see Figure 15.17) as they are affected by many factors, including the chocolate viscosity, the pressure, emulsifier type and the rate of set of the chocolate (Haedelt *et al.*, 2005). It is very easy to incorporate other large ingredients such as nuts and nougat within the aerated product. Vacuum systems however tend to be difficult to maintain in a hygienic condition and often need a relatively high labour rate to operate, so high pressure aeration systems tend to be more widely used.

15.7.3 High pressure aeration systems

These systems incorporate gas into tempered liquid chocolate under high pressure. Some of the gas dissolves and any remaining gas is dispersed as fine bubbles using a high speed beater. Sufficient cooling must be supplied to prevent the chocolate temper being destroyed by the process. The beater may be a separate unit, such as those manufactured by Haas-Mondomix or Asser Oakes, or integrated into the tempering unit such as the Sollich Turbotemperer® Airo (Figure 15.18). The pressure will also affect the product bubble size, as it is the release of this pressurised chocolate into normal atmospheric pressure that causes it to froth and form the bubble structure. Special depositors are needed to feed the chocolate into moulded shells or to extrude it as a continuous sheet.

Figure 15.17 Different sizes of bubbles in aerated chocolate.

Figure 15.18 Sollich Turbotemperer® airo (Source: Sollich).

There are several patents for these depositors but, as with single shot systems, it is very difficult for large pieces of other ingredients to be added.

The type of gas that is used is very important. For visible bubbles carbon dioxide is often used, although nitrous oxide is said by some workers to give a more intense cocoa flavour and a different texture (Murphy, 2005). If nitrogen is used however only very fine bubbles are formed and micro-aerated products are produced. This difference is believed to be due to the different solubility of the individual gases in chocolate.

15.7.4 Water evaporation methods

The earliest description of a process to make this type of product was in a patent by Cadbury (1975) and resembles one of the crumb-making processes described in Chapter 6. Sugar is dissolved in water before being emulsified with cocoa liquor and milk solids. The mixture is then concentrated to approximately 10–12% water in a scraped surface vacuum evaporator. The resulting paste is dried to less than 2% water in a continuous vacuum band drier. This type of aerated "chocolate" can be made with a low fat content, below that required to meet the legal definition of chocolate. It has a very low density (0.1–0.3 g/cm^3) and is able to be cut into pieces or granulated for use as inclusions in other products such as ice-cream or cakes.

Figure 15.19 Light aerated chocolate from Japan.

An alternative way of producing this type of product is described in a patent by Nestlé (1999) with a higher fat version in a patent by Meiji Selk Kaisha Ltd (2001) and was said to be used to produce a product called Poff® which was sold on the Japanese market (Figure 15.19). The process involved emulsifying water with liquid chocolate before solidifying it into sheets or the shape of the product. This was then freeze dried to remove the water. The space previously occupied by the water is filled by air forming a low density aerated chocolate. This too can be cut or granulated if required.

15.8 Cold forming technologies

15.8.1 Background

Traditional chocolate forming processes rely on the chocolate being cooled relatively slowly to give the fat phase time to crystalise in the correct form. Too low a temperature in a cooling tunnel will result in the creation of less stable polymorphs and the final product will be susceptible to the formation of fat bloom during storage. However, it has been known for some time that very low temperatures can also be used in certain circumstances.

Boyd and Yates (1923) were issued a patent which showed a cooled metal plunger being pushed into a mould, which was partly filled with chocolate. The idea being that the chocolate would form a partly set shell, which would retain its shape once the plunger was withdrawn. This system suffered from the problem that it was difficult to remove the plunger from the chocolate in the relatively short time allowed by a production plant and much of the patent was concerned with release agents, such as alcohol or water, which could induce a

Figure 15.20 Bindler CoolCore™ process (Source: Bühler).

quick separation of the plunger. The release agent tended to spoil the surface of the chocolate and the system was never sold commercially.

Aasted's Eriksen dragee moulding plant (Chapter 14) is the oldest commercial application of cold forming, dating back at least to the 1940s. Tempered chocolate is passed between chilled steel rolls with surface indentations designed to produce the desired shape. The chocolate emerges as a plastic sheet of dragee centres held together in a web and passes through a conventional cooling tunnel until set. The sheet is broken and tumbled to separate the dragee centres from the web and to smooth their surface. The broken pieces of web are returned to the start of the process and the centres sent forward for sugar panning and so on.

Interest in cold forming technologies resurfaced in the late 1980s and a Mars Inc. (1998) patent claims that cooling tunnels can be operated at high speeds and sub-zero temperatures [preferably below –5 °C (23 °F)] and yet produce glossy products with increased bloom resistance. Aasted applied for a patent (Aasted, 1993) with a similar process to that described in the Boyd and Yates work but with much colder forming tools and without the need for release agents. They have subsequently sold machinery based on this technique under the FrozenCone™ trademark. Other companies have similar offerings; Bindler sells equipment under the CoolCore™ name (Figure 15.20) and Knobel have their ColdPress™ system.

15.8.2 Typical cold forming process

Sufficient tempered chocolate to form the shell and to allow for a small excess is deposited into the mould. The excess is required to ensure that the chocolate reaches the top of the mould all the way around (it may preferentially be pushed

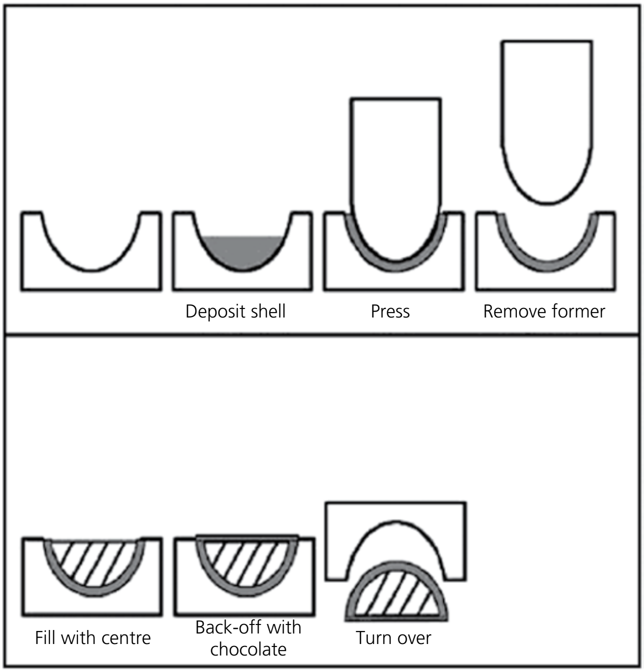

Figure 15.21 Schematic diagram of cold forming process. Reproduced with permission of Bühler AG, Switzerland.

up through part of a non-symmetric mould) and also there will be small differences in sizes between different moulds.

A frozen plunger, with the shape of the inside of the shell, is then inserted into the chocolate. The liquid chocolate is thereby squeezed up around the plunger and forms the shell (see Figure 15.21). It is necessary for the air to escape and not form bubbles or surface marks (Kniel 1997) and so the rate of entry of the plunger into the chocolate can be important. Aasted have developed a system in which the final millimetre of the insertion is relatively slow.

The length of time the plunger stays in the chocolate depends upon its temperature. The Aasted system operates at –15 to –21 °C (+5 to −6°F) (Aasted, 1997) and it only takes about 2 s or less for the chocolate shell to be hard enough for the plunger to be removed. In the Bindler system, the stamp is only at –5 °C (23 °F), which means that it must be kept in the chocolate for 4 or 5 s.

Once the plunger has been removed a scraper removes the excess chocolate from the mould and the centre is deposited in the shell. The products are then backed-off with liquid chocolate, as for traditional shell moulding, and the mould and product cooled, before de-moulding and wrapping.

As with Eriksen rolls it is necessary to keep cold stamping units in a humidity-controlled environment to prevent the formation of ice on the cold surfaces. Bindler have suggested that this is easier with their system, since it is operating at a slightly higher temperature than other designs. Where the chilled cone or cold plunger fails to separate satisfactorily, it is possible to spray it with an alcohol/glycerol mixture. This lowers the freezing point and appears to give satisfactory results with, for example, ball-shape moulds which have previously caused problems.

As was noted earlier, it would be expected that the very cold temperature of the plunger would cause the fat to set in its unstable crystalline form and so rapidly form bloom. This has been shown not to be the case, with even the inside of the products remaining glossy after long periods. It is assumed that this is because the surface of the shell is setting as a glass during the rapid cooling and only crystallising in the cooling tunnel as the heat generated by the crystallisation of the remaining liquid fat in the chocolate passes through this surface layer. Dr. Ziegleder, of the Fraunhofer Institute in Freising in Germany, has confirmed that the fat crystal forms found in cold-formed chocolate are similar to those from conventional processes. The surface of the shell may reach temperatures below 11 °C, but only for a few seconds (Boehme *et al.*, 2003) whereas chocolate crystallisation rates peak at 15 °C (59 °F) and requires some 7 min for solidification (Ziegleder, 1995). This supports the idea that fat crystallisation is occurring entirely in the cooling tunnel.

As would be expected, during storage trials traditionally produced and cold-formed shells show more or less similar stability against migration and bloom. In some trials, however, traditionally moulded pralines were found to develop fat bloom earlier than cold-formed ones, probably because the migrating filling oil penetrates faster through the thin areas of the shell that can be produced during conventional shell forming (Boehme *et al.*, 2003; Ziegleder, 2004). In other trials, cold-formed pralines were found to be less stable, possibly because of their accelerated production speed (Hinterberger *et al.*, 2007). The bloom stability of pralines is strongly dependent on the production speed and cooling time. If the time in the cooling tunnel before filling is too short, shells from all types of moulding technique have a reduced resistance to fat migration and bloom.

15.8.3 Advantages of cold forming technologies

15.8.3.1 Greater consistency

Shell thickness is controlled by the shape of the mould and plunger rather than chocolate viscosity and the mechanical forces on the mould (from shaking and gravity). Consequently there can be greater consistency of shell thickness and shape across the mould providing increased scope for product optimisation.

15.8.3.2 Controlled shell thickness

This improved control also makes it possible to produce shell shapes unattainable on conventional shell plants. Shells can be thicker at points where they are most likely to break (e.g. the neck of a Santa Claus figure). They can also be produced with very thin rims to facilitate backing off or joining two halves in a book-moulding process.

15.8.3.3 Less chocolate is required than for a shell moulding plant

Little or no chocolate is scraped off the moulds in cold forming system compared with the 50%, or even more, which is tipped out of the mould during traditional processing and then requires reheating and re-tempering. Cold forming thus requires smaller temperers and storage tanks and changeovers between chocolates require less cleaning.

15.8.3.4 Very low fat chocolates can be processed

The forming process is largely independent of the chocolate viscosity. This has enabled "chocolates" with fat contents as low as 22% fat to be made into shells (Aasted, 1997).

15.8.3.5 Reduced plant size

The process no longer requires a section for mould inversion and chocolate draining thus reducing the plant size to something similar to a moulding plant. It may also be possible to reduce the length of the cooling tunnel to reflect the heat removed during the forming process.

15.8.3.6 Multi-product moulding

With conventional shell-making it is difficult to form differently-shaped shells in a single mould efficiently and the need to recycle some 50% of the chocolate constrains the process to a single chocolate at each depositing stage. These constraints are removed in cold forming technology and it is therefore possible to produce a complete assortment with multiple chocolate types at a single depositor (Figure 15.22) dramatically simplifying robotic packing operations.

Figure 15.22 Complete assortment produced with a single deposit (Aasted, Denmark).

Figure 15.23 Robot loading complete boxes using the ChocoAssort™ system (Aasted, Denmark).

Aasted-Mikroverk has developed this concept in their ChocoAssort™ process (see Figure 15.23).

15.8.4 Disadvantages of cold forming

15.8.4.1 The need for air conditioning in the processing zone

As was noted earlier the cone or plunger must be used under relatively low humidity conditions.

15.8.4.2 The requirement for very precise mould manufacture and positioning

If the cone is not in the centre of the mould, then one side of the product will be thin and the opposite one thicker. This means that both the mould itself and the positioning mechanism must be very accurate. Kniel (1997) showed that, at Chocolate Frey, the maximum tolerance for a 1000 mm (3.3 ft) wide production line was only ±0.3 mm (0.01 in). Depending on the shape of the product to be made and the size and format of the mould, the minimum shell thickness may be in the range 1.5–2 mm (0.05–0.07 in). To achieve this accurate alignment of the plunger tool to the moulds, care must be taken to adjust the plunger tool.

15.8.4.3 Cost of plungers and moulds

Moulds and formers are much more expensive than conventional moulds because of the greater precision required by the process.

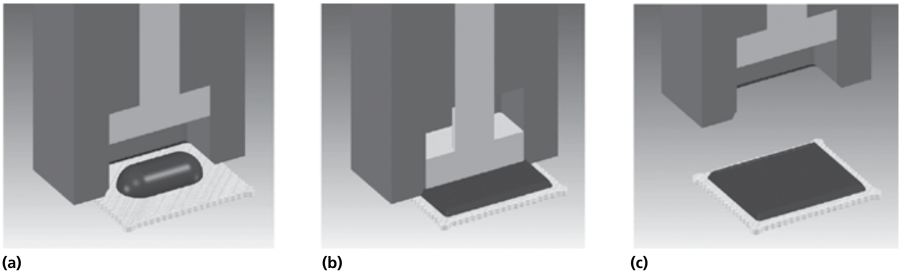

Figure 15.24 Schematic diagram of the operation of mouldless plant (Aasted, Denmark). (a) Deposit of chocolate on biscuit. (b) Cold pressing. (c) Removal of cold press.

15.8.4.4 The need for additional cooling for the cone/plunger

Additional cooling carries additional costs.

15.8.4.5 Possible difficulties with some larger products

Kniel (1997) indicated that Chocolat Frey had had difficulty in producing equal thickness edges when producing 100 g (3.5 oz) filled tablets.

15.8.4.6 Possible difficulties with some smaller products

For some systems the number of mould impressions is limited by the pitch of the tooling. Therefore it may not be economical to produce small products using this technology.

15.8.5 Cold forming variants

15.8.5.1 "Mouldless" system

With this technology the chocolate is deposited directly onto an existing steel or plastic belt line or onto other components such as biscuits, nuts, raisins and so on. A cold shaped pressing tool then descends upon the chocolate and moulds and sets it into the required shape (Figure 15.24). The tool can be made with a wide variety of shapes and designs and is able to put a high definition image onto the chocolate. All pistons are mounted individually and can be exchanged, so that different shaped articles can be made in one pressing operation.

The Aasted Company in Denmark make this system under the name FrozenConeMouldless™. It is relatively easy to fit such units to existing plant. The production speed can be high; the factory of the Danish manufacturer Carletti has two pressing devices, each with 75 closely arranged plungers. This plant produces 63 750 moulded 4 g (0.14 oz) articles per hour. The pressing time in each stroke is below 1 s. The chocolate is reported (Aasted, 2007) to be in Form V and so gives good bloom resistance.

15.8.5.2 Solidification on plunger

Chocotech Gmbh manufactures a mouldless cold forming system which they market as Frozenshell®. A chilled former is dipped into a bath of tempered, liquid chocolate where a thin layer solidifies around the former. The former is removed and positioned over a conveyor belt before the shell is ejected from the former by air blowing through small holes in the former face. The system has the advantage over conventional cold forming of only having one forming part and so should be cheaper to purchase and easier to set up. It is, however, relatively slow and weight control, which is achieved by varying the time the former spends in the chocolate bath, is less accurate than with other systems.

15.9 Paste conching

Conventional conching (Chapter 10) is carried out on the (almost) complete chocolate mass following refining; but the last few years have seen several equipment manufacturers offer paste conching: a vigorous mixing of the raw ingredients prior to particle size reduction. Treatment of the mixture at this stage has several advantages:

- The process can be carried out at relatively low fat contents, making volatile and moisture removal much easier.
- The process can operate at relatively high temperatures, above the glass transition temperature, to crystallise the lactose in any milk powder used, as described in the Hershey (2003) patent. In conventional conching this would give rise to “grits” but this is not a problem here as the mass will subsequently be refined.
- The equipment can be designed specifically for this high-shear mixing operation rather than all three phases of conching (dry, pasty and liquid).

Such a process can only replace the “dry phase” of conching and a final liquefaction stage is still required; but this is a relatively simple mixing process and, again, the equipment can be designed specifically for this function. Some companies, for example Netzsch in their ChocoEasy™ process, include paste conching from necessity, as dry conching of a low viscosity mass emerging from a ball mill is clearly impossible. Others, such as Lipp Mischtechnik in their ECO2-CHOC®, make a feature of the reduced plant size and energy consumption that the process requires.

Conclusions

The chocolate industry is relatively young; eating chocolate has only been available for 150 years or so and might be considered a novel food. Even so, much of the basic technology was established in the first 100 years and most of the developments described in this chapter, significant though their impact might be, represent an evolution of old ideas, making use of better scientific understanding or improvements in engineering and control systems. In common with most industries, such developments are aimed either at producing some novelty with a higher consumer value or at reducing production costs through reductions in material waste, energy use or manpower requirements. This will surely continue.

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CHAPTER 16

Chocolate panning

Marcel Aebi, revised by Mark S. Fowler

16.1 Introduction

16.1.1 History

Historical records on the subject of panning show that it was first used to coat pharmaceutical products. Over 1100 years ago, a gentleman named Razes coated pills or tablets, using materials such as mucilage or slime from *Plantago psylium* seeds. Over time, honey, gold, silver and finally sugar was used to cover the bitter taste of the pharmaceutical ingredients. To this day much of the equipment and techniques is common to both confectionery and pharmaceutical industries.

The first confectionery-coated mouth-sized pieces were believed to be made in Nîmes, France, around the year 1200. Over the years, new ingredients and centres were mixed and dried in pots and pans, with a final separation by hand. (These techniques can still be used today for the quick production of prototypes.) Descriptions exist of large parabolic dishes hanging from the ceiling on two ropes or chains and being moved over an open fire. This required both stamina and strength to produce the goods. Around 1840, a confectioner in France invented a pan mounted on a shaft, which could be turned manually. The principles of this process and the techniques used then are still valid today, even with the development of ever bigger and more sophisticated equipment. All still involve a rotating container containing the centre pieces. The coating material, whether it be chocolate (e.g. for coating nuts, raisins etc.) or sugar for coating chocolate (Smarties™ and M&Ms™ etc.), is then added in a form in which it can coat the outside of the centres, as they tumble over one another in this container.

16.1.2 Definitions

Coated goods were first termed “dragees” in Europe and were probably derived from the Greek word *tragein* meaning nibbling. The definition of pan coating may best be described with the following words:

> “Pan coating is the build-up of a centre (kernel) with a liquid or liquid and powder substances with multiple layers or continuous phases, which are set, hardened or dried to

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Figure 16.1 MacIntyre classic manual pan. Source: Reproduced with permission from Hamburg Dresdner Maschinenfabriken GmbH.

> smooth or pearled surface and often finished with a sealant and or a polishing agent, utilising rotating pans or drums creating a fluid bed."

The machinery used is often compared visually with a cement mixer. The drums or pans are horizontal or have their front slightly elevated and are fitted with internal ridges, which are used to aid mixing (see Figure 16.1). As the product mixes, thin layers of liquid are added to coat the centre material. It is during the drying or setting of this coating that the tumbling action causes the surfaces to rub against each other to form a smooth finish.

Care has to be taken before marketing the products made by panning, because some countries have standards covering pan coated goods and it is always advisable to check local laws and regulations. Frequently, panned goods are named by their centres and/or the shell applied to the dragee: an almond centre with a chocolate shell would be called a chocolate almond and so on.

16.2 Panning methods

Although this book is concerned with chocolate, it is worth briefly mentioning all the different types of panning, because more than one technique can be used to make some varieties of panned sweets. The different methods are listed in order of relevance to the chocolate industry.

16.2.1 Chocolate panning

Chocolate panning is a temperature-dependent method in which the coating solutions are melted by heating and hardened again by cooling. Several layers of warm melted coating are applied to the centres and solidified again. Although chocolate is still the predominant coating medium today, compound and yoghurt coatings are fast gaining popularity.

16.2.2 Soft coatings

Soft coatings are produced with the absorption and desorption of moisture. A liquid is applied and allowed to flow over the centre before it is dried out using absorbing solids. The liquid should have adequate bonding properties to hold all the solid particles (usually a sugar) in place. Frequently multiple layers of powder will be required to completely dry out the whole wet layer as far as the centre material. Relatively thick layers can be applied to the centres and so the product rapidly gains weight, which makes this technique particularly useful in the confectionery industry.

Depending upon the amount and type of the powder used, soft coatings harden over time to almost the same hardness levels as hard coatings. Sugar eggs and jellybeans are just two of the more well known products made utilising this method.

16.2.3 Hard coating

Hard coating is a method where the solids are dissolved in their respective solvent. In confectionery, water is predominantly used for this task. Any type of sugar can be dissolved in water to a concentration close to its saturation point at the usage temperature. The higher the solids content in the liquid, normally the shorter will be the drying time. Care should be taken not to over-dry and cause cracking or to dry too quickly because of encapsulating moisture that will later migrate through the sweet and damage the finish of the product. Hard coating is also known as warm or French coating. The name French coating goes back to a time when this type of process was mostly carried out in France. Warm coating is a process where the pan was heated with steam coils or by an open gas-flame placed under the pan. Today most hard coatings are carried out at lower temperatures to prevent the centres from deforming (e.g. in caramels and chewing gum) or melting (e.g. the chocolate in M&Ms™ and Smarties™).

16.2.4 Film and suspension coating

These techniques are most often used in the pharmaceutical industry and often involve ingredients not generally approved by national food legislation. The solvents used here include alcohol and ether, which perform a similar function to the water in hard coating. Great care has to be taken due to their explosive nature and to avoid air pollution. Some of the more modern equipment available incorporates side-vented pans in which some of these volatile chemicals can be captured and reused.

Surprisingly, suspensions are not widely used in the confectionery industry as an alternative to the absorption process for making soft coatings. Suspensions can easily be produced by mixing, followed by further homogenising in a colloid mill. The suspension can then be sprayed onto the product, thereby avoiding a lot of the dust normally generated when the powder is applied onto the wet product in the pan.

Polymers, both in solution and in suspension, can be continuously sprayed in order to form a film on the product. By continuous application and simultaneous drying, an exact balance can be reached, whereby the viscosity of the solution on the product surface slowly increases and eventually produces a hardened coating. Film coatings have the advantage of being relative quick to apply and they will form an even coating around the centres, thus preserving the shape of the sweet centre.

16.3 The process of chocolate panning

The range of equipment available is very large, ranging in size from a few kilogammes to 3 t, and includes conventional pans (round or tulip shaped), semi-automatic belt coaters and fully automated self-contained units. However, over the years, the principals of chocolate, compound and yoghurt coating have not changed and by and large the following steps have to be taken into consideration in order to obtain a good panned product:

- Centre selection;
- Centre preparation;
- Coating selection (largely dictated by the marketing requirements);
- Engrossing, which involves
  - Building the base with chocolate or compound and so on;
  - Engrossing – giving rapid weight gain;
  - Smoothing;
- Polishing;
- Sealing;
- Packaging.

16.3.1 Centre selection

A wide range of centres can be used for chocolate coating. Natural centres, such as nuts or raisins, are particularly popular. Many manufactured centres have to be treated immediately after their production to preserve the quality or be panned before oxidation or other deterioration sets in. Centres should be of a slight convex shape, with no sharp edges, in order to avoid irregular build up and uncoated spots. Almonds, peanuts and cashews are some of the more difficult samples to coat. Almonds generally have sharp edges, which often give rise to uncoated areas. Roasted peanuts have a tendency to split, causing “doubles” due to their concave split area, whereas cashews tend to have a blank underside because of their natural curve.

It is also important to minimise the size variations of the centres, as every type and shape of pan will act as a classifier and separate smaller pieces from the larger ones. This means that certain sizes become localised within the pan and this segregation tends to become magnified by the end of the process.

The hardness and brittleness of the centres also has a large impact on batch size distribution and throughput of the final product. Soft centres like raisins can easily deform, which results in the coating flaking off later in the process.

The temperature of the centre pieces also affects production in several different ways. Cool centres will aid the setting of the coating, but centres that are too cold can provoke irregular finishes or cracking of the shell, causing the coating to flake off. With light and porous centres, the temperature should not deviate too much from that of the future storage conditions of the final product. This is to avoid subsequent expansion or shrinkage, which once again would result in cracking of the coating.

The following centres are very commonly used:

- Nuts: these are the most popular natural centres (e.g. almonds, peanuts, hazelnuts and cashews);
- Fruit: either in dried form or as an infused product (e.g. raisins, orange peel, apricot, prunes etc.);
- Soft and hard caramels and hard boiled sugars in honeycombed form (e.g. Maltesers™);
- Liquid-filled shells, which are initially solid, but are converted into liquids after coating;
- Fondants, creams, jellies, and so on.

It is important that the coating manufacturer communicates with the centre supplier in order to obtain the correct centres within a relative narrow specification.

16.3.2 Centre preparation

Preparing the centres is one of the most important tasks in pan-coating. There are many reasons for this, for example irregular centres cause deformed product, oil/fat migration will spoil the surface, oily and smooth surfaces will not allow the chocolate coating to grip, frail centres will break and so on.

The preparation step is known in the industry as sub-coating, gumming, isolating and stabilising.

Each name is probably based on the purpose for which the process was intended. However, carefully selected centres like dry roasted nuts, centres with little or no oil migration, free-flowing raisins with water content of no more than 13% and kernels providing good grip (chocolate adhesion) do not require any of these sub-coating procedures.

16.3.2.1 Gumming

In gumming, in the soft pan method, the wetting masse contains colloids together with some kind of drying powder. Currently, starch- or dextrin-based wetting masses are preferred because of the limited availability of gum arabic (*Acacia* *senegal*) and the fact that gelatine is not liked in some markets as it may not be kosher or hallal. Gum arabic and gelatine are, however, ideal for this task.

In the gumming process, irregularities and ridges caused by the processing of the centres are rounded off. Many natural products also have a tendency of being pan unfriendly and need this process. The syrup should be around 40–50% solids with a high content of glucose to ensure proper sticking and prevent crystallisation of the sugar.

The pans are filled with a predetermined amount of the centres. Using a ladle or other form of container, the liquid is poured over the centres as they roll over one another, so that they quickly become wetted. It is very important to determine the right amount of liquid to use. If not enough is added, the centres will emerge with uncoated spots and have a generally uneven appearance. If too much liquid is added, the centres will start lumping and very wet areas will attract excessive amounts of dusting powder. In addition to this, with the sticky high glucose masse, the formation of double- and multiple-centred panned goods will occur.

As soon the centres are evenly wet, dusting with a powder can begin. The powder must be added as quickly as possible in order to make sure that the product pieces separate easily. With a slow powder application, the water in the wetting solution can dissolve part of the sugar, creating a paste in the pans. This increases the viscosity of the tumbling masse, resulting in the formation of large balls. In addition, as more sugar is dissolved by the wetting masse, the sucrose/glucose ratio will change and it will start to crystallise. This results in a more brittle and harder masse (hard coating effect). Fine crystalline sugars are preferred to powdered sugar because this coats the surface of the centre much more evenly and the ridges and cracks are filled in much better. Once again lumping must be expected when powdered sugars are used, especially when the amount of liquid used is incorrect. The exact amount is difficult to determine due to variations in the surface to weight ratio of the natural products.

Once the pan load is wetted and dried again with dusting material, the process is repeated again up to five times. If free powder is detected in the back of the pan, the product should be removed and the pan cleaned before the next layer is applied, otherwise free powder will adhere on the centres in an uneven manner during the subsequent wetting process, creating lumpy and irregular product. It is not possible to suggest exact quantities to use in this process and only trial and error will give the right formula for the product being coated.

Once the required number of coating layers has been applied, the centres should be removed from the pan and layered onto shallow trays for drying (e.g. overnight). It is important for air to circulate between the trays, when they are stacked.

16.3.2.2 Isolating

Isolating is a term used where there is an actual physical separation required between the centre and the chocolate coating. Many of the centres used in chocolate panning contain oils or fats. Most of this oil/fat is not compatible with the cocoa butter in the chocolate and so the centre must be isolated from the chocolate, in order to prevent migration of the oils, with the consequent blooming and softening of the chocolate (see Chapter 7). In addition, many product centres have a fatty surface which will not allow the chocolate coatings to stick properly during the early stages of the coating process. To make matters worse, should the chocolate coating subsequently crack, a full or partial de-shelling will occur. However, as was mentioned earlier, some of these issues can be reduced or prevented with the careful selection of centres.

Gelatine forms a good continuous film on many centre products and is more elastic and less prone to cracking than an isolating film of gum arabic. The process used for isolating is identical to that for gumming.

16.3.2.3 Stabilising

Stabilising is a step used in the panning procedure to prevent fragile centres from breaking under the tumbling action during the early stages of panning, before the coating itself makes the product strong enough to withstand collisions between the pieces. Some typical fragile centres and the processes used to stabilise them are described below:

1. *Soft raisins* are very difficult to pan. The centres are flexible and the chocolate coating is unable to build up on them without cracking, and this will result in deshelling of the product. To counteract this problem, one of two techniques can be used.
   - **(a)** The raisins are firstly wetted with a high glucose starch syrup, with care being taken to make certain that the liquid penetrates into the wrinkles of the dried fruits. Fine crystalline sugar is then sprinkled onto the wet centres. This solidifies in the cracks and keeps them rigid during the further processing. As with gumming it is desirable to let the product dry in shallow layers overnight.
   - **(b)** A low-viscosity, high-fat chocolate is used to wet the raisins. This is then dried with powdered sugar before the fat sets. The sugar can be coloured with cocoa powder to avoid the formation of a contrasting white layer between the raisin and the chocolate.
2. *Sugar crust coatings on liquid centres* (e.g. liqueurs) will break very easily in a coating pan, releasing the liquid, which in turn causes significant damage to the product bed. In this case a small and slow-turning pan (10 rpm) should be used. Be careful not to break these centres as they are loaded into the pan, and commence wetting the product with a gelatine based masse before starting the pan. Rotation is then started and the wetting completed. As soon as the centres are wet, powdered sugar is added. The pan is stopped immediately after the powder is distributed over the surfaces. The key to success is not to rotate the pan excessively, thereby avoiding cracks in the shells. The treated centres are carefully removed and dried overnight in shallow layers. This process may have to be repeated again the following day.

3 *Flaky centres* (layered, honeycombed etc.) disintegrate as soon they come in contact with a sticky or heavy masse. The product can be sprayed with melted flavoured fat, which impregnates the surface. Once the centre is cooled the fat layers set, strengthening the pieces. This product must then be isolated before applying the chocolate coating.

These examples illustrate ways in which several challenging problems can be solved.

16.3.3 Selection of chocolate and compound coatings

Panning is often called an art, and in reality panning operators do have to be very flexible and adjust the process according to variations in the ingredients and in the environment. Very often insufficient attention is paid to the selection of the chocolate or coatings used in panning.

First, if the product is to be sold with the word chocolate on its packaging, then it is necessary to make sure that the recipe being used conforms to local standards (see Chapter 28). The colour and flavour must also take into account the centre being used. In general, stronger and darker coatings are selected for sweet and strongly flavoured centres, whereas milkier chocolates are required with milder centres so that both flavours can be distinguished.

The coating particle size is based on the end use of the product or the composition of its centre. If it is anticipated that the product will be savoured and slowly melted in the mouth, a coating with a small particle size has to be selected. On the other hand, if the piece is being chewed or the centre has a coarse texture, it is possible to select a grittier coating, which may be cheaper to produce (Chapters 9 and 20).

The plastic viscosity (Chapter 11) of the coating is generally not critical. The real issue is the yield value (value of stress used to sheer coating, tensile strength). Terms like heavy coating (high viscosity, high sheer) and light coating are frequently used. Manufacturers of spray systems (used to spray chocolate onto the tumbling centres in the pan) usually recommend a viscosity range which is best for their equipment. Low yield values are recommended for light and low-density centres, to prevent clumping of the product. Higher yield values may be used if the centres are sufficiently heavy and fast moving to break away from each other. Very liquid coatings have no adhesive properties and tend to "slip" on the product, resulting in bare patches, whilst very high yield value coatings tend to build up unevenly on the centres and also form deposits on the pan walls.

The setting properties of the coating greatly influence the final throughput of the product and this means that there are big differences between panning with chocolates and with compound coatings. Chocolate will be considered first of all. Experts continually argue as to whether chocolate is best used in a tempered or untempered state. There are however reasons why each might in fact be preferred. Untempered chocolate will process somewhat slower, but is easier to handle. Because of the shearing that is exerted on the chocolate during tumbling and the cooling of the centres by the air system, a self-tempering takes place in the pan. Low-fat and soft cocoa butter (e.g. Brazilian) will set somewhat more slowly and will appear gummier in character at the beginning of the process. Harder and higher fat chocolate will set more quickly and harder, which may increase the throughput but make it more difficult to produce a very smooth surface. However, there are no real negatives with either type of chocolate. Butter oil (milk fat) can have a greater impact on the setting of the chocolate than the selection of the type of cocoa butter.

Untempered chocolate has one characteristic which makes it easier to pan than any of the compound coatings: the initial setting temperature of cocoa butter is lower [approx. 25 °C (77 °F)] than the temperature at which it will melt [approx. 30 °C (86 °F)]. This temperature difference will give the operator a wide temperature range to work in, for smoothing and engrossing purposes.

Compound coatings are made with either fractionated or hydrogenated fats. Fractionated fats set very quickly, which results in a fast throughput rate. Hydrogenated fats have a wider range of fractions with different setting temperatures and may include some which are still liquid at room temperatures. Setting times therefore can be long, which may make the coating stay soft for a very long time and also make it difficult to coat the centre evenly. Products made with a soft coating shell should be stored for overnight before polishing is performed. Water-based polishing agents can easily interfere with the soft or oily fraction of hydrogenated fats, forming an emulsion, which prevents the surface from getting hard (a requirement for a good and highly glossy polish). With the correct information it is possible to produce a coating that is tailored to the centre and process. This makes the production procedure much more robust and is a step towards the removal of art in panning.

16.3.4 Chocolate and compound engrossing

This section explains the actual chocolate coating step. If all the preparation and the issues previously discussed have been carried out correctly, the actual chocolate engrossing will be relatively easy.

Since there are three major panning systems (manual pans, belt coaters and jumbo pans) in use within the confectionery industry, the engrossing process will be described in general terms for all systems and the differences indicated where appropriate. No matter how automated the systems have become over the years, the principles of chocolate panning have remained the same.

The engrossing process with chocolate can be broken down into three segments for smooth-surface products and two segments for pearled-surface ones.

1 *Smooth Surface*
   (a) Base coating (establish the foundation);
   (b) Rapid engrossing (weight gain);
   (c) Smoothing.

2 *Pearled Surface*
  (a) Base coating (establish the foundation);
  (b) Pearling (weight gain).

16.3.4.1 Base coating

The base coating is usually the most important part of the engrossing process. The aim of this part of the process is to build a solid layer of coating and cover natural ridges, for example the edges and tips of almonds. Chocolate temperature for the engrossing process should be 31–35 °C (88–95 °F) for manual pans and 35–40 °C (95–104 °F) for automated pans with spray systems. Compound coatings should be kept 3–6 °C (5–10 °F) higher than for chocolate.

To start the process, a predetermined quantity of the previously pre-treated centres is loaded into the pan. The centres should be free from dust and other debris. Should a variable speed drive be available, the pan should be adjusted to a lower speed setting to minimise flaking of the precoating from the centres. Immediately after starting the pan, the application of chocolate can begin. Cooling of the coating should start immediately the centres have a nice even covering layer. The centres are still relatively cold at this time, so the chocolate will set very quickly. Once the first coating layer has set, this procedure is repeated three to five times. In small manual pans it can be helpful to support the product bed with your hand in the direction of rotation, in order to assist the mixing and tumbling action. Large pans have built in baffles for this purpose. Care should be taken to properly cool and set the product, but not to harden the fresh shell layer in a way such as to make it brittle and thereby cause deshelling.

16.3.4.2 Rapid engrossing

Rapid engrossing is the step in the process where most of the coating weight is applied. The pan can be speeded up to get a faster product flow. A 1.07 m (42 in) pan can be run at approximately 22–25 rpm. The product crest will reach half way up the pan wall (Note: a wet bed will be higher than a dry one). The two-thirds by two-thirds rule should be used to determine the best place for the introduction of chocolate into a manual pan, using a drip feed or spray system. This means the position where the product speed is at its greatest is a point with an elevation two-thirds up the bed and two-thirds into the pan from the front (see Figure 16.2). Other pan systems containing multiple nozzles are aimed two-thirds up on the bed and are equally spaced across the length of the pan.

As already mentioned, the speed of application can now be increased. Chocolate can be applied rapidly with cool air blowing at the same time. The bed temperature will increase quickly due to the added warm masse, the latent heat created by the crystallisation of the fat in the coating and the friction existing in the wet bed. This will be a balancing act; if the air is too cold, very rough and bumpy surfaces will develop, which will slow down the process, and additional

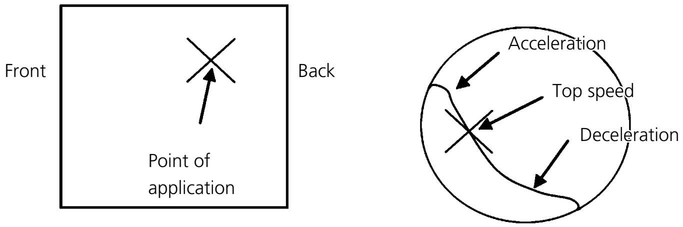

Figure 16.2 Point of addition of chocolate into a manual pan.

time will be required for smoothing. However, if the temperature in the product bed goes up too far for too long, then the outcome will be twofold, depending on the type of coating being used. A low-fat, high-viscosity chocolate coating will become too soft and will start to deform. Deformation is recognised by the coating being pinched and squeezed towards the narrow end of the centrepieces and, even worse, the layers may peel off. With a high-fat coating, the opposite happens: thin layers of coating will start to melt off the tips and start to adhere on the flat side of the centres (where there is less friction and pressure), causing the centre to be exposed at the tips. With drip feeding or ladle application, an additional defect can happen. Chocolate which is too warm and applied in a thick stream will melt the nearby coating layers where they are in contact with the fresh chocolate and bare spots will develop. This can be avoided by letting the product bed cool and solidify from time to time. Intermittent cooling is well worth carrying out as a better product and shorter engrossing times can be obtained, provided that not too much heat has to be removed through a thick layer of chocolate. The smoothing process can begin when about 80% of the total chocolate has been applied to the centre. Weight gain can easily be determined by weighing 10 or 20 average sized sweets throughout the process. Large panning systems often have the advantage of load-cells fitted under the drum or under the chocolate feed tanks. Load-cells under the drum are not recommended, due to the difficulty of reading an unstable signal caused by the rotating drum and shifting of the product.

16.3.4.3 Smoothing process

The smoothing process is critical in order to obtain a good polished product. The product should be checked for appearance shortly before the final layers of the coating are applied to the centres. The product should be cooled in order to avoid overheating of the inner layers once the smoothing process begins. The air is then turned off and the product is allowed to continue to tumble for a while. Manual pans with lids should be covered to expedite the warming process. The ridges, if any, developed during the rapid engrossing will start to warm up and the coating will begin to move into any cracks. The remainder of the chocolate should then be added to prevent the natural ridges on the centres becoming exposed (e.g. the tips of almonds). Care must be taken at all times not to overheat the product bed.

The sweets will now develop an unruffled and even surface. As soon the product appears smooth, cool the bed one last time. The product can then be carefully removed from the pan and stored overnight. The chocolate will then have time to crystallise properly before the polishing begins. In large operations, overnight storage is often omitted for scheduling reasons and the polishing step then has to begin immediately after the product has cooled and properly set.

16.3.4.4 Pearling

Pearling is a type of product appearance now not often seen but is none the less very attractive in assortments. The pearled sweet is covered with ridges and cracks. The polishing process will then only highlight the crests, giving the chocolate piece a very contrasting surface, even more so in the case of dark coatings. The pearling begins immediately after the formation of the base coat. Coating is continuously sprayed or dribbled onto the product bed. At the same time, cold air, possibly at a relative high pressure, is blown onto the product. This will not allow the coating to spread but will start to build ridges and bumps. It is important to have coating continuously entering the pan so that the crests do not smooth out, but not at such a rate that the product bed starts to warm up. The chocolate viscosity can control the fineness and distribution of the ridges. A thin low-yield value coating will give a small grained appearance, whereas high-viscosity coatings produce relative large ridges. Once the product has reached its final weight, the polishing process can begin.

16.3.5 Polishing and sealing

Polishing and sealing makes a product look attractive. There is nothing more appealing to the customer than a highly polished, glossy chocolate sweet. Like all the previous panning stages, polishing is a two-step process. In theory, one or two coatings of shellac (shellac is the refined resinous secretions of the lac insect) would be sufficient to produce a good shine. However shellac, diluted in alcohol, will interact with the chocolate or the compound coating, so the final surface is poor. To avoid this interaction, a sub-coat is applied as a barrier. The polishing masse consists of colloids (gum arabic, dextrin, starches etc.) in sugar syrup, with glucose added as an adhesive and to prevent crystallisation. To reduce the possibility of the product bed sticking together, it is advisable to add 3–5% of cocoa butter or hard fat as a separating agent. The polishing masse should then have a total solids content of 55–65%. Polishing solutions, which are available commercially, are in general a lot easier to use than home-made ones. This sub-coat has a high polish of its own. Unfortunately, it is a water-based coating which loses its brilliance very quickly in a humid environment and so requires a sealant and/or packing in a suitable moisture-resistant pack.

It is useful to understand what causes a high gloss. With the elimination of cracks, scratches, impurities and so on, a narrow spectrum of light is reflected from the surface instead of being absorbed, thus giving the glossy appearance.

A good gum solution, or shellac, both acts as a filler and forms a continuous film over the surface, thereby providing all the requirements for a high gloss.

Polishing is usually carried out in pans dedicated to this task. The environment should be dust-free, cool and dry. The pans are equipped with ribs or baffles to prevent the product bed from slipping, once the product has been polished. Where no ribbed pans are available, a smooth pan can be modified by coating the inside with a thin layer of dark chocolate. Before the chocolate hardens, scratch it in the direction of the pan axes. This will then create enough resistance to roll the product bed. The ideal drying air temperature is 13 °C (55 °F) with a relative humidity (RH) below 55%. A RH of less than 45% can cause the formation of a skin, trapping moisture and leading to subsequent flaking off of the polishing material.

The chocolate coated sweets, free of dust and debris, which have been set overnight at room temperature or well cooled (for large-scale operations), are loaded in the polishing pan. The product can then be tumbled for a short period to further improve the surface (care must be taken not to heat up the product). Once the product has reached the desired smoothness, cold air is turned on to start hardening the surface, usually producing a product bed temperature of 15–17 °C (59–63 °F). The air is then switched off and sufficient polishing masse is applied with a ladle or spray to coat evenly all the sweets. Once the chocolate pieces have a wet appearance, the air is applied again and the product bed is dried. The drying time for the first coat takes around 5 min and should not be shortened, otherwise the polishing layer will surface dry and flake off. Once the sweets are no longer clammy to the touch, the step can be repeated. The second layer will normally give best results when the drying takes about 8–10 min. If the product still has only a very poor gloss, a third or even fourth layer may be required. The product is subsequently further dried and tumbled until a high gloss is achieved. When completely dry, the product is ready for the sealant. (Dust from flaking polishing materials can damage the surface if tumbling continues when the product is too dry.)

Sealing of the panned and polished product can now begin. Shellac, also known as confectionery glaze, is very commonly used for this process. In the United States three to four pound cut shellac [pound cut is a ratio term equalling three or four pounds of shellac to one gallon of alcohol (approximately I kg in 2 l)] with some added wax is readily available from suppliers. When using a spray system, the sealing masse is usually thinned down even further with alcohol (or other solvent) to counteract evaporation of the solvent in air before it reaches the product.

The centre must be thoroughly dried before sealing, as any moisture still present will form a grey haze under the shellac.

As soon as the product is evenly covered with sealing solution, cold dry air is turned on to evaporate the solvent. Care should be taken that the correct amount of shellac is being applied. Insufficient sealant will give a blotchy surface, whilst excessive amounts of shellac will result in stretch marks. Often operators keep the pan stationary as the solvent evaporates, with only the occasional turn. Preferably, however, newer commercial sealants can be used, which contain waxes that enable the pans to run continuously. Once the solvent has evaporated, the pan can be rotated slowly for 5–10 min to produce a high gloss.

The processing is now finished but, in order to obtain the best results, the product should be stored overnight, as it takes shellac almost 24 h to cure and become moisture-resistant. Placing the cool product in relative humidities above 50% will however cause it to become sticky. This is reversible and will go away with time or as soon as the product warms up. Should sticking occur, the tray containing the product should be shaken with one blow. Trying to separate the product by hand will permanently mark the surfaces.

The solvents used for the sealants have to be handled correctly because, if they are not, there is a danger of explosion in the storage facilities. Air pollution from volatile organic compounds (VOCs) is another major concern. For these reasons the polishing area should be well ventilated. Some countries also restrict the use of VOCs and it is therefore necessary to ensure that the process is being carried out within the local legislation. Systems are available to contain and destroy the VOCs, for example wet scrubbing, condensation, biofiltration, thermal oxidation and so on. High capital cost installations tend to have smaller operating costs and vice versa. The cheapest system with the highest operating cost would be a direct flame afterburner. This can be made more environmentally friendly by re-using the resulting heat.

Alternative sealing masses and techniques are being developed, but do not yet give a high gloss. Suppliers of polishing solutions should be contacted to obtain up to date information regarding alternatives and current legislation. In temperate climates shellac may indeed not be required at all, if the product is sold in high-quality packaging.

16.4 Packaging and storage

The type of packaging is frequently determined by the sales and marketing departments. It is however important to realise, however, that the packaging should not only be attractive at point of sale but should also protect panned products. Problems such as moisture transfer, scratching, splitting and light-induced rancidity must be prevented in order to preserve texture, flavour and appearance. Packaging material suppliers can be of great assistance in this respect. A highly glossy surface is one of the biggest attributes of most panned confections. Once hazing, bloom and scratches have started to form on panned chocolate, the customer will think that the product is old and stale, no matter how fresh it might be. In all cases, a storage test should be carried out to determine the right packaging material.

For the customer to receive the best possible product, care must be taken during its packaging. It is very easy to damage the chocolate coat, and the risk should be minimized by keeping handling and transfer-points to a minimum. Long drops and large storage containers of unpackaged product should be avoided. Damaged and broken sweets as well as loose parts from the shells will detract from the appearance of the product. Relative humidity in the packaging department should ideally be 60%, if the product has been previously stored in these conditions and has reached equilibrium. If, however, this is not possible, the room air has to be treated in such a way that the humidity at the chocolate surface temperature is lower than 60%, in order to avoid a tacky slow-flowing product.

16.5 The panning department

16.5.1 Room conditions

The temperature and humidity are critical to good panning and the room therefore should have some form of control. Shielding the room from the influence of the elements can be a great cost saver and will maintain good conditions throughout the year. The preferred temperature is no more than 15–18 °C (60–65 °F) at a relative humidity of less than or equal to 60%. Chocolate is set by cooling, not evaporation; but moisture can greatly influenced its setting properties, especially if spray systems are in use. The exception to these requirements is large volume panning equipment, which is self-contained and has internal temperature and humidity control.

Polishing and sealing should be carried out in a dust-free environment. If possible, the polishing pans should be separated from the engrossing pans by a wall, or at least some distance should be kept between the pans doing these two processes. The temperature and humidity should be similar to that in the engrossing area. In most cases, alcohol is used as a solvent for the shellac application and this requires additional ventilation. Manufacturers of some large panning equipment claim that it is possible to polish and engross in the same pan. This is only possible if the panning equipment is free from dust accumulations and additional polishing agents are used to repolish the pan walls.

Because of the relatively cool room environment, all the coating supply pipes must be water-heated and/or well insulated to prevent freeze-ups, which could cause long stoppages in production.

A good process air supply is required to obtain high-quality products, but this is often undersized. A 1.05 m (42 in) pan requires approximate 8.5 m^3/min (300 ft^3/min) of treated air at a maximum of 10 °C (50 °F) and it is best if the air can be cooled to remove moisture and then reheated. Once again, when obtaining large volume panning equipment, the manufacturer should be consulted as to the type of fan that is needed for the intended product. In all cases, a low-pressure high-volume system is the most satisfactorily, the one exception being for pearled products, where a high-pressure high-volume system is needed to deliver intensely cold air to the product.

16.5.2 Quality and troubleshooting

There is some inevitable variation in ingredients and conditions. Care is needed at each step of the process to produce good quality product consistently. Table 16.1 lists some of the common faults and possible ways to correct them.

16.5.3 Panning equipment

Considerable development of new panning equipment has taken place over the last 30 years. From the original round pans mounted on a tilted shaft, ever-larger pans have been built, often mounted horizontally. This type of equipment is normally called a drum rather than a pan. In addition, belt coaters (described below) are available for the medium-sized production plant.

Great progress has been made in the area of control systems, turning panning from an art into a science. An endless discussion can be held on the relative merits of different types of panning machinery but there is a useful review in Boutin (2012).

Traditional pans are still the most common equipment in use. They are relatively cheap but require a skilled operator. This type of pan was originally made of copper, but they are now made from stainless steel. Copper was easy to fabricate

Table 16.1 Troubleshooting guide to chocolate panning (adapted from Fame, 2010).

Fault	Possible causes	Possible corrections
Bumpy/rough surface	Coating too thick, air too cold	Soften (smooth) the final layer, increase pan speed, remove air, add reduced viscosity chocolate
Poor coverage	Uneven centres, low coating/centre ratio, pan speed too fast, low air velocity/temperature	Pre-coating, use additional coating, reduce pan speed, increase air flow and/or temperature, or reduce chocolate flow
Fat bloom	Incompatible fats or high temperature	Change to compatible coating, pre-coating centres or lower coating temperature
Crushed centres	Overloading pan with centres, rib design in pan	Reduce pan load or start pan before loading
Peeling	Excessive cooling, pan loads too high, speed too high, centres too soft	Reduce load on pan
Chocolate not sticking to centre	Centres too warm, oil on centres, thin coating, coating temperature too high, air temperature too high	Reduce temperatures, pre-coating centres
Doubles	Coating added too fast, coating too thick, pan speed too slow, centres sliding in pan rather than tumbling	Reduce coating addition, change to spray system, increase pan speed, coat side of pan with chocolate before engrossing

into the bowls and has a high thermal conductivity, giving excellent heat transfer. On the other hand, it can act as a catalyst in promoting fat oxidation and will react with some of the more acidic coatings. Shapes range from almost disk-like, with large diameter to depth ratio, which is ideal for sugar coating with its deep bed, to elongated tulip-shaped pans, which are preferred for chocolate coating applications. Tulip pans, as they are called, have a relatively larger load capacity, in spite of having little mechanical friction against the back wall and a relative shallow bed depth. Engrossing pans should be smooth on the inside to avoid pockets where product can easily stick and build up. If the product is expected to slide, as it should towards the end of the polishing cycle, then a ribbed pan must be used to assist the product to roll. The angle of the shaft is normally between 18° and 22° to the horizontal, depending upon the relative amounts of mixing action and friction that are required. Pan turning speed is normally in the range 20–28 rpm. The actual speed is dictated by the pan size and the desired peripheral speed. As a guideline, the product should be about three-quarters of the way up on the pan wall. Foot-operated start and stop switches are very beneficial, because they give the operator easy manipulation of the product during start-up and unloading.

Belt coaters are based on an endless slate or wire belt. The pocket for the product is created with the help of two large disks on both sides (Figure 16.3). This type of coater is very easy to use and can be equipped with computer controls. Their open design makes them very easy to load and unload. Unloading is performed by simply reversing the belt and the product is discharged into any means of transportation available. Large dropping doors isolate the process from the room environment. The product pieces tumble well, although there is very little lateral mixing. These systems are relatively inexpensive, have a short process time and are ideal for the medium-sized production plant. Several pan manufacturers have recently also marketed belt coaters.

Automatic panning systems have been built for large capacity production facilities (see Adele, 2005). These machines can contain up to 3 t (6600 lb) per charge and several configurations are available (see Figure 16.4). The

Figure 16.3 Schematic diagram of Belt coater.

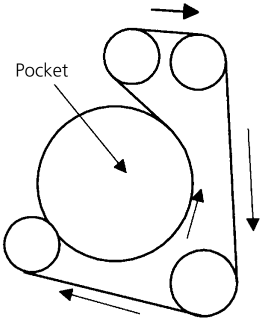

Figure 16.4 Drum coating machine for chocolate coating, polishing and varnishing. Reproduced by permission of Dumoulin.

manufacturer should be fully informed about the intended product to be produced on the machines, in order to obtain a well tailored piece of equipment.

The drum diameter can range from 1.5 to 2.0 m (5.0–6.5 ft), with the load capacity being controlled by changing the drum depth. (Wider diameters relatively reduce the product's exposure to spray and to the air.) Baffles are used to move the product backwards and forwards to get an even mix and counteract the regional variances resulting from localised spray systems, powder applicators and air supplies. As the drums grow in length, however, it becomes an engineering challenge to build manifolds supplying >40 spray nozzles and to ensure that each supplies the same amount of fluid.

Two drum types are available: solid drums with all the auxiliaries entering from the back (opposite end from the operator) and perforated drums (side vented), where the air enters from the drum sides and is pushed through the product bed. Perforated drums work well with a process where evaporation takes place, for example sugar coating. Loading, unloading and the coating process can be controlled by a programmable logic controller, and minimal supervision is required. All pan manufacturers offer automated cleaning systems (clean in place). Being self-contained, automatic panning systems are virtually independent of the panning room's atmospheric conditions. Such fully automated systems remain, however, very expensive.

The names and addresses of some of the manufacturers who are able to supply panning equipment and advice on its operation are given in the Appendix at the end of this chapter.

Conclusions and future developments

Chocolate panning produces some very attractive, nibbling sized items of confectionery which are well appreciated by the consumer.

Even today, many people still regard chocolate panning as an art and there is still a role for the skilled confectioner in smaller, more traditional operations. Great care is required during the processing and, if all steps are followed carefully, high-quality products are produced. Short cuts seldom work and attempts at cost savings often create large quantities of waste. As our fundamental understanding of the processes improves, batch sizes and automation are increasing. However, we are still some way off a continuous process for chocolate panning, although continuous processes for the base coating and polishing steps exist.

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Appendix: Manufacturers of panning equipment

There are many manufacturers of pans, belt and drum coaters and inclusion/exclusion on this list does not imply any recommendation or otherwise.

- Bosch Packaging www.boschpackaging.com (belt coating and polishing machines).
- DRIAM Anlagenbau GmbH, Aspenweg 19–21, D-88097 Eriskirch, Germany (e.g. Driamat, Driacoater – large-scale drum coaters).
- DT&G Limited, Park Works, Old Bidstone Road, Birkenhead CH41 8BP, UK (Finn belt coaters).
- Ets Dumoulin et Cie, 5 Rue Auguste Perdonnet, ZI Le Closeau, 77220 Tournan En Brie, France (automatic high-capacity panning systems).
- Freund-Vector Corp., 675 44th Street, Marion, IA 52302, USA (laboratory to production coaters).
- MacIntyre Chocolate Systems/LADCO, Sir William Smith Road, Kirkton Industrial Estate, Arbroath, DD11 3RD, UK (chocolate coating pans).
- Nicomac srl, Via Curiel 12, I-20060 Liscate, Italy (laboratory to production drum coaters).
- Thomas Engineering Inc., 575 W. Central Road, Hoffman Estates, IL 60195, USA (bench- to production-scale Accela cota drum systems).
- The Schebler Company, 5665 Fenno Road, PO Box 1008, Bettendorf, IA 52722, USA (Revolv belt and drum coaters).

CHAPTER 17

Chocolate rework

Edward Minson and Randall Hofberger

17.1 Introduction

Rework is a fact of life for manufacturers of all food products and this includes those handling chocolate and confectionery (compound) coatings.

Almost equally universal is the policy that “we should create no rework”. This lofty goal is admirable but certainly not practical in everyday operations. Indeed, the very nature of chocolate processing and handling inevitably results in the generation of rework. As machinery making fat-based coatings should definitely not be cleaned out with water-containing solutions (see Chapter 25), product changeovers and “cleaning” are often accompanied by the generation of significant quantities of rework.

17.2 Rework

Rework can be minimised by techniques including:
- Proper order of processing;
- Appropriate equipment layout and installation;
- Evaluation of and training in proper processing procedures;
- Selection of suitable quality raw ingredients;
- Proper front end design of the product. Consider developing it with expected amount of rework incorporated into the finished product. Make a confection that is robust in formula and processing so that little rework is ever generated.

Rework generation can often be minimised by processing products in the right order. It is relatively easy to go from a white coating base to a darker chocolate, but difficult to go in the other direction without the generation of significant rework quantities in the cleaning stage.

Proper equipment layout can often assist in minimising rework when multiple products are being processed. The investment in extra piping or efficient pigging systems (see Chapter 12), for example, can help maintain the separation of different coatings and fats. If possible, all pipelines should be slightly sloped to

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assist in the removal of the coatings or fats. This means that less clean-out material may be produced minimising this additional source of rework. In addition, finished products contain less cross contamination and are therefore of a higher quality.

A thorough determination of proper process procedures, followed by the training of employees to ensure their implementation, is vital in assuring that finished products are up to standard and not destined for the rework bins. The consistent use of suitable raw materials, with predetermined quality levels, is also an important factor here.

Once rework is generated, however, it is very necessary to understand where the rework can be best utilised. Well thought out procedures (on how to reclaim and use the rework) should be determined for all sectors of the production facility. However, adequate pre-planning may not be possible. Rework is not always predictable and one cannot invariably make good advance decisions on its possible use.

There is one thing that it is essential for all manufacturers to take into account, that is the maximum permitted usage levels of rework *must* be carefully determined. These maximum levels must then be monitored and strictly enforced.

17.3 Constraints

Many constraints limit the possible utilisation of rework. These include:

- Legal;
- Functional;
- Flavour;
- Hygiene;
- Quality control (including lot tracking);
- Allergens.

Legal and regulatory issues largely involve the labelling of the finished product into which the rework is incorporated. First, one must be sure the rework ingredients can be legally used according to the laws of the country where the final product (now containing the rework) is sold (see Chapter 28).

A major issue is assuring that the final product's ingredient statement or declaration includes all the constituents of the rework. This is vital, as greater emphasis is now being placed on full label disclosure of all ingredients, including those used at trace levels. Nowhere is the issue more acute as with allergenic constituents. Many individuals are sensitive to a wide variety of proteins. Their responses to extremely low levels of these proteins can be life threatening. Their only defence is one of avoidance. It is therefore vital that all rework ingredients appear on the final finished product label declaration, for example this product may contain nuts.

Legislation has been enacted in many countries requiring special identification of allergens. If any allergens can be carried in with rework, it is mandatory that the allergen be highlighted in accordance with the specific national regulation. However, while a manufacturer needs to label if there is any possibility of introducing an allergen via rework, they must also be careful not to label if the allergen will not be present. Otherwise, there will be little available for the person with allergies to eat. Manufacturers should consider moving their allergen containing products (and rework) to separate, specialised facilities, ensuring their other products are not exposed to allergen.

Mandatory nutrition labelling has also become the norm in many countries. Although some deviation from stated values is permitted, to allow for differences in analytical methods as well as raw material variations, improper usage of rework could result in values which breach the regulatory standard.

Many companies have a "like into like" procedure for rework. Although this will help control the inadvertent introduction of improper ingredients, it is by no means enough to entirely avoid the addition of undeclared components. A thorough review of each lot of rework must be undertaken to ensure the ingredient label of the finished product is not compromised. For product consistency every effort should be made to use a consistent percentage of rework into the product. For example do not use 25% rework in one batch and 0% in the next.

Additionally, many countries have standards of identity for finished goods. These rules commonly dictate mandatory ingredient levels, as well as prohibiting the presence of certain components. Decision on the use of rework batches must take into account any compositional requirements for the finished product.

The maintenance of functionality in the finished product is of utmost importance and it is vital that any rework ingredients do not interfere with its processing or textural characteristics. Perhaps the biggest number of problems arises when rework alters the functional properties of the fat base. Incompatible fats in rework could render a chocolate or coating susceptible to poor texture, fat bloom and inconsistent processing temperatures (see Chapter 7).

Flavour is always critical for the manufacturer of any food item. Variability in flavour often occurs due to the natural deviations within the basic raw materials. The use of rework can exacerbate the already complicated job of maintaining a consistent flavour profile. The ability of the general public to detect changes to a product's flavour should never be underestimated.

Hygiene is also a very important issue (see Chapter 25), and the use of rework can greatly increase the risk from microbiological and other contamination. First of all, rework is subjected to extra handling, which in itself increases the opportunity for contamination. Rework can often be left in storage for extended periods of time (while it awaits the right "home" or until enough has been produced to be worth reprocessing); the longer the period the bigger the risk of infestation from insects.

The age of the chocolate rework needs to be carefully monitored. A general rule is not to hold rework longer than 25% of the shelf life of the existing finished product. This will vary because of the product composition and storage temperature; generally the colder the storage temperature the longer the shelf life. Another general rule is that for every 10 °C (18 °F) reduction in storage temperature will result in double the shelf life. If the material is held too long and deterioration has occurred, this will have a negative impact on the flavour and shelf life of the recipient product. This is especially true when the rework's fat has degraded (a problem particularly with many compound coatings which may go soapy/rancid).

As chocolate products are very sensitive to microbiological contamination (De Luka, 1996), extra care is vital. In addition, during storage, rework (as with any ingredient) can be subjected to insect and rodent infestation. It must therefore be stored in proper sealed containers. Rework must be treated with the extra care afforded an ingredient and not like a scrap/waste material.

17.4 Economics

Chocolate and related ingredients are often among the most expensive of the ingredients in a confectionery or bakery item. Accordingly, rework containing chocolate must be used wisely. Economically, the best solution is one where chocolate or coating rework goes back into itself.

Whenever possible, it is desirable to separate the chocolate components from any other ingredients that have already been combined with them. This may be as simple as remelting the product and physically sieving out the other components, for example nuts. Caution needs to be exercised, when using chocolate rework, that any fat-containing inclusions have not already released excess quantities of the "foreign" fat into the chocolate. The consequence could be bloom, tempering problems, poor mould release and fat bloom (Rittenberg, 1996).

In addition, the effective separation of chocolate from other components is often difficult. For these processes to be economically viable, a large pool of rework is necessary (Beckett, 1990). This author described several machines which could be useful in recovering chocolate from finished confections and baked goods. Many food manufactures have invented their own devices to carry out this separation into one of the three channels illustrated in Figure 17.1.

For a hard centred good (such as a cookie or cracker), it is important to first eliminate any loose debris. This is followed by a mild heating process and then a blower to force the now liquefied coating from the surface of the reworked product. Temperatures must be moderated to inhibit heat damage to the coating (recommended temperatures are under 50 °C (122 °F).

Beckett (1990) further noted a process for recovery of chocolate from soft centred confections. This involves dissolving of the centre with water, followed by drying of the chocolate. In this process, cool temperatures are maintained to

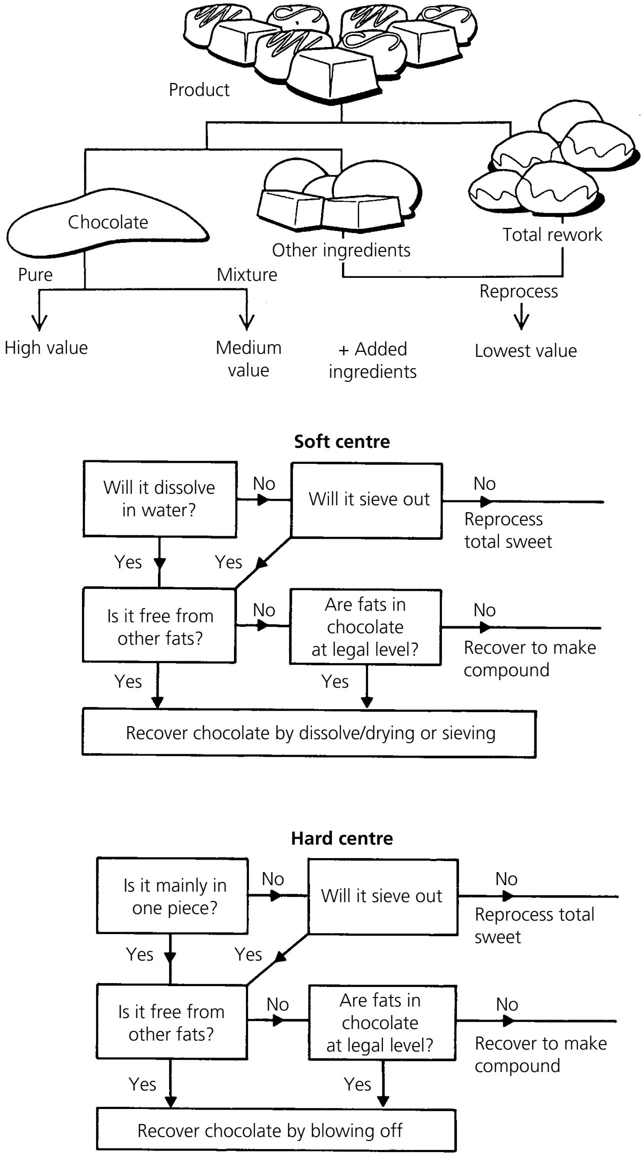

Figure 17.1 Schematic diagram showing the different approaches to processing rework (Beckett, 1990).

keep the fat of the chocolate in a solid form. Water is then used to dissolve any non-coating constituents. It should be noted that the process of moisture elimination from chocolate can be quite difficult.

Alternatively, the chocolate and other ingredient combinations may be reworked together into an appropriate portion of the processed product. Careful selection of the best use for this type of rework requires extensive knowledge of the finished goods' processes and where the rework can be used most advantageously (with the maximum economic value as well as the least change in product quality). An example is to take chocolate coated caramels/toffees and melt them. You will further dilute them with water to the original moisture of the premix. Sugars/corn syrup solids should be rebalanced and then this mixture can be added to the premix and recooked into caramel/toffee.

Another alternative is to use the rework do develop a new product. As in the example above, the chocolate coated caramel/toffee can be remelted and have additional ingredients added to make them into cream centres or fudges. Chocolate coated crispy centre pieces that have become rework (such as from a cookie, cracker or pretzel) can be chopped and have additional coating added to them. They can then be reformed into a variation of the original confection. Another example of product transformation is to make them into a chocolate sauce or syrup. Finally, one of the most successful outlets for rework is to convert it into ice cream inclusions (provided that it meets the right criteria). Some have become so successful that demand exceeded rework and resulted in "good" product being chopped into inclusions.

We should also examine why the product has become rework. If the enrobed product is underweight it is possible to re-enrobe the confection and increase its weight. In like manner when product has become bloomed or excessively scuffed – it can be re-enrobed with a low viscosity coating to give an acceptable appearance.

An outlet of last resort for difficult to rework confections is for sale as animal feed or fat reclamation. While it will provide little or no income, it may prevent paying a disposal fee.

Conclusions

A final word of warning is appropriate. When in doubt, stop! If you have not already considered all the pitfalls associated with the use of rework and planned around them, stop! Nothing can be worse than ruining a good batch of product due to the injudicious addition of rework. Do not let a little rework leave you with a lot of rework.

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CHAPTER 18

Artisan chocolate making

Sophie Jewett

18.1 Introduction

The global chocolate industry has experienced increased demand for chocolate products while on-going environmental pressures put increasing strain on the supply chain. Cocoa prices are widely anticipated to increase. With a growing global middle class, opportunities for growth still exist for hand-made artisan chocolates. This chapter examines some of the factors to consider when planning to make chocolates on a hand-made scale.

18.2 Chocolate trends in mature markets

Although chocolate consumption in mature markets such as Europe, United States and Australia has seen a slowing down in growth of per capita consumption, there has also been a shift in chocolate purchasing behaviour (see also Chapter 27). Consumer trends have had an ongoing impact on the types of products being produced, with key opportunities for hand-made, artisan products emerging.

18.2.1 Value-seeking consumers

Chocolate consumption in mature markets has seen limited growth together with a shift towards consumers seeking greater value for their purchasing. In the United Kingdom (UK) retail sector there has been an increase in “two for one” offers, small convenience bars and packets. Although customers are not consuming more chocolate, they are seeking better value from their purchases, with a role for more luxury, premium and indulgent treats on an occasional basis.

18.2.2 Premium quality chocolate consumption

An increase in consumers with disposable income has seen an increase in demand for “moments of happiness” products. Consumers are choosing to spend more on occasional chocolate purchases of premium products, and to want to

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savour moments of happiness to accompany their value seeking chocolate purchases. Small scale, artisan production methods are ideally placed to serve and to benefit from the growing consumer demand for premium chocolate products.

18.2.3 Sustainability

The chocolate industry has seen growing pressure to ensure that crops, sourcing and methodology are more sustainable (see also Chapter 2). Consumer demands have identified growing opportunities in mature markets for brands and products that identify and feature sustainable sourcing techniques. Products that identify origin of beans (Figure 18.1), certification of sustainable practices, provenance of ingredients and traceability are increasingly important.

18.2.4 Nostalgia and tradition

Quality is increasingly becoming a feature with consumers selecting quality of product over quantity. There has also been a growth in demand for products that use perceived higher quality and traditional ingredients. Small businesses and artisan craftsman are ideally suited to revisit traditional confectionery and chocolate making techniques as consumers increase demand for nostalgic products that remind them of their childhood with simpler ingredients and manufacturing processes.

18.2.5 Health and wellbeing

An increase in consumer concern with health and wellbeing has seen high growth in sales of dark chocolate, and products with higher content of cocoa solids have the highest growth (see also Chapter 22). The general perception

Figure 18.1 Product declaring origin of ingredients as well as species of cocoa beans. Reproduced with permission of Duffy Sheardown, Red Star Chocolates.

that dark chocolate is better for you together with an increased awareness of the flavour profiles and health benefits of certain components of dark chocolate has seen a shift away from milk chocolate consumption towards dark chocolate; in the UK this currently represents 24% of chocolate consumption. This is an area that generally focuses on the higher quality, premium market where growth in demand has given greater profitability.

18.3 Selecting the right product lines to make

Starting out selling chocolates may seem an exciting, yet overwhelming prospect with endless choices. There are increasing opportunities for artisan producers creating hand-made chocolates that respond to changes in consumer behaviour, to growing demand for sustainable chocolate with high quality ingredients and for a premium indulgent treat.

Chocolate can be an attractive and versatile ingredient to work with and to create a whole range of products. The following list of suggestions is not intended to be exhaustive for all possible product lines or suitable markets, but is confined to the traditional remit of a chocolatier rather than that of a confectioner or patissierre making fresh baked products with chocolate.

18.3.1 Filled chocolates

Filled chocolates are ideally sold boxed in the gift market and represent 22% of UK chocolate consumption. Chocolates can be moulded using high quality moulds, filled with an array of fillings, alternatively cut or cast and set centres can be hand-dipped in chocolate. Filled chocolates can include:

- *Ganache*
  - Ganache is a mixture of chocolate and cream or butter. Additional flavours can be easily incorporated into ganache based chocolates by combining with or substituting the liquid cream for other liquid flavours. Ganache can be piped into moulded chocolate shells, can be piped and hand-shaped, or can be set firm and cut into segments before being hand-dipped in chocolate. The shelf life of ganache filled chocolates can vary depending upon how the chocolates are sealed. Quality products with no air bubbles will last longest, but their shelf life is still shorter than the distribution chains of big confectionery companies. Additional preservatives can be added to ganache based chocolates using inverted sugars such as liquid glucose to maintain texture and reduce the water activity (see Chapter 4).
- *Pralines*
  - Praline is the Belgian word for filled chocolates, traditionally the name refers to nuts that are preserved by caramelising them in sugar. The preserved nuts are ground and blended into a smooth paste that can then be added to chocolate. As the nuts naturally contain oils they can be combined with chocolate to create a smooth consistency that can set firm but not brittle (see Chapter 7).

  Pralines are able to maintain their quality and flavour over a considerable length of time.

- *Fondant creams*
  - Crystallised sugar fondant can be combined with flavoured oils, fruit purees and jams to create fresh flavours with a long shelf life. Traditional fondants are made by boiling sugar, water and liquid glucose to 120 °C and then cooling it down on a marble slab or metal tray, crystallising and creaming the setting sugar in the process. Fondants can be left to set by hand-piping into corn starch moulding cavities; they are then left to form a hard crystallised shell, enabling the centre to be hand-dipped in chocolate. Alternatively flavoured fondant creams can be piped into moulded chocolate shells for a glossy finish.
- *Caramels*
  - Caramelised, liquid sugar can be used with a range of complementary flavours. Caramel has a high sugar content and therefore can maintain quality and shelf life for a longer period of time than conventional ganache and praline filled chocolates.
- *Chocolate liqueurs*
  - Alcohol flavoured sugar syrups can be the ultimate decadent chocolate, but do not forget that alcohol can evaporate!

18.3.2 Hand-dipped or enrobed chocolate confectionery

Hand-dipping at the point of sale is an excellent way of attracting customers. In addition a hand-decorated, hand-dipped chocolate (Figure 18.2) looks distinctively different from a mass produced one and can demand a premium price.

Confectionery is a sugar based delicacy, that was historically used to make medicines taste more palatable and also to work with like porcelain to form decorations for the dining tables of eighteenth century Europe. Confectionery centres that are hand-dipped often have a crystallised centre that sets harder than the softer ganache filled chocolates. The higher sugar content in these confections tends to lead to a lower available water content, therefore enabling the confections to have a longer shelf life. The high sugar content nature of these products means that they usually reach a high temperature in the making process and are then left to crystallise and cool. These products must therefore be set into shape or cast into a large container to set before forming into shape. The traditional processes and nature of ingredients of confectionery items make them a popular product for artisan confectioners to create and add value to. These items can be made on a sizeable scale, with a long shelf life without compromising quality. An increase in the retail price of these products can be obtained by hand-dipping in chocolate so that nostalgia and traditional methodology adds to their perceived value.

Niche product lines of single confectionery items in a range of flavours and finishes can create an outstanding addition to existing sweet shops and cafes. By

Figure 18.2 A selection of hand-made chocolates using a range of techniques including filled, moulded chocolates, clusters and hand-dipped centres. Reproduced with permission of The Chocolate Tree.

specialising in a single product type, equipment costs, processes and consistency can be achieved whilst still giving the consumer a wide choice.

- *Marshmallow*
    - Traditionally made with whipped egg white, gelatine and boiled sugar, variety can be created using fruit purees, essential oils, colours and flavourings. For commercial purposes recipes with unpasteurised egg white should be avoided. Alternatively dried egg white can be used or a fondant crème-based recipe that incorporates gelatine.
- *Fudge*
    - Traditional recipes involve boiling milk, butter and sugar together to achieve an 85% sugar concentration in the mixture before cooling and leaving to set and form into pieces. Flavours can be added to the process for variety, whilst multiple flavoured batches can be used to create different combinations.
- *Toffee*
    - Can be prepared to a variety of consistencies based on the types of ingredients used and the temperature to which the sugar is boiled. Toffee is often mixed with butter and nuts to create variety. The caramelised sugar can be formed into a hard, brittle structure when boiled to high temperatures or kept soft, chewy and sticky when boiled to lower temperatures or with added ingredients.
- *Nougat*
    - Made using honey, nuts, whipped egg white and sugar, nougat can often create a complementary texture and often a cheaper filling to chocolates. Similar in ingredients to marshmallow but more like toffee-making in the process. A range of finishes, consistencies and ingredients can be utilised to develop a variety of products.

Possible Issues:

Care should be taken to ensure that confectionery items have fully crystallised in pieces, before hand-coating in chocolate. Unstable centres can give seepage when covered in chocolate which contracts during the setting process.

Centres with a high fat content such as toffee or fudge can be susceptible to fat migration. This will appear as a white bloom on the surface of the chocolate due to incompatibility between the fats in the centres and those in the coating (see Chapter 7). Whilst not unsafe to consume, it can be unsightly and devalue the product. Actions can be taken to minimise fat bloom in these products, such as using a fat-based barrier prior to enrobing in chocolate, as well as taking care to ensure the products are stored at a constant temperature.

18.3.3 Moulded chocolate forms

Chocolate can be moulded and formed into a variety of different shapes, designs and decorations. Working with chocolate moulds can be a simple way of creating a professional looking finished product that can be fitting for key chocolate buying seasons and festivities such as Easter eggs, chocolate hearts for Valentine's day and chocolate snowmen and figurines for Christmas. Simple chocolate shapes such as lollipops and novelties can be an effective way of creating something with a low price. Moulded novelty items like chocolate shoes (Figure 18.3) can offer new retail opportunities by placing along side of complementary products, that is in fashion outlets.

Good quality chocolate moulds can be expensive and take up considerable storage space. Consideration should be given to the amount of product that can be expected to sell. It may be more cost effective to start with a good number of a single shape of mould, whose product can then be adapted by decoration and finishing techniques to give variety.

Figure 18.3 Chocolate shoes. Reproduced with permission of Azra's Chocolates.

18.3.4 Chocolate bars or fragments

Chocolate bars are a simple and consistent product line that can be adapted for a variety of tastes, flavours and markets with a moderate to long shelf life. Chocolate bars provide an effective and efficient range of products that can be created easily with limited space and equipment requirements and are ideal for a chocolate or sweet shop owner to incorporate their own product ranges to complement a wider selection for consumers. As an alternative to standard chocolate moulded bars any of the following processes can be adopted to producing fragments of chocolate that can be retailed in moulded form or by the bag or by weight.

- *Inclusions*
  - Adding ingredients such as dried fruit, nuts and sweets into the chocolate prior to moulding. For long shelf life products it is essential that inclusions used are dried and do not contain high moisture levels. Chocolate should be used in small batches to ensure temperature constancy once it has been tempered. The addition of inclusions will often cool it down.
- *Decorated or studded bars*
  - Similar ingredients to inclusions can be used to decorate chocolate bars once they have been made (Figure 18.4). As before care should be taken to ensure the ingredients used are dried and does not incorporate moisture into the chocolate product. These products can be worked with on a larger scale than products with inclusions as the ingredients are added once the bars have been made, enabling greater efficiencies to be generated.
- *Flavoured*
  - Flavourings such as essential oils, powdered fruits, spices or herbs can be used on their own or together to create unique, signature flavour combinations for products. Essential oils and flavourings must be compatible with oils, rather than water based, to ensure they can mix with the chocolate

Figure 18.4 Hand-made chocolate bar using a single mould shape with a range of additions to create interest. Reproduced with permission of The Chocolate Café.

without spoiling. Freeze dried fruit can be ground into powder and can be an effective addition to chocolate to complement flavours and textures of other ingredients.

- *Single origin*
    - There is an increasing public awareness in the comparison between the enjoyment of chocolate tasting and that of wine. Single origin chocolate products provide a range for chocolate connoisseurs to discover flavours, origins and processing effects. Single origin products have increased in popularity with chocolate consumers over the last five years as they became increasingly aware of the range of possible flavours.

18.3.5 Bean to bar chocolate products

Chocolate consumption in both the United States and Europe has been going through a change in perception and processes with a growing number of chocolate shops, bakeries and chocolatiers making their own chocolate from single origin cocoa beans or cocoa mass. Equipment and small quantities of beans are now available to enable the creation of 2–60 kg of chocolate per week on a small scale with modest space requirements. Indeed a small conche can be operated within a shop to attract customers. Once the chocolate is made it can be handled normally and used to create chocolate products to be consumed both on the premises and for retail use. Creating signature chocolate blends can give a greater value to product ranges both in consumer perception and quality output, but there are a number of warnings that should be heeded.

Sourcing beans – cocoa beans in their raw state can come in a variety of sizes (Figure 18.5), conditions and with added contaminants from their origin locations that can cause micro-biological concerns in food production environments. Clear process management and hazard control procedures should be implemented to ensure any risks of contamination are minimised.

Sourcing equipment – Traditional chocolate making methodologies can be employed to the stages of chocolate making from roasting the beans, crushing, winnowing, grinding to the final conching stages. Equipment can be expensive to invest in, whilst some stages can be undertaken with basic processes – such as using domestic ovens for the roasting phase, consideration should be given to the required level of productivity in the longer term, ensuring equipment with the necessary capacity is identified.

Complexities in processing – Bean to bar chocolate products revisit a traditional, artisan methodology for chocolate making, however this is very different to the complex processes that consumers are used to in mature chocolate markets. Grinding in particular plays an important role in providing a good flavour and texture. It is critical to ensure that any purchased equipment can produce a smooth chocolate. Attempts at revisiting traditional chocolate making methodologies should celebrate the origin of ingredients and the artisan nature of the product as a strength over comparisons to large production-scaled confectionery. Origin of beans, quality of bean variety and added ingredients such as cocoa

Figure 18.5 Inspection of dried cocoa beans by hand. Care must be taken to ensure separation of processes and to minimise risk of contamination of the finished product. Reproduced with permission of The Chocolate Tree.

butter, sugar, milk powder and vanilla as well as conching time all add value to and differentiate the final product.

Artisan chocolate making from raw materials is anticipated to play an increasingly important role in mature chocolate markets where growth opportunities are anticipated at the connoisseur end of the market as consumers move towards products and brands with greater transparency and evidence of sustainability. Equipment, ingredients and access to knowledge is likely to become increasingly accessible for small-scale chocolate production to play a role in adding value to existing chocolate and confectionery-based businesses.

18.4 Critical considerations

Creating a successful artisan chocolate-based business is not down to any single factor. It is necessary to understand and consider a number of impacting factors that play a role in the decision-making process. The following points need appropriate consideration as they limit or provide guidance to the sort of products created.

18.4.1 Ingredients

The quality of the final product will be dependent upon the quality of the ingredients used. Ingredients for commercial products must come with the relevant ingredients and allergen declaration and from credible and traceable sources to ensure the integrity of the end product. When selecting the appropriate chocolate to work with, consideration should be given to the desired quality of the end result. The freshness and make up of ingredients will have a direct impact on the shelf life and the durability of flavour and quality. For example the use of fresh fruit flavours can create an outstanding product that is best consumed fresh, whilst the ingredients can be preserved to achieve a safe longer life, the quality of the flavour in a longer shelf life product may be compromised. Choice of flavours and quality of ingredients will depend upon the desired shelf life, price point and perceptions of quality, which must be effectively communicated through the sales environment, packaging presentation and shop staff prior to the chocolate being consumed.

18.4.2 Equipment

Equipment for manufacturing can be costly and requires space and storage room. A machine that can be used to temper chocolate in batches of 3–15 kg can be useful for any chocolatier needing to save time and aid an effective production process, but this does not remove the need to fully understand how to successfully crystallise chocolate. Unless additional machinery is purchased, hand-tempering techniques are still necessary to enable working with different chocolate types. The following is intended to be a helpful list of equipment for anyone starting out initially in working with chocolate:

- Marble chopping board;
- Plastic mixing bowls;
- Flat scrapers;
- Plastic spatula;
- Dipping forks;
- Angled pallet knife;
- Chocolate thermometer;
- Heat gun or small hair-dryer;
- Variety of chocolate moulds for pralines, bars and novelty shapes.

18.4.3 Working environment

The working environment plays an important role in being able to successfully work with chocolate. Any professional environment should be free from temperature fluctuations and should ideally be around 20 °C and free from excessive humidity. Kitchen environments that have a large amount of heat sources such as boilers, ovens and fryers may not be suitable for attempting to work with chocolate.

18.4.4 Shelf life

Hand-made chocolates can last from a few days kept refrigerated in the case of fresh cream-based ganache recipes to up to 18 months for solid or hollow moulded chocolate products with no added ingredients (see also Chapter 23). Typically the longer the shelf life requirement for filled chocolates the more sugar, fat and flavourings are required to extend quality as well as shelf life. Decisions around the appropriate shelf life will impact upon the types of products that can be made. Products in a small café with limited space may benefit from quality ingredients made with small product runs with a short shelf life that can be consumed quickly. Products that are for wholesale distribution are likely to require a longer shelf life and have a lower profit margin. It is also important to be able to make these consistently on a large scale. Business plans must involve scale of production and product shelf life and should also include likely volume of sales and turnover.

18.4.5 Storage

Chocolate should be kept at a constant temperature between 12 and 20 °C and not in the fridge. Chocolate is sensitive to humidity, condensation, odour, air, light as well as being fragile. Care should be taken to ensure that ingredients and finished product are safely protected with the appropriate packaging to ensure product quality.

18.4.6 Packaging

Packaging plays an important role in the presentation, preservation and perception of products (see also Chapter 26). It is important to select appropriate packaging that fulfils the needs of these wider influences. Customers eat with their eyes before they enjoy a product, it is important to consider how the chocolate will look on the shelf or be protected prior to consumption. It must at least protect it from chemical, physical or biological contamination until it is consumed. The quality of packaging can play an important role in positioning the product in the market, and chocolates at a high price with unique ingredients should have packaging that is reflective of that value. Packaging solutions that come in direct contact with food products must be of food grade quality. It is not necessary as an initial entry to the market to consider that packaging solutions must deliver full labelling requirements, as this can be fulfilled through signage, inserts, labels or attached tags where appropriate. Consideration should also be given to the durability requirements of packaging, especially when planning online ordering and product transport.

18.4.7 Labelling

Regulations and requirements for the labelling of food and chocolate products are subject to localised legislation. Information about products for sale should be clearly labelled or be available to inform customers of the content of their purchase. Should there be an issue with a product it is good practice to be able to trace the time, staff, location, ingredients and any other essential variables involved in the creation of that product. A product identification code should relate back to production records maintained by the producer. At present there is no requirement regarding the specific origin of ingredients, however it is anticipated that this may come in an effort to establish full traceability and transparency in the chocolate industry. Basic information required should include:

- Product name;
- Product description;
- Ingredients list;
- Quantity of cocoa solids contained in the chocolate product (usually expressed as a percentage);
- Allergens contained;
- Weight;
- Best before date;
- Product identification code;
- Storage instructions;
- Preparation instructions (where necessary).

Producers should be aware of the specific requirements for labelling in the country they are selling in. This is especially relevant to export sales or internet sales with potential customers abroad.

18.4.8 Costings and pricing

Costing of chocolate products for retail sales is usually based upon the five cost considerations in the equation:

- One-fifth = Cost of ingredients and packaging;
- One-fifth = Cost of staff;
- One-fifth = Contribution to cost of overheads;
- One-fifth = Contribution to cost of sales and marketing;
- One-fifth = Profit.

The cost of the final product to the consumer will often include sales taxes for large retailers, whilst some chocolate products can be exempt from such taxes. Wholesale prices are often in the region of 60% of the recommended retail price to allow for the retailers' mark-up to be incorporated, because they have further expenses to take the product to market, including: costs of staff, overheads, sales and marketing the product.

When setting prices it is advisable to benchmark against prices for comparable products in the market to ensure favourable and appropriate comparisons can be made, with prices being adjusted accordingly.

18.4.9 Skills

Working with chocolate is a skill that professional chocolatiers master over many years of training. As a minimum, an aspiring chocolatier should be able to confidently temper chocolate using a number of methods before investing in machinery to undertake the task. A confident ability to work with moulds and to hand-dip chocolates are essential basic skills that are perfected through practice. A number of short courses exist with chocolatiers and professional catering schools. Individuals wishing to start their own business or introduce chocolate product lines should attend short courses as well as practice hand-making skills and if possible find work experience or placements with a chocolate professional. Chocolate can be an expensive ingredient to practice with, so it may be better when perfecting tempering skills to use ingredients that can be re-used.

18.4.10 Health and safety

As with all food production requirements, care should be taken to ensure the processes undertaken conforms to nationally legislated standards (see also Chapter 25). Application of the internationally recognised Hazard analysis critical control points (HACCP) methodology is an essential starting point, as other internationally recognised standards have a basis in this methodology. The seven stages identified in HACCP should be undertaken for each product being made and are as follows:

1 – *Conduct a hazard analysis.*

Identify physical, chemical or biological contaminants in the process of making your product that may cause the product to be unsafe for human consumption and the steps that can be taken to prevent them.

For example in fresh cream ganache made with fresh fruit there could be a risk of leaves, pips, pesticide residue, insects.

2 – *Identify critical control points.*

Identify points in the process when risks of hazards can be prevented, eliminated or reduced.

For example ensure the fruit is sourced from a reputable supplier, is inspected visually, cleaned prior to use, and taken to a temperature where any bacteria present will be reduced to a safe level.

3 – *Establish critical limits for each critical control point.*

Identify maximum and minimum values that a physical, chemical or biological hazard must be controlled at that critical point to prevent, eliminate or reduce risks to an acceptable level.

For example fresh fruit is heated to a temperature of at least 75 °C to kill most harmful bacteria that may be present.

4 – *Establish critical control point monitoring requirements.*

Create systems to effectively monitor the safety of procedures.

For example a visual check may be sufficient to clearly observe that the fruit is reaching a boiling temperature, with occasional temperature measurements to verify.

5 – *Establish corrective actions.*

What actions will be undertaken if there is a deviation from the established critical limits?

For example if there is a risk of bacteria being present, actions might be taken to reduce the shelf life of the product and ensure it is consumed within a shorter than usual period; alternatively it may be identified that the batch should be withdrawn from sale.

6 – *Establish procedures for ensuring the HACCP system is working as intended.*
Identify ways that the procedures that are being followed are validated as being suitable.

For example product samples could be kept and tested intermittently to ensure that they are fit for consumption within the parameters of the operation. This might be conducted visually by the business; alternatively services of external laboratories can be employed to test for water activity, bacteria levels as well as monitoring the DNA profiles of ingredients.

7 – *Establish record keeping procedures.*
Businesses should create a written HACCP plan, make an analysis of hazards and maintain records and documents to effectively monitor, verify and validate the daily business procedures and handling of process deviations.

For example identify how chocolates is made and create a HACCP plan for each product. Keep records when products are being made that can verify that the appropriate processes are followed, measured and that corrective action is taken when necessary.

18.5 Taking products to market

Successful artisan chocolate making is as much about the presentation, price, type of product, the people that are selling it, where it is sold, how it is promoted and how easy it is to purchase as it is about quality. Outstanding chocolate skills can be of minimal value if products are not positioned and sold appropriately to the market. Consideration should be given to identify where artisan products are to be positioned, along with where they are being sold.

18.5.1 Market stalls and food festivals

Market stalls and participation in food festivals are an ideal opportunity to test out new products as well as starting to understand the interests, tastes and demographics of your customers. Consider a small range of products and types with a mixture of items with different shelf lives and package sizes. Samples are an essential way of building a perception of quality and customer loyalty.

- *Product* – Traditional, niche recipes. Well presented personal indulgences and gifts. Bars and filled assortments. Seasonal figurines and moulded chocolates are ideal lines at seasonal fairs, especially around Christmas and Easter. Avoid product lines with too short a shelf life or over extending the range of products that can be produced with quality. Avoid delicate items that require additional care for transportation.
- *Price* – Avoid high-end luxury lines that are expensive and require greater “moments of happiness” to sell effectively. Prices at specialist markets where “artisan” is celebrated can be set at a higher than usual price point.
- *Process* – Engage with customers, offer free samples of products.
- *Place* – Local food markets, food fairs and specialist shows.

- *Promotion* – Ensure products are clearly labelled, staff should be able to explain about the quality of the product and promote how it is made.
- *Physical appearance* – Dress the stall smartly, cleanly and attractively to the desired audience.
- People – Staff should be keen to listen to comments and feedback, these are ideal opportunities for artisan producers to engage with customers, test new recipes and respond to customer comments.

18.5.2 On-line retail sales

Consider products that are easy to dispatch and travel without spoilage or damage. Products will need to be consistently available, so start with a small number of product lines with a moderate shelf life that you can make at a reasonable and profitable scale and keep in stock.

- *Product* – Unusual chocolate bar flavours, interesting individual filled chocolates that can be boxed for the gift market. Avoid fragile items or a large range of products with a short shelf life that may require a short product run to fulfil orders.
- *Price* – Remember when setting prices that products will be instantly comparable to other discount brands on-line.
- *Process* – Ensure the ordering process is clear and easy to follow and that products are dispatched promptly. Website content must be sufficiently accurate and up to date with stock numbers.
- *Place* – Additional investment may be necessary to ensure your website and products stand out where customers are unable to easily sample them.
- *Promotion* – Invest time in building a web audience and bringing your website into contact with potential and regular customers using social media and customer engagement activities.
- *Physical appearance* – Build credibility in the products and the processes by telling stories about ingredients, inspiration behind the recipes and clear and detailed product information to re-create the personal shopping experience.
- *People* – Respond promptly to customer’s questions.

18.5.3 Private orders and commissions

These are ideal opportunities for large batch runs of individual items or for more intricate, high-quality items, particularly good opportunity for a highly skilled chocolatier to be able to command a higher price for a quality item or gift. Agreed order and consumption dates allow for short shelf life, high-quality items.

- *Product* – Personalised chocolate bars and gift boxed chocolates, bespoke chocolate displays and artwork, wedding and party favours or gifts. Offer a small but varied range of product lines, large orders can be profitable but this can be reduced if large quantities of equipment are required to fulfil a special order.
- *Price* – A highly skilled chocolatier is able to command a higher price for a quality item or gift.
- *Process* – Customers are engaging with the expertise and personal touch for higher priced, bespoke items. Ensure full requirements are understood and the ordering process is simple and contains all order details.

- *Place* – Use website on-line presence to profile experience and catalogue examples of work undertaken.
- *Promotion* – Customers often value skill and quality and their word of mouth recommendation together with high class visual examples are essential ways of selling products and gaining reputation.
- *Physical appearance* – Ensure all pictures, equipment, packaging and finished products reflect the position in the market the customer is paying for.
- *People* – The skill level of the artisan and the personal touch of the producer is essential where personalisation is being sold. Customer confidence in the artisan to deliver is essential.

18.5.4 Wholesale distribution

For the small-scale manufacturer this is an ideal opportunity to market niche, high-quality product lines. It is important to take into account profitable product run levels, minimum order sizes, shelf life requirements, the client's product knowledge and any compulsory labelling legislation for third party sales. Design product lines in conjunction with your customers to ensure costly expenditure on packaging and product design is fit for purpose.

- *Product* – Chocolate bars, traditional niche products like fudge or toffee that can be made on a moderate large scale with a good shelf life while retaining quality. Caramels, fondant and praline filled chocolates for gift market in attractive packaging. Seasonal figure and moulded product lines.
- *Price* – The retailer will need to make their own mark-up and often need to incorporate additional sales tax, so products must be priced accordingly. Trade customers may expect to pay following delivery, which will have an impact on cash flow, especially for large orders. Special care should be paid to ensure order and stock rotation procedures can be effectively managed.
- *Procedures* – Establish ordering procedures, minimum orders, delivery dates and payment terms, as well as ensuring prompt and pro-active responses to questions and issues.
- *Place* – Target retailers that fit with the desired price point and market position. Control of display and location of product is unlikely, but should be considered.
- *Promotion* – Samples, point of sale graphics, effective labelling as well as brand reputation and recognition are all essential to generate product sales.
- *Physical appearance* – Attractive packaging and displays are important to ensure that products stand out on the shelves.
- *People* – Good product knowledge of well informed staff is essential in selling hand-made products via other retailers.

18.5.5 Chocolate concessions

Chocolate concessions (franchising) in shopping centres, department stores, stations and other locations can be an ideal way to develop a brand presence and position and involves working with complementary brands in areas of guaranteed footfall. Brands can be established with a strong visual and product identity with a shared liability for overheads in some instances. A concessionary approach is ideal for rapid expansion of chocolate products that can be made on a large scale with a long shelf life. Consideration should be given to making products on site where possible, incorporating a theatrical, entertainment/educational dimension to the product story. Chocolate products that can have simple product extensions in a range of flavours can be an inexpensive way of creating choice while utilising equipment effectively.

- *Product* – Fudge, toffee, fondant creams, chocolate bars. A consistent, limited range of product lines with multiple flavours and price points will offer variety of choice with a greater profit retention while establishing a brand reputation.
- *Price* – Moderate prices with quantity sales will differentiate the products in competitive environments.
- *Process* – Watching the making process will generate interest, and loyalty. It will add value and encourage customers to buy once they have tried a sample.
- *Place* – Concessionary opportunities in shopping centres, department stores and train stations can offer guaranteed footfall but can often have overheads linked to performance. A well-branded stand or outlet can benefit from footfall of the surrounding outlets and is ideal for a newly created brand to get established.
- *Promotion* – Offer samples, utilise the footfall to generate theatrical and engaging experiences such as demonstrations, tastings and sampling events to establish reputation, loyalty and quality of the product.
- *People* – Personable sales by friendly staff willing to engage, entertain and educate the customer is essential.

18.5.6 Chocolate making for sweet shops and cafés

Sweet shop and café owners can increase profit margin as well as control and protect market position, reputation and differentiate their location by developing their own product lines. Ideal for traditional niche confectionery lines, diversifying into different flavour combinations for variety, consider space, skill, storage and display solutions.

- *Product* – Fudge, toffee, fondant creams and own-line bean to bar chocolate product lines with signature blends. A consistent, limited range enables greater profit retention, and will generate a greater reputation and profitability – do one thing exceptionally well! Too many lines can dilute effectiveness, consumers may be adventurous, but they will expect consistency.
- *Price* – Higher prices can be achieved with unique signature products through clear demonstration of artisan production processes and personal product knowledge.
- *Process* – Hand-made product sales can add value. Direct sales can help with market testing and product and skill development while generating loyalty.
- *Place* – Own made products are an ideal compliment at cafes and retailers where customers already buy chocolate and confectionery.
- *Promotion* – Creating a reputation for quality, niche products can add significant value to the experiences of existing customers.
- *People* – Personable sales by friendly staff and engagement with the artisan chocolatier can help command a higher price point due to added perceived value.

18.6 Selecting the right chocolate

Selecting the right chocolate means choosing the correct flavour, smoothness, rate of melt and viscosity. The right choice will depend upon other components of the final product as well as the method of manufacture.

18.6.1 Flavour, smoothness and speed of melt

This requires the skills of the chocolatier. Peppermint, or a similar strong flavour, will mask the taste of most chocolates, so a strong flavour dark chocolate is needed. It might indeed only be partly conched. A high-quality praline, on the other hand, needs a less intense chocolate flavoured coating, perhaps somewhat milky, to compliment it. Pralines are also often finely ground and melt easily in the mouth. These properties must be reflected in the chocolate being used, as any grittiness or waxy melt in it will lower product quality.

18.6.2 Viscosity

A product being made on an enrober needs chocolate with different flow properties to one being used for hand-dipping/decorating, which is different again from one needed for moulding (see also Chapter 11). An incorrect viscosity will lead to poor quality and even mis-shapes.

18.6.3 In-house manufactured or purchased chocolate

Chocolate can be purchased with a very wide range of flavours, fineness and flow properties, but in-house manufacture can give increased consumer interest and perceived value. It is also possible to develop a house signature flavour.

Chocolate manufacturing machinery is however very expensive and the artisan producer tends to be limited to the choice between small scale (about 10–100 kg per week) or using some partly processed ingredients. The former is very good for gaining consumer interest, but it is very difficult to make consistently a high-quality product.

Starting with cocoa beans is extremely expensive and great care is required to prevent microbiological contamination from the raw beans. Perhaps the easiest option is to use shelled, roasted and milled beans in the form of cocoa mass. Grinding and conching is then needed, although it is possible to buy pre-milled sugar and fine milk powder and just use a conche.

18.6.4 Legal and recipe requirements

The information given below is applicable to the "fine" chocolate industry, where it is generally accepted that products will meet the prescribed reserved description for chocolate products (see Chapter 28) *Note:* the legal term cocoa solids means cocoa mass (liquor), plus cocoa butter, plus any cocoa powder present.

Dark Chocolate – Contains not less than 35% total dry cocoa solids, including not less than 18% cocoa butter and not less than 14% of dry non-fat cocoa solids.
Typical ingredient list might look like:
Cocoa mass, sugar, cocoa butter, lecithin, natural vanilla flavouring

Milk Chocolate – Contains not less than 25% total dry cocoa solids, not less than 14% dry milk solids, not less than 2.5% dry non-fat cocoa solids, not less than 3.5% milk fat and not less than 25% total fat content (cocoa butter and milk fat)
Typical ingredient list might look like:
sugar, cocoa butter, whole milk powder, cocoa mass, soya lecithin, natural vanilla flavouring

White Chocolate – Contains not less than 20% cocoa butter and not less than 14% dry milk solids of which not less than 3.5% is milk fat.
Typical ingredients list might look like:
sugar, cocoa butter, whole milk powder, soya lecithin, natural vanilla flavouring

18.7 Hand-tempering techniques

A knowledge of the science behind chocolate tempering is essential to understanding and mastering the process (see also Chapters 7 and 13). All chocolate practitioners should ensure they understand the chocolate tempering process and be able to practice at least two tempering methods. Demonstrating hand-tempering in a shop, café or even on a website can develop customer interest. It also requires very little chocolate.

18.7.1 Why does chocolate need tempering?

Without tempering, the cocoa butter in the chocolate will set in the wrong crystalline form. This gives the chocolate a soft crumbly texture and a short shelf life as the surface turns white due to a phenomena called “bloom”.

Chocolate must be tempered to create a stable crystal structure. During this process heat is utilised to melt some of the cocoa butter and break down the crystal structure enough for the chocolate to be able to be pushed/scraped around. The crystals must not all be melted, however. When chocolate sets the cocoa butter solidifies and forms a solid crystal structure which is like a jigsaw puzzle that can go together in one of six different ways. Only one crystal form will give the desired effect, all other forms will give an appearance of chocolate “bloom”, developing a whiteness or streakiness across the surface of the chocolate dependent upon the conditions of the cocoa butter and the working environment.

To temper chocolate consistently the procedure should start by melting out any existing crystals. It is then cooled to create several different types of crystals in a chocolate that can be poured and worked. Next it is reheated by 2–3 °C in a manner that is gentle enough to ensure that some solid cocoa butter crystals

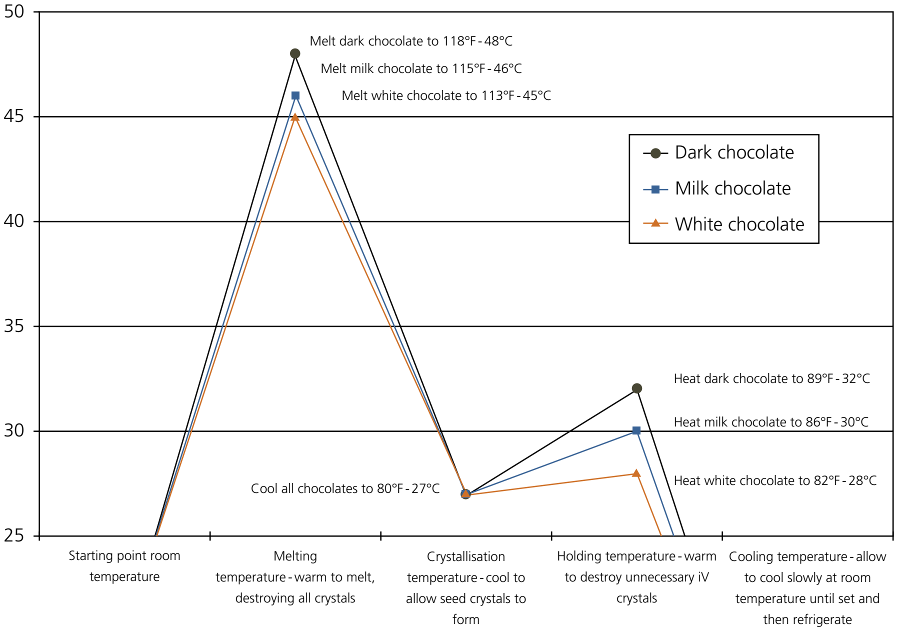

Figure 18.6 Tempering procedures.

remain. These are the stable type and act as a template when the chocolate is re-cooled to set it.

Figure 18.6 shows the procedure each type of chocolate must go through to get a good temper. The more non-cocoa fat containing ingredients that are added to the chocolate the harder it is for the cocoa butter to form a network of crystals to hold the solid particles together and the more cooling is required. Whilst each chocolate has a different temperature range, they all behave in a similar fashion.

18.7.2 Hand-tempering methods

Several methods can be used to successfully temper chocolate:

Slab tempering

Needed:

- A bowl of 500 g of melted chocolate;
- A chocolate thermometer;
- A marble slab;
- A scraper;
- A spoon.

Using this method is ideal for batches of chocolate of at least 500 g.

1 Melt the chocolate so that all the crystals are broken down, 47 °C (118 °F) for dark chocolate, 46 °C (115 °F) for milk chocolate and 45 °C (113 °F) for white chocolate. Chocolate can be melted in the microwave on a moderate heat or in a bowl over a saucepan of hot water (plastic bowls work most effectively). Use a chocolate thermometer to measure the temperature of the chocolate.

2 Pour two-thirds of the bowl of chocolate onto the marble slab, and use the scraper to cool the chocolate down on the marble slab, keep piling it together so that the heat is evenly distributed throughout the chocolate as it cools. The chocolate will become thicker, less glossy and more resistant. This stage cools the chocolate down so it reaches its setting temperature, mixing the chocolate stimulates the crystals to form evenly throughout the chocolate.

3 Scrape the chocolate off of the marble slab and place back into the bowl with the remaining, much warmer chocolate. Mix the chocolates together thoroughly, so that the cold chocolate contains the necessary formed crystals but is too cold to work with and the warm chocolate contains heat but lacks the correct crystal structure. By mixing the two together the properties of both are shared to produce a bowl of chocolate with the correct concentration of crystals but enough warmth to make it thin enough to work with.

Seed tempering

Needed:

- A bowl of 350 g of melted chocolate;
- A bowl of 150 g of finely cut, small chocolate pieces or shavings;
- A chocolate thermometer;
- A wooden spoon;

This method is ideal for larger batches where space is not available for the slab method of chocolate tempering.

1 As previously melt the chocolate so that all the crystals are melted, 47 °C (118 °F) for dark chocolate, 46 °C (115 °F) for milk chocolate and 45 °C (113 °F) for white chocolate. Use a chocolate thermometer to measure the temperature.

2 Slowly pour a spoonful of the finely cut chocolate pieces in, one at a time. The "seeds" should be thoroughly stirred into the warmer chocolate each time. The cold chocolate contains all the necessary crystals that have melted out of the warm chocolate. By adding them back into the liquid chocolate the whole bowl of chocolate is cooled down. This process needs to continue with spoon full of chocolate until the chocolate starts to thicken and gives a resistance while stirring, at this point the chocolate should be in the region of 26 °C (80 °F) in temperature. If the desired temperature is reached before all the chocolate has been added then do not add any more. Or if all chocolate is added and it is still too warm, more chocolate must be added to introduce sufficient of the right crystals.

3 The chocolate must be gently warmed again by a few degrees to ensure it can be worked most effectively. This can be done easily with a few moments over a pan of hot water or by using a heat gun or hair dryer to gently add enough heat to remove some but not all of the crystals.

The above methods are required if working with chocolate that has bloomed already. The crystal structure is completely removed and then brought back by cooling the chocolate on the marble slab or by adding well crystallised chocolate to seed the melted chocolate.

Pre-crystallisation

Needed:

- A plastic bowl with 500 g of chocolate pieces;
- A spoon;
- A heat gun or hair dryer;

This method is very simple and can be done with a very small amount of chocolate if necessary. The chocolate should not be bloomed and be already in the right crystalline state. This method effectively utilises well crystallised chocolate rather than removing all crystals by melting the chocolate first.

1. Set the heat gun or hair dryer on a gentle heat and warm the top layer of chocolate in the bowl. When the chocolate is melted on top, turn off the heat and stir the chocolate thoroughly. The chocolate on top has had the cocoa butter crystals broken down by heating to a high temperature, while the chocolate underneath is still at the cold, set temperature. This method systematically breaks down the crystals and then incorporates them back in using the cold chocolate underneath.
2. Once thoroughly stirred the heat and the crystals have been evenly distributed, the process should be repeated until there is a bowl of chocolate with just a few lumps remaining. Turn the heat off and gently press any remaining pieces of chocolate against the side of the bowl. The desired result is a bowl of smooth chocolate that is liquid enough to work with but that has some resistance when stirred with a spoon.

An alternative method to get the same effect utilises a microwave oven to give short, sharp bursts of about 30 s. The chocolate must be stirred thoroughly to move the heat around between each burst of heat. A bain-marie method with a saucepan of hot water with a bowl of chocolate on top can be used. Care should be taken to avoid introducing heat and steam to the working environment, and there is also a danger that the bowl will retain the heat.

18.7.3 Testing chocolate for temper

Prior to working with tempered chocolate it is always worth testing to ensure the right crystals have formed. There are a number of methods to check temper, measuring the temperature of the chocolate is just one of those. But it should be noted that just because the chocolate is at the right temperature it does not mean that the chocolate is tempered. There are special tempermeters (Chapter 24), but they are very expensive and the following simple tests usually provide adequate information.

- Chocolate has a temperature of 28 °C (84 °F) for white chocolate, 30–31 °C (86–88 °F) for milk chocolate and dark chocolate.
- The chocolate when drizzled from a spoon should leave a pattern of ribbons in the bowl which should smoothly disappear when vibrated.
- Take a knife and dip it into the chocolate, clean one side of the knife and leave it, chocolate side up, for approximately 5 min. If the right crystals are present, the chocolate should start to set around the edges where it goes slightly dull.

This should start to spread so that all the chocolate is set and dry to the touch within 5 min. If this process takes less than 5 min the chocolate is too cold and needs warming a little. If it takes much longer than 5 min there are not sufficient crystals present, and therefore additional crystals need adding to the chocolate.

When the chocolate is well tempered there should be no streaks on the chocolate when it has set and hardened. It is only when it has hardened that chocolate should be put in the fridge, usually for about 20 min. This will ensure that the chocolate has a long lasting snap and gloss.

Conclusions

Making chocolates by hand can be incredibly rewarding. Making a profit is however hard work when there are an increasing number of brands and cheaper chocolate products for consumers to choose from. The skills of the artisan should be valued and celebrated in the making and marketing process. Artisan chocolate makers should consider each of the factors identified to select the best product for the market and consider the implications on product specifications, resources required, available capacity and skills. The flexibility of the artisan to respond rapidly and creatively to customers' requests should be celebrated and used to ensure that products are priced appropriately.

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CHAPTER 19

Chocolate compounds and coatings

Stuart Dale

19.1 Introduction

Chocolate compounds and coatings are many and varied but share one thing in common: they do not meet the legal criteria to be classified as chocolate (see Chapter 28). This is usually because a fat other than cocoa butter has been used to produce the compound or coating, but it can be because insufficient cocoa solids are present or that other ingredients have been included that are not permitted in chocolate. In some markets, it can be purely because the legal maximum for the inclusion of vegetable fats other than cocoa butter has been exceeded. They are generally much more cost-effective to produce than chocolate and offer much greater flexibility in both texture and melting profile. They offer the manufacturer a simpler manufacturing process with less capital investment.

19.2 What are chocolate compounds and coatings?

Legal aspects aside, the general understanding of what constitutes a chocolate compound or coating is that a vegetable fat other than cocoa butter is used in the manufacture of the product. They can be divided into several categories depending on the type of cocoa butter alternative that is utilised. Apart from this major difference, the ingredients used to manufacture a chocolate compound are much the same as those used to manufacture chocolate. Cocoa solids are used in the manufacture of chocolate compounds and coatings being sourced from either cocoa mass or fat reduced cocoa powder, depending on the type of fat that is used. Milk solids are also used and can come from whole milk powder or skim milk powder but more cost-effectively from whey powder. Alternatively, soya milk can be used to make a diary milk-free product.The same emulsifiers commonly utilised in chocolate can be used in chocolate compounds and coatings: namely lecithin and polyglycerol polyricinoleate and have the same effect on the

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Mark S. Fowler and Gregory R. Ziegler.

viscosity parameters of a chocolate compound or coating as they would for a chocolate recipe. Chocolate compounds and coatings usually have their flavour enhanced by the use of artificial vanilla (vanillin) flavours in much the same way that chocolates often do. Market pressures to move away from artificial flavours can increase the cost of a chocolate compound or coating considerably if a decision is made to move to natural vanilla.

Several different types of vegetable fat can be used in place of cocoa butter to produce a chocolate compound or coating. First, a chocolate compound can be produced by the inclusion of cocoa butter equivalent (CBE) into the recipe at a level above 5% (in markets that allow a 5% addition of CBE) or as a 100% replacement of cocoa butter (sometimes termed a super compound). The CBE fat has the same physical and chemical properties as cocoa butter due to it having a very similar triglyceride composition to cocoa butter. The disadvantage of using CBE is that the chocolate compound still needs to be tempered; hence the manufacturer would have the same capital outlay as that for a chocolate product. CBE is compatible with cocoa mass so that chocolate compounds indistinguishable in taste from an equivalent chocolate recipe can be manufactured. That said, a CBE fat does deliver a much cleaner (odourless) flavour than even the best deodourised cocoa butter. A CBE fat is also white in colour as opposed to the yellow colouration of cocoa butter. Hence, if the desire is to manufacture a white “chocolate” product with the same melting profile as one using cocoa butter but with a cleaner colour and flavour, then CBE fat in place of cocoa butter is one option and is also more cost-effective than using cocoa butter. Some would argue there is no such thing as a white chocolate, as only cocoa butter and not cocoa mass is present in the formulation. The lack of yellowness in the product when using a CBE makes colouring of the compound coating much easier if desired.

It is more usual to find either a cocoa butter substitute (CBS) or a cocoa butter replacer (CBR) used in the manufacture of chocolate compounds. The properties of these fats are more extensively covered in Chapter 7. A CBS fat is referred to as a “lauric” fat due to their high content of lauric fatty acid. They are manufactured from either palm kernel oil or coconut oil that has been refined, fractionated and hydrogenated. CBS fats have a sharp melting point, giving similar texture properties to those of chocolate. They do not require tempering and crystallise rapidly. Due to the shape of the crystals formed, CBS fat is incompatible with cocoa butter and, if the two are mixed, there will be a softening or lowering of the melting point (eutectic effect). The inclusion of more than 5% cocoa butter in a compound chocolate manufactured using CBS will almost certainly result in bloom. Therefore CBS chocolate compounds must be manufactured using fat reduced cocoa powder (10–12% fat) and cannot benefit from the use of cocoa mass to deliver chocolate flavour. The degree of alkalisation used in the manufacture of the cocoa powder and the source of the cacao beans used will help improve the flavour achieved.

A CBR however is non-lauric, being manufactured from the partial hydrogenation of other vegetable fats such as palm olein, cottonseed or rapeseed amongst others. CBR fats contains palmitic, oleic and stearic acid in much the same way as cocoa butter. The triglyceride composition is however much more complex than that found in cocoa butter, the hydrogenation process leading to the formation of some *trans* geometric isomers that crystallise and pack differently to the *cis* geometric isomers found naturally in cocoa butter. The high level of *trans* fats and possible link to heart disease means that CBR fats are often no longer used by manufacturers. CBR fats do not exhibit polymorphism in the way that cocoa butter does so that they do not require tempering. Chocolate compounds manufactured from CBR fats are not entirely compatible with cocoa butter due to the differences in crystallisation and do cause eutectics, although not as pronounced as those from the mixing of CBS and cocoa butter. Chocolate compounds manufactured using CBR fat will tolerate sufficient cocoa butter (up to 25%; Talbot, 2003) to allow the cocoa content of the chocolate compound to come from cocoa mass rather than fat reduced cocoa powder. This allows for the flavour of the chocolate compound to be much closer to the flavour of chocolate, providing the subsequent processing, in particular conching, is of a similar standard (see Section 19.8 and Chapter 20).

19.2.1 Ice cream coatings

Finally, we have chocolate coatings that do not try to mimic the properties of chocolate. The most common usage of these is for the coating of ice cream. Due to the manufacture and storage of ice cream products occurring at temperatures between –18 and –30 °C, it is often desirable to use fats that are more suited to consumption at low temperatures and that can give the texture desired despite the extremes of temperature. When eating ice cream the temperature in the mouth is reduced due to the coldness of the ice cream. Therefore fats with low melting points between 25 and 30 °C are less likely to give a waxy sensation in the mouth than is the case when chocolate is used. Using chocolate on ice cream, often used in premium chocolate-coated ice cream products, more often than not results in a product that cracks and crumbles when bitten into. It is also necessary to use fat contents in the region of 50% to achieve the necessary viscosity parameters for the chocolate to solidify on contact with the ice cream coating and to give the correct thickness of chocolate on the product so that the chocolate to ice cream ratio is at its most desirable level. Such high usage of cocoa butter makes the use of chocolate on ice cream expensive. The use of vegetable fats other than cocoa butter gives much greater cost-effectiveness. The manufacturing process for chocolate-coated ice cream also makes tempering infeasible as the cooling of the product in freezer conditions does not promote the desirable crystal growth. Tempering is not necessary as the resulting storage temperatures do not allow the transitions in fat crystal structure to occur that would result in bloom forming on the product. Cooling is exceptionally rapid, hence fat incompatibility and eutectic concerns do not really play a part when the reality is that the chocolate or chocolate coating used transforms from liquid state to solid state in less than 10 s. This allows a much wider range of vegetable fats to be used in the manufacture of chocolate ice cream coatings.

Chocolate ice cream coatings can be as simple as a standard chocolate (with fat content in the region of 30%) that has its fat content raised to the 50% level with the addition of a vegetable oil. Most commonly used are coconut oil, palm kernel olein or palm olein but, if a softer texture is required, a fat with lower melting point such as rapeseed or cottonseed oil can be used. This can be purely for cost reasons without impacting greatly on the flavour of the chocolate or may be to improve the texture, creating a less brittle coating. More common is to replace the entire cocoa butter content with vegetable fat. This gives a much greater advantage in terms of material cost. Again, coconut oil palm kernel olein and palm olein are the most common fats utilised but other fats are also used. This is particularly the case if the texture needs to be softer or if a greater time is required between the dipping of the ice cream product into the chocolate and the time that the chocolate coating becomes solid, for example where inclusions such as biscuit pieces or cereal flakes are to be adhered to the coating. In these cases often the coating needs to remain semi-solid for up to 15 s to allow inclusions to adhere and therefore requires the use of lower melting point oil such as sunflower, rapeseed or cottonseed oil to be used in conjunction with coconut oil, palm kernel olein or palm olein. Using mixtures of vegetable oils to give a desired melting point is also used in chocolate sauces for use in pouring onto ice cream desserts. The intention being for the chocolate sauce to be liquid at ambient (20 °C) temperature but to solidify rapidly on contact with the ice cream dessert (–18 °C). The use of such vegetable oils gives great flexibility but ensures that the coatings do not meet the legal requirements to be considered chocolate.

19.3 Manufacture of compounds and coatings

The manufacture of chocolate compounds and coatings is similar to that of chocolate. First, there needs to be a mixing process to combine the raw materials together, then the particle size must be reduced to a size that is not coarse on the palate and, finally, the product needs to be conched or liquefied to make it suitable for intended purpose. When deciding what method of manufacture to use one should consider the type of chocolate compound to be manufactured, the intended usage of the chocolate compound, how large the production area available is and how much investment will be required.

A traditional chocolate manufacturing process can be used utilising a mixer, pre-refiner, refiner and conch, but this requires an expensive initial outlay of capital to purchase such equipment and a substantial available floor area to install such equipment. However, better quality chocolate compounds are achieved using this methodology, particularly when using cocoa mass as an ingredient. As with the manufacturing of chocolate, all the ingredients requiring particle size reduction must be added to the mixer along with sufficient free fat (20–22% if using granulated sugar) to ensure an efficient refining process. The refined flake is then added to the conche to be liquefied and for some degree of flavour development. Unlike chocolate, if cocoa mass is not used, there is very little evaporation of volatiles during the conching process because the moisture content of the raw materials is already likely to be in the 0.5% region. Hence there is little to be gained from forced ventilation of the conche or from unnecessarily long conching times. The three phases of conching (dry, pasty and liquid) still occur and during the pasty phase the particles will be sheared and coated with fat, although additional fat or emulsifier may need to be added as there is often little bound fat to be liberated to achieve this coating of particles. During the pasty phase the temperature can be elevated to manipulate the flavour profile. The manufacture of chocolate compounds, particularly those using cocoa powder as the source of cocoa, lends itself to continuous conching. The limitations of moisture, volatile removal and flavour development often experienced when manufacturing chocolate in continuous conches is not the case when manufacturing chocolate compounds using cocoa powder.

An alternative method is to use a refiner conche of the type manufactured for many years now by MacIntyre Chocolate Systems (Scotland) and Lloveras (Spain) and more recently by Varsha (India) and Skywin (China). This requires a much lower capital investment and space as the mixing refining and conching processes all occur within the one machine. Although the investment is less, it can take considerable time to achieve the required particle size. This needs to be considered when one calculates the desired production outputs.

Refiner conches can be used in conjunction with a bead/ball mill (Figures 19.1 and 19.2). This obviously requires a greater initial investment cost but reduces the processing time as the ball mill assists with the particle size reduction. The component parts can be purchased individually or as a complete system such as supplied by Royal Duyvis Wiener (Netherlands) or Lloveras (Spain).

Bead/ball mills can also be used in conjunction with a mixer or conche. The raw materials are fed into the mixer or a conche, where they can go through a conching cycle if desired, but this is done prior to the reduction of particle size so that all the particles remain coarse. This has the disadvantage that not all of the surface area will be available at this stage to be coated in fat. Once mixing/conching is complete the liquid masse is passed through the bead/ball mill to reduce the particle size and then into a storage tank. The reduction in particle size and its creation of more, new surface area will cause a large increase in viscosity. Further addition of emulsifier may be required after the bead/ball mill to ensure good flow properties. Again the component parts can be purchased and assembled individually or as a complete system such as supplied by Netzsch.

Figure 19.1 Lloveras Unicom system combining a refiner conche with a ball mill. Source: Aasted. Reproduced with permission of S.A. Martin Lloveras.

Figure 19.2 Duyvis Royal Wiener Uniroto system, combining a ball mill and refiner conche. Source: Royal Duyvis Wiener. Reproduced with permission of Royal Duyvis Wiener.

If cocoa powder is to be used in the manufacture of the chocolate compound then a further method of manufacture that can be utilised is the pre-milling of the dry materials, sugar, cocoa powder, milk/whey powder and vanillin before adding them to a mixer or conche to be combined with the fats and emulsifiers. Air classifier mills will give the tightest particle size distribution if this methodology is to be used, preventing the production of large quantities of super fine particles which have the greatest surface area to volume ratio. This is advantageous because the lower the surface area to volume ratio, the lower the quantity of fat that is required to achieve the desired viscosity. If cocoa mass is to be used in the recipe formulation, milling can still be used to reduce the particle size of the sugar and milk powder products, but the cocoa mass must also have its particle size reduced to final fineness prior to the conching/mixing step. It can either be purchased this way or be passed through a bead/ball mill or disc mill to reduce its fineness. This increases the capital investment and floor space required.

19.4 How compounds are used

Chocolate compounds and coatings have many uses throughout the food industry. It is possible to use them for depositing (either into a formed mould or as an individual formed piece), for enrobing (or bottoming), for dipping of ice cream products, for spraying or for the formed centres of sugar panned products. The main uses are in the manufacture of biscuits, cakes, confectionery and ice cream products. They can be found being used as choc chips, in ganache, as a moisture barrier (e.g. to protect an ice cream wafer) or even as pet treats (e.g. where the cocoa has been replaced by carob flour as the theobromine in cocoa is harmful to dogs).

19.5 Benefits of using chocolate compounds

In addition to the lower manufacturing cost of compounds, there are several important benefits.

19.5.1 Non-tempering

For the manufacture of confectionery using chocolate compounds, one of the main advantages is that there is no need for tempering unless the fat used in the recipe is a CBE. A CBE fat needs to be tempered in the same way that cocoa butter needs tempering. Not having to temper a compound chocolate removes the major capital expense of having to purchase tempering machines and simplifies the process enormously.

Not having to temper also allows the chocolate compound masse to be used at a temperature where all the fat is still in its liquid state. Normal usage temperatures are between 37 and 40 °C. Being able to use the compound chocolate at the same or a similar temperature to that which the viscosity measurement is made ensures the user can much more accurately assess how the compound coating will perform on plant. Being able to use the compound coating at a temperature of 40 °C gives much better flow properties than an equivalent viscosity chocolate that would need to be tempered and would therefore typically be used on plant between 29 and 33 °C. Much thinner enrobed coatings can be achieved with a lower fat content than is possible with chocolate. When moulding, flow into intricate designs of a mould is much more readily achieved being able to use a compound chocolate at 40 °C as opposed to a chocolate tempered and being used at 29 °C. The chocolate would require a fat content 4–6% higher than the chocolate compound to achieve the same result.

19.5.2 Cooling

Cooling is also simpler for CBS- and CBR-containing chocolate compounds. The cooling does not need to be designed to allow the fat crystals to be seeded, as is the case for chocolate. Instead, more intense cooling to promote a more rapid transformation of the fat from liquid state to solid state is possible and desirable. This makes for shorter cooling tunnels and hence shorter production startup times and throughput times. It is necessary to not allow the cooling temperature to drop below the dew point temperature in the cooling tunnel otherwise condensation will occur and sugar bloom can become an issue.

19.5.3 Heat resistance and fat bloom

Fat bloom is not as big an issue for compound coatings as it is with chocolate but the user should be aware that it is still a possibility. Exposure to heat that causes a chocolate to bloom (due to de-tempering the cocoa butter) does not have the same impact with a compound coating. The product may still deform under heat stress but when cooled again should still have a glossy appearance. However contamination with incompatible fats, particularly cocoa butter with a CBS-based compound, will cause bloom to occur. This is due to cocoa butter and CBS having completely different crystalline structures (Lonchampt and Hartel, 2004). If contamination with cocoa butter cannot be kept below 5% due to using lines that also manufacture chocolate products, it is better to use CBR than CBS to manufacture the compound. The CBR is much more compatible with cocoa butter. Compound chocolates manufactured using CBS can also display signs of fat bloom if cooling is not sufficiently rapid. The presence of anhydrous milk fat also has the opposite effect in CBS-based compounds than it does in cocoa butter-containing chocolates. It actually promotes bloom formation rather than inhibiting it. So if using whole milk powder in the formulation, it is important that as much of the milk fat as possible is “bound” and is not free to cause disruption to the crystallisation of the CBS. It is better that any milk solids present are in the form of either skim milk powder or demineralised whey powder, thus avoiding the presence of milk fat. Although CBS fat does not need to be tempered it does display some polymorphism: rapid cooling ensures rapid formation of the stable fat crystals and removes the latent heat of fusion. Sorbitan tristearate is often used in the manufacture of CBS containing chocolate compounds and, although it is listed as an emulsifier in ingredient lists, it functions primarily as an anti-bloom agent. Ideal storage conditions of chocolate compounds after manufacture are different to those of chocolate products. Whereas chocolate products should ideally be kept below 18 °C to prevent bloom occurring, chocolate compounds manufactured using CBS should be stored between 20 and 25 °C (Talbot and Smith, 2005) to best prevent the formation of bloom. Hence compounds and coatings often perform better than chocolate in warm climates.

19.5.4 Texture and prevention of cracking

Using chocolate compounds in place of chocolate gives the manufacturer much more flexibility in terms of the texture and can overcome many of the issues experienced when using chocolate. Examples would be in cake decoration: where a chocolate may crack and break away from the cake, a softer compound chocolate would not do so. This requires the selection of a suitable CBR or perhaps the use of some coconut oil in conjunction with CBS to give a softer texture. With chocolate the only option is the use of anhydrous milk fat to modify texture. It is also possible to manufacture ice cream coatings to enrobe an ice cream dessert that can be cut with a knife without cracking the coating after storage in a domestic freezer (–18 °C). This requires the use of lower melting oils such as sunflower oil, rapeseed oil or cottonseed oil in conjunction with coconut oil or palm olein to give the right texture.

19.5.5 Health benefits

The use of compound chocolates also permits the manufacturer to step outside of the rigorous chocolate legislation to produce products with dietary or health benefits. Milk- or lactose-free products can be manufactured using milk substitutes which would otherwise likely leave the manufacturer short of the milk solids required to meet milk chocolate legal requirements. Low-calorie or calorie-reduced products are more readily achieved if using compound chocolates. With fat delivering 37 kJ/g (9 kcal/g) of energy and carbohydrates and proteins both delivering 17 kJ/g (4 kcal/g) of energy, it is clearly desirable to keep the fat content to a minimum when attempting to produce a calorie-reduced product. Being able to use a compound chocolate at higher temperature (40 °C) than chocolate due to tempering not being required allows a much lower fat content to be utilised for a similar usage viscosity. Fat contents between 22 and 24% are easily achieved with the use of emulsifiers (lecithin and polyglycerol polyricinoleate), which would compare in viscosity to a chocolate containing 30% fat when it is used at 30 °C (tempered). If polyols or other sugar replacers are used to reduce or replace the sugar component of the chocolate compound then, in conjunction with the lower fat contents that are achievable, significant reduction in calories can be achieved. It is possible that the pathway to healthier confectionery will involve a new generation of compounds combining the benefits of cocoa polyphenols with low calories, lower fats and high fibre.

19.6 *Trans* fatty acids in chocolate compounds

Along with the potential health benefits (see above), there are also some health concerns associated with some types of compounds and coatings.The process of manufacture for CBR fat has traditionally involved hydrogenation or partial hydrogenation of a vegetable fat. Partial hydrogenation results in the formation of saturated fats but also results in some level of *trans* fatty acids being present. Note that full hydrogenation does not produce a fat containing *trans* fatty acids. CBS fats are usually manufactured using fractionation but some hydrogenation may be used. Consequently, CBS fats are lower or free from *trans* fatty acids but contain a greater amount of saturated fat. As chocolate is manufactured from a naturally occurring vegetable fat, cocoa butter, it also contains levels of saturated fat, but it does not contain *trans* fatty acids. These *trans* geometric isomers do not occur naturally in vegetable fats, and only occur naturally in some animal fats. Only the *cis* geometric isomers occur naturally in vegetable fats. The partial hydrogenation of a vegetable fat produces both *cis* and *trans* isomers of fatty acids. For example, in producing the *cis* geometric isomer oleic acid the *trans* geometric isomer elaidic acid is also produced. This in the past has been highly desirable for the fat manufacturers as the *trans* geometric isomers pack much more closely together in crystal formation due to the carbon chain being of a much more linear structure and hence they have a higher melting point.

There is now considerable evidence that *trans* fatty acids in the diet contribute to the onset of cardiovascular disease and increase the risk of coronary heart disease. The *trans* fatty acids contribute to the increase of low density lipoproteins (sometimes called bad cholesterol) and the decrease of high-density lipoproteins (sometimes called good cholesterol) in the blood stream. There is a drive, supported by legislation, in many markets to remove or reduce *trans* fatty acids from the diet. Major fat manufacturers have already succeeded in manufacturing CBR fats that are either low in *trans* fatty acids or free of *trans* fatty acids and these are now in widespread use. The alternative for the confectionery manufacturer is to switch to a CBS fat which is fully hydrogenated and hence does not contain *trans* fatty acids or to use a CBE fat (super compound) which then has the disadvantage of requiring tempering.

The health concerns surrounding saturated fatty acids are less clear, with many contradictory claims. Most health and governmental bodies, however, advise that high quantities of saturated fat in the diet can contribute to cardiovascular disease. Again, major fat manufacturers are producing alternatives that have reduced quantities of saturated fat.

19.7 Environmental aspects

Both CBS fats and CBR fats require palm or palm kernel oil for their manufacture. Many other consumer products, such as soap and soap powders, personal care products, margarine and biodiesel for example, also use large quantities of palm oil for their manufacture. The demand for palm and palm kernel oil has resulted in vast plantations in south east Asia, primarily in Malaysia and later in Indonesia. This has caused large areas of deforestation resulting in the loss of rain forest; the loss of habitat for many species, in particular the Orang Utang, and a dependency on palm and the commodity trading price for palm for income amongst the local populations. As people become aware through social media, the pressure for palm cultivation to be sustainable has grown. The Roundtable on Sustainable Palm Oil (RSPO) was formed involving palm growers, palm oil processors, environmental groups, social non-government organisations, consumer goods manufacturers, retailers, financiers and investors in 2004. The RSPO vision states; “RSPO will transform markets to make sustainable palm oil the norm”. As of 2014, 16% of world palm oil production is certified as sustainable by the RSPO. As consumers become more aware, it is essential for the manufacturers of chocolate compounds to ensure the CBR and CBS fats they use are sustainable.

Similar concerns exist with cocoa but these are not unique to chocolate compounds and exist for chocolate too. Sustainable cocoa is becoming more prevalent; however, the certification is spread across several independent bodies. Cocoa can be certified as sustainable by UTZ, the Rainforest Alliance and Fairtrade, and some major manufacturers run their own sustainability programmes. Cocoa powder is the main cocoa ingredient used in chocolate compounds and it is significantly harder to source cocoa powder that is certified sustainable than it is to source cacao beans or cocoa mass. It is advisable to ensure the cocoa used is certified as sustainable (see Chapter 2).

19.8 Summary of the properties of compound coatings

There are advantages and disadvantages to each of the different types of compounds and these are summarised in Table 19.1.

19.9 The future of compound coatings

The need and desire to manufacture compound chocolate was initially driven by cost benefits which needed to be balanced against the compromise with flavour when comparing to chocolate. In the future these cost benefits are only likely to become greater as the demand for cocoa increases from developing markets and crops are depleted by disease. Unless cacao growers can produce varieties with

Table 19.1 Summary of the advantages and disadvantages of the different types of compounds.

	Type of chocolate compound		
	CBE "super" compound	**CBR compound**	**CBS compound**
Advantages	Most similar to chocolate in terms of flavour and texture. Can be used with cocoa mass. Can be used for any purpose that chocolate is also used, for example, moulding, enrobing, depositing.	Can be used with cocoa mass (non-lauric). Do not require tempering, hence simple to use and lower machinery investment. Higher usage temperature allows reduced fat content in comparison to chocolate. Can tolerate contamination from cocoa butter without blooming, can use same equipment as used for chocolate manufacture.	Good snap and sharp melting point similar to cocoa butter. Do not require tempering, hence simple to use and lower machinery investment. Can be used for any purpose that chocolate is also used for including moulding. Higher usage temperature allows reduced fat content in comparison to chocolate. Less likely to contain trans-fat than CBR compounds.
Disadvantages	Needs to be tempered. CBE is the highest ingredient cost of compound chocolate fat options. Needs greater investment in machinery as tempering is required. Usually contains palm oil, sustainable sourcing options are available.	Difficult to use for moulding due to poor contraction. Texture different from chocolate, poor snap. Often contain trans-fat. Usually contains palm oil, sustainable sourcing options are available.	Do not tolerate cocoa butter, will bloom if cocoa butter content above 5%. Cocoa mass cannot be used in manufacture giving inferior flavour. Must be made on separate machinery to that used for chocolate or machines must be thoroughly cleaned. Usually contain palm kernel oil. Sustainable sourcing options are available.

much greater yields than currently exist, then the prices will continue to rise or growers will turn to alternative tropical crops for greater income, depleting cacao crops further. As manufacturing methods and flavour of compound chocolates improve, the cost differential in comparison to chocolate will make them a more desirable option.

As the fat manufacturers develop healthier alternatives to the traditional CBR and CBS fats, *trans* fat issues disappear and saturated fat contents reduce; then the point is likely to come when they appear healthier than cocoa butter itself. Coupled with the flexibility to manufacture products with lower fat contents and reduced energy levels then chocolate compounds may become the treat of choice for the health conscious.

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CHAPTER 20

Recipes

Edward G. Wohlmuth

20.1 Chocolate tastes in different countries

20.1.1 History

If this chapter had been written 45 years ago, it would have been about 10 milk chocolate types, five dark versions and 10 vegetable fat coatings for the cake and ice cream industries. Today, the company the author worked for produces over 450 different recipes for four different sectors of the food industry:

1. Chocolate confectionery;
2. Sugar confectionery;
3. Ice cream industry;
4. Bakery and baked or chilled goods.

Often there is a different flavour profile depending upon the sector of the industry and also a different flavour and viscosity profile, according to its use and global location. It is not only a question of cocoa solids and taste, but also of the claims that will be put on the final product. There are recipes for organic chocolate, Fairtrade, kosher, origin, special estates, low fat, chocolate and fillings without added sugar and many more. In addition there are those produced for special processing, for example chocolate suitable for freezing, chocolate for panning and shell moulding or for "one-shot" systems and so on.

20.1.2 Taste in different countries

20.1.2.1 United Kingdom

In the United Kingdom (UK), the traditional milk caramelised "chocolate crumb" flavour (Chapter 6) still predominates for milk chocolate tablets and cake coatings, but the Belgian mild and creamy taste is also liked and used in the chocolate confectionery industry. Dark chocolate now has much higher total cocoa solids content than 15–20 years ago. White chocolate, traditionally a children's product, is now an acceptable product for adults, and many assortment boxes now have at least 25% white chocolates. There are now many "artisan producers" who specialises in very high quality and other niche markets.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

20.1.2.2 Belgium

Belgian chocolate is famous for its mild, full-milk flavour. This type of chocolate has now found favour all over the world and in many countries you will see products labelled “Made with Belgian Chocolate”. It is a sign of quality and consistency. White chocolate produced in Belgium is also popular.

20.1.2.3 France

France is the home of dark chocolate. It has many recipes and flavour profiles; many specialised chocolate recipes with the cocoa beans coming from small cocoa bean growers in a specific region. The industry has even started using the word of “Grand Cru” for its very special products (a term borrowed from the wine industry).

20.1.2.4 Switzerland

Switzerland is the home of some of the finest milk chocolate. This is largely due to the fact that the maximum particle size of the refined chocolate is almost always below 20 μm, making a very smooth chocolate, together with the care taken with the conching process. The quality and flavour of Swiss milk powder has always been very good. This gives Switzerland a very good name for milk chocolate bars and confectionery. Swiss milk chocolate often has a “nutty” taste due to the addition of hazelnut or almond praline.

20.1.2.5 Germany

A large proportion of chocolate making machinery is manufactured in Germany, but the chocolate products themselves tend to be designed mainly for the local market apart from brands such as “Milka” or “Ritter Sport” which are now sold worldwide.

20.1.2.6 Italy

Italy is famous for producing of “single items” chocolate confectionery, rather than tablets. Products like Ferrero Rocher are sold throughout the world.

20.1.2.7 United States

The top selling brand has a milk flavour that is quite strong and robust. European chocolate types and flavours are making some inroads into the confectionery market.

20.1.2.8 English speaking countries (other than USA)

These generally follow the UK type of flavours for historic reasons; due to the fact that UK companies set up factories in these countries.

20.1.2.9 Other countries

Many major multinational companies have factories in these countries, which have followed the “European route”. There are also many imports from Europe. Local brands and flavours co-exist, for example in Russia some milk chocolate has a very strong cocoa taste. Also, many European chocolate manufacturers are now producing high quality chocolate in Eastern Europe, Far East and Russia.

20.2 The basic ingredients

The ingredients and processing of chocolate are described in detail in other parts of this book. It is, however, useful to review the most important aspects, before examining different possible chocolate recipes.

20.2.1 Sugar

This can be refined cane or sugar beet, white or slightly grey in colour. Granulated sugar with a low percentage of sugar dust is preferable for roller refining.

20.2.2 Milk

Milk chocolate is still the most popular chocolate in the world; even in places like China, where very little milk is consumed, milk chocolate is highly regarded.

The milk powder used in the production of milk chocolate is normally spray dried or roller dried. Both can be purchased in full cream or skimmed versions. Milk crumb (Chapter 6) is manufactured by co-drying sugar and milk together with cocoa mass. It is then often milled to the size of bread crumbs and thus the title "chocolate crumb". This process adds cooked or caramelised notes to the final taste.

The flavour profile and hardness of a milk chocolate is determined by the choice of the ingredients being used. Spray dried, full cream milk powder will produce a "harder" milk chocolate suitable for tablets and chocolate confectionery. Using skimmed milk powder and milk fat (anhydrous) or roller dried full cream milk powder, results in a softer chocolate, more suitable for the bakery and the ice cream sectors.

The quality of the milk powder is determined by the age, the time of the year it is produced, the type of feed for the cows and the location of the pastures and so on.

It is interesting that there are many different milk chocolate flavours, which are often suited to a particular country, for example the United States milk chocolate type has a mature milk, slightly cheesy taste.

20.2.3 Cocoa beans and mass

This ingredient will have potentially the biggest influence on the flavour of the chocolate, especially dark chocolate. The higher the total cocoa solids the higher the flavour influence will normally be. There are two main botanical types of cocoa beans. The "Forastero", being the main type, gives a characteristic strong cocoa flavour, which can be slightly acid and bitter if over-roasted or underconched. The second type, Criollo, gives a much gentler and finer flavour.

To describe all the various types and regions of cocoa bean growing would take a book on its own. For a medium to high quality chocolate, cocoa beans from West Africa may be used, for example from the Ivory Coast, Nigeria, Ghana and Cameroon (see Chapter 2).

Substantial training has been given to many cocoa bean growers to improve the quality and consistency of the crop, mainly in West Africa and South America, and has concentrated on organic, Fairtrade and, in particular, the quality of regional and single estate crops. The blending of the cocoa beans/mass and level of roasting is very important and is dependant upon several factors:

1 Cocoa bean quality;
2 Producer experience in blending cocoa beans and roasting times and temperatures;
3 The equipment available and its use;
4 Purchasing practice.

Cocoa mass is normally produced in one of two different ways. Whole bean roasting involves blending, cleaning, roasting, breaking, winnowing, pre-grinding and grinding. Alternatively, nib roasting is carried out by blending, drying (or pre-roasting), breaking, winnowing, roasting, pre-grinding and grinding. Chapter 3 describes these processes in more detail.

The finer cocoa bean, such as the Criollo type is normally roasted at a lower temperature range than the bulk Forastero type. For milk chocolate the lower roasting temperatures are normally preferred to give a good balance of milk and cocoa flavour.

Roasted cocoa nibs and mass can also be modified by heat or steam treatment.

The treatment modifies the roasted flavour by reducing undesirable acids as well as providing some sterilisation of the cocoa mass and reducing conching times.

Normally a blend of West Africa cocoa is used by European chocolate manufacturers. The ratio will depend on the type of chocolate being produced, the cocoa availability, which varies from season to season and its cost.

Currently there are many fine chocolates being made in smaller quantities and using cocoa beans from specific “origins”: countries, specific regions or estates, variety or type of cocoa. These are normally dark chocolate with a high cocoa mass content to emphasise specific flavours. There is now quite a large number of artisan producers of these specialised chocolates aimed towards the highest quality and price market, normally using specialised ingredients, machinery, production and product knowledge (see Chapter 18).

20.3 Conching to develop flavours

During conching (see Chapters 8 and 10), the flavour changes or modifications are affected by the following:

1 Type and action of the conche;
2 Temperature of conching: (white 40–50 °C (104–122 °F); milk 40–70 °C (104–158 °F); dark 50–90 °C (122–194 °F);

3 Time of conching (4–36 h, depending of type of chocolate and conches);
4 Exposure to air;
5 The time and amount of addition of the additional fat and emulsifiers;
6 The addition of flavours, normally vanilla or nut paste, often hazelnut.

20.4 Chocolate recipes

There are many recipes depending upon the final use. The main types of use are:

1 Chocolate bars/tablets;
2 Chocolate confectionery products;
3 Ice cream and frozen desserts/confectionery;
4 Bakery and biscuit products (including chocolate chips);
5 Speciality products;
6 No added sugar chocolate;
7 Compound and coatings (made with vegetable fats other than cocoa butter).

For all the chocolate recipes, up to 5% of the cocoa butter can be replaced with cocoa butter equivalents (CBE – fats compatible with cocoa butter), in countries where the regulations permit (Chapter 28). The final product must be clearly labelled that it contains vegetable fat. Most chocolates would also contain a flavour. Legally this cannot be a chocolate flavour, but is normally natural vanilla extract or synthetic vanillin. For certain applications a small amount of salt may be added to enhance flavour.

20.4.1 Chocolate bars/tablets

In this sector, many factors have to be taken in consideration, particularly regarding flavour, smoothness, snap and mouth melting profile. Multinational producers have their own “house” flavours and there are also national and regional tastes.

To the customer this chocolate bar must bring the ultimate in eating pleasure, by giving the expected flavour, smoothness and melting profile.

The fineness of most bars, whether dark, milk and white, is 15–20 µm for top quality products, 22–25 µm for medium quality bars and 25–30 µm for bars with inclusions, such as fruit, nuts and cereals (see Chapter 9). The fineness profile is not just a guide on the smoothness of the chocolate, but also a quality and price statement: the lower the particle size, the higher the cocoa butter requirement for a given viscosity. Also, the lower the particle size the less throughput of the chocolate refiner: all adding extra cost, but adding perceived quality to the end product as well.

A range of different dark chocolate recipes is given in Table 20.1.

The most popular solid eating chocolate is still milk chocolate, either as a milk chocolate bar or with added fruits, nuts, cereals and so on. Typical recipes are given in Table 20.2.

Table 20.1 Recipes for dark tablet chocolate.

Ingredient	Range for dark chocolate (%)	Typical medium quality bar (%)	Typical high cocoa solids recipe (%)
Cocoa mass	45–80	55	70
Sugar	20–55	44.5	30
Added cocoa butter	0–5		
Lecithin	0–0.5	0.5	
Flavour	<0.5		
Approximate total fat content		29	38–40; depends upon cocoa type and quality

If a given viscosity is required the quantity of cocoa butter can be adjusted or, in some cases, if the cocoa mass percentage goes over 60%, some of the cocoa mass is replaced with natural or slightly alkalised cocoa powder.

Table 20.2 Recipes for milk tablet chocolate.

Ingredient	Range for bar milk chocolates (%)	Typical medium quality bar recipe (%)	Typical high quality milk bar recipe (%)
Sugar	34–58	48	42
Non-fat milk solids	12–18		
Full cream milk powder		24	25
Cocoa butter	18–25	19.5	24.5
Cocoa mass	8–12	8	8
Milk fat	3.5–6.5		
Lecithin	0.3–0.5	0.5	0.5
Approximate total fat (milk fat plus cocoa butter)	26–38	26.5	35

The milk chocolate recipes could also be made using “chocolate crumb” to replace some or all of the cocoa mass, milk powder and sugar (see Chapter 6). If a softer milk chocolate is required, the full cream milk powder can be replaced with skimmed milk powder and milk fat (butter oil).

Table 20.3 contains recipes for different types of white chocolate that can be made into tablets.

When making white chocolate it is important that good quality fresh milk powder and high quality deodorised cocoa butter are used. It must be conched at 40–50 °C (104–122 °F). When a higher conching temperature is used, there is danger of “browning” the chocolate. If a “caramelised flavour” is preferred, the use of “white” chocolate crumb should be considered. When a “softer“ white chocolate is desired, the full cream milk powder can be replaced with skimmed milk powder and milk fat.

Table 20.3 Typical recipes for white bar chocolate.

Ingredient	Range of ingredients (%)	Typical medium quality white bar chocolate (%)	Typical high quality white chocolate bar recipe (%)
Sugar	37–50	48	37
Non-fat milk solids	18–24		
Milk fat	4–7		
Full cream milk powder		29.5	33
Deodorised cocoa butter	22–35	22	30
Lecithin	0.2–0.5	0.5	
Approximate. total fat content (milk fat plus cocoa butter)	29–40	29.5	37.8

20.4.2 Chocolate confectionery products

The chocolate used for the confectionery industry is normally split in to three applications:

1 Bar forming and enrobing;
2 Shell moulding and one-shot systems;
3 Panning.

20.4.2.1 Chocolate for bar forming and enrobing

The requirements for bar forming and enrobing chocolate are:

1 Good hardness and contraction for bars, but not too hard to crack if used on firm or hard enrobed centres;
2 Flavour profile in harmony with the end product;
3 Viscosity and yield matching the requirement of the product and manufacturing plant.

Typical recipes for the major ingredients in milk, dark and white bar moulding and enrobing chocolate are given in Table 20.4.

The actual viscosity that is needed depends very much upon the type of temperer and enrober being used. It may be necessary to modify the flow properties of these recipes. A more fluid chocolate can be obtained by decreasing the sugar by 2–3% and increasing the cocoa butter. For a thicker chocolate the reverse applies, that is decrease the cocoa butter by 2–3% and increase the sugar by the same amount.

20.4.2.2 Shell moulding and one-shot systems

For shell moulding the chocolate can be similar to that used for enrobing, provided that the shell moulding plant has efficient vibrator and shaking systems, so as to be able to adjust the shell thickness to suit the products. If there is a problem with the “backing off” of the filled shells due to too high

Table 20.4 Typical recipes for milk, dark and white enrobing chocolates.

Ingredient	Milk chocolate (%)	Dark chocolate (%)	White chocolate (%)
Sugar	45	43.5	45
Skimmed milk powder	15.6		17.9
Milk fat	5.3		4
Cocoa mass	10	44	
Cocoa butter[a]	23.6	12	32.6 (deodorised)
Lecithin	0.5	0.5	0.5
Approximate total fat content	35	35	36.6

[a] Where legislations permits, up to 5% of the cocoa butter can be replaced by CBE fat.

Table 20.5 Recipes suitable for one-shot systems.

Ingredient	Milk chocolate recipe (%)	Dark chocolate recipe (%)	White chocolate recipe (%)
Sugar	49	52	50
Full cream milk powder	20		20
Cocoa mass	10	35	
Cocoa butter	20.5	12.6	29.5
Lecithin	0.5	0.4	0.5
Approximate total fat	32	32	33.5

a viscosity, then a small amount of cocoa butter should be added to the “backing chocolate“.

With one-shot systems (see Chapter 15), depending on the type of equipment and the product centres; a less fluid hard chocolate with good contraction may be advantageous. Typical recipes for milk, dark and white chocolates that are suitable for one-shot systems are given in Table 20.5. If a more fluid chocolate is required for any of these recipes, up to 3% of the sugar can be replaced by cocoa butter.

20.4.2.3 Panning

A wide range of chocolate types and viscosity (and yield value) can be used depending upon the panning system itself and the products to be panned. The chocolate should not be so hard it causes splitting on panning or so soft it causes sticking together of the panned products after cooling.

Typical panning chocolate recipes for use with a spray system (Chapter 16) are given in Table 20.6.

If using round or onion-shaped pans, letting the panned product “rest” and “harden” for 24 h before glazing may be beneficial for a good gloss and no clouding of the glaze.

Table 20.6 Chocolate recipes suitable for panning.

Ingredient	Milk chocolate recipe (%)	Dark chocolate recipe (%)	White chocolate recipe (%)
Sugar	46	54	48
Skimmed milk powder	15		10
Full cream milk powder			10
Milk fat	4	4	4
Cocoa mass	8	27	
Cocoa butter	26.5	14.5	27.5
Lecithin	0.5	0.5	0.5
Approximate total fat content	34.5	33	33.5

20.4.3 Ice cream and frozen desserts/confectionery

Over the last 30 years, many changes have taken place in the use of real chocolate in frozen products. Despite these, the ice cream and frozen product industry worldwide still uses more chocolate flavoured coatings than real chocolate. Adding vegetable fats and oils to real chocolate can also be beneficial, enhancing the melting profile and flavour release of the frozen chocolate in the mouth. The normal vegetable fat used to soften or modify real chocolate is coconut oil and the ratio is up to 20%. This procedure will normally adjust a basic chocolate into a dipping ice cream chocolate. Check with your local chocolate regulations regarding labelling.

Both ice cream chocolate and coatings have to meet a wide range of applications, from enrobed choc ices to sprayed cones and from after dinner ice confections to dipping lollies.

The rules of having to temper real chocolate and cool it slowly do not apply for real chocolate or coating products below 0 °C (32 °F), where very rapid solidification takes place. Real chocolate, which may or may not contain added vegetable fats, at a temperature of 42 to 45 °C (108 to 113 °F) before enrobing or dipping comes in contact with the frozen product which is –25 to –40 °C (–13 to –40 °F).

For best results when dipping or enrobing with real chocolate, the ice cream should not have an "overrun" (additional volume after aeration) of more than 60%. If a chocolate flavour coating is used, the depositing temperature is normally between 28 and 35 °C (82 and 95 °F) and the "overrun" can be up to 100% or in special cases even higher.

With enrobed products, an after-freezer is normally used to rapidly set the chocolate or coating. Dipped lollies may be rapid cooled by spraying with liquid nitrogen. (*Note:* For real chocolate, there is a slight softening of the chocolate after the initial hardening, which lasts about 10–15 min.)

The total fat percentage to give the correct pick up weight and cover for real chocolate dipped and enrobed ice cream, is between 42 and 48%, but up to 60%

Table 20.7 Chocolate recipes for dipping and enrobing high quality ice cream and frozen confectionery.

Ingredient	Real milk chocolate (%)	Real dark chocolate (%)	Real white chocolate (%)
Sugar	42	39	40
Skimmed milk powder	9		15
Full cream milk powder			
Milk fat	7	7[a]	8
Cocoa mass	8	39	
Cocoa butter	33.4[b]	14.4[b]	36.4[b]
Lecithin	0.6	0.6	0.6
Normal approximate total fat content	44.4	42	44

The above recipes can also be used for disc spraying, but for nozzle spraying replace a total of 5% of the sugar and skimmed milk powder with 5 % cocoa butter or CBE (cocoa butter equivalent).

[a] If regulations allow, if not replace with cocoa butter.

[b] 10% or more of the cocoa butter can be replaced with other vegetable fat, normally soft coconut oil, where regulations allow. The labelling will usually need to be changed to, for example: "chocolate with added vegetable fat".

if the chocolate is used for air or airless spraying. Recipes, including real chocolate, that are suitable for dipping and enrobing high quality ice cream and frozen confectionery are shown in Table 20.7.

White chocolate or coatings should always be stored in stainless steel containers and transported using stainless steel pumps and pipe work. The container water jacket temperature must be kept below 45 °C (113 °F) or "browning" of the white chocolate will occur.

The example of a milk chocolate recipe with added vegetable fat is "softer" at frozen temperatures and "cracks" less on the product and at the point of consumption. If local regulations do not allow the addition of vegetable fat (coconut oil, or similar soft fat) it can normally still be used, but with a description such as "chocolate flavoured" coating. The chocolate can be made as normal, but up to 20% of coconut oil is added at the point of use.

20.4.3.1 Chocolate flavour coatings for enrobing and dipping

The main fat used for ice cream coatings is coconut oil or a similar soft vegetable fat with a slip point (Chapter 7) of approximately 18–24 °C (64–75 °F). The percentage of fat in chocolate flavoured coatings suitable for the frozen food sector is in a range from 45% for cone spraying to 65% for thin layer enrobing and dipping. Recipes suitable for enrobing and dipping medium quality ice cream and frozen cake products are presented in Table 20.8. If it is necessary to make the milk recipe more "creamy", up to 5% of coconut fat can be replaced with milk fat.

Table 20.8 Coating recipes suitable for enrobing and dipping medium quality ice cream and frozen cake products.

Ingredient	Milk chocolate flavoured coating (%)	Dark chocolate flavoured coating (%)
Sugar	35	40
De-fatted cocoa powder	4	10
Skimmed milk powder	7	
De-mineralised whey powder	4	
Soft coconut fat	49.4	49.4
Lecithin	0.6	0.6
Approximate total fat content	49.4	49.4

For air or airless (disc) spraying of wafer cones or an ice cream barrier spray, an even thinner coating is needed, which means having even more fat. A typical recipe might have a total of 60% fat of which 56% might be coconut oil, with the remaining 4% being milk fat. Other ingredients could be 26% sugar, 7% skimmed milk powder and 7.5% de-fatted cocoa powder. If there is a problem of moisture permeating through the chocolate or chocolate flavour coating layer, it is advisable to omit the lecithin and adjust the viscosity with the addition of extra fat.

20.4.4 Bakery and biscuit products (including chocolate chips)

For many years, only chocolate flavoured coatings were used for cake products due to the warm atmosphere in bakeries, the exception being the Sacher Torte of Vienna with its very high butter oil content, which makes it cuttable at room temperatures, and the half and fully enrobed biscuits and chocolate chip cookies, which came via the United States to Europe.

Using real chocolate on cakes requires a reasonably soft chocolate, which can be easily cut without splintering at room temperature. The trick is to use a normal medium soft chocolate and add 3–4% milk fat to the milk chocolate and up to 8% of milk fat to plain chocolate. Very little white chocolate is used for cakes, due to its sweetness. Typical milk and dark recipes for enrobing a sponge cakes, gateaux or Swiss rolls are given in Table 20.9.

Owing to their high milk fat content, these chocolates need to be tempered approximately 1 °C (2 °F) lower than normal chocolate and the cooling tunnel dwell time may be 2–4 min longer than a normal confectionery product.

20.4.4.1 Half coated or fully enrobed biscuits

A medium hard, relatively fast setting, chocolate is desirable for two reasons:

1. Most biscuit plants run at a much faster speed than confectionery systems so fast setting is required.
2. To stop the half coated or enrobed biscuits from sticking together as they are packed.

Typical recipes for enrobing or half coating biscuits are given in Table 20.10.

Table 20.9 Typical recipes for enrobing a sponge cakes, gateaux or Swiss rolls.

Ingredient	Milk chocolate recipe (%)	Dark chocolate recipe (%)
Sugar	45	52
Skimmed milk powder	15	
Cocoa mass	11	30
Milk fat	7.5	7.5
Cocoa butter	21	10
Lecithin	0.5	0.5
Approximate total fat content	34.5	33

Table 20.10 Typical recipes for enrobing or half coating biscuits.

Ingredient	Milk chocolate recipe (%)	Dark chocolate recipe (%)
Sugar	47	52
Full cream milk powder	7	
Skimmed milk powder	5	
Whey powder[a]	5	
Cocoa mass	8	30
Milk fat	3.5	
Cocoa butter	24	17.5
Lecithin	0.5	0.5
Approximate total fat content	33.3	33.5

[a] If regulations allow, otherwise replace with skimmed milk powder.

20.4.4.2 Chocolate chips

Chocolate chips or chunks can be used for biscuit production, or for inclusions in cakes, muffins or toppings. The addition of chocolate chips should take place towards the end of the dough mixing. The ideal mix temperature of the biscuit dough should be below 18 °C (64 °F). The flour, sugar and fat may have to be cooled to achieve this biscuit dough temperature. If water is used in the biscuit dough this can be chilled or replaced with the same weight of ice. Additionally, cooling or freezing the chocolate chips/chunks before adding to the biscuit dough can be beneficial.

The baking times and temperatures can vary greatly, depending on type and size of biscuit and type of finish required. The baking temperature normally varies from 150 to 190 °C (302–374 °F) and the baking profile is also very important to the appearance and taste of the finished biscuit.

Great care must be taken if using milk chocolate chips/chunks not to "brown" the milk chocolate chips/chunks to the point where the chips are caramelised or taste of burned milk.

Table 20.11 Typical recipes for chocolate chips or chunks.

Ingredient	Dark chocolate recipe (%)	Milk chocolate recipe (%)
Sugar	49	52
Full cream milk powder		20
Cocoa mass	47	10
Cocoa butter	3.6	17.7
Lecithin	0.3	0.3
Salt	0.1	
Approximate total fat content	27.6	28

After baking they must be cooled as quickly as possible, to get firm chips showing on top of the biscuit/cookie and to stop biscuit fat migration into the chocolate. The temperature of the baked biscuit should be reduced to 23 °C (73 °F) or lower within 20 min. The temperature in the packing room should not be higher than 23 °C (73 °F) and should preferably be in the range 16–18 °C (61–64 °F).

For finished and packed chocolate chip biscuits and cookies the storage temperature should be between 16 and 18 °C (61–64 °F) with a relative humidity of 60% or less.

All the above procedures and temperatures also apply if chocolate chips are used for sponges and cup-cakes.

Typical recipes for dark and milk chocolates suitable for chocolate chip production are given in Table 20.11.

20.4.4.3 Chocolate-flavoured coatings for cakes and cake rolls

There are many chocolate-flavoured coatings used in the cake industry, due to cost or production implications (no tempering required). Most recipes are made with hardened or hydrogenated palm kernel oil (HPKO, Chapter 7) or other hardened vegetable fats, depending on application, cost, geographical location and so on.

Table 20.12 gives three recipes for chocolate-flavoured coatings based on HPKO fats, which are available in various melting profiles and hardness. It is necessary to work with your fat supplier to evaluate the best type and melting profile fat for your products. There are health concerns with some partially hydrogenated fats due to their trans fatty acid content (see Chapters 7 and 19).

Chocolate-flavoured coatings with HPKO fats have a short shelf life due to fat bloom.

If the shelf life needs to be extended beyond four weeks, an anti-bloom agent will have to be added to the coating fat. If further shelf life is required alternative fat to HPKO should be considered.

Table 20.12 Typical chocolate-flavoured coating recipes, suitable for coating/enrobing cakes and rolls.

Ingredient	Milk chocolate flavoured coating recipe (%)	Dark chocolate flavoured coating recipe (%)	White chocolate flavoured coating recipe (%)
Sugar	42	48	42
De-mineralised whey powder[a]	11		6
Skimmed milk powder	5		15
De-fatted cocoa powder	5	16	
HPKO	36.5	35.5	36.5
Lecithin	0.5	0.5	0.5
Approximate total fat content	36.7	37	36.5

[a] Replace with skimmed milk powder, where regulations do not permit use of whey.

20.4.5 Speciality products

Nowadays there are so many possibilities with all the new ingredients that are available, together with all the knowledge on how to use these products that a book could be write on speciality products alone. Many samples are available from the technical or development departments of the suppliers.

For chocolate bars and chocolate confectionery, there are many fillings available, some made with chocolate as an ingredient together with added moisture (cream, condensed milk, glucose, sugar syrup etc.). These are “fresh” products with a short shelf life.

This section contains recipes for soft melt chocolate bar fillings that can be made using standard chocolate machinery, including the single stage grinding systems, for example Macintyre (Chapter 10), together with a traditional shell moulding plant.

A typical soft melt chocolate filling crème uses a soft coconut fat, or one of the many other appropriate vegetable fats to provide a “fast melt” in the mouth and a long shelf life. Three typical recipes are given in Table 20.13.

The light coloured recipe gives a “milky” base coating, which will readily mix with fat-based flavours and pastes, such as hazelnut, almond praline or coffee paste. Because it contains no moisture, rice crispies or other small extruded cereals can be added without the danger of the cereals becoming soft and soggy. If a darker filling is required, 10% of the skimmed milk powder can be replaced with de-fatted cocoa powder. This filling complements alcohol flavours such as rum and brandy and so on and is also suitable for strong flavours, for example cappuccino paste and bitter orange. If a higher quality filling is required, the cocoa powder can be replaced by cocoa mass and 5% of coconut fat with 5% of milk fat.

The white filling crème is ideal for fat based fruit flavours and colours, such as caramel, orange, lemon, fruit of the forest and so on. If a less rich filling crème

Table 20.13 Recipes for typical soft melt chocolate flavoured filling crèmes.

Ingredient	Light coloured (milk) crème recipe (%)	White filling crème recipe (%)	Dark filling crème recipe (%)
Sugar	35	35	48
Skimmed milk powder	15	20	
Milk fat		2	
De-fatted cocoa powder	5		15
Soft coconut fat	44.5	42.5	36.5
Lecithin	0.5	0.5	0.5

If a softer filling is required, up to 5% of the soft coconut fat can be replaced with sunflower, rape or other good quality vegetable oil.

is required, some or all of the skimmed milk powder can be replaced with powdered pre-cooked rice or tapioca.

The dark filling crème is ideal both for a chocolate flavoured filling and for the addition of most fat-compatible alcohol flavours. If a really good quality chocolate filling is required, the de-fatted cocoa powder should be replaced with cocoa mass.

Cereal additions can be incorporated within all three types of filling crème, without the cereals becoming soft.

20.4.5.1 Speciality products

Under the heading of "speciality products" one must mention the many products sold with labels stating origin cocoa, plantation cocoa, organic, Fairtrade, kosher, functional and so on. All of these products have a consumer following and enrich the range of products available to the consumer.

For the production of these products, both normal and specialised equipment is used, as each manufacturer wants to produce something different and special. In many cases, by giving added care and attention to the ingredients and manufacturing process, it is possible to produce special chocolates that can demand higher price margins than standard products.

20.4.6 No added sugar chocolate

Traditional chocolate contains between 30 and 55% of added sugar (sucrose), which may be from cane or sugar beet. There is also a type of sugar which is called lactose that is naturally present in dairy ingredients such as milk and whey powders (Chapter 5). It is possible to make sugar-free chocolates, but these are either dark or, if they are milk or white, they are made with special lactose-free milk ingredients.

Some consumers avoid sugar (generally only sucrose) for reasons usually associated with life style or health. This may be due to concern about obesity or tooth decay, or that they are on a diet which restricts added sugars, perhaps because they are diabetic. There are many chocolates and fillings made for diabetics, which are made using manufacturing processes very similar to that for normal chocolate or fillings.

Three of the main of sugar replacers (Chapter 4) are sorbitol, fructose and maltitol. Sorbitol is very heat sensitive, therefore difficult to use on mass production equipment. It is also very hygroscopic. Its sweetening power is also less than sugar and it has a laxative effect if more that 100 g/day is consumed.

Fructose or fruit sugar, is less heat sensitive in production, but is about 20% sweeter than sugar.

Maltitol is now widely used in no added sugar products, as its sweetness power is only slightly less than sugar, it is not very heat sensitive in production and also it has a taste profile similar to normal chocolate made with sugar. It has a lower calorific value than sugar (–40%) and is therefore used, often together with polydextrose, to make low calorie chocolate. As fat contains more calories per gram than the other major ingredients, this type of chocolate should be made with the minimum amount of fat possible, whilst maintaining adequate liquid flow and eating properties.

For no added sugar chocolate and fillings, it is possible to use normal chocolate recipes, but replace sucrose with maltitol. When using sorbitol and/or fructose, all processing, pumping and storage temperatures must be kept below 50 °C (122 °F).

20.4.7 Compounds and coatings

This section covers two of the three types of non-cocoa butter chocolate-flavoured coatings, which are often called confectionery coatings or compounds (see also Chapter 19). These types of coatings are normally made of a variety of fat types (Chapter 7) and are designed to replace real chocolate, but still give a relatively good flavour, a good melting profile in the mouth and long shelf life.

20.4.7.1 CBE fats

These are available in a range of hardnesses, both to suit the product and to suit the environmental temperatures of the region. Chocolate-flavoured coatings made with this type of fat are mainly used for biscuit and cake enrobing and half coating. Basic recipes are similar to real chocolate, but with the CBE replacing cocoa butter. At point of usage, the coatings need to be handled exactly as real chocolate, which includes tempering and the correct cooling profile after enrobing.

20.4.7.2 Cocoa butter substitute or lauric fats

Cocoa butter substitute (CBS) coatings are made with lauric fats, such as HPKO and coconut oil. As lauric fats are not compatible with cocoa butter a low fat cocoa powder has to be used.

The shelf life of these coatings is normally up to 4–6 months, before fat bloom occurs, but this can be extended by the addition of an anti-bloom ingredient.

Table 20.14 Typical recipes for lauric fat coatings.

Ingredient	Milk coating recipe (%)	Dark coating recipe (%)	White coating recipe (%)
Sugar	45	53	50
Skimmed milk powder	15		15
De-fatted cocoa powder	5	11.5	
Lauric fat[a]	34.6	35.1	34.6
Lecithin	0.4	0.4	0.4

[a] If the anti-bloom agent is not already present in the fat, it will replace about 2% of the lauric fat.

This must always be added to hot liquid fat, but it is often preferable to have it added by the fat supplier. Occasionally, CBS coatings can also develop a soapy taste. This is caused by the action of an enzyme (lipase) which breaks down the fat into free fatty acids.

These coatings are normally used for enrobing sugar confectionery, wafers and bakery products. They set rapidly and have good melting properties in the mouth. Three typical recipes for lauric fat based coatings are given in Table 20.14. As with the chocolate recipes, a small amount (such as 0.02%) of vanillin flavour is used in almost all coatings.

All three chocolate-flavoured coatings are ideal for enrobing wafer and sugar confectionery products, where the use of real milk chocolate is too expensive or likely to melt easily in high ambient temperatures. They can be mixed with nuts, dried fruit and cereals, for a children's type of confectionery bar (sold in warm climates).

The milk coating can also be used as a base for ganache and truffle paste by the addition of condensed milk and glucose, but the shelf life may be short.

The white coating is often coloured and flavoured with fat soluble colours and flavours and is widely used in the United States for very colourful cake and candy decorations.

Conclusions

This chapter has provided a guide to the many different recipes that can be used for the wide variety of confectionery products found on the market. There is however no substitute to trying oneself. A product can be completely transformed by changing the flavour, texture or melting profile of the chocolate. Always however use high quality ingredients coupled with careful processing.

CHAPTER 21

Sensory evaluation of chocolate and cocoa products

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21.1 Introduction

When challenging the human senses to evaluate chocolate products, the evaluation of flavour may be the obvious first choice. Flavour is an integrated perception arising from distinct anatomical inputs: taste, smell, and oral somatosensation. Taste qualities have been traditionally defined as sweetness, sourness, saltiness, bitterness, and savory/umami that result from stimulation of specialised receptors on the tongue. Smell refers to sensations perceived via receptors in the nasal cavity, whether stimulated ortho- or retro-nasally. Oral somatosensations refer to the touch sensations that can be experienced in tandem with, but are not categorised as, tastes; these include burning, cooling, stinging and so on. For chocolate, the oral somatosensations of interest are generally astringency and cooling. However, when evaluating chocolate, visual appearance and even sounds (generally experienced as a component of texture) may also be important cues to distinguishing different products. The human senses present a set of unique and useful tools for the evaluation of chocolate and cocoa products. Sensory evaluation facilitates the scientific application and analysis of these tools.

The discipline of sensory evaluation provides a wide array of tests and tools that can be used to explore the human perception of, and reaction to, different items or products. Here we will briefly review many different types of sensory tests and the information they can be used to gather about products. In addition, we will review some special considerations that should be made when planning the evaluation of chocolate and/or cocoa products, as well as additional general considerations for planning sensory testing.

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Mark S. Fowler and Gregory R. Ziegler.

21.2 Types of sensory tests

There are numerous, diverse tests that can be used for the sensory evaluation of chocolate products. The question of interest ultimately determines the appropriateness of each test. Frequently, multiple tests can be used to tackle the same research question. When that is the case, the practicality of the test (time and cost considerations, generally) will determine which method is most appropriate. Additionally, it is important to note that, for chocolate, research has exposed large semantic gaps in the language used to describe chocolate by children (often the target consumer) and trained adults (Sune *et al.*, 2002). Thus, the nature of the study participant (i.e. age/experience, degree of training) must be determined appropriately for the research goals. Multiple tests are often used in conjunction with one another to provide a more complete answer to the research question.

21.2.1 Threshold tests

Threshold tests are a class of methods that attempt to estimate the point at which a stimulus, or a change in stimulus, becomes perceptible. Gustav Fechner, arguably the father of experimental psychology, believed a stimulus at threshold was one that "lifted the sensation or sensory difference over the threshold of consciousness". The detection threshold estimates the minimal physical stimulus that an observer can detect, irrespective of quality; this is sometimes called the absolute threshold. Recognition thresholds for a stimulus are almost always higher than the corresponding detection threshold, as they require the observer to identify the quality of the sensation, not just the presence of an ephemeral sensation. The difference threshold has special utility in food applications, as it asks how much a stimulus must change before an observer notices. For example, we may wish to know how much sugar can be removed before a product becomes noticeably less sweet: this amount can be quantified as the "just noticeable difference". Critically, while thresholds are given in seemingly precise physical units (lamberts, mM, ppm etc.), they are a probabilistic concept that depends heavily on the definition and experimental procedure used to estimate them. Also, thresholds can be determined for individual observer (requiring many trials) or for a group of observers. Moreover, it is important to consider that threshold tests are generally carried out in the simplest of models systems (e.g. a single tastant in water), and this becomes a much more complicated task when carried out in a complex stimuli such as chocolate. Thus, caution must be used if attempting to extrapolate the results of threshold tests in water to their potential values in chocolate or chocolate products.

Though there are few studies in the literature utilising these techniques in chocolate, the application potential exists nonetheless. Recently, the rejection threshold was defined as not the point at which a group of observers can perceive an off-flavour, but rather the point at which it became objectionable (Prescott *et al.*, 2005). For example, rejection thresholds have been successfully determined for the bitterness of sucrose octaacetate in solid milk chocolate-flavoured compound coating

(Harwood *et al.*, 2012) as well as for high cocoa flavanol containing cocoa powder in semisweet chocolate (Harwood *et al.*, 2013).

Threshold tests, specifically detection thresholds, have also been historically recommended in sensory evaluation texts as a means to determine the sensory acuity of individuals who are being considered for trained panels or other tasting roles. While these approaches have some limited utility in identifying individuals with gross defects in chemosensory function, modern understanding of human sensory systems suggests threshold-based approaches to screening panelists may have been an intellectual dead-end. Specifically, the relationship between detection threshold and suprathreshold intensity is not a simple one (see Keast and Roper, 2007; Bartoshuk and Klee, 2013), so knowing an individual's detection threshold reveals little about their responses at higher levels, Additionally, given the wide diversity of human bitter receptors and ligands that bind to them (Meyerhof *et al.*, 2010), as well as the genetic variation across receptors and individuals (Hayes *et al.*, 2011; Hayes *et al.*, 2013), screening individuals with a single bitterant like caffeine does not reveal any meaningful information about responses to other bitter compounds. For example, we recently demonstrated that the bitterness of the sweetener Acesulfame potassium (AceK) is totally unrelated to that of the stevia derived sweetener RebaudiosideA (RebA; Allen *et al.*, 2013). Accordingly, best practice when screening participants is to use the stimulus of interest at suprathreshold concentrations, rather than exemplars like caffeine at perithreshold levels.

21.2.2 Discrimination tests

Discrimination tests can be defined as "any method to determine if differences among stimuli are perceptible" (ASTM, 2013). These include but are not limited to tests such as triangle tests, tetrad tests, duo–trio tests, paired comparisons, difference from control tests and so on; these methods have been successfully carried out in chocolate products. For example, Aguilar and colleagues (1995) utilised triangle tests to determine if perceptible differences existed between chocolate samples processed via two different conching methods.

Discrimination tests can be set up to determine either difference (i.e. are the products different enough for the consumer to tell them apart?) or similarity (i.e. is a change in recipe small enough that it is not noticeable to the consumer?) between samples, depending on the statistical basis of analysis. Discrimination testing can also be directional. That is, the assessor can be asked to differentiate between samples based on a specific attribute. For example, directional paired comparisons (i.e. which sample is more sweet?) or n-alternative forced choice (n-AFC) tests can be carried out (i.e. of these samples, please identify which is the most sweet). This can be a particularly useful tool for claim substantiation [see ASTM E1958-06 (2014) for more information].

Discrimination testing is most useful when the differences between samples are subtle. That said, this also however increases the risk of type II errors in judgment, where a real difference may be missed (a false negative; Lawless and Heymann, 2010). This is particularly concerning when dealing with a complex product such as chocolate, where the increasing complexity of the product is generally accompanied by an increase in noise in the samples, making true differences more difficult to detect. In this case, the sensory scientist must consider the relative signal to noise ratio for the specific product when determining the appropriate sample size and size of α (control of type I error) to ensure the power of the test to correctly identify differences.

21.2.3 Affective testing

Hedonic testing can be a useful tool for understanding how consumers perceive and react to specific products affectively. Liking, preference and/or acceptability can all be measured, both for products as a whole and for specific attributes. There is an abundance of tools that can be used to accomplish these types of goals. For acceptability and appropriateness, common tools could include scales, such as the nine-point hedonic scale (Peryam and Pilgrim, 1957) or Just About Right (JAR) scales. Additionally, liking can also be measured using the Army Quartermaster nine-point hedonic scale. Preference implies the comparison of at least two samples, and it can be measured for example via paired preference testing (i.e. 2-AFC methods) or a ranking task with three or more samples. Hedonic testing is generally carried out with untrained assessors, as the goal is usually to capture and quantify the consumer experience. Hedonic testing has been carried out successfully in chocolate (e.g. Bordi *et al.*, 2002; Lee *et al.*, 2002). However caution should be used when interpreting these types of results because ratings of chocolate are often skewed towards the higher/more well liked/more acceptable end of a given scale. When this is the case, seemingly small differences between samples may carry more weight and the interpretation of scores may come down to understanding the difference between statistical significance and consumer relevance for that particular attribute/those particular samples.

21.2.4 Descriptive analysis

There are many different methods that have been developed and described in detail in the literature for descriptive analysis and which have been applied to chocolate. These types of tests allow for the construction of a sensory profile of one or numerous products using words that are often linked to precise definitions and representative standards or references. Additionally, these methods provide quantitative information about the relative intensities of the attributes within the product. Descriptive analysis is generally performed by extensively trained panels of 8–12 assessors. Descriptive analysis results can be paired with discrimination testing or consumer testing to give further insight in interpreting results found in other types of testing. For example, if consumers prefer one chocolate over another, descriptive panel data quantifying how "waxy" each sample is can inform the results of the consumer test and guide product developers in refining the product to meet consumer wants/needs.

Traditional descriptive analysis methods include: Quantitative Descriptive Analysis (QDA®; Stone *et al.*, 1997), Spectrum™ Descriptive Analysis Method (Muñoz and Civille, 1992), the Flavor Profile method (Keane, 1992) and the Texture Profile method (Muñoz *et al.*, 1992). Each of these methods differs in areas such as panel training procedures, intensity scales and more. For chocolate research, modified or hybrid methods of descriptive analysis are also frequently used in addition to or in place of traditional descriptive methods (e.g. Guinard and Mazzucchelli, 1999; Silva *et al.*, 2013). Often this is to facilitate investigation of a very specific research question, or in an effort to reduce time and/or cost. An alternative descriptive analysis method previously applied for the evaluation of chocolate products is Free-Choice Profiling (e.g. Thamke *et al.*, 2009). In contrast to other conventional descriptive methods, in Free-Choice Profiling, untrained panelists assign descriptors individually. This method can be useful when considering the semantic differences in how different populations would describe chocolate samples. Choice of descriptive analysis method should be based on the end goal of the research (i.e. does the end goal require comparison of data across time? Is a full profile needed, or is there a focus on specific attributes?).

21.2.5 Time–intensity analysis

Time–intensity analysis is a particularly useful method for the evaluation of chocolate products. This method allows for the investigation of the temporal nature of attributes, which, as chocolate melts, can have a significant influence on its perception. For instance, a study by De Melo and colleagues (2007) utilised the Time–Intensity method to evaluate the temporal profile of sweetness in milk chocolate samples formulated with different sweeteners (De Melo *et al.*, 2007). Chocolate has very unique melting characteristics, and this method of analysis can potentially illuminate differences that may be overlooked by other methods.

In addition to Time–Intensity analysis, another method called Temporal Dominance of Sensations has potential for application in chocolate products. Whereas in Time–Intensity analysis the intensity of a sensation is quantified over time (Lee and Pangborn, 1986), Temporal Dominance of Sensations evaluates which sensation(s) dominate the integrated profile over time (Pineau *et al.*, 2009). While this method has yet to be used in the published literature to evaluate chocolate products, it may prove insightful for investigating chocolate flavour.

21.3 Special considerations

As chocolate and cocoa products are such unique products, they may require some special considerations when planning and executing sensory evaluation. Attention should focus on good sensory practices in an effort to reduce noise or bias and to gather accurate data. While this list is not exhaustive, examples and some recommendations are listed below:

21.3.1 Use of coloured lighting

Chocolate samples have the potential to look very different from one another in colour. Whether the difference stems from alkalisation processes or the presence of milk ingredients and so on, it may be an important aspect in some tests. Particularly, differences in colour are of great concern when conducting a discrimination test. If the desired outcome is to determine if differences observed under natural circumstances are detectable, then these colour differences are part of that overall experience. However, if the objective of a test is to evaluate specific differences in say for example flavour or melting, it may be helpful to disguise colour differences by using coloured lights. Similarly to what is used for meat products, a red light or a combination of red and green lights may be used together to minimise the detectable differences.

21.3.2 Sample presentation

Presentation order is always important as it can aid in avoiding systematic biases in the results of a sensory test. Here we define bias as "systematic error manifested as a persistent positive or negative deviation of the method average from its accepted true value" (ASTM, 2013). Randomisation of samples, whether complete or incomplete depending on the requirements of the test, can help prevent order effects that may be seen for samples in the first position or in latter positions. In milk chocolate specifically, panelist performance for evaluating samples was compared for simultaneous and monadic sample presentation (Mazzucchelli and Guinard, 1999). The authors concluded that, while the panels showed better discrimination using simultaneous presentation, monadic presentation was significantly faster. Each presentation technique has pros and cons that must be thoughtfully considered for the specific test.

Additionally, order is important for the limitation of potential carry-over effects. Chocolate, especially dark chocolate or high cacao solid-containing chocolate, has attributes such as bitterness and astringency that are known to linger and can potentially influence the ratings of subsequent samples. Thus in some instances, rather than randomising the presentation order of the samples, it may be important to evaluate samples with the highest risk of carry-over at the end of the sample set. Rinsing and waiting between samples is very important for avoiding the carry-over effects and will be discussed under the next section.

21.3.3 Palate cleansers

Cleansing the palate between samples is essential for the accurate evaluation of chocolate samples, especially as chocolate tends to have bitterness and/or astringency that can build up or carry over and potentially interfere with subsequent ratings. Many proposed solutions have been explored in the realm of palate cleansers. These have ranged anywhere from plain water at room temperature to hot water, carbonated water, water with added citric acid, pectin rinses that simulate natural saliva, milk, chewing wax and the list goes on. Additionally, it is common practice to use unsalted plain crackers to cleanse the palate between different samples. While different palate cleansers may have different benefits, Lee and Vickers (2010) demonstrated that, when evaluating astringent samples, the palate cleanser that allowed best discrimination between samples was plain room temperature water. This is important to keep in mind, as chocolate and cocoa are often astringent.

Additionally, it is important to consider the amount of time given for rinsing between samples. When possible, it can be helpful to enforce a time delay between samples to ensure that there is sufficient time taken between samples for adequate rinsing and resting to reduce carry-over effects. While it may not be possible to ensure that all participants are rinsing between each sample when running for example a large-scale consumer test (i.e. a Central Location Test), an enforced time delay may encourage adherence to rinsing instructions. Computerised data collection systems that allow the experimenter to enforce pauses and breaks before the participant can proceed to the next question may be especially useful in this situation.

21.3.4 Fatigue and sample size

Fatigue is a critical concern when planning sensory tests. Fatigue can be influenced by both the size of the individual samples and the number of samples per testing session. Additionally the complexity of the task can lead to fatigue. That is, if the task is simple, it may be possible to evaluate a greater number of samples. If a very large number of samples needs to be evaluated, it may be wise to break the samples into multiple testing sessions, or explore possibly using an incomplete block design (e.g. Li *et al.*, 2014). When considering the quantity of samples, it may be important to decide whether panelists should be instructed to expectorate. Expectoration can allow the panelist to continue evaluating without the physiological effects of feeling full, or at least slow the onset as it can be difficult to fully expectorate chocolate samples.

The size of the samples can also have a significant influence on the outcome of a test. When deciding on the physical size of samples, it is important to determine whether the panelists should have the ability to re-taste samples. If so, a larger piece may be required. If re-tasting is to be avoided and panelists are going to be instructed to consume the entire sample, smaller samples may be ideal. It is important to provide large enough samples that the participant can establish an opinion of the product, especially if the panelists are to consider texture and/or melting profile in their evaluation, which may require multiple bites.

21.3.5 Evaluation temperature and product form

Generally, when evaluating solid chocolate samples, the pieces should be allowed to equilibrate to room temperature (~22 °C) before tasting. If the samples are kept in cold storage, it is common practice for samples to be brought to room temperature either overnight or for 24 h before a test. While it does not always require this amount of time, it is usually chosen for convenience. Additionally it is important to ensure that all samples are being presented and tasted at the same temperature, in case this could have potential effects on flavour, texture or even appearance.

If the decision has been made to evaluate melted/molten samples, again it is very important to ensure that all of the samples are presented and tasted at the same temperature. If a molten sample is to be evaluated for any textural attributes, such as particle size (i.e. smoothness or grittiness) the chocolate should be heated to a temperature where the majority of the fat crystals are melted to ensure consistent evaluation. Also, when heating chocolate, be mindful to keep careful control over temperature so as not to alter the flavour, especially by burning. For this reason, microwaving chocolate to melt it is usually cautioned against. Best practice is to bring samples to temperature in an incubator.

In some instances, such as for quality assurance purposes, it may be necessary to taste cocoa components other than finished products, which raises more questions around proper tasting procedures and protocols. For example, when tasting chocolate liquors, which are particularly fatiguing as they are naturally quite bitter and may be astringent, proper rinsing and resting time is necessary for accurate evaluation. When tasting components such as cocoa butter, it may be helpful to evaluate molten product, with the same considerations as above – ensure a consistent temperature and do not burn the ingredient. If tasting cocoa powders, it may be helpful in some instances to suspend a specific amount of the powder in an unflavoured carrier such as melted deodorised cocoa butter to make the evaluation process easier. However it is important to ensure that the carrier chosen is flavourless so as not to impact the evaluation.

21.3.6 Tasting instructions

The end goal of the test will dictate whether giving specific tasting instructions to the evaluators is appropriate or not. Tasting instructions would refer to specific directions on how to evaluate the samples. Here, we provide an example of what tasting instructions may look like, with the caveat that they need to be adjusted for the specific needs of the test:

> "First, assess the appearance of the chocolate by evaluating the richness of colour, uniformity, smoothness and glossiness or shine of the surface. Next, the sample should be broken in half to judge the snap and the friability of the chocolate. Using one of the halves of the sample, evaluate the aroma of the chocolate before it enters the mouth. Place the sample on the tongue and close the mouth, allowing the sample to begin to melt and evaluate the retro-nasal aroma qualities of the sample. Once the sample has

> begun to melt, press it with the tongue to the roof of the mouth to judge the smoothness and detect the presence of any discernible particles. The flavour and oral sensations of the chocolate should now be assessed, while masticating and working the chocolate around the mouth dissolving it in the saliva and clearing it from the palate. Finally, using the other half of the sample, bite through with the incisors to gauge the hardness of the chocolate."

In some cases, these instructions would be considered unnatural. For example, in situations where the goal is to assess the consumer experience with a product it may be unnecessary and unnatural to provide tasting instructions. However in other instances, tasting instructions may be necessary in order to replicate testing and obtain comparable results across either different groups of evaluators or different products. Carvalho da Silva and colleagues (2011) demonstrated that, within a typical sample of the population in the UK, there are three distinct groups of eating behaviours that exist naturally when consumers evaluate chocolate. It is possible that these differences in eating styles could influence the consumer experience with and therefore their perception of chocolate products. With this in mind, when carrying out descriptive analysis, it may be important for participants to evaluate in the exact same manner to get consistent, comparable impressions of the products; whereas in consumer testing it may be important to avoid these types of instructions to accurately capture these different product experiences.

21.4 General considerations/good sensory testing practices

21.4.1 Blinding codes

Similarly to the use of coloured lights and presentation order, the purpose of using blinding codes on samples is to avoid systematic bias as well as personal biases that evaluators may unintentionally impose upon the samples being tested. For example, an individual participating in a sensory test may for some reason think that certain samples are the same and try to make their evaluations accordingly (to get the "correct" answer). To encourage the individual to consider the samples separately, they should be labelled with different blinding codes. Blinding codes generally consist of randomly assigned three digit numbers. As much as possible, it is best to ensure that these numbers do not have potential connections that the participants could be familiar with, such as local area codes, or other prior connotations (e.g. 666, 911, 888 etc.).

21.4.2 Sensory testing environment

There are many thorough resources available for the design of sensory testing facilities (i.e. Eggert and Zook, 2008). However, when the design of a brand new facility is not possible, it is important to follow principles of good sensory practice to ensure that the data collected is valid and consistent. The sensory testing environment must be kept clean and organised so as to avoid any potential biasing of participants. For example, if sample wrappers are left in the waste basket where participants can see, this may bias their responses. Best practice requires the sensory testing environment to be free of distractions. These may present themselves in the form of noises, odours, high foot traffic, bright colours, poor lighting, poor air flow or climate control and so on. Therefore, interruptions should be minimised when possible, all areas should be decorated with neutral colours and climate controls should be set so that the participants are comfortable, while odours are minimised. Additionally, evaluation areas should have sufficient space and light to accommodate evaluations.

21.4.3 Sample serving containers

Similarly to the design of the sensory testing environment, ideal sample serving containers should be plain, so as to not distract the participant. This is one way in which sensory testing differs from market research, where the package design would be included as part of the overall experience. If using containers with lids, the lids should be easy to remove so as not to be a source of frustration or distraction for the panelist. Serving containers or plates should be plain and of neutral colour or clear and should be consistent across all samples. Additionally, samples should be clearly labelled with their corresponding blinding codes so there is no confusion as to which sample is which, and which sample is to be evaluated when. Additionally, if more than one sample is being presented at the same time to the panelist, it can be useful to include a visual aid to reiterate the order in which the samples will be evaluated. For example, when presenting numerous samples on a serving tray it may be useful to include a template on the tray that shows which sample is which, and when it is tasted, in addition to the instructions that are given to the participant.

21.4.4 Recruitment

It is not usually difficult to get individuals to volunteer to taste chocolate! However, the appropriateness of the incentive should always be considered, if one is provided. Additionally, it can potentially be beneficial if panelists are pre-screened for known defects of taste or smell, temporary or permanent upper respiratory conditions that could negatively affect their ability to taste and/or smell (i.e. a head cold), a history of choking or difficulty in swallowing or allergies to any of the ingredients in the samples being evaluated. The specific research goals of a given test will determine if there are other screening factors, such as familiarity with the product or liking of the category. Additionally, as mentioned previously, panelists can be screened beforehand for sensory function.

Conclusions

The human senses provide a wealth of insight for chocolate and cocoa products. Sensory evaluation provides a scientific approach to testing and analysis. In test design and set-up, there are some specific considerations to take to ensure that data will be accurate and meaningful, as chocolate and cocoa products are particularly complex stimuli. Well designed tests can capture actionable information from a “snap shot” of the product in time for the overall consumer experience.

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CHAPTER 22

Nutritional and health aspects of chocolate

Joshua D. Lambert

22.1 Introduction

Chocolate is a food with worldwide popularity. Having a high sugar and fat content, chocolate is often viewed as an indulgence that should be consumed sparingly or eliminated from the diet entirely. Chocolate and cocoa, however, contain a number of essential minerals and vitamins, as well as non-nutritive bioactive components including polyphenols, methylxanthines, and monounsaturated fatty acids. Emerging evidence suggests that chocolate and cocoa have beneficial health effects related to cardiovascular disease, metabolic syndrome, neurodegenerative diseases, and other chronic health conditions. Although the existing results are promising, additional studies, especially randomised clinical trials, are needed, to clearly demonstrate efficacy, identify the relative contributions of individual chocolate components and provide information to consumers which allow rational dietary choices to be made.

According to the National Health and Nutrition Survey (NHANES), 12.9% of adults in the United States in 2004 were chocolate consumers and the mean chocolate consumption was 40 g/day (O'Neil *et al.*, 2011). Although often viewed as an indulgence food, containing high amounts of sugar and fat which should be avoided or consumed sparingly, chocolate contains a number of important vitamins and minerals. There is also growing evidence that cocoa-derived phytochemical constituents in chocolate may mitigate the potential health impacts of the added sugar and fat derived from consuming chocolate (Gu and Lambert, 2013; Sokolov *et al.*, 2013). In addition, evidence suggests that relative to other foodstuffs with similar amounts of fat, the fatty acid composition of cocoa butter has neutral to beneficial effects on cardiovascular disease risk factors. The nutritional composition of a particular chocolate product is dependent on the amount of cocoa solids present and, therefore, discussions on the relative health benefits of chocolate should be more nuanced and focused on particular product formulations (see Chapter 20).

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Table 22.1 Typical macronutrient and energy content of the major kinds of solid chocolate[a].

	Nutrient content (per 100 g)			
	Protein (g)	**Fat (g)**	**Carbohydrate (g)**	**Energy (kcal)**
Type of chocolate				
Milk	7.65	29.7	59.4	535
White	5.87	32.1	59.2	539
Dark (45–59%)	4.88	31.3	61.2	546

[a] USDA National Nutrient Database for Standard Reference, Release 27.

22.2 Macronutrients

Chocolate contains varying amounts of energy-providing macronutrients depending on the type of chocolate and the amount of cocoa solids present. Table 22.1 shows the amount of fat, protein and carbohydrate, as well as energy present in the major solid chocolate types.

22.2.1 Fats

The fat content in chocolate is principally derived from cocoa butter. Cocoa butter consists primarily of stearic acid (C18:0, 34%), oleic acid (C18:1, 34%), and palmitic acid (C16:0, 27%). Stearic acid has been reported to have minimal effect on serum cholesterol levels, whereas an increasing body of data suggests that oleic acid may improve serum cholesterol levels and other cardiovascular risk factors (Lopez-Huertas, 2010; Sales-Campos *et al.*, 2013). Palmitic acid has been shown to moderately increase serum cholesterol levels. Tropical oils typically used as cocoa butter substitutes (e.g. shea butter) are also rich in stearic acid.

22.2.2 Carbohydrates

Sucrose added during chocolate manufacture is the largest carbohydrate source in the final product. Other carbohydrates, including glucose, dextrins, flours and starches, may be included during the manufacture of confectionery products. In addition, cocoa powder contains a significant amount of fibre (37% by dry weight). The final fibre content in solid chocolate is dependent on the amount of non-fat cocoa solids in the product: dark chocolate tends to have the highest amount (7 g/100 g) whereas white chocolate (0.2 g/100 g) has very little fibre content.

22.2.3 Proteins

Cocoa is not a significant source of protein and the protein present is poorly digestible. Milk chocolate contains the greatest amount of, and most digestible, protein of any type of chocolate due to the addition of milk proteins.

Table 22.2 Vitamin and mineral content of cocoa and chocolate (per 100 g)[a].

Ingredient	Weight of ingredient	Cocoa powder	Chocolate		
			Dark (45–59%)	Milk	White
Iron	Milligram	13.8	8	2.35	0.24
Calcium	Milligram	128	56	189	199
Zinc	Milligram	6.8	2	2.3	0.45
Magnesium	Milligram	499	146	63	12
Manganese	Milligram	3.84	1.42	0.47	0.008
Selenium	Microgram	14.0	3.0	4.5	4.5
Potassium	Milligram	1524	559	372	286
Phosphorus	Milligram	734	206	208	176
Thiamine	Microgram	78.0	25.0	112	63.0
Riboflavin	Microgram	241	50	298	282
Niacin	Milligram	2.19	0.725	0.386	0.745
Vitamin B_{12}	Microgram	0	0	0.75	0.75
Vitamin E	Milligram	0.1	0.54	0.51	0.96

[a] USDA National Nutrient Database for Standard Reference, Release 27.

22.3 Vitamins and minerals

Cocoa and chocolate contain a number of minerals (Table 22.2). Potassium, magnesium and calcium are the most abundant minerals in cocoa powder. Lesser amounts of iron, selenium and magnesium are also present. The mineral content of the cocoa is dependent on the soil conditions in which the cacao is grown. Cocoa powder also contains lesser amounts of several vitamins including thiamine, riboflavin, and vitamin E (Table 22.2). The final concentrations of vitamins and minerals in chocolate products are dependent on the amount of non-fat cocoa solids, the amount of cocoa butter and the presence of other ingredients including milk and nuts which can enhance the levels of certain vitamins and minerals (i.e. calcium and vitamin E).

22.4 Flavanols and proanthocyanidins

Cocoa beans contain high concentrations of polyphenols. Although total polyphenol content depends on the variety of cocoa beans, growth conditions, and processing steps, typically studies have reported levels of 12–18% by dry weight (Miller *et al.*, 2009; Hurst *et al.*, 2011). The monomeric polyphenols [largely (–)-epicatechin (EC) and (+)-catechin] account for approximately 10% of the total polyphenols, whereas the oligomeric and polymeric proanthocyanidins (PaC)s represent nearly 90%. Processing has been shown to impact the polyphenol content and composition of cocoa products. Fermentation, roasting and alkalisation have generally been shown to reduce the levels of total polyphenols in the finished cocoa powder (Miller *et al.*, 2009; Hurst *et al.*, 2011). With regard to individual polyphenols, both roasting and alkalisation has been shown to induce epimerisation of EC to catechin. Roasting appears to induce polymerisation of PaCs, and studies in our laboratory have shown that the lower degree of polymerisation (dp) PaCs (i.e. dimers and trimers) decrease as a function of roasting time, whereas the higher dp PaCs increase (Stanley, personal communication). Alkali treatment reduces PaC levels as a function of time, however the identity of the end products of this reaction are unclear.

22.5 Methylxanthines

Cocoa and chocolate contain significant levels of the methylxanthines, theobromine and caffeine, with the former being more abundant. The theobromine and caffeine components of chocolate have been suggested to play a role in the human health effects of chocolate, principally through their antagonism of the adenosine receptor (Franco *et al.*, 2013). These compounds can stimulate the central nervous system and cardiac muscle, induce smooth muscle relaxation and bronchodilation and induce diuresis. In general, studies have shown that caffeine is more potent at inducing these effects than theobromine. The amount of these compounds present in the final cocoa product depends on the source of the cocoa beans used, the processing steps and the composition (i.e. amounts of non-fat cocoa solids, cocoa butter etc.). The levels of theobromine and caffeine in non-fat cocoa bean solids are typically 2.5% and 0.24% of the dry weight, respectively (Franco *et al.*, 2013). Although variable from product to product, an average bar of milk chocolate (50 g) contains 10 mg caffeine, whereas a similar size bar of dark chocolate may contain 50 mg, depending on the non-fat cocoa solid content.

22.6 Cardiovascular disease

Since 2000, 68 human intervention studies have examined the effect of cocoa and chocolate-based interventions (or cocoa-derived compounds) on biomarkers of cardiovascular disease (CVD) risk. In addition a number of epidemiological and laboratory studies have examined cocoa and chocolate in relation to CVD. Although considerable effort has focused on the polyphenolic fraction of cocoa (i.e. flavanols and PaCs), other studies have demonstrated beneficial effects on CVD from cocoa fibre and cocoa butter lipid components. In general, epidemiological studies have shown the consumption of 50–100 g of chocolate per week may reduce risk of CVD. For example, Buijsse *et al.* (2010) have reported that CVD mortality was inversely associated with long-term cocoa consumption.

Human intervention studies have tended to focus on markers of inflammation, platelet activation, and endothelial function (Ellam and Williamson, 2013; Gu and Lambert, 2013). Consumption of dark chocolate, flavanol-rich cocoa preparations and purified cocoa flavanols (i.e. (–)-epicatechin) have been shown to enhance flow-mediated dilation of peripheral blood vessels and decrease blood pressure both in healthy subjects as well as those with increased risk of CVD (West *et al.*, 2014; Berends *et al.*, 2015). In animal models and *in vitro* studies, cocoa and cocoa-derived components have been shown to enhance endothelial nitric oxide synthase levels and increase intracellular nitric oxide levels. Given the role of nitric oxide in vasodilation, it is likely that this mechanism accounts in part for improvements in vascular endothelial function and reduced blood pressure observed in human intervention studies.

Although studies both in humans and in animal models have shown that pure EC can reduce blood pressure, the importance of other cocoa components has been suggested by some studies. For example, dietary supplementation of spontaneously hypertensive rats with soluble cocoa fibre (SCF) has been reported to decrease both systolic and diastolic blood pressure (Sanchez *et al.*, 2010). Given the complex nature of chocolate as a food product, it is likely that multiple bioactive components interact to produce the overall health beneficial effects reportedly associated with chocolate consumption. Further studies are needed to determine the relative contribution of each and the mechanisms of interaction.

22.7 Obesity and metabolic syndrome

Obesity (body mass index ≥ 30 kg/m^2) is a growing public health problem worldwide and has been linked to the development of a number of chronic diseases including diabetes, cancer, fatty liver disease and others. Metabolic syndrome (MetS) comprises a cluster of metabolic abnormalities, which has been defined by the International Diabetes Foundation as including central obesity and at least two of the following: low high-density lipoprotein (HDL) cholesterol, high triacylglycerols, high systolic or diastolic blood pressure and increased fasting glucose (Ford, 2005; Cherniack, 2011).

A growing number of epidemiological, human intervention and laboratory animal studies have shown that consumption of chocolate and cocoa can mitigate obesity and symptoms of MetS. For example, a cross-sectional study of 1108 adults from San Diego, California, found that chocolate consumption was inversely associated with body mass index (Golomb *et al.*, 2012). Although other studies have observed similar effects in other populations (O'Neil *et al.*, 2011), some population-based studies have shown an opposite trend. For example, a prospective study of more than 12 000 subjects in the Atherosclerosis Risk in Communities cohort found a direct correlation between chocolate intake and body weight gain (Greenberg and Buijsse, 2013). The reasons for these different results are not clear, but may be the result of differences in background diet, chocolate products consumed or subject genetics. Additional studies are needed.

Studies of cocoa and cocoa polyphenols in animal models have tended to support the obesity preventive effects of chocolate. For example, Yamashita *et al.* (2012) found that treatment of high fat-fed C57BL6/J mice with a PaC-rich cocoa liquor extract (0.5 and 2.0%) for 13 weeks promoted glucose transporter 4 translocation and significantly reduced body weight, blood glucose, insulin and total cholesterol levels in obese mice. In addition, phosphorylation of AMP-activated protein kinase α was enhanced by PaCs (2%) in skeletal muscle adipose tissue and liver.

In another recent study, Min *et al.* (2013) found that C57BL/6 mice fed a high fat diet containing cocoa polyphenol extract for five weeks significantly reduced body weight and epididymal fat mass, as well as decreased plasma TG levels.

Studies in our laboratory on the effect of dietary supplementation of high fat-fed mice with cocoa powder failed to find a significant decrease in final body weight or reduction in body fat mass, but did show a reduction in fasting plasma insulin levels and an amelioration of obesity-related fatty liver disease (Gu *et al.*, 2014a).

Although a great deal of attention has been paid to the cocoa polyphenols, other components of cocoa have been reported to contribute to the obesity and MetS preventive effects observed in animal models. For example, administration of methylxanthine-rich cocoa extract for four weeks significantly reduced plasma free fatty acid, total cholesterol, triglyceride and oxidative stress biomarker (8-isoprostane) in obese-diabetic rats (Jalil *et al.*, 2008).

The effects of SCF have been studied in Zucker fatty rats (Sanchez *et al.*, 2010). Zucker fatty rats were fed either standard diet or 5% SCF-enriched diet for seven weeks. The SCF group showed less body weight gain and food intake than the standard group. Lower values of the total cholesterol/HDL-cholesterol ratio, index of insulin resistance and plasma triglyceride levels were observed in those fed a cocoa fibre-enriched diet.

22.8 Inflammation

Chronic inflammation plays a causative role in the development of a number of diseases, including arthritis, cancer and diabetes, and represents a mechanistic link between obesity and its comorbidities. There is growing evidence from both observational and experimental studies that consumption of cocoa and chocolate may reduce inflammatory biomarkers, including serum levels of c-reactive protein (CRP) and pro-inflammatory cytokines.

In a study of 4849 Italian subjects free of any chronic disease, 1317 people reported having eaten any chocolate during the past year and 824 ate chocolate regularly in the form of dark chocolate only (Di Giuseppe *et al.*, 2008). After adjustment for multiple confounders, regular consumption of dark chocolate associated with lower levels of serum CRP concentration ($P = 0.038$). A J-shaped dose–response relationship was observed with those consuming ≤ 20 g of dark chocolate per day having significantly lower serum CRP concentrations than either non-consumers or those consuming ≥ 20 g chocolate per day.

In a randomised, crossover trial of 20 obese but healthy subjects given a control beverage or one of three cocoa beverages containing 180–900 mg flavanol daily for five days, cocoa consumption dose-dependently decreased the circulating levels of CRP by 16% and 8-isoprostane by 5.7% (Stote *et al.*, 2012).

Several studies have failed to find an anti-inflammatory effect in unhealthy patients. In a study of 20 hypertensive patients, consumption of a flavanol-rich cocoa drink (900 mg flavanols/day) for two weeks failed to decrease the plasma levels of tumour necrosis factor α, interleukin (IL)-1β or IL-6, although the average brachial artery diameter was increased compared to placebo group (Muniyappa *et al.*, 2008). Monagas *et al.* (2009) reported the effect of a four week randomised cross-over trial of 40 g cocoa powder in skimmed milk daily versus skimmed milk in 42 patients at high risk of cardiovascular disease. Plasma levels of monocyte chemotactic protein (MCP)-1, IL-6 or CRP were unchanged; however, serum concentrations of P-selectin and intracellular adhesion molecule-1 were lower after the cocoa powder intervention. Thus, there is some evidence that cocoa and cocoa-rich foods might reduce low-grade systemic inflammation but additional human intervention studies are needed.

Dietary supplementation with cocoa and cocoa polyphenols has been shown to reduce inflammation in a number of animal models. For example, we have reported that dietary supplementation with cocoa powder reduced plasma levels of MCP-1 and IL-6 in high fat-fed obese mice (Gu *et al.*, 2014a). Moreover, supplementation reduced the expression of inflammatory mediators by adipose-associated macrophages (Gu *et al.*, 2014b). These cells play a key role in the development of insulin resistance and type II diabetes.

22.9 Neuroprotective and cognitive effects

A somewhat limited number of studies have examined the neuroprotective and cognitive function effects of cocoa and chocolate. Caffeine and, to a lesser extent, theobromine, are known to have central nervous system (CNS) stimulatory effects. Consumption of these compounds is associated with increased awareness and heightened focus. Recent studies have also focused on the polyphenols present in cocoa.

Population-based studies on the neuroprotective effects of chocolate are limited, but the results tend to be positive. For example, a cross-sectional study of elderly Norwegians found a positive association between cognitive performance and intake of flavonoids from chocolate, tea and wine (Nurk *et al.*, 2009).

A prospective cohort study of 1650 subjects aged 65 years or older found that, after a 10-year follow-up, subjects in the lowest quartile of chocolate consumption showed a loss of cognitive performance (Mini-Mental State Examination) that was twice as large as subjects in the highest quartile (Letenneur *et al.*, 2007).

Animal model studies tend to support the neuroprotective effects suggested by population studies. Oral administration of high flavanol-containing cocoa mitigated age-related declines in maze performance in rats. Interestingly, treatment also extended lifespan (Bisson *et al.*, 2008). In a study of Tg mice, which overexpress human amyloid precursor protein and develop amyloid plaques, supplementation with a diet enriched with cocoa and dried fruits, reduced plaque formation in the brain and reduced amyloid-associated cognitive decline (Fernandez-Fernandez *et al.*, 2012).

The methylxanthines present in cocoa, especially the caffeine, likely contribute to the neuroprotective effects of chocolate and cocoa. Both observational studies as well as human intervention studies have suggested neuroprotective and psychostimulatory effects of caffeine. For example, a population-based cohort study of more than 7000 French subjects aged 65 years and older found an inverse association between caffeine consumption and loss of verbal recall and visuospatial memory (Ritchie *et al.*, 2007). Interestingly, the effects were confined to women, and there was no association between caffeine consumption and risk of dementia. The results may suggest that caffeine can mitigate the symptoms of cognitive decline, but not the underlying cause. Human intervention studies have shown that caffeine has been shown to affect cognitive performance even at doses as low as 12.5 mg (Smit and Rogers 2000). This finding is significant, because the effective doses are similar to those found in chocolate (20–43 mg/100 g).

Chocolate and cocoa consumption have been shown in some studies to improve memory and mood. In mice, dietary treatment with pure EC increased angiogenesis in the hippocampus, the area of the brain associated with memory and learning (van Praag *et al.*, 2007). This effect would be expected to result in enhanced blood flow to the hippocampus. Consistent with this finding, a small study in 16 healthy subjects found that ingestion of a high cocoa flavanol beverage (450 mg dose) resulted in increased cerebral blood flow in a time-dependent manner (Francis *et al.*, 2006). The kinetics of this increased blood flow correlated well with the pharmacokinetics of EC in human subjects (Lee *et al.*, 2002). Studies to examine the effect of cocoa and chocolate on cognition are limited and have mixed results (Sokolov *et al.*, 2013). Additional studies are needed to determine if consumption of chocolate and cocoa-containing foods really do improve memory.

Studies in both animals and human subjects have demonstrated effects of chocolate and cocoa consumption on mood and mood-related biomarkers. For example, treatment of rats with cocoa for two weeks improved performance in the elevated T-maze test, an indication of decreased anxiety (Yamada *et al.*, 2009). Longer-term tests, showed that cocoa treatment increased brain concentrations of serotonin. Pase *et al.* (2013) reported similar findings in human subjects. Treatment of 72 healthy participants (age 40–65 years) with a cocoa-based beverage (500 mg/day cocoa polyphenols) resulted in an increase in subjective calmness and contentedness compared to control. More studies are needed to better understand these mood modulating effects including larger human intervention studies to demonstrate efficacy and animal model studies to determine mechanism of action.

Conclusions

Although chocolate is often viewed as an indulgence food by virtue of its high fat and sugar content, chocolate and cocoa contain a number of essential nutrients in significant quantities, as well as several classes of chemicals with putative non-nutritive bioactivity, including polyphenols, monounsaturated fatty acids and methylxanthines. The results of existing literature are promising with regard to the potential health beneficial effects of chocolate and other cocoa-containing foods, but additional studies are needed to more fully demonstrate efficacy, better understand the underlying mechanisms of action and inform producers in the development of novel cocoa and chocolate products with enhanced health beneficial effects.

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CHAPTER 23

Quality control and shelf life

Marlene B. Stauffer

23.1 Introduction

This chapter focuses on the quality parameters required to manufacture industrial chocolate from the cocoa bean to the finished user of bulk chocolate. Meeting the quality parameters for chocolate must follow the government regulations specific to the country the product is being manufactured in or is shipped to as well as quality requirements to meet customer specifications.

Areas of discussion will include but are not limited to: United States Code of Federal Regulation (CFR) requirements, United States Food Safety Modernisation Act (FSMA) quality aspects, Codex regulations, particle size, roasting controls, sensory, physical quality properties of cocoa and chocolate, tempering and shelf life. The process of manufacturing chocolate will be discussed from bean to chocolate ready to be made into fine confections with an emphasis on control of quality throughout manufacturing.

The chocolate manufacturer receives specific varieties of cocoa beans dependent on the final chocolate outcome desired by either the candy maker or the consumer (Table 23.1). Chocolate manufacturers around the world supply bulk chocolate to retail confectioners to make their special products. There are two types of chocolate manufacturers. One processes the cocoa bean to finished chocolate and supplies retail confectioners with everything from chocolate to chocolate liquor, cocoa butter, and/or cocoa powder. The other type may take the cocoa beans direct to finished chocolate products for retail sale.

23.2 Finding the perfect bean

Before the chocolate manufacturer receives cocoa beans into their factory, selection and sampling must occur. This is typically at the port of entry of the ship transporting the cocoa beans or through pre-ship sampling. Certified Samplers will perform the “Cut test,” sampling individual lots of cocoa beans to assess the internal bean quality, size, and moisture (see Chapter 2).

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Table 23.1 Bean blends influencing quality.

Product type	Bean selection
Milk chocolate	Africa, South America, Pacific areas
Light milk chocolate	Java, Cameroon, Madagascar
Dark chocolate	South America, West indies, special select beans
Cocoa butter	Africa, Pacific areas, West Indies
Cocoa powder	Africa, Pacific areas, West Indies

Example of a quality procedure: Cut test

1. The bean count per 100 g should be calculated to include all estimates on partial beans, shells and nibs.
2. Flats and shrivelled beans will be recorded as one and the same as the number per 100 g (not as a percentage).
3. Cut 100 beans either by a knife or using a guillotine.
4. All trash (twigs, stones and other non-bean plant material) should be noted as number of pieces (recorded as trash).
5. The number of fermented beans may be obtained by adding up all fully brown beans; purple and brown-purple would be separated out and used to determine a bean type specific attribute; yellow, pink and white beans would be considered unfermented (omit mouldy, slaty, flat, infested and trash from this total) and subtract their sum from 100.
6. Yellow mould or black mould should be noted separately. Example: count beans with yellow mould and record, then count the rest of the mouldy beans and record weight. Mould is expressed as yellow mould and total mould.

Beans are examined based on this cut test to let the evaluator know if the beans are the size that will process well and not have a large amount of waste or shell. The perfect cocoa bean is one that is large in size with a very thin shell for protection and ease of removal. The inside of a perfect bean depends on the exact origin of that cocoa bean to provide precursors to develop the cocoa flavour desired. For example, Ivory Coast beans give a sour, mild chocolate flavour, whereas Ecuadorian beans can produce a fruity, full flavour chocolate. The amount of fermentation will dictate if a cocoa bean is sour, winey or fruity. Unfermented cocoa beans tend to have more astringent flavour, shell removal is more difficult and they lack cocoa notes, but they still can be utilised as cocoa beans for cocoa butter and cocoa powders. Over-fermented cocoa beans can be very dark in colour, putrid and undesirable. The food defect action levels (DALs) for cocoa bean cut tests are shown in Table 23.2.

The Food Safety Modernization Act (FSMA), signed into legislation in 2011, is the most sweeping change to the United States food safety system since 1938. All foreign suppliers must meet the same stringent United States Food and Drug Administration (FDA) requirements. FDA is a government agency established in

Table 23.2 FDA defect action level.

Defect	Action level
Mould	<4%
Infestation	<4%
Total mouldy and infested	<6%
Degree of fermentation	Bean type dependent
Moisture	<8%
Count per 100 g	Bean type dependent

Figure 23.1 De-shelled cocoa beans.

1906 with the passage of the Federal Food and Drugs Act. The agency is currently separated into five centres, which oversee a majority of the organisation's obligations involving food, drugs, cosmetics, animal food, dietary supplements, medical devices, biological goods and blood products.

The Codex Alimentarius Commission, established by FAO and WHO in 1963, develops harmonised international food standards, guidelines and codes of practice to protect the health of the consumers and ensure fair practices in the food trade. The Commission also promotes coordination of all food standards work undertaken by international governmental and non-governmental organisations.

Cocoa bean samples are pilot roasted, de-shelled and ground into chocolate liquor for flavour evaluation, a critical quality investigation step (Figure 23.1). Free fatty acid (FFA) testing may also be performed to indicate freshness or how well the cocoa beans have been prepared and handled in the supply chain. FFA content of cocoa butter should not exceed 1.75 % expressed as oleic acid. The higher the FFA content, the more likely the cocoa butter will be soft, possibly causing tempering and solidification problems and unstable crystal forms (see Chapter 13). The cocoa bean quality and origin will influence the final cocoa butter melting characteristics (see Chapter 7).

Upon approval, lots will then be distributed by trailer, truck, container or railcar to the chocolate manufacturing facility. Fumigation would typically occur at the port of entry or port warehouses if necessary prior to delivery. Organic cocoa beans will follow organic storage requirements – no fumigation. Inspection of warehouse storage facilities is necessary to ensure receipt of cocoa beans in good condition without pests or other integrity concerns.

23.3 Cocoa bean preparation on arrival

The cocoa beans arrive at the chocolate processing facility typically in large jute sacks or bulk containers (Figure 23.2). The integrity of the product and the condition it arrives in are critical. Trucks must arrive with tamper evident seals cross checking that all seals match the incoming paperwork. The trailer and product will be examined based on criteria specific to each receiving facility. The beans are gently unloaded to be cleaned prior to storage with lot control.

The cocoa beans go through a cleaning process involving screening, aspiration, magnets and de-stoning to remove strings, clumps, dried cacao pulp, pod pieces, stones and other foreign material. If this cleaning process does not take place efficiently, foreign materials may damage downstream equipment and jeopardise product integrity causing chocolate liquor or cocoa powder to fail to meet the FDA DALs for extraneous matter.

23.4 Cocoa bean cleaning

Screening cocoa beans will remove both coarse and fine residue. Friction between the bean and the screen surface removes dust and sand sticking to the shells. Lightweight particles are pulled out by aspiration. The beans can then be passed over a magnet and on to a de-stoner. This operates on a fluidised bed theory. The beans are lifted into the air slightly and held back by air currents. The denser stones remain on a screen or platform where they can be accumulated and discharged. Insufficient cleaning of cocoa beans can cause excessive wear on equipment further down in the process and can contribute unwanted flavours to the chocolate liquor impacting final quality. At completion of cleaning, the cocoa beans are typically weighed and transported as gently as possible to isolated finished storage silos. The outer shell protects the integrity of the inside of the cocoa bean (the nib or the meat of the cocoa bean).


(a)


(b)

Figure 23.2 (a) Ship transporting cocoa beans entering port. (b) Unloading cocoa beans from ship.

23.5 Roasting of cocoa beans

Roasting is the process where precursors developed during fermentation are turned into chocolate flavour through a selected heating process (see Chapters 2 and 3). This step of chocolate manufacturing is critical to the final chocolate quality. Recipes are selected based on the origin of the bean and how low or high a roast is needed. Goals in roasting are to obtain a clean, even roast with good flavour development and sufficient lowering of microbiological counts using a validated roaster. A validated roaster will ensure the required log kill specific to the roaster, plant and or regulatory requirement. Low, medium and high roasts can be developed by adjusting time, temperature and humidity in the roasting process.

A low roast will produce mild flavours and lighter colours, a high roast will produce stronger flavours and darker colours. The degree of roast chosen depends on the final flavour desired. The chocolate manufacturer can blend beans or blend chocolate liquors to make their final chocolate (Figure 23.3). More than 400 volatile compounds have been found in cocoa following fermentation, drying, roasting and conching (see Chapter 8). During the roasting process (typically from 120 to 200 °C) several reactions occur. These include Maillard or non-enzymatic browning reactions between reducing sugars and amino acids. Some flavour elements in a chocolate are: (i) highly volatile compounds contributing sour notes, (ii) moderately volatile compounds contributing roasted or flowery notes and (iii) compounds of low volatility

Figure 23.3 Bulk unloading of cocoa beans at factory.

contributing milky and caramel notes. The ensemble of all of these flavour components produces unique chocolate flavour (see Chapter 8).

In a cocoa bean processing facility, modern technology today transports the cocoa beans to the selected roasters to begin the process. There are several types of roasting processes; the two most common methods of roasting are “whole bean” roasting or “nib” roasting (see Chapter 3).

23.5.1 Whole bean roasting

Whole bean roasting takes place typically on a fluidised bed or chamber at a specific temperature and dwell time. The bean flow rate, depth of beans being roasted and internal bean temperature are critical variables to optimise. De-bacterialisation through condensation is a method to pretreat whole beans prior to roasting to improve the reduction of bacteria and prepare the cocoa bean for shell removal (Figure 23.4). The moisture content is reduced from about 7% to slightly less than 2%. As the moisture is driven off, the temperature of the bean mass slowly rises. Flavour development is said to occur between 110 and 140 °C. Bean roasting allows for variety in the degree of roast and development of flavour but, due to variability in bean size, it can be difficult to

Figure 23.4 Debacterialisation system in whole bean roasting.

achieve an even roast for all beans. A great deal of energy is required to transfer heat through the insulating layer of the bean shell. Penetration of the shell with this heat may result in a less even roasted internal nib with more harsh, over-roasted outer sections. During this process as much as 0.2–0.3% fat can migrate to the shell and be lost.

23.5.2 Winnowing (separation of shell from nib)

Winnowing takes place after whole bean roasting (see Chapter 3). Cocoa bean shell is approximately 10–14% of the bean weight and contains adhering pulp with foreign material and fine sand. Winnowing relies on differences in density between the shell and the nib to separate them.

Warm beans are first subjected to an impact crusher where the beans are broken or cracked. It is more difficult to remove the shell from some beans than others so adjustments to process controls may be required. The key is to be as gentle as possible to create large pieces of nibs and not too many fine particles. A combination of sieves and air currents complete the separation. The light density shells are blown away leaving behind nibs of similar size. Aspiration removes any fine dust. Efficient cracking and winnowing results in acceptable quality of less than 1.75% of shell remaining in the nib. Continuous monitoring is required to prevent insufficient removal of shell or loss of nib and to properly control flavour, quality parameters, profitability and wear on equipment.

23.5.3 Nib roasting

In nib roasting, a pre-thermal treatment is given to the cocoa beans to remove some of the moisture and aid in removal of the shell without roasting the nib. By removing some of the moisture, the shell will loosen and detach from the nib, allowing its removal prior to the roasting process. Steam vapour developed causes the shell to burst, expand out and detach from the nib. An added benefit of this process is that foreign material on the outside of the shell is burnt off, resulting in reduced microbiological contamination. The beans then go through the winnowing process and on to nib roasting (Figure 23.5). Nibs travel to the nib roasters as gently as possible to avoid creation of fines. Roasting is performed through convection and conduction. Moisture can be introduced in varying stages for flavour and colour development and microbial sterilisation. This type of system can be continuous or a batch type and specific recipes with careful controls optimise flavour.

23.6 Cocoa nib grinding

Once the roasting process is complete, the cocoa nibs are ground into cocoa liquor which can be referred to as baking chocolate, unsweetened chocolate, bitter chocolate, cooking chocolate, chocolate coating, unsweetened chocolate

Figure 23.5 Cocoa nib roaster.

coating or chocolate according to 21 CFR Part 163.11. Chocolate liquor or cocoa mass is considered the solid or semi-plastic food prepared by finely grinding the kernel or nib of the cocoa bean.

Cocoa nib grinding is usually performed in two or three stages. Pre-grinding and final grinding by multiple mill types (see Chapter 9). The key quality needs in this area are to evaluate the degree of particle size reduction in each stage of the process. This can be done through particle size distribution utilising laser diffraction or by sieve analysis typically through a 75 μm sieve. Specifications will be set up based on the needs required for the specific liquor. The setup of machinery will greatly impact the final size distribution and milling efficiency. The resulting chocolate liquor can be used to manufacture chocolate, used in cocoa butter pressing to produce cocoa butter and cocoa cake or shipped to other chocolate manufacturers in liquid or solid form. Chocolate liquor will be evaluated for particle size (fineness), total fat, moisture, flavour, colour and microbiological testing. Monitoring of extraneous matter, heavy metals and pesticides is also critical to meet all regulatory requirements of the producing country.

23.7 Cocoa butter pressing

This process involves the blending of select chocolate liquors to successfully separate the component parts of chocolate liquor – cocoa butter and cocoa press cake Figure 23.6. Hot chocolate liquor is fed into hydraulic presses that remove a predetermined percentage of the cocoa butter, leaving behind a press cake that may contain 10–24% cocoa butter. The cocoa cake must be evaluated for total fat content and the presses monitored for operational integrity of the screen quality and cocoa butter clarity. The cocoa butter is then filtered to a golden yellow colour and stored in tanks for use in chocolate manufacturing. It may also be shipped in liquid tankers to other chocolate factories or in moulded form to small users of cocoa butter. Cocoa butter is unique among vegetable fats because it is a solid at normal room temperature and melts at 32–34 °C (90–93 °F), which is just below body temperature. It is very resistant to oxidation and rancidity making it very practical for long shelf life products. Critical tests for cocoa butter would be FFA and moisture. Target levels of <1.75% FFA and <0.1% moisture are standard for the chocolate industry.

Deodorisation of cocoa butter through steam distillation may also be performed for the manufacturing of white chocolates or to take away flavours that are undesirable and not beneficial to the final flavour of the chocolate being manufactured (see Chapter 3). Quality parameters include FFA by AOCS Ca 5a-40 and Lovibond colour measuring the colour of liquid oils and fats in terms of Lovibond red, yellow, blue and neutral units (AOCS Method Cc 13e-92). Melting characteristics are also critical to the temper ability of the cocoa butter. The “degree of hardness” or the “melting and crystallisation properties” of a cocoa butter are commonly measured using the Jensen cooling curve methodology.

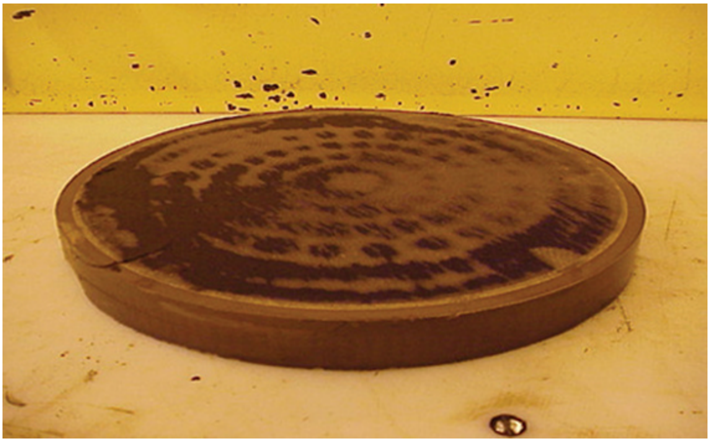

Figure 23.6 Cocoa press cake.

23.8 Cocoa powder

The co-product of cocoa butter pressing is cocoa powder. The press cake remaining after a portion of the cocoa butter is pressed out of the chocolate liquor can be ground into fine cocoa powder. Cocoa powder is defined in 21 CFR Part 163 as the food prepared by pulverising the material remaining after part of the cocoa fat has been removed from ground cocoa nibs. Alkalisation of cocoa powder can also be performed to adjust colour, pH, and flavour of the cocoa powders. Powders can range from very light in colour to brown to red to black (Figure 23.7). Cocoas are used in many industries today to enhance special characteristics to make chocolatey products for the bakery, confectionery, dairy, beverage and nutraceutical industries.

Cocoa powder final testing consists of microbiological and physical testing. Aerobic plate count, coliforms, *Escherichia coli* and possibly Enterobacteriacea, yeast, mould and *Salmonella* are required microbiological tests. Physical testing would include pH (AOAC Official Method of Analysis 970.21 pH of Cacao Products), colour either visual or by colorimeter, percentage fat (AOAC 963.15), moisture (AOAC 991.02) and particle size (% through a 200 mesh screen). Colour and pH will vary based on the actual cocoa powder and whether it has gone through an alkalisation process. Total fat will range from 10–12% most commonly; 15–17 and 22–24% fat are less common. Moisture would be <5% and a typical particle size is >99.0 to 99.5% through a 200 mesh screen – again cocoa type and final product usage will dictate physical requirements.

23.9 Chocolate manufacturing

The chocolate factory will manufacture milk chocolate, semi-sweet, sweet chocolate or white chocolate, using specifically selected raw materials following vendor approval programmes. The CFR specifies the following permitted ingredients for "chocolate" with other optional ingredients:

Figure 23.7 Various cocoa powder colours.

Milk and white chocolate contain milk. Dark or semi-sweet chocolate can also contain milk as part of its formula. Almost all chocolate contains soy lecithin (added as an emulsifier). Milk and soy are considered allergens. The chocolate manufacturer develops formulas and processing procedures if possible to segregate a dark chocolate without milk ingredients from a dark chocolate containing milk ingredients. This is not always possible in some factories and would require appropriate changeover procedures and labelling where necessary (see Chapter 25).

Processing steps in chocolate making:

1. Mixing;
2. Refining;
3. Conching;
4. Standardising;
5. Storage and shipment.

A chocolate manufacturer must develop a recipe based on meeting the Standards of Identity for Chocolate, which can be found in 21 CFR Part 163, in the Codex or in the specific country standard of identity. The raw materials chocolate liquor, cocoa butter and dairy ingredients may have been manufactured

Table 23.3 Requirements for products labelled "chocolate" in the United States (21 CFR Part 163).

Milk chocolate 21 CFR Part 163.130	**Semi-sweet or sweet chocolate 21 CFR Part 163.123**	**White chocolate 21 CFR Part 163.124**
Nutritive carbohydrate sweetener	Nutritive carbohydrate sweetener	Nutritive carbohydrate sweetener
Chocolate liquor – at least 10%	Chocolate liquor – 15% for sweet chocolate and at least 35% for semi-sweet or bittersweet chocolate	Chocolate liquor is not added
Cocoa butter	Cocoa butter	Cocoa butter – 20% minimum
Dairy ingredients – at least 12%, no whey; 3.39% minimum milk fat	Dairy ingredients – less than 12%, no whey	Dairy ingredients – 14% minimum, 5% maximum Whey, 3.5% minimum milk fat
Soy lecithin – an emulsifier; less than 1% total emulsifiers	Soy lecithin – an emulsifier; less than 1% total emulsifiers	Soy lecithin – an emulsifier; less than 1.5% total emulsifiers
PGPR – polyglycerol polyricinoleate; an emulsifier or other approved emulsifiers	PGPR – polyglycerol polyricinoleate; an emulsifier or other approved emulsifiers	PGPR – polyglycerol polyricinoleate; an emulsifier or other approved emulsifiers
Vanilla; a natural flavouring	Vanilla; a natural flavouring	Vanilla; a natural flavuring
Vanillin; an artificial flavouring	Vanillin; an artificial flavouring	Vanillin; an artificial flavouring
Flavourings not imitating any ingredients singly or in combination	Flavourings not imitating any ingredients singly or in combination	Flavourings not imitating any ingredients singly or in combination

internally at a chocolate factory or purchased through a vendor assurance programme. Additional ingredients requiring purchase would be sugar, emulsifiers and flavourings. Typical dairy ingredients could be whole milk powder, milk crumb, non-fat dry milk, anhydrous milk fat, sweetened condensed milk and whey powder (see Chapter 5).

23.9.1 Mixing

Mixing is the first step in making milk or dark chocolate. Sugar, chocolate liquor, dairy ingredients if desired and a portion of the cocoa butter are mixed together to form a paste. This process may be by batch or automatic. The consistency of the paste is very important in obtaining the correct setup for the next step in the process.

23.9.2 Refining

Refining is where the mixture will be turned from a paste to a fine flake. This is typically a two-stage process going through a pre-refiner to condition the mass for the final finishing refiner. A refiner is a large machine with steel rolls mounted vertically with the bottom feed roll offset (see Chapter 9). The rolls are slightly crowned so when the machine is in operation, the pressure exerted will ensure a film of chocolate of even thickness spreading over the entire roll surface. The speed of the rolls increases from bottom to top and allows the chocolate film to be transferred from one roll to the next resulting in shearing action. The gap between the rolls will be adjusted to crush particles of sugar, cocoa and milk ingredients if present to the desired fineness. It is important to envelope the particles with fat. Refining will increase the number of particles, increase the surface area and thus turn this paste mixture into a light coloured, fine powdery mass. Fine chocolates will have an average particle size of 15–20 μm and more coarse chocolates would be 30–35 μm. The fineness required depends on what final product will be made using this product. Truffles would need very fine chocolate whereas a crisped rice product would not need quite as fine a chocolate. Operations must have trained operators to maintain the consistency of the mass and measure fineness and colour on-line to ensure the correct quality outcome. The proper particle size and distribution will impact the quality of the product texture, mouth feel and colour. It will also affect the amount of cocoa butter required to meet specific flow properties adjusting the cost of the final product.

23.9.3 Conching

Conching is an essential process for the development of the final texture and flavour of a chocolate greatly determining the product final quality (see Chapter 10). After refining, the refiner flake travels to a conche. Conches are large machines designed to work the chocolate mass and can be manipulated by time, temperature and shear. This mixing–kneading operation incorporates energy into the mass and is said to remove unwanted volatiles, reduce moisture, round particles, reduce viscosity, promote flavour development, reduce agglomeration and reduce acidity and bitterness (see Chapter 10).

Conching temperatures range from 45 to 75 °C for milk chocolates and 55–90 °C for dark chocolates. Temperature adjustments will aid in the degree of caramelisation. Conching time may vary from a few hours to several days. A conched chocolate flavour will be more rounded, with smooth chocolatey notes and have a more fine taste. An unconched chocolate may have flavour spikes, not be rounded, with hints of raw notes.

23.9.4 Standardising

Standardising is a very important step to fine tune the product with emulsifiers and flavourings and prepare it for final usage. Once the conching process is complete, the emulsifiers and flavourings will be added to the chocolate mass. Additional cocoa butter may also be added at this stage to bring the chocolate to the desired viscosity and yield value. Strict laboratory control and analytical equipment is used to evaluate the chocolate and determine the viscosity, particle size, fat content, colour and moisture content. The product will also be tested microbiologically to make sure product is safe for consumption. Once approved, it will be pumped through large fine screens to remove any agglomerates, through magnets and on to tank storage.

Viscosity is a measurement used to describe the flow properties of a product – specifically its resistance to flow (see Chapter 11). Some ways of measuring viscosity are using MacMichael, Brookfield and Haake instruments. All of these methods are used in industry today, with Brookfield being the most common in the United States.

The MacMichael is a single-point system. The product is measured at a specific temperature, using a specific cylinder diameter and depth. It gives a number indicating how thick or thin a product is, but does not tell a lot about the flow characteristics of the product. This is not commonly used today, but the original numbers generated from this method are still referred to when selecting a specific coating. For example, a 65 viscosity refers to a chocolate for hollow moulding; a 145 viscosity might be used for enrobing or moulding with inclusions and a 200 viscosity for solid moulding.

The Brookfield viscometer can be used to measure MacMichael numbers, but it can also show a more complete measurement of the chocolate performance or flow properties. Using a Brookfield, at a specific temperature, one can take readings at increasing rates of shear ranging from 1 to 50 rpm, followed by similar readings at decreasing speeds. Using Casson’s calculations, viscosity can be determined (see Chapter 11).

A lower yield value is desired for moulding so product will flow evenly into a mould, especially with inclusions, so proper shakeout can occur and removal of air pockets is successful. A higher yield value is desired in enrobing to prevent decorations from collapsing and to avoid feet formation on the bottom of pieces.

Emulsifiers also influence flow properties of chocolate. Lecithin is the most typical emulsifier utilised in chocolate manufacturing. Lecithin has both lipophilic (fat-loving) and hydrophilic (water-loving) properties. This surface active agent greatly affects chocolate fluidity (see Chapter 11). The addition of 0.1–0.3% lecithin has the same viscosity reducing effects as over 10 times this amount of cocoa butter. Polyglycerol polyricinoleate is an approved emulsifier for the chocolate manufacturer that greatly reduces and can even eliminate yield value of chocolate. Actual values for yield value and plastic viscosity need to be determined based on what will work best in a specific application and equipment.

23.9.5 Particle size

A particle is any object having definite physical boundaries in all directions without respect to size. Traditionally, fineness (how coarse or fine) is determined by handheld micrometers measuring only the largest particle in the sample (Figure 23.8).

Example procedure:

- Calibrate micrometer to read 0.
- Open the surfaces up and add a small amount of sample to the anvil.
- Close slowly until the anvil and spindle barely start to touch.
- Use ratchet to close and stop after a minimum of three gentle clicks (too much pressure gives a lower particle size reading). Note: a micrometer reads in microns and inches.

The micrometer does not measure the distribution of the particles, only the largest particle, but it is a great tool to use on-line in the production process or for a quick check as products are received in to the manufacturing plants.

Laser-light scattering measuring equipment has been developed and is widely used to look at all the particles of a mass today (see Chapter 24). This unit can identify the size and amount of all particles within the determining

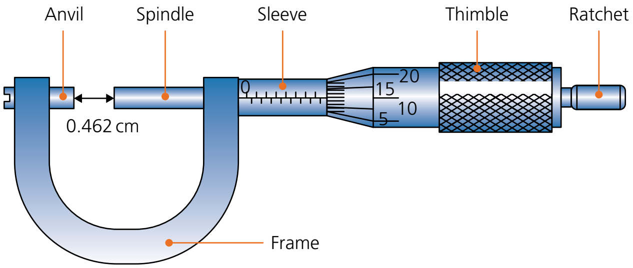

Figure 23.8 Hand held micrometer (schematic provide by www.tutorvista.com).

range of the instrument. Particles will diffract the laser beam at different angles depending on their size. The laser beam is focused on a field of particles and then the angle of diffraction is observed. Smaller particles diffract light at wider angles and different intensities than larger particles. This type of analysis can tell the distribution of the particles – information that is needed to evaluate fat requirements, equipment operation, yield value and mouth feel.

23.9.6 Type of fats

Cocoa butter is the ultimate fat with desirable melt in the mouth enabling proper flavour release. Cocoa butter with its unique melting characteristics requires tempering. Tempering is the process of inducing partial crystallisation of cocoa butter to ensure a finished product with acceptable gloss and shelf stability when cooled properly (see Chapter 13).

Recipes for semi-sweet chocolate and milk chocolate will vary in the amount of milk fat they contain; semi-sweet chocolate typically contains low amounts to no milk fat. Milk chocolate must contain a minimum of 3.39% milk fat and high quality milk chocolate will contain more.

The ratio of milk fat to cocoa butter can result in different functional properties of the chocolate (see Chapter 5). Milk fat tends to soften chocolate making it more plastic and less heat resistant than semisweet chocolate. Since milk fat is 75% liquid at room temperature and does not share the same crystal form as cocoa butter, it is incompatible at high concentrations (see Chapter 7) and creates a softening effect. It is known that a small amount of milk fat is semi-sweet chocolate aids in bloom stability.

Rules of thumb:

- >5% milk fat will require modification to tempering and cooling parameters;
- 2–3% milk fat in semisweet chocolate will provide protection against bloom.

23.10 Specifications

23.10.1 Physical parameters

Some physical parameters that could be listed on a specification sheet might be:

- Viscosity;
- Fineness;
- Percentage total fat.

A viscosity of:

190–200 MacMichael;
55–60 Brookfield at 20 rpm, 40 °C;
13 750–15 000 Centipoise;

would indicate a heavy or thick product.

A viscosity of:
65–75 MacMichael;
19–22 Brookfield at 20 rpm, 40 °C;
4750–5500 Centipoise;
would indicate a very thin product.

If you were to specify in plastic viscosity (PV) and yield value (YV), this would be where to analyse what works best in the specific plant finished product application.

23.10.2 Fineness (particle size)

Fineness specification would typically be reported in inches or microns:

15–20 μm (0.0006–0.0008 in) would be very fine and silky smooth to the tongue.

45–50 μm (0.0018–0.0020 in) would be a more coarse product and perceived as sandy to the tongue.

23.10.3 Fat content

24–26% fat would be a very low fat content for a chocolate and would result in high viscosity and most likely a lower cost product.

34–36% fat would be a high fat content for a chocolate and would result in a very flowable, thin product with a higher cost.

23.10.4 Microbiological specifications

Microbiological testing would be performed using AOAC/BAM Methodology by an accredited laboratory. With good manufacturing practices, there should be no issue meeting microbiological requirements.

- APC <25 000/g;
- Coliforms <10.0 MPN/g MPN;
- *E. coli* <3.0 MPN/g MPN;
- Yeast and mould <100/g;
- *Salmonella* – 2 × 375 g Negative/750 g.

Once chocolate is manufactured in a chocolate factory, it can be pumped, tempered and deposited into drops or moulded into ten pound bars or shipped in liquid tankers to the confectioner that will then make their fine candies. The integrity and quality of the shipping containers is crucial to maintain product quality during transit.

23.11 Tempering

Tempering is the process to ensure the formation of stable fat crystals (see Chapter 13). Correctly tempered chocolate will yield a bright, crisp and shiny chocolate (Figure 23.9). Measuring temper utilising a temper meter will assist with maintenance of product quality. A general guideline is as follows:

Figure 23.9 Examples of tempered chocolates.

- Obtain a tempered sample at the closest point to depositing into mould;
- Place into temper meter;
- As fat solidifies, it releases heat of crystallisation;
- The chocolate temper unit (CTU) ranges from 0 to 12, with 6 being a good level of temper:
  - As the readings go below 6, the product moves into the under-tempered side;
  - As the readings go above 6, the product moves into the over-tempered side;
- SLOPE scale: 0 is a good level of temper:
  - Perfect temper is a 0 slope – the amount of heat produced is balanced by the amount of heat being removed during the cooling and a plateau or zero slope is seen;
  - Negative readings indicate overtempered – crystallisation already occurred before taking the sample to the unit, less heat produced and insufficient heat could not cause a temperature rise;
  - Positive readings indicate undertempered – a lot of heat is released as the chocolate solidifies causing the temperature to rise (not enough stable crystals).

23.12 Shelf life of finished confections

All foods are perishable by nature. Numerous changes can take place in foods during storage and distribution. We would like to think that we do not change with age, but we know we all do and this is the same case with all foods. Conquering shelf life issues in confections can be challenging.

23.12.1 What is shelf life?

The shelf life of a food product is the period of time during which it will retain acceptable appearance, aroma, flavour and texture. Key elements of shelf life for the confectioner would be microbiological safety, formation of eutectics, fat and sugar bloom, migration (fat, ethanol or moisture), loss of texture and rancidity. Chocolate is very shelf stable due principally to the unique properties of cocoa and its low moisture content. As a result, most chocolate products can be classified as medium- or long-life products. When adding inclusions and making candies using chocolate, the shelf life can be altered and categorised into two main classes:

- Shelf life is inherent in the product itself and *cannot* be extended by packaging alone;
- Shelf life is dependent on the environment and *may* be controlled by proper packaging.

In a perfect world, making mouth-watering confections today and selling them tomorrow is ideal, but many factors influence how these candies get to our consumers, such as raw material availability, seasonality, distribution and consumer demand. Microbiological safety is critical in confectionery products. Raw nuts may contain pathogens therefore products must be processed and stored to prevent this. Milk may contain *Listeria*, making it critical to keep milk-containing products away from moisture and condensation. A raw material and finished product testing programme needs to be in place to monitor your environment and products going out the door. A hold/release programme will prevent any products from getting out of your control to guarantee product safety is not an issue.

23.12.2 Effect of formulation

The formulation chosen for a confection can directly impact how well the flavour and texture are maintained. Eutectics could form (see Chapter 7), decreasing shelf life and causing the product to bloom with the possibility of fat deterioration when incompatible fats are blended together in a formula. Cocoa butter and palm kernel oil are not compatible and will cause softening when just small amounts are mixed together. A general rule of thumb is do not mix more than 4% of other vegetable fat with cocoa butter when manufacturing a compound coating.

Everything likes to come to equilibrium – a balanced state or unchanging system.

Centres and coatings will exchange fats, moisture and ethanol altering the texture of both the filling and chocolate. Migration of nut oil may cause chocolate fat bloom. The migration of moisture and ethanol may cause sugar bloom. Consult your specialty fat supplier to formulate in the correct fat for your recipe. Milk fat is often added to dark chocolate to provide protection against bloom delaying transitions from form V to form VI (the highest melting polymorphic form). Keeping a meltaway smooth upon storage may require actual tempering of the chocolate with the added fat before coating. Oxidative rancidity can occur relatively rapidly when high-fat centres or roasted nuts are used in a formulation.

23.12.3 Manufacturing

Whether confections are manufactured by hand or using factory equipment, conditions must be maintained to maximise shelf life. Moulded pieces must use properly tempered chocolate cast into room temperature moulds, passing through a cooling tunnel to set the product for shrinkage and easy demoulding. Improperly tempered chocolate will continue to stabilise after the product is wrapped and has left the factory, which may lead to soft texture and the appearance of fat crystals or bloom. Lack of contraction (shrinkage) so the product is not easily released from the mould can be due to improper tempering. Dull appearances, poor snap and long set times can be from improper tempering. Improperly designed moulds can lead to poor quality products. Warm moulds can delay onset of crystallisation or break temper causing bloom. Cold moulds can expose chocolate to premature cooling, forming incorrect crystals.

Enrobing is when a centre is passed through a curtain of chocolate or compound coating and then over a bottomer to coat the base. Bases may first be coated with a compound coating to aid in integrity or to prevent fat migration and then enrobed with chocolate. Pieces can also be double enrobed to ensure extra coating if the centre is vulnerable to softening or leakage or difficult to coat. If enrobed centres are cooled too rapidly, the chocolate could crack; if cooled too slowly, it could end up discoloured and soft. This problem may not be apparent right away and could emerge later in the distribution process or when your customer purchases the product. If centres are too warm, they can detemper the chocolate. If a piece has an uneven surface to coat, this could cause the centre to be exposed creating conditions for reduced shelf life. Incorrect viscosity may also alter coverage rate as well as increase feet formed at the base of each piece.

Chocolate and compound require different cooling tunnel conditions. Chocolate needs to be cooled gently at 12–15 °C (55–60 °F) with moderate air flow. Compound coatings are best cooled in colder 4–7 °C (40–45 °F) tunnels because they spontaneously solidify in a stable crystal form. The temperature of all tunnels should increase close to room temperature at exiting to prevent moisture condensation.

23.12.4 Packaging and storage

Packaging types will have a great influence on the stability of the confectionery product over time (see Chapter 26). The goal is to keep flavour and texture in and moisture or off flavours out. Moisture can cause cracking of, for example, pretzels coated with chocolate and could make them soggy. Milk chocolate is more susceptible to flavour degradation if packaging is not controlled. There are many types of packaging materials such as polypropylene, metalised or multilayered films. Packaging suppliers are excellent resources for the best type of packaging for a specific product.

Some things to take into consideration:

- Heat sealing – be careful if shrink filming is used, this could cause bloom due to excessive heat.
- High moisture pieces may lose and trap moisture, this could cause moulding if tight packaging is being used. Sometimes wax paper would be the best option due to its semi-permeability.
- Packaging material could cause off odours and flavours from inks used, the type of material in the packaging and from where the packaging has been stored.
- The Robinson Test can be used to evaluate if packaging materials are a source of off flavours. Place a piece of the packaging material (20 × 22 cm) into a sealed jar with 15 g of grated chocolate so they are not in contact. Place the jar in the dark at room temperature (20 °C; 68 °F) at 75% relative humidity (if needed, add saturated salts to create a high humidity) for 48 h. The flavour can then be evaluated as compared to a standard. Specific tolerances as to how much flavour pickup is acceptable for the product should be developed. This would be approximately equivalent to nine months of shelf life.

Storage of confections is critical to maintaining the original flavour and texture when the piece is fresh. Confections do not tolerate temperature variation well and prefer constant temperature and constant humidity. It may be difficult to control what happens during storage, distribution and display on the store shelves. Ideal storage conditions would be in a cool, dry environment, away from off odours at 12–18 °C (55–70 °F) at <60% relative humidity.

Points to consider:

- The fat phase of a confection is partially solidified at this point which will either continue to solidify or remain liquid depending on how a product is stored.
- If products are stored at too low of a temperature, condensation can form and create sugar bloom when coming back to room temperature.
- Be careful if freezing candies to preserve freshness and halt centre oil migration. Care must be taken with delicate shells to not crack during the rewarming process. This must be carefully controlled to prevent condensation from forming on the products.
- Compound coatings would be more heat resistant than chocolates mainly due to higher melting points with some compound coatings and the fact that they do not require tempering.

23.12.5 Distribution

All of the hard work maintaining the product to this point would be for naught if the product is not transported and distributed in similar conditions as the product is stored. The need for refrigerated trucks and controlling the product on the docks and in storage at the distribution centres will all influence how well the product will hold up until it reaches consumers.

What needs to occur?

- During warm months, refrigerated sealed or locked containers are required.
- Distribution systems must know how to handle confectionery products.
- Light in display cases can influence the quality of a confection – white chocolate is especially susceptible to light-induced degradation of flavour due to its lack of natural antioxidants; and exposed nut pieces would also be susceptible to light-induced rancidity.
- Infestation can also occur during transportation and distribution. Examining transporting vehicles and keeping the temperature controlled greatly helps eliminate this concern. Sealed packages can deter insects from trying to penetrate through folds or bore through packaging.

23.12.6 Shelf life determination

Shelf life is governed principally by temperature, humidity, light and exposure to oxygen (packaging). Shelf life is determined by the mode of failure for the particular confection (e.g. taste, bloom or microbial growth).

Table 23.4 lists the shelf life recommendations for products stored properly, sealed and away from light for the purpose of the "Best Before" date. This knowledge can be used as a tool to assist with shelf life determination.

The final shape and form of the confection will also impact its shelf life. Small discs with greater surface are will tend to degrade more quickly than a ten-pound bar. Using conditioned cabinets at specific temperatures and relative humidity for a specific time can also be used to predict accelerated shelf life. An example would be:

Bloom stability potential of a product – a tool to aid in shelf life determination:

- General reference: 1 week of cycling is equivalent to 1 month of shelf life.
- Hold samples at 30 °C (84 °F) for approximately 12 h.
- Hold samples at 20 °C (68 °F) for approximately 12 h.

Table 23.4 Shelf life recommendations for products stored properly, sealed and away from light for the purpose of the "Best Before" date.

Category of product	Shelf life (months)	
	Temperate conditions	Tropical conditions
Milk chocolate	16	12
Dark chocolate	24	24
White chocolate	16	12
Fondant cream filled chocolates	18	12
Chocolate with nuts etc.	12	9
Wafer/cereal centred product	12	9

- Continue until bloom is observed.
- If a sample holds its integrity for 12 weeks, the product can be predicted to maintain its integrity for 12 months.

Many factors contribute to loss of shelf life and failure of a customer to return to purchase a product. Not everyone has resources to perform stability or shelf life testing but we all have the ability to perform sensory analysis on our products to look for degradation and loss of product integrity.

CHAPTER 24

Instrumentation

Ulrich Loeser

24.1 Introduction

Confectionery production involves the measurement of a large number of parameters, and many instruments already exist on the market. These are continuing to be developed together with improved control and operator interface systems. To use these instruments correctly, however, it is very important for the production team and project technicians to have the knowledge and skills to understand the processes and also to interpret data to obtain meaningful solutions to production-related problems. In addition it is desirable to be able to work together with instrument manufacturers and system specialists to tailor machine/plant modifications according to need.

24.1.1 General measurement tasks

It is legally and economically important that all companies comply with ISO Standards, laws and regulations concerning food safety and HACCP, GMP/QA/SS+E and so on (Chapter 28) and measurements concerning these become part of daily life. Food safety standards must be continuously improved and implemented throughout the entire factory, not only in production areas. Appropriate hygiene standards must be applied by employees and suppliers prior to repairs, installation and commissioning and so on, and large-scale cleaning operations must be performed at regular intervals. This also provides information concerning the current hygiene situation. Long-term preventive measures, for example rodent or insect traps and other infrastructure monitoring, produce useful data regarding trends and critical point analysis.

24.1.2 Microbiological measurements

Measurements of the microbiological conditions are required to ensure product safety. Raw material must be checked for compliance with specification. In addition, the microbiological condition of intermediate products, for example cocoa mass after de-bacterisation, must be examined. The microbiological conditions in the surroundings (machinery, equipment, storage areas) as well as the environment

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

around a production site are determined with the aid of smears collected on a systematic basis. The condition of finished products is the most important and must be determined in accordance with in-plant guidelines and food safety laws and regulations. This includes routinely determining the overall bacteria count and ensuring the absence of *Salmonella*. Very often these specialised analyses are carried out at a central laboratory or out-sourced and they are not described in this chapter.

24.1.3 Use of data analysis

The first step is to determine the reason for obtaining the data and the possible advantages arising from the analysis itself. Good experimental design provides the best insights into interactions within processes.

Instrumental results, called measured values, give a numerical value for each individual measurement together with a unit of measure. The overall error in the value obtained must be taken into account and depends upon the accuracy of the measurement, as well as such things as the bit width and scanning rate of the analogue to digital converter, where this is used.

After the measurements have been performed and the data recorded, the measured values should be subjected to statistical analysis in order, for instance, to assign the type of mathematical distribution characteristic of each series of measurement. Distribution functions, confidence intervals and standard deviations can be determined. It is important that the appropriate statistical evaluation procedure be correctly used, for example parametric hypothesis test for quantitative variables, proportion hypothesis test qualitative variables, Chi-squared fit test (test for type of distribution), Chi-squared test for independence, F-test for significant differences of location (means) or correlation test for linearity of a relationship in order to be able to interpret it correctly. It is then possible to explain the important parameters more certainly on the basis of graphic representations and also to distinguish between primary and secondary effects. In this way, misinterpretations can be largely excluded and improper handling of the data becomes detectable. Such an analysis is required when problem solving, or before plant optimisation, or new product/ process development.

24.1.4 Use of data analysis to provide long-term production stability

The determination of measured values with a known distribution function and errors is the first step towards automated production using programmable logic controllers (PLC), as control circuits can then be designed, tested and engineered.

Costumers’ trust in the manufacturer and his products is very important in developing a long-term relationship. Manual or mechanical (automatic) process controls represent one component of a manufacturer's specification and are a way of achieving reliable quality assurance. The actual value of the measurements depends upon how the data are obtained and used. As already mentioned, several methods exist to quantify process data and draw meaningful qualitative solutions.

24.2 Production measurement technology – in-/on-line, off-line

There is a huge number of instruments and it is impossible to cover them all within a single chapter. The following sections are therefore limited to selected methods of measurement using examples that are important to the confectionery industry. The following applications are often part of control systems.

24.2.1 Recording time

When monitoring product throughput for example counting packed bars, the elapsed time is measured. In this way machine operating hours can be specified for specific lot sizes. Determining the useful life of individual refiner roll is another example. A time period is obtained for which desired product features or machine settings can be maintained. Time measurements can be obtained automatically, for example in the case of synchronised measurements based on trigger signals and can be saved in machine-readable form. Typical examples of time-dependent measurements are shown in Table 24.1.

24.2.2 Recording position (location)

Over the past 10 years radio frequency identification (RFID) technology has revolutionised the use of chocolate moulds. A data carrier and transmitter mounted within the mould front (see Figure 24.1) individualises each mould and permits data transfer each time it passes one of the fixed on-line detection points. This opens up new opportunities for chocolate manufacturers, for example:

- Full traceability and documentation of individual moulds.
- "Mould lifecycle management" is possible as the entire life cycle of each mould is recorded.
- The expected maximum lifetime can be predicted with greater accuracy and maintenance planning improved.
- Wash cycles, conditions and mould run time length between wash cycles can be optimised. This can help to improve food safety.
- Environmental conditions can be monitored in operating cooling tunnels.
- Data is available in real time at any time, so all the moulds on a moulding line can be sorted according to required criteria such as age or operating hours.

Currently some limitations exist due to the restricted data capacity of the sensors.

Table 24.1 Typical time-dependent measurements.

	Dimension as an example	Typical examples
Time as basic variable		
Day:Hour:Minute:Second	dd:hh:min:s	Start of a cycle time, e.g. a fill, Time stamp from a database,
Second	s	Time interval
Frequency		
Hertz	Hz = 1/s	Line frequency, Scanning rate of a scanner
Number	units	Quantity produced.
	bars/min	Output of packaging machine.
	moulds/min	Output of a moulding plant
Revolutions/time	rev./min	Speed of a motor
Velocity, speed	m/s	Belt speed, Air velocity in a cooling tunnel, Flowpack – packaging rate
Angular velocity	rad/s	Feature of a stepping motor
Acceleration	m/s^2	When re-starting packaging equipment
Angular acceleration	rad/s^2	Feature of a stepping motor
Volumetric flow rate	m^3/h	Cooling water flow rate, Volumetric air flow from a fan

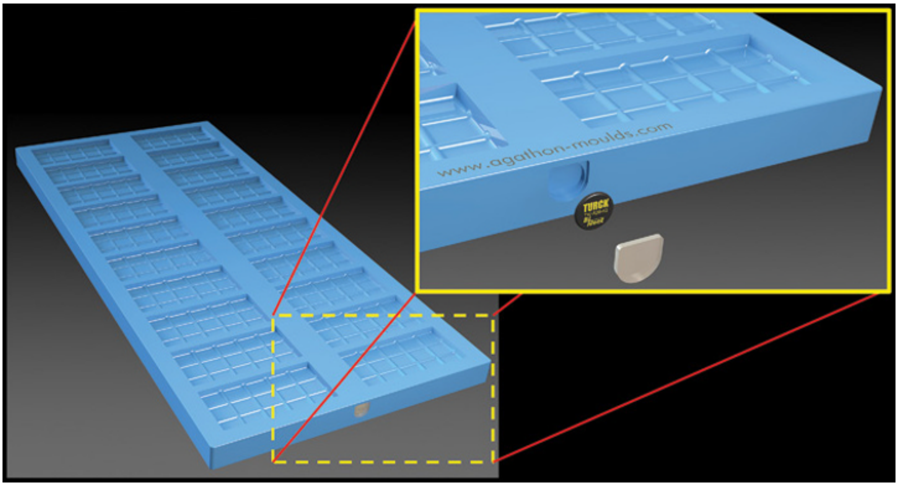


Figure 24.1 Mould with built in RFID sensor. Reproduced with permission of Agathon, Germany, and Turck, Germany.

A further example involves the position of the individual products along a feed conveyor. This can be used, for instance, to control the feeding of several packaging machines and storage units. The handle position on directional control valves indicates the current port size in relation to the fully open port. The change

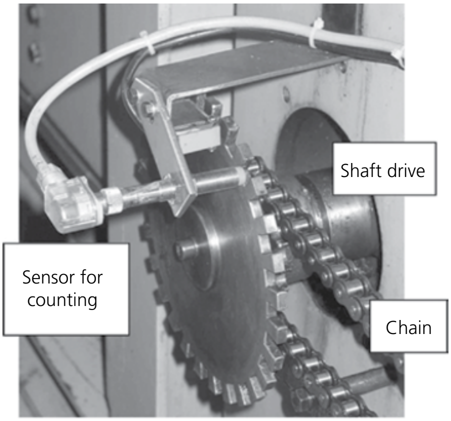


Figure 24.2 Incremental encoder on a drive shaft.

Table 24.2 Typical examples of length/position-based measurements.

	Dimension as example	**Typical examples**
Dimension		
Length as basic variable,	mm	Effective roll length in a roll mill
Distance	mm	Crown: increase in roll diameter in a roll mill
Gap size	units	Gap between two matched rolls in a roughing mill
Diameter	mm	Diameter of balls in a ball mill
Surface area	m^2	Surface area in a heat exchanger
Volume	m^3	Volume of air provided for ventilation

in handle angle with time is an indication of variations in throughput in a control loop. Alternatively rotary motions can be monitored for example by attaching an incremental encoder to the drive shaft of a conveyor belt (Figure 24.2). Typical location/position measurements are listed in Table 24.2. Charge couple device (CCD) cameras are often used where two-dimensional information is required. Depending on the measurement task, a CCD linescan or CCD array camera can be used. Triggering ensures undistorted information, which is then converted into an image by a computer system. (see Figures 24.3–24.7).

Imaging methods record specific areas of the product, as well as detecting defects and their type, for example Figure 24.3 (chocolate tablet 1 without defects, chocolate tablet 2 with damage at lower right, chocolate tablet 3 with damage at the upper right). As a further refinement, 3-D sensors can obtain height information for specific locations in order to provide complete spatial imaging of surfaces (see Figures 24.4, 24.6 and 24.7). The principle of operation employed in 3-D sensors is based on triangulation (see Figure 24.5).

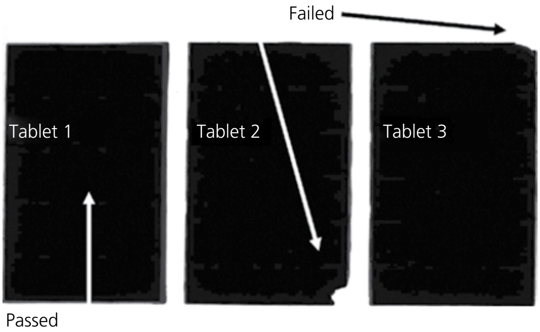


Figure 24.3 Results from a CCD line scan.

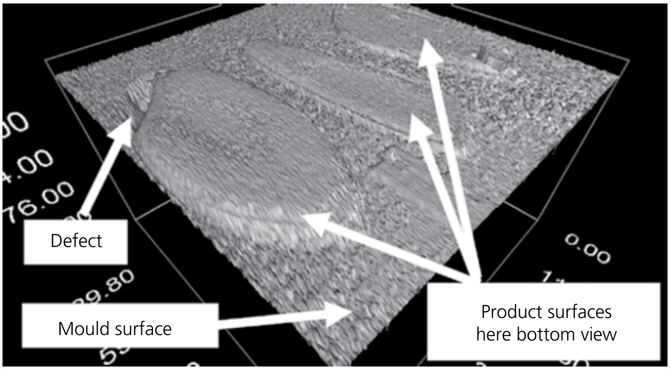


Figure 24.4 Use of a 3-D scanner. Reproduced with permission of Rohwedder AG, Germany.

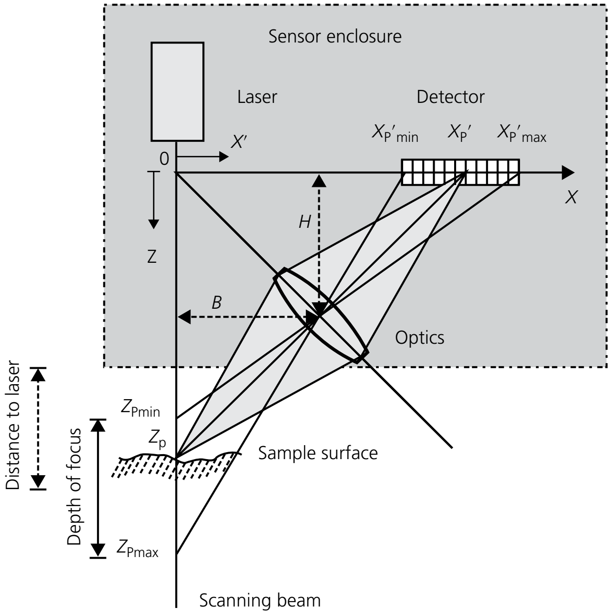
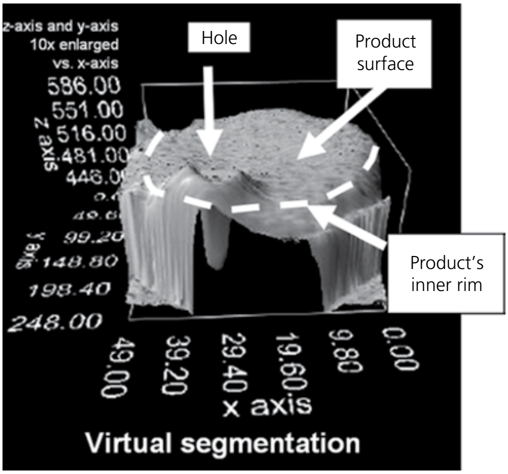


Figure 24.5 Triangulation. Reproduced with permission of Rohwedder AG, Germany.

Figure 24.6 Example of a 3-D scan. Reproduced with permission of Rohwedder AG, Germany.



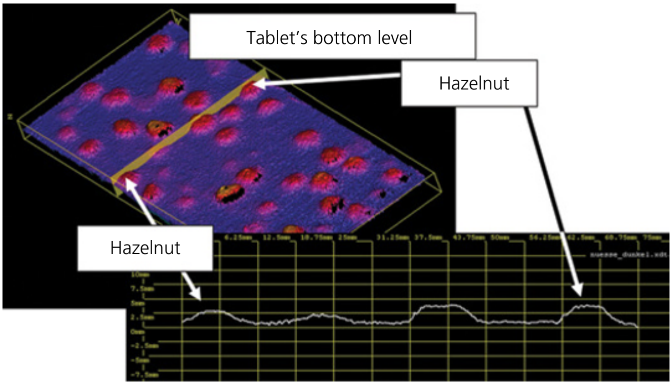


Figure 24.7 Nut distribution in a bar. Reproduced with permission of 3-D Shape, Erlangen, Germany.

24.2.3 Recording by numbers

Counting can be relatively simple. A few applications are as follows:

- Rotary motion is recorded using the individual segments of a disc with a specially manufactured edge. A predetermined number of teeth produce counting pulses in a sensor during rotation (see Figure 24.2).
- For deliveries, the number of tankers, pallets, big bags and so on are counted.
- Determining the number of loaded conching units, when producing the masses in batches.
- Counting the number of unpackaged products entering and leaving a storage unit.
- Calculating the number of finished products in final stock department by weighing the container (stock keeping unit; SKU), five-count package, filled box of chocolate, multipacks and so on.
- Guaranteeing components in the overall recipe.

24.2.4 Recording "patterns"

This involves recording a more complex measurement parameter. The term "pattern" covers the results of measurements such as intensity diagrams of spectra, or the reproduction of product images as grey-scale distributions and their comparison with a specified range for such a pattern. Principles of pattern recognition are used to recognise foreign matter, to identify defined defects, to read alphanumeric characters (e.g. best before date coding), to read a bar code or codes invisible to the human eye, to distinguish for example between products with identical shape but with different fillings (Loeser, 2009). Many different methods of data analysis are used here, including mathematical statistics and artificial intelligence.

24.2.5 Recording the degree of filling (fill level)

The term "degree of filling" (fill level) applies to many situations. It is usually recorded as a percentage or often refers to a volume. Some examples are as follows:

- In a silo for bulk goods: comparison of the measured amount added to and leaving the silo;
- In a tank for liquids: level in a sight glass, weighing before and after filling, ultrasound probes;
- In a tank or hopper for tempered masse: dropping below the minimum sensor or rising above the maximum sensor;
- In a hopper of a pre-refiner/refiner;
- In a cooling tunnel, before emptying after a break down;
- Within a storage unit for chocolate bars, prior to feeding the packaging machine: tracking the difference between entering and exiting items;
- On a feeding conveyor inside a packaging system: tracking the difference between items entering on the feeding conveyor and those leaving it;
- Ball mills: volume occupied by the balls inside the milling chamber;
- In a gas bottle filled with N_2 for aerating of the filling masse: by determination of total weight, for example at the start and at the end of a shift or by means of a consumption sensor.

24.2.6 Recording by weighing

In addition to counting and temperature measurement, determining the weight or mass is one of the most common measurement tasks (examples of operations based on mass and force are given in Table 24.3). The weight of bulk goods such as sugar, milk powder or fractured cocoa nibs is determined using bulk material scales or belt conveyor scales. Mixers are connected directly to weighing systems. This takes place in a continuous or semi-continuous manner. Automatic weighing systems can be employed throughout, from cocoa processing to final bar. For example, they can be located downstream from a conventional winnower in order to check and track level of shell (Chapter 3). All further weight measurements, for instance, when adding other ingredients such as nuts, and

Table 24.3 Typical examples of mass/force-based measurements.

	Dimension as example	Typical examples
Mass as basic variable		
in grams	g	Product weight, e.g. 100 g
in kilograms	kg	Weight of balls in a ball mill
in tonnes	t	Amount of raw material to be processed
Density		
Mass/volume	g/cm^3	Density of aerated chocolate
Force		
in Newtons	1 N = 1 m/kg/s^2	Moment for non-positive connections, such as nuts or screws
Moment of force Force* distance	N m	
Pressure, tension Force/ area in Pascals	1 N/m^2 = 1 Pa	Mass pressure downstream from a pump, Contact pressures between rolls in a refiner and in a cocoa press, air pressure
Dynamic viscosity, Kinematic viscosity = dyn. viscosity/density	1 N*s/m^2 = 1 Pa*s (N*s/m^2)/ (kg/m^3) = m^2/s	Is used to describe the flow characteristics of chocolate masses, cocoa butter, special fats
Work, energy in Joules	1 J = 1 N m = 1 Ws = 1 m^2 kg/s^2	Installed refrigeration capacity
Power in Watts	1 W = 1 J/s = 1 m^2 kg/s^3	Motor performance
Mass flow rate Mass/time	Kg/h	Output of a moulding plant, throughput of a ball mill,
Mass/Mass	dimensionless	Proportion of shell in the nibs (%)
Mass flow density	kg/s*m^2	Related to fat migration

maintaining the specified ratios to ensure adherence to the recipe. Comparisons between *target* and *actual* values within the recipe database, product database, weighing records or process control charts can be automated and documented. Finished products are weighed once again in their package, before being placed in the multipack.

Often, the addition of solid recipe ingredients relies upon weighing operations. This is especially true for the process steps of ingredient addition and mixing when producing the initial chocolate masse, but it also applies to ingredients being discharged from silos with the aid of feeders. With the aid of belt weighers, milled material can be fed directly into the mixer, pre-refiner or conches in accordance with the recipe. Their operation requires regular cleaning and calibration. Smaller amounts of dry material, such as free-flowing vanillin, are added to the mixer automatically with the aid of screw feeders.

A belt weigher (Schenk, 2014) in a refining line has been developed with an additional control circuit to automatically adjust the belt load. By changing the speed of the belt drive motor, it can always measure the load on the belt within its optimum operating range. The result is that the error in measurement is independent of the number of operating refiners, as well as their location.

In another example the time it takes for the masse to reach a particular refiner is controlled by a PLC to be dependent upon its position in the refining line.

24.2.6.1 Weighing liquids

Often, the addition (metering) of liquid recipe ingredients is connected with solid weighing operations, for example for mixing and conching. With some liquids, the amount to be metered can easily be adjusted using solenoid valves in conjunction with a weighing scale. The type of metering pump chosen depends strongly upon the viscosity of the material, in particular the yield value (see Chapter 12). Smaller amounts of liquid ingredients, such as lecithin, can be added using rotary piston meters. In contrast to piston-type metering devices, rotary piston meters generate no signal when idle and so are more useful for control systems.

24.2.7 Measuring temperatures

Temperature represents one of the most important measured variables in cocoa and chocolate production (see Table 24.4 for typical measurement units). A few examples of frequently used temperature measurements are:

1. In conventional tempering to ensure chocolate is de-crystallised before returning to the temperer.
2. The viscosity of chocolate and filling masses depends directly upon their temperatures.
3. To maintain the correct temperature in air, refrigerants, water heating jackets on piping, depositing heads, holding tanks and so on.
4. Dew point determination and other relative humidity measurements.
5. Product surface temperature and internal product temperature are important criteria for the cooling process.
6. Uniformity of the mould temperature after re-warming and of the product temperature itself gives good processing consistency.
7. During conching, texture changes and formation of enhanced flavours can be influenced by altering the temperature and shear conditions.
8. By changing the temperature of alkalised cocoa mass/fractured cocoa nibs, the release of cocoa butter from the cell structure is changed.
9. Changing the temperature during the roasting of cocoa beans is a critical process parameter for expelling water, enhancing aroma and loosening the shell.
10. Temperature and time are critical in controlling microbiological growth.

Measurements in *the gaseous state* include ambient air, the chilled air in refrigerators and steam. In other situations, solid–gas mixtures are present, for example milling and cooling cocoa press cake and powder. Here the temperature measurement is essential for controlling the process.

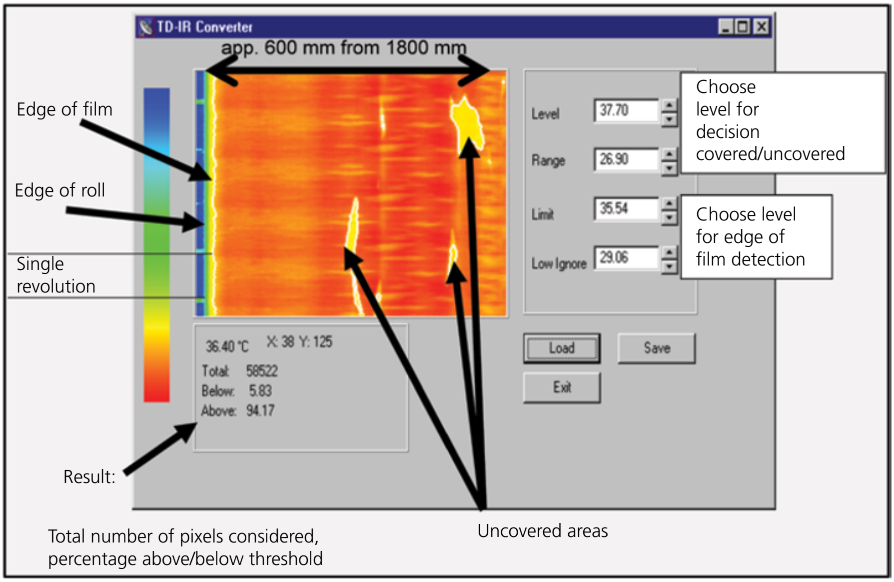
The most common temperature measurements however involve *liquid* masses. With tempered chocolate and filling masses, it is especially important to

Table 24.4 Examples of the units used for temperature-based measurements.

Temperature as basic variable	Dimension as example	Typical examples
in Kelvin,	K	Usually in °C: masse temperature, air temperature in refrigerator, Surface temperature Internal (core) temperature of the finished product during cooling in a refrigerator
in degrees Celsius,	°C	
in Fahrenheit	°F	
Tempermeter application Rise from the inflection point of temperature over time under isothermal measurement conditions	Scale divisions	Determining the degree of tempering of tempered masses
Amount of heat in Joules	J	Example: amount of heat released during crystallization
Specific amount of heat	J/kg	
Heat capacity	J/K	Material property
Specific heat capacity	J/(kg*K)	
Entropy	J/K	Entropy change in a systom
Specific entropy	J/(kg*K)	
Heat flow	W=kcal/h	Process variable
Heat flow density	W/m^{2}=kcal/m^{2}h	
Heat transfer coefficient	W/m^{2}*K	Material and process condition
Heat transmission coefficient	W/(m*K)=Kcal/(m*h*K)	
Thermal conductivity		Material property
Thermal diffusivity	m^{2}/s	Material property

know the accuracy of measurement. Digital converters operate in conjunction with Pt100 sensors with an accuracy of ±0.3 °C. Older devices can often only achieve accuracies of ±0.7 °C. This must always be kept in mind when reading temperature displays.

Apart from measuring the temperature at individual locations by thermometers, it is also important to monitor the temperature distribution over a mould area for example a mould surface to detect hot and cold spots. This can give rise to sticking of the bars in the mould, the so-called cooling stress marks or cooling spots, or bloom in the final product. Pyrometers are often employed to record such surface temperatures. Images of two production situations in the visible and infra-red regions are compared in Figures 24.8 and 24.9. Such measurement systems can record individual mould positions over time and, as individual images are available in digital form, it is possible to monitor the changes in surface temperatures at specific locations. The emission coefficient (emissivity) of different materials should be taken into account.



Level 37.70
Range 26.90
Limit 35.54
Low Ignore 29.06

36.40 °C X: 38 Y: 125
Total: 58522
Below: 5.83
Above: 94.17

Figure 24.8 Imaging of fifth top roll in real time motion within several singular revolutions across roll length displayed in infra-red light range coded as false colours. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

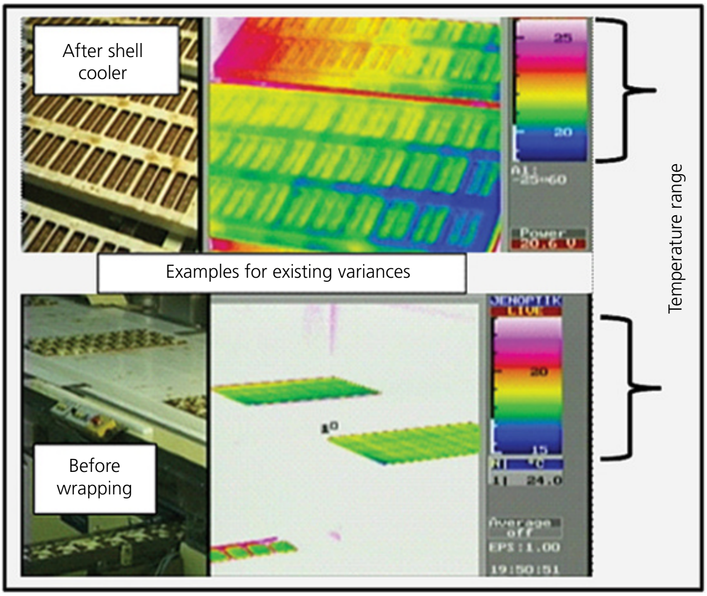


Figure 24.9 Imaging in the visible and infra-red light regions. Through false-colour imaging, the surface temperature becomes visible. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

24.2.8 Recording the degree of temper

Temperature measurement is also necessary to determine the degree of temper of masses containing fats that solidify polymorphically (see also Chapter 13). These include cocoa butter and other special fats with similar fatty acid compositions (Chapter 7). The tempered condition is a result of pre-crystallisation by a process known as tempering.

Without correct tempering many problems arise, for example lack of contraction (sticking in the moulds) and gloss on the product. In addition fat bloom can rapidly appear, leading to customer complaints. The sensitivity to incorrect tempering depends upon the chocolate recipe and it is very important for the manufacturer to know the robustness of the process for each particular product in order to be able to minimise these faults.

24.2.8.1 Preparing to measure temper

The frequency of sampling and the accuracy of the measurement are important when monitoring tempering systems. The degree of temper can be determined manually or automatically, but the use of automatic sampling permits more measurement cycles per hour and complete tracking of fluctuations in the temper. If correction is necessary, the degree of temper can be influenced by changing the temperature settings for the individual stages of the tempering machine (further details are given in Chapter 13). If this is not adequate, the residence time within the temperer can be changed, but the throughput will then be affected. Machine settings should be stored in recipe databases.

Every temper measurement normally assumes that all the equipment is installed and operating correctly. This is not always the case, however, and some common faults are given in Figure 24.10.

Typical positions for measurements connected with conventional tempering are:

- Decrystallisation: masse temperature at the inlet for new masse and/or of the masse from the return line must be between 43 and 45 °C (109–113 °F) for the masse not to contain any crystals. The water temperature in the water jacket of pipe systems should be 50–55 °C (122–131 °C), or preferably 60 °C (140 °F). Depending on the design, the decrystallisating unit can also be part of the inlet to the tempering machine.
- Water circuits for the cooling stage and warming stage to ensure stable water temperatures within the range specified by the manufacturer and that water pressure and water temperature are free from seasonal variations and independent of usage by other production lines.
- Return flow of masse must always be maintained so that no build up occurs near the depositing head during production shut-down.

24.2.8.2 Tempermeter

Several commercial tempermeters exist, all based on monitoring the change in temperature, as fat crystals melt within a defined volume and conditions. A typical tempermeter is shown in Figure 24.11. The measurement cup is filled with

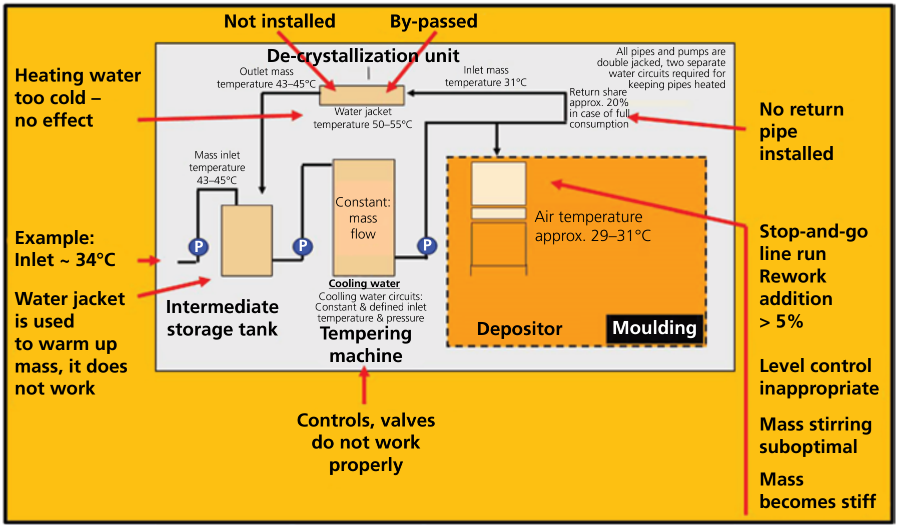


Figure 24.10 Common faults found in conventional tempering systems.

Figure 24.11 Typical tempermeter.

chocolate and then placed into the pre-warmed sample holder (Figure 24.12) and the temperature sensor positioned exactly with the aid of a spacer (not shown). This temperature sensor is normally connected to a computer able to record the change in temperature over time. Upon completion of the measurement, the position of the inflection point illustrated in Figure 24.13 is read out automatically and the temperature rise calculated. The degree of temper can be established from the position of the inflection point in the tempering curve, which is governed by the amount of heat released during crystallisation (see also Chapter 13).

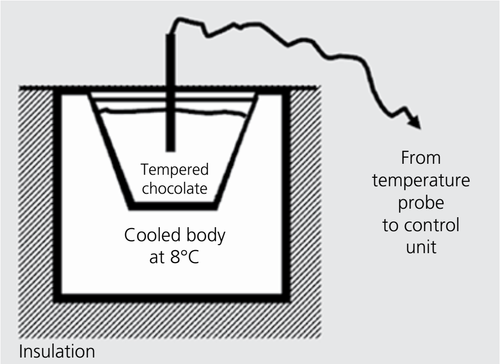


Figure 24.12 Schematic diagram of measurement head of tempermeter.

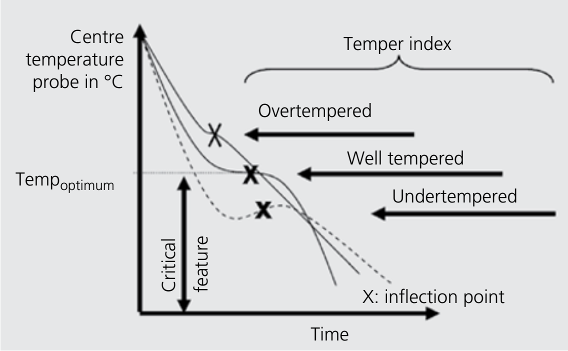


Figure 24.13 Typical temper curves from tempermeter.

Although such systems can quantify the degree of temper, the information is limited. It cannot for instance determine if certain crystal modifications are taking place and it can be distorted when an incompletely decrystallised masse is present.

24.2.9 Pressure measurement

Pressure sensors usually operate by converting the movement of a diaphragm into an electrical signal. They can be used, for example, for checking the masse pressure for aerated masses, the air pressure of the compressed air supplied to the infrastructure and the pressure in hydraulic drive. Within the confectionery industry they are particularly important to ensure a minimum pressure when providing cooling water to mills, roll refiner, tempering machines and conche units. Without this cooling flow, the output and quality are reduced and wear increases. In addition pressure sensors are often placed in closed circuit flow systems, for example the masse within a circuit of ball mills, the hydraulic circuits to the rolls in roll refiners, cocoa presses and hydraulically driven depositing systems, the reactor contents in alkalising units, refrigerant circuits in chillers and refrigeration equipment with direct evaporators, pneumatic systems and pressure relief valves in pump systems. They can even be used as a means of determining the fill level of storage tanks. Examples of different pressure measurement applications are summarised in Table 24.5.

24.2.10 Measuring moisture/relative humidity

Water content of cocoa beans/cocoa nibs: In order to optimise the yield it is important to measure the moisture content at regular intervals. As a natural product, the composition of cocoa beans can vary. This applies to the fat and water content as well as to the attainable yield. Under production conditions, the water content of cocoa beans and cocoa nibs can be determined by halogen moisture analysers. These heat samples uniformly and the moisture present is determined from the loss in weight.

Water content of cocoa mass: When adjusting cocoa masses to a specific fat content, the moisture content must first be measured. This can be determined by measuring the adsorption/reflection of infrared radiation at the surface; the typical accuracy of measurement is 0.3–1.0%. This method requires a special calibration regime.

Air relative humidity: Water in the gas phase (air) is often recorded as relative humidity (%) or as a concentration (g/kg). In combination with the air temperature, it is then possible to determine the dew point, that is the temperature below condensation sets in, see Figure 24.14. Every time condensation forms on the product's surface there is a danger of mould growth or sugar bloom.

24.2.11 Recording flow characteristics

Flow characteristics of chocolate and filling masses are described in simplified form by means of the term "viscosity" (η). This is obtained by determining the interactions involving the shear stress (τ) at different shear rates (D). Viscosities are often measured either in separate laboratory rooms close to production or directly in the laboratory. Various models exist for describing curves mathematically; see Windhab *et al.* (2008), Tscheuschner (2004) and Chapters 11 and 12. Single-point measurements are not suitable when determining the viscosity of non-Newtonian fluids such as chocolate. Measurements should be made at least at two shear rates, with great care being taken with the sample preparation and in using the viscometer according to standardised procedures.

Flow characteristics depend on the condition of the material (texture) and the processing conditions (such as temperature, shear etc.). If production conditions are being adequately controlled, when manufacturing chocolate masses for making tablets it is not necessary to conduct viscosity measurements on a continuous basis. It is, however, common to record related variables, such as the power consumption of a conche shaft, to draw conclusions about the condition of the masse during processing, thereby permitting automation of the process

Table 24.5 Example of different pressure measurement applications (F.B. Lehmann, Aalen, Germany).

Application	Medium	Type of device	Installation	Bar	Accuracy (%)
Monitoring the pressors in the milling chamber of agitator ball mills	Liquids	In-line seal with analogue transmitter and sensor signal evaluator	Directly in pipe between feed pump and milling chamber	0–2.5	0.3
Pressure monitoring in barrier pressure systems for mechanical shaft seals	Compressed air, nitrogen	Pressure switch with adjustable contacts	Directly on the barrier fluid reservoir in the airline	0–7	0.5
Pressure differential in filter systems as an indicator of the degree of filter clogging	Air	Differential pressure transmitter with diaphragm	In the vicinity of the filter	0–0.05	0.2
Fill level measurement in vessels with an agitator	Liquids	Piezoresistive pressure transmitter	At the bottom of the container in direct contact with the product	Depends on application	0.3
Weight sensing in silos and vessels with an agitator	Bulk goods liquids	Pressure sensor (load cell) with analogue transmitter and sensor signal evaluator	Under the feet of silos and containers	Depends on application	0.3
Airflow regulation on winnowing equipment	Air	Differential pressure transmitter with diaphragm	Separately in a control cabinet	$2 \times 10^{-5} - 0.002$	0.07

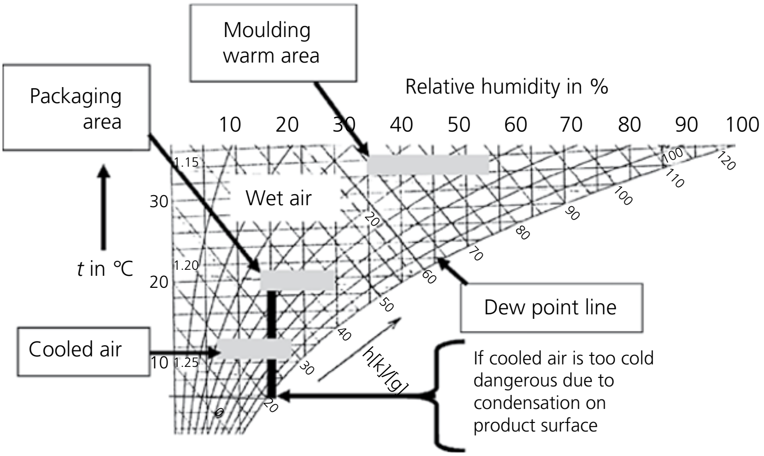


Figure 24.14 Extract from Mollier i,x diagram showing the relationship between temperature and the relative humidity when condensation occurs (dew point).

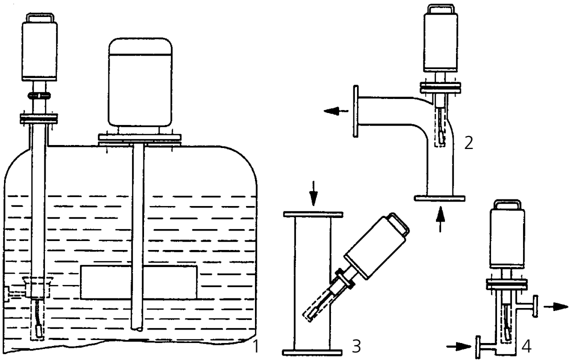


Figure 24.15 Typical installation positions for convimeter type of viscometer.

and the automatic correction of the flow properties. When making other products where more precise flow properties are required, for example enrobing to an exact weight declaration, the viscosity often needs to be modified by adding fat. In this case, off-line batch measurements should be made. These measurements are also required when manufacturing aerated masses and the yield value is lowered by adding an emulsifier, such as PGPR (Chapter 11).

An in-line viscometer can be used and Figure 24.15 shows possible positions for installing a process viscometer to measure non-Newtonian flow. Most concentric instruments pose the problem that the same chocolate remains between two cylinders, while the product intended to be measured flows by. The convimeter (Figure 24.16) overcomes this by having the bob set at an angle and so acting as a pump and changing the sample.

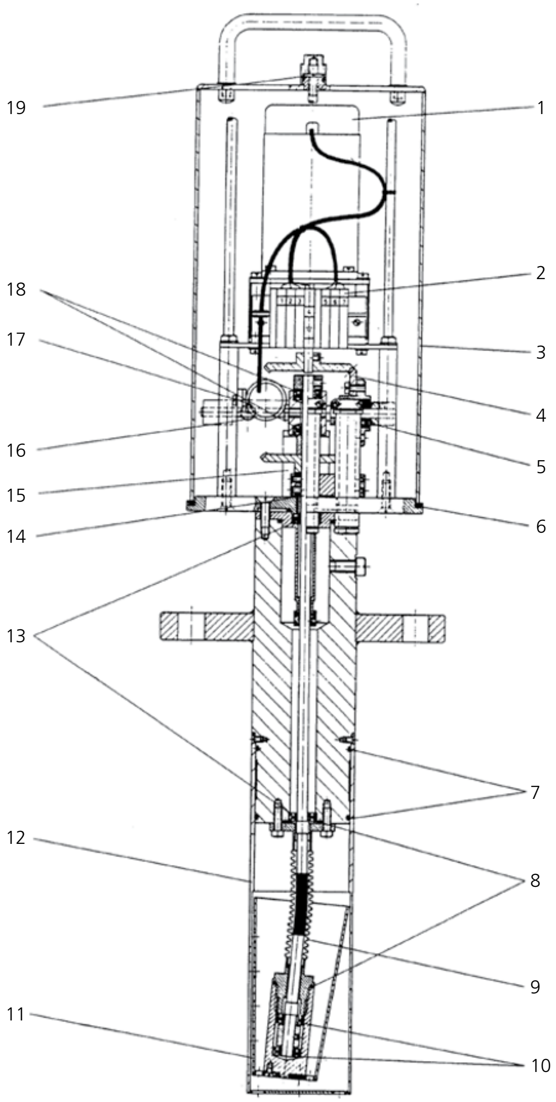


Figure 24.16 The convimeter: (1) geared motor with gear control; (2) terminal, explosion proof, cover; (4) bevel driving pinion; (5) two ball bearings, 6/19 mm, for nylon bevel driving pinion, rubber gasket; (7) two O rings Vitons for seat of protection sheath; (8) two O rings for connection pieces metal bellow; (9) metal bellow, with connecting pieces; (10) two ball bearings 7/19 mm, for drive shaft, lubricated with special oil; (11) conical mantle with three screws M4x6; (12) protection sheath, with two screws M4x6; (13) two ball bearings 7/19 mm, for drive shaft, lubricated with special oil; (14) drive shaft, with Teflon sleeve; (15) dash pot with Teflon sleeve; (16) metering spring, No. 1, 11 or 111, with barrels; (17) inductive transducer, explosion proof, with drive eye; (18) two ball bearings 7/19 mm, for dynamometer drive shaft; (19) cap nut for cover, with spring washer and O ring.

24.2.12 Recording particle size

This is the most commonly measured quality parameter, since it can be perceived directly by the consumer, with chocolate tasting grainy if the particles present are too coarse. This even overcomes the expected pleasant melting sensation. On the other hand, if extremely fine particles are present in excess, a large amount of free fat can be bound up, or the particles can come in contact with one other and form clusters, resulting in a sticky feeling in the mouth. In this case as well, the pleasant melting sensation is masked. Both of these sensations must be avoided by correct processing. To accomplish this, it is necessary to determine the fineness of the particles and monitor it appropriately.

The particle size is measured for raw materials and intermediate products as well as for finished products. Various measurement methods can be used. The micrometer and laser diffractometer methods are used in both the laboratory and production. Both methods are described in greater detail in Section 24.3.4.

The method of expression of the results usually depends on the method of measurement, as shown below:

- *Laser diffractometer*: Here the measured value D(90) = 25 μm means that 90% of the particles are less than or equal 25 μm.
- *Micrometer*: Here the measured value = 20 μm means that the largest particle is 20 μm in diameter.
- *Wet screen method (sieving)*: Here the measured value 1% > 75 μm means that 99% of the sample is less than 75 μm in size. This is based on the residue remaining on the 75 μm screen. The traditional sieving method can only be used within a separate laboratory because of the organic solvent employed. It has mainly been replaced by laser diffractometry.

Particle size measurements are also made on cocoa mass. In this particular case, oversized particles need to be removed. They can form during passage through ball mills and are removed by sieving the entire batch prior to further processing.

Milled material is produced during the manufacture of chocolate and filling masses. In order to measure its particle size, a bulk sample is often taken at the discharge from the milling line in order to determine the D(90) value. To check the settings of a five-roll refiner, for example (Chapter 9) as part of a throughput-fineness test, samples are taken from the left and right side as well as the centre of the upper roll. The throughput of a five-roll refiner can be determined with the aid of a belt weigher or similar monitor. In this way, it is possible to graphically chart fluctuations in the finenss over time. This procedure assumes that the throughput of the refiner can be held constant. It must be remembered that achievable fineness, operating hours of a roll set, consistency of the masse after the two-roll refiner, throughput, roll wear and five-roll refiner settings are all interrelated.

24.2.13 Production monitoring

24.2.13.1 Five roll refiner technology

A typical five roll refiner and its monitoring sensors is illustrated in Figure 24.17. Some of the sensors (Figure 24.18) will be described later in more detail.

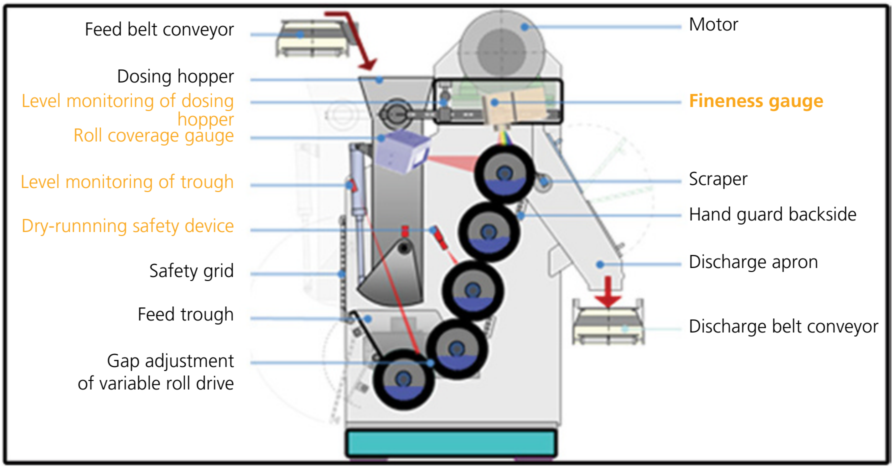


Figure 24.17 Overview of five roll refiner with its parts as schematic cross section view. Control elements are marked in red colour. Reproduced with permission of Bühler, Uzwil, Switzerland.

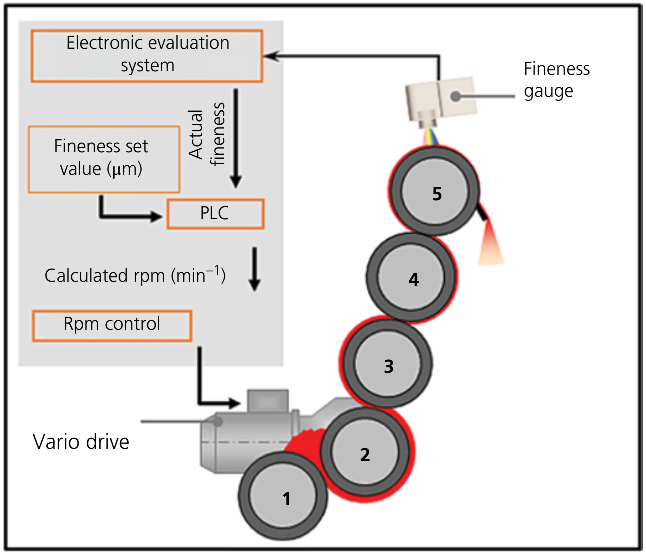


Figure 24.18 Refiner (schematic) with automatic particle size control (FineSense®). Reproduced with permission of Bühler, Uzwil, Switzerland.

Particle size control In state of the art chocolate production (dosing, mixing, refining and conching) the particle size of flakes after refining is an important quality criterion. Achieving the designated particle size is both important for the product quality as well as for economical production. Too coarse a particle size will result in rework, too low a particle size is lost throughput. An in-line thickness gauge combined with a refiner is able to adjust the particle size automatically and prevents such losses. Particle size is controlled by the product intake conditions varying with the masse consistency (the rest of the refiner remains fixed). The intake can be set either by adjusting the gap between roll 1 and roll 2 or the variable speed of the first or second roll within a certain speed range. Machines with variable speeds are preferred for automatic fineness adjustment.

The fineness of chocolate flake can be measured by different methods, which are summarised in Table 24.6.

Roll coverage control An uneven chocolate film coverage of the rolls reduces the throughput as well as increasing roll wear. Even more importantly, a uniform particle size distribution over the roll length is needed to produce a chocolate with consistent flow properties.

The roll coverage is influenced by the feed texture/plasticity and the refiner parameters such as roll temperature and pressure and the cooling intensity. A highly specialised machine operator is able to adjust the refiner parameters according to the type of pattern he sees on the rolls.

The coverage measurement of the fifth roll can be recorded by a camera with an in-line pattern detection system. The recorded pattern and its behaviour (stable, moving etc.) is compared with a data base and the necessary adjustments calculated and automatically reset by the machine.

The roll coverage can also be recorded with a laser scanner. The laser beam is used to detect the stripes and defining their position. This information is then transformed into a binary image as shown in Figures 24.19 and 24.20.

Before commercialisation of this technique, a pilot plant study (Figures 24.21 and 24.22) was performed to optimise the degree of coverage of the rolls in five-roll refiners and to investigate alternative automatic control systems. Figure 24.21 shows schematically the light source and the line camera. An incremental encoder on the fifth roll (not illustrated) synchronises the line camera with the aid of a frame grabber card. Automatic adjustment to optimal values in this way is much more frequent and accurate than would be possible even with the best machine operator.

Trough level control The discharge trough allows product to be deposited in the first roller gap. The trough should be filled with as little product as possible, but should contain enough product for the rollers to never run dry. The level is also important to produce a uniform film and therefore get a steady particle size

Table 24.6 Overview of in-line fineness measurement methods. Reproduced with permission of Bühler, Uzwil, Switzerland.

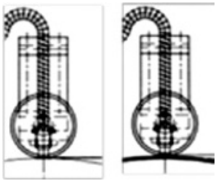
	Direct	Indirect	
Type	Distance measurement	NIR Spectrometer	Throughput measurement
Position	Center of the 5th roll	Center of the 5th roll	After the discharge apron
Picture			
Principle	The sensor runs with its wheels at the top of the chocolate layer and measures the distance between the wheels and the 5th roll surface.  Right: Film is displayed	The sensor measures the absorption of a certain wave length in the NIR Spectrum. The calculated value will, after a product related calibration, correlate with the film fineness.	Weights the chocolate masse (flakes) after refining per time. Out of the weight the fineness can be calculated as: $\mu = \frac{Q}{d \cdot \pi \cdot l \cdot n \cdot \gamma \cdot F}$ Q = Throughput d = Diameter 5th roll l = Usable length 5th roll n = rpm of 5th roll μ = End fineness in micrometer γ = Specific gravity masse F = Roll coverage 0…100%
Advantages	Direct measurement • Only one point measurement • Wear and tear of the wheels • Needs to be recalibrated very often • Stable film for accurate measurement	Touch less • Only one point measurement • Calibration for all recipes necessary once • Full film at the measure point necessary for accurate measurements	Measure the whole roll length. • Depends on roll coverage F • Only an average measurement • Depends on mass density γ

Figure 24.19 Different black-and-white patterns (whole roll length) for different incorrect control adjustments. Black is covered, white uncovered roll. Reproduced with permission of Bühler, Uzwil, Switzerland.

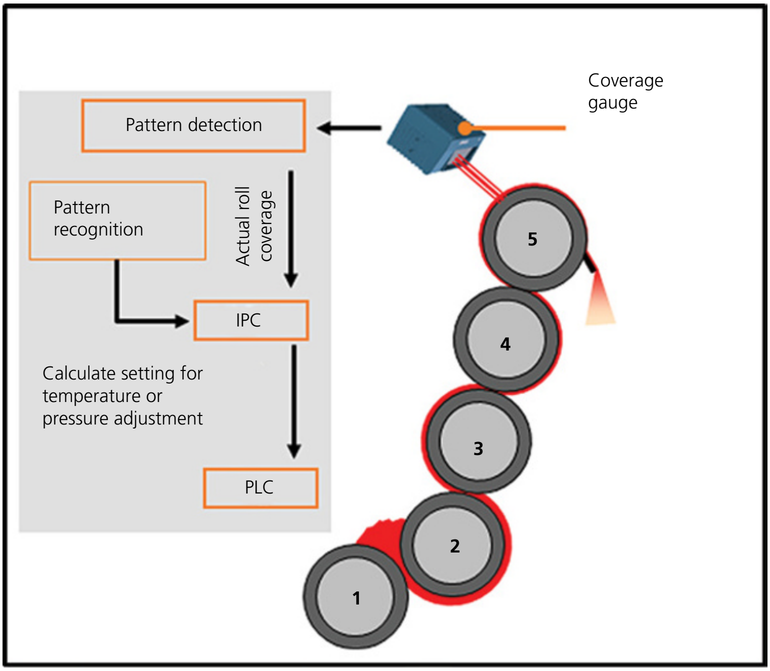


Figure 24.20 Refiner with automatic roll coverage control (FineFilm®). Reproduced with permission of Bühler, Uzwil, Switzerland.

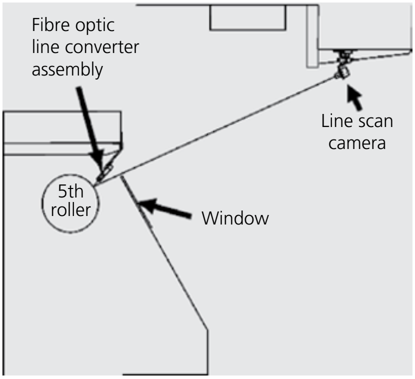


Figure 24.21 Experimental pilot rig. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

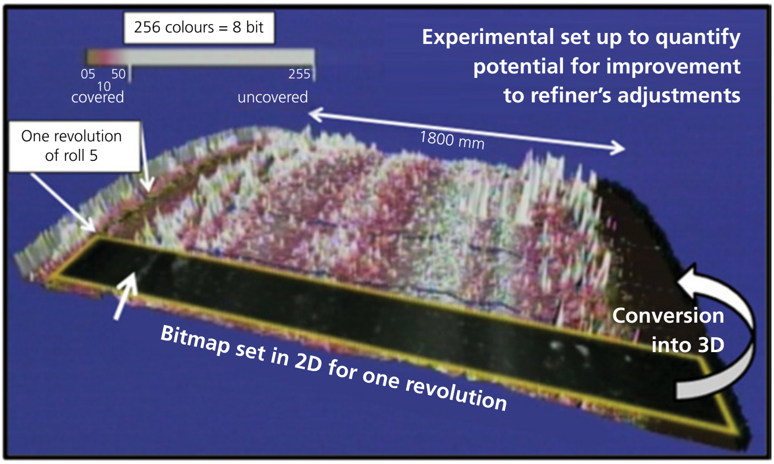


Figure 24.22 Image of computer illustration (degree of coverage of the refiner roll) generated from the results obtained with the experimental pilot rig shown in Figure 24.21. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

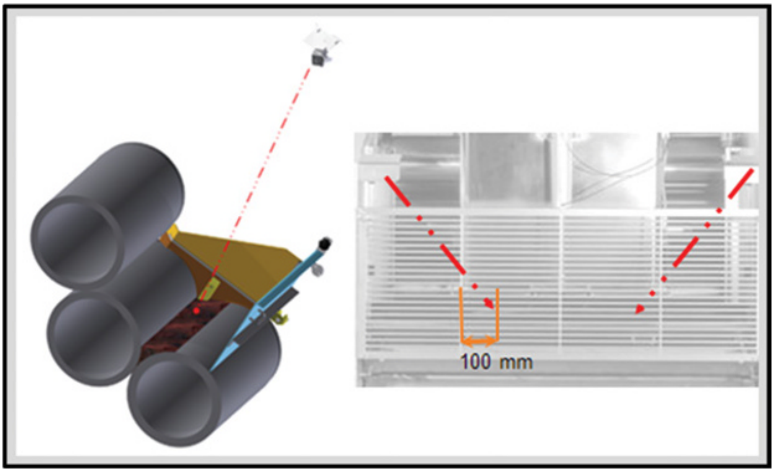
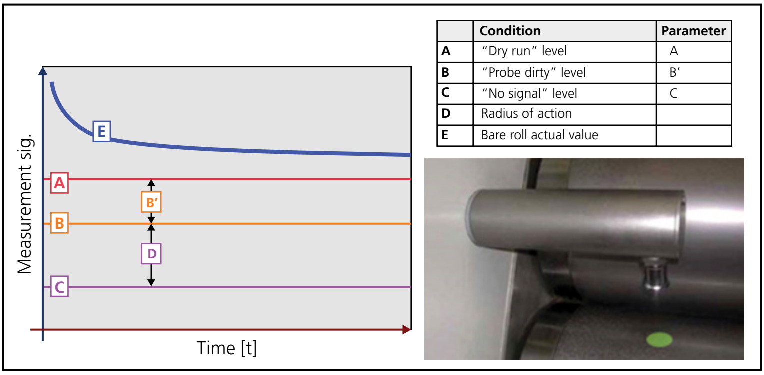


Figure 24.23 Refiner trough level control. Reproduced with permission of Bühler, Uzwil, Switzerland.

over a long period of time. (see Figure 24.23 for a three roll refiner). The level in the trough is detected using a digital infrared distance probe (two points) and controlled by the opening level of the dosing hopper flap.

If the minimum level is not exceeded for a pre-set time, the machine shuts down to prevent the rollers from running dry.

Dry running protection If there are a lot of stripes or even no product at all, the rolls could touch each other and run dry. If this happens the rolls get damaged



	Condition	Parameter
A	"Dry run" level	A
B	"Probe dirty" level	B′
C	"No signal" level	C
D	Radius of action	
E	Bare roll actual value	

Figure 24.24 Contrast levels and position. Reproduced with permission of Bühler, Uzwil, Switzerland.

at least with burned strips on each roll. The product transfer between the rolls then gets worse and the life of the rolls is shortened.

With a contrast sensor the level of the reflection can be detected and produces information about the coverage status of the roll (Figure 24.24). This difference in the transmitted signal enables machine parameters to be automatically set for different products under a wide range of conditions.

The sensors are placed on the left and right of the third or fifth roll about 250–300 mm from the roll edge. As the optical sensor only has a detection spot diameter of about 30–50 mm the dry run detector is of limited but sufficient accuracy. This is because most dry runs occur at these positions on the roll.

Newer technology uses a camera system to detect dry runs. Dosing techniques and imaging software can calculate the contrast difference from the pictures. These systems are able to detect a dry spot of about 30–40 mm diameter on each side of the roll. It is also possible to use the roll coverage detectors – described above – to prevent dry runs. These work along the entire roll length and are the best solution.

24.2.13.2 Moulding technology

Product variation during cooling Monitoring cooling processes is a very complex task (see also Chapter 14). Besides controlling conditions within the actual cooling chambers, there are none obvious factors such as those caused by the attached packaging machines which can significantly disturb the moulding line and reduce its output. Here the use of buffer elements between moulding and packaging area and/or before the packaging machine can only damp or delay slightly the losses and shorten the length of line downtime. Inconsistent cooling conditions remain and have the potential to influence the product quality (increased breakage, bending, formation of hair cracks, cooling spots,

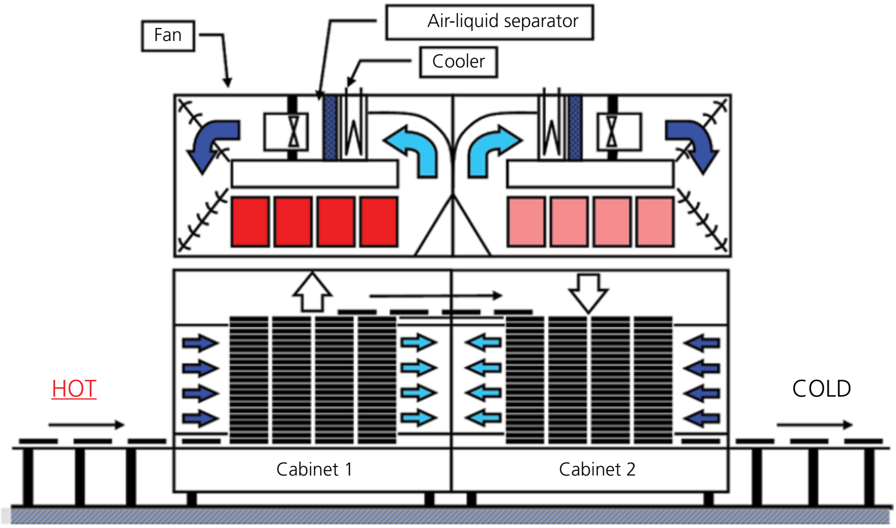


Figure 24.25 Schematic drawing of a paternoster-type cooling tunnel. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

fat bloom and dull surface appearance). All of these are the result of uneven line speed, which gives an inconsistent residence time of chocolate products in the cooler.

Paternoster-type cooling tunnels (Figure 24.25) are often part of continuous moulding lines. Another monitoring option exists in addition to traditional technology based on temperature data loggers. This involves viewing mould/product surfaces by infrared cameras just after leaving the cooler. The quality of the data sets can be improved if the images are synchronised so that all products appear at the same position, have identical size and the images are ready for further analysis. Besides making surface temperature pattern visible, (Figure 24.26) differences between different positions can be quantified over time (Figure 24.27). The possibility to combine the thermal history of a product with surface temperature data can be utilised for example in shelf life studies, see Figure 24.28, which shows three sets of data.

1. Taken at the outlet of cooling tunnel, the results in the lower part of Figure 24.28 show a typical cooling tunnel design-related surface temperature pattern. Patterns can be observed for some machine designs, which result from transient heat exchange conditions during transit through the cooling tunnel. The heat transfer conditions changes spatially along the layer of the moulds while travelling through the 75 stages of the two-cabinet elevator. Selected simulation results of temperature distributions whilst travelling through a cooling tunnel are illustrated in Figure 24.29.

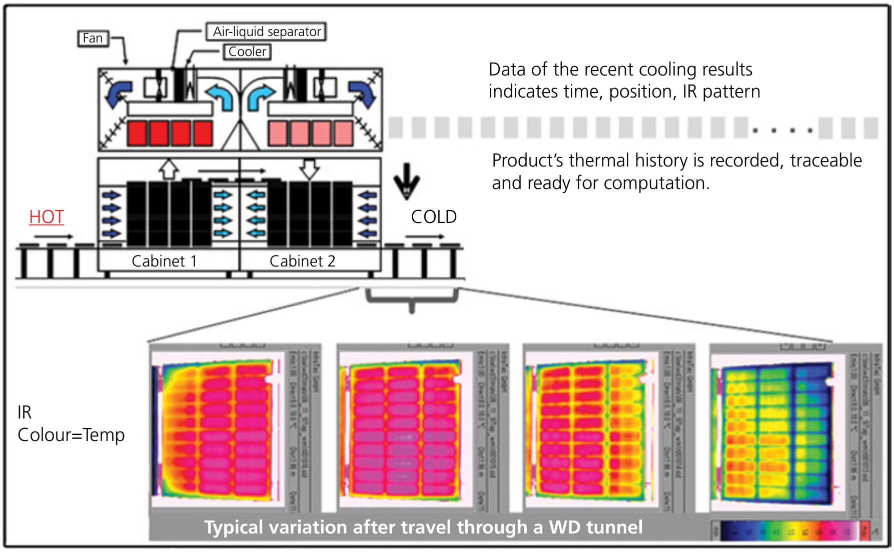


Figure 24.26 Schematic of IR imaging of moulds containing product, four moulds per stage, 75 stages. Below there are seen the individual mould patterns. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

2 For sensitive products, especially filled chocolates, some areas of the surface distribution pattern show the position of early and intensive fat bloom formation (see Figure 24.30).

3 In parallel to a traditional sensory test, this approach gives proof of concept for chocolate fat bloom assessment by computer. Results are visualised in Figure 24.28.

An alternative approach to the problem of sub-optimal heat transfer is described by Rocklage *et al.* (2012). Windhab *et al.* (2008) are also developing the so-called DETACHLOG principle. Using this approach it is possible to determine the exact time that the product will release from the mould cavity in a given cooling tunnel. This means that the minimum time for cooling can be determined. In addition this technology will enable the chocolate manufacturer to determine cooling profiles tailored for individual products and recipes together with performing shelf life studies.

24.2.14 Detecting foreign matter

External matter removal is vital in ensuring the safety of food products (Chapter 25). It involves not only control of foreign matter, but is also part of the processing guidelines for chocolate, filling masses and rework. Depending upon the processing stage, foreign matter can be removed manually or by equipment such as metal detectors, separators, magnets, filters, screens, traps and optical detectors.

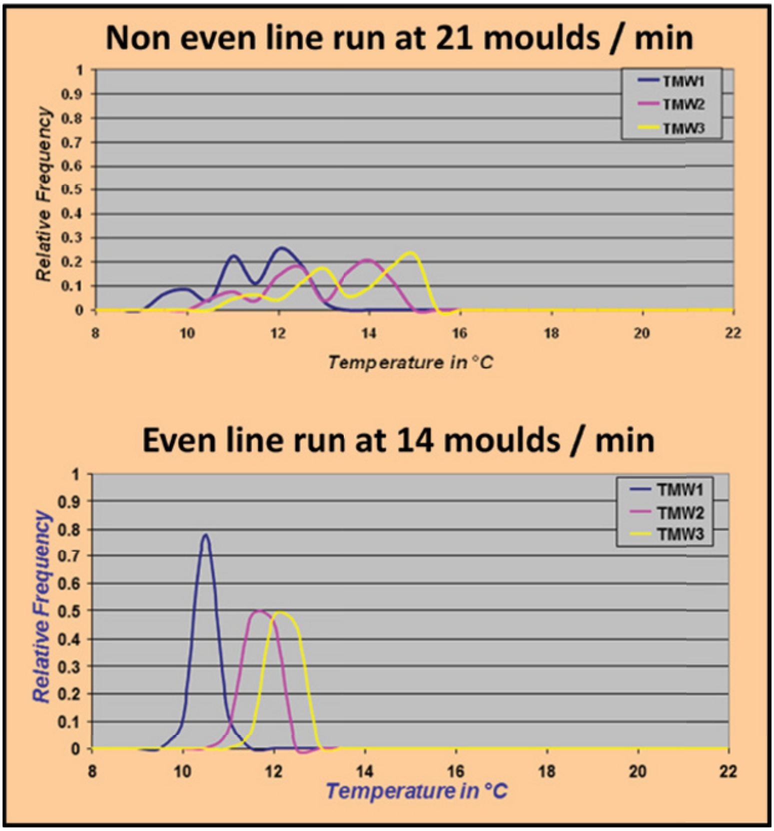


Figure 24.27 Typical surface temperature tracks measured along three virtual lanes (left: TMW1; centre: TMW2; right: TMW3) in full-scale production. A dedicated pyrometer was mounted above each track. They were all connected to a control unit which could identify chocolate surface area over run time. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

Metal detectors are always coupled with reject devices to divert non-conforming products. The product is carried on a non-metallic conveyor through an aperture around which are wound three coils. An operating and analysis system enables ferrous metals, non-ferrous metals and stainless steel to be detected within the chocolate. In addition a magnetic field method is capable of distinguishing ferrous metals in products packaged in aluminium foil.

When using the differential transformer method to detect pieces of metal, three coils encircle the detection aperture. An oscillator drives the signal voltage in the primary coil. Two secondary coils, on a common axis with the primary, are coupled into the field of the primary coil in such a manner that the system is in balance and the induced voltage in the two secondary coils cancel each other out. A piece of metal introduced into the detection aperture will distort the primary

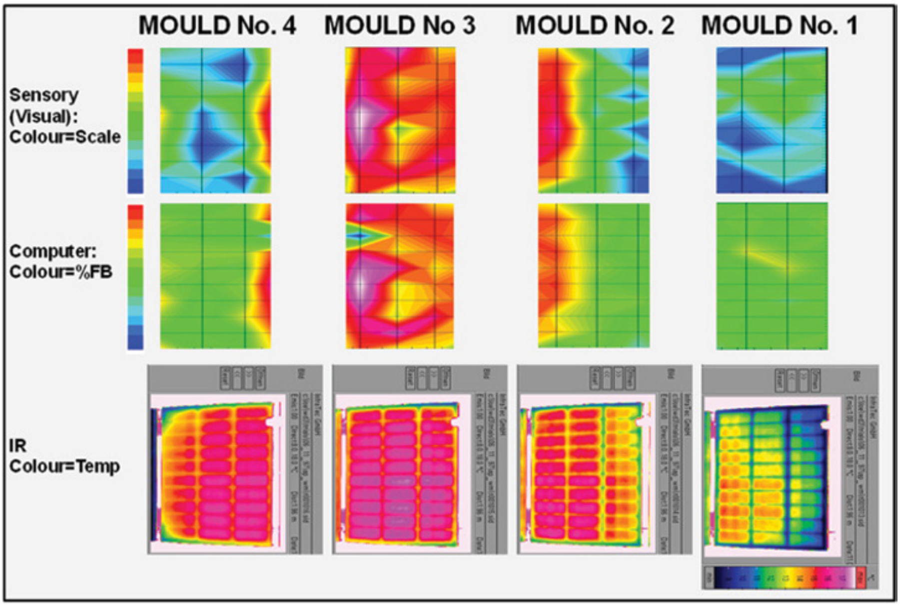


Figure 24.28 Typical test results. *Upper level*: Traditional sensory test and fat bloom results of a product"s top side visualised by intensity graphs of chocolate surfaces after 264 days storage at 18 °C. *Centre*: Results of a computer aided fat bloom assessment of same samples as were taken for the upper level (FB = fat bloom). *Lower level*: IR pattern of mould set containing filled chocolate tablets (here shown bottom side) after leaving last cooler of a moulding line. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

field and cause a difference in induced voltage in the secondary coils. This voltage difference constitutes a signal that is amplified and manipulated to extract the amplitude and phase angle with respect to the oscillator input signal. This information is used to decide whether the signal represents metal or the product. If it represents the product, it is ignored and if it represents metal and if the signal exceeds a pre-set level, the metal detector generates a signal which is used to activate the reject mechanism.

24.3 Laboratory analysis

The examples of laboratory analysis presented in this chapter are as would be found in the laboratories of a large chocolate manufacturer. Smaller production sites may have to out-source analytical testing and to rely on suppliers to deliver raw materials to certified standards. This chapter is designed to give the reader an overview of the complexity of the quality assurance measurements that are

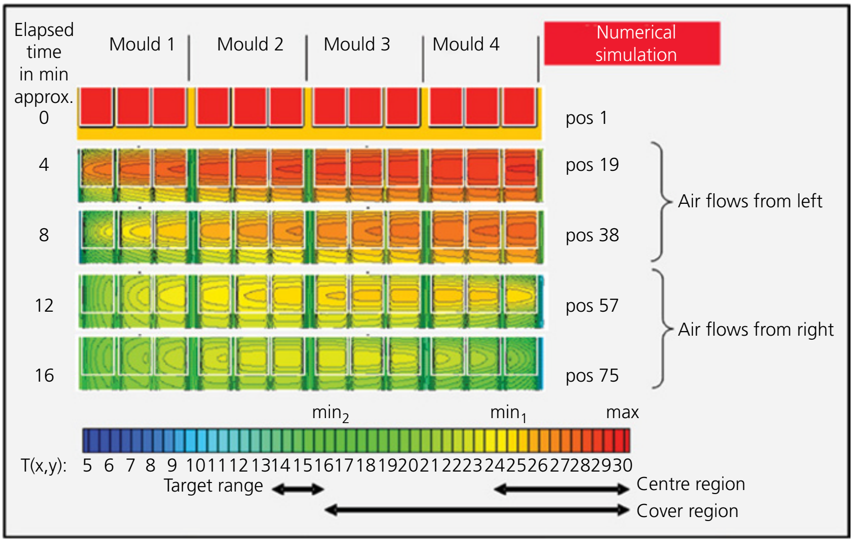


Figure 24.29 Qualitative result of a 2D heat transfer simulation of filled moulds while travelling through a cooling tunnel, simulation by Dr.-Ing Thomas Demmer. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

required within the confectionery industry and not to cover the huge range of methods actually available or indeed the recent technological advances that are currently taking place.

24.3.1 Moisture measurement

As was noted in Chapters 10 and 11, a very small amount of moisture can greatly increase the viscosity of chocolate and indeed the presence of an extra 0.3% water needs approximately another 1% of fat to compensate for it. Any analysis used must be repeatable to better than about 0.2%. Two methods are often used within the industry, namely oven drying and Karl Fischer titration. The former measures of “free” moisture that affects the flow properties, whereas the titration also measures “bound” moisture for example that in crystalline lactose monohydrate (in milk) that has little, if any, effect on viscosity.

Oven drying involves mixing a small sample of chocolate with a weighed quantity of dried sand in a metal tray. This is then reweighed to determine the weight of the chocolate before being placed in a hot oven for a set time and temperature. Typically this is about 98 °C (208 °F) for about 12 h and, provided a strict regime is followed within a laboratory, results can be obtained with a good enough repeatability to monitor factory production. Karl Fischer titration is based upon the reaction between sulfur dioxide, iodine and water shown in equation (24.1).

$$I_2 + SO_2 + H_2O = SO_3 + 2HI \qquad (24.1)$$

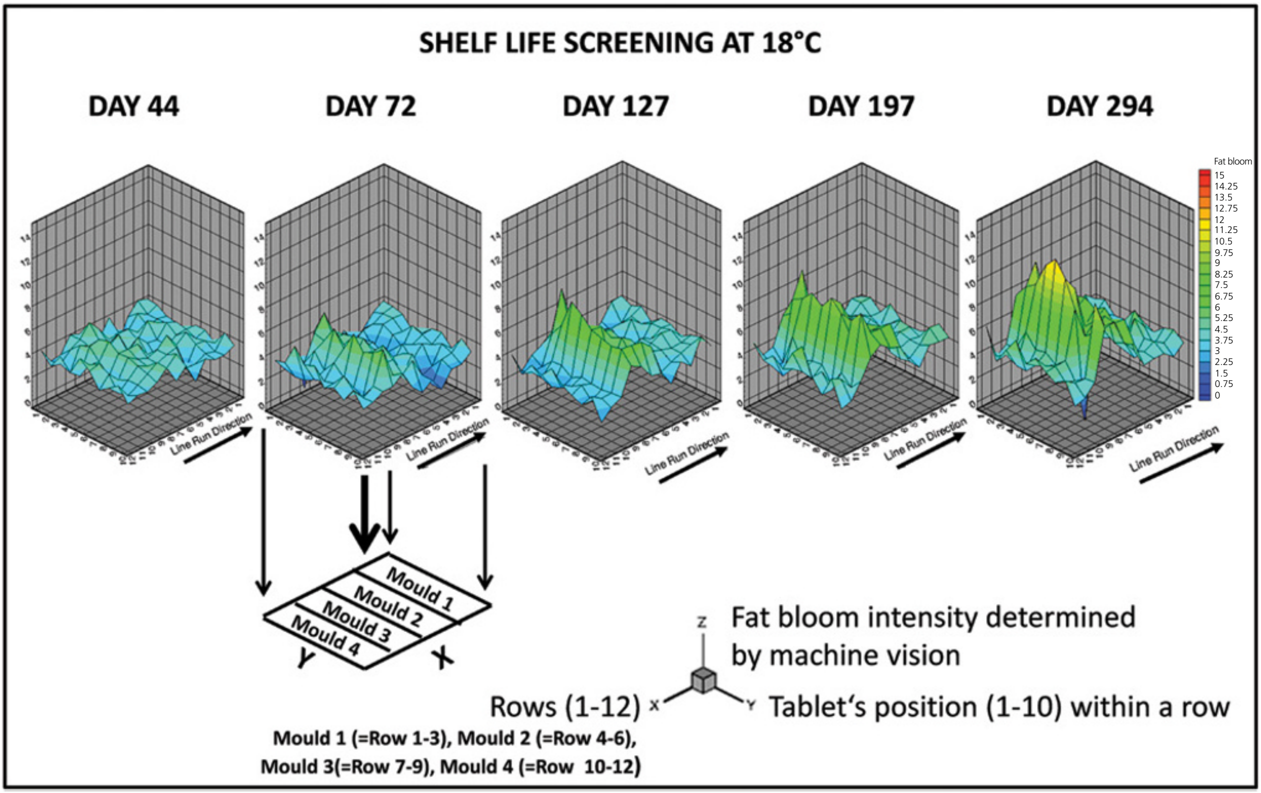


Figure 24.30 The intensity surfaces above visualise the evolution of fat bloom depending on the mould position in a cooling tunnel, see also Figure 24.28. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

The reaction takes place with pyridine in another solvent, which may be methanol and is such that one molecule of water reacts with one molecule of iodine. Automatic systems exist that can give a measurement within a few minutes. In these systems a pre-weighed amount of chocolate is dispersed in a liquid (e.g. formamide, chloroform and methanol) in a reaction vessel. This is tightly sealed to stop moist air entering the container with its stirrer and two platinum electrodes. Any iodine present will depolarise the cathode and allow a current to flow between the electrodes. A Karl Fischer reagent containing pyridine is then added slowly in controlled amounts. Once the iodine is used up the current will stop. At this point the amount of added reagent corresponds to the amount of water present in the original chocolate. The result is normally higher than for oven drying, because it includes the bound water, but it is highly reproducible and the analysis time is shorter.

24.3.2 Determination of fat content (Soxhlet)

In-line fat measurement systems, such as those based on near-infrared reflectance, are used in the industry especially for ingredients such as milk powder. Often they are affected by other parameters such as particle size or colour and they need recalibrating for each product. In order to carry out this calibration, or to perform routine laboratory fat analysis on chocolate, the traditional Soxhlet method is often used (Beckett 2000).

The principle of the method is to use a solvent to dissolve the fat out of chocolate, before evaporating the solvent. This leaves the fat, which can be weighed directly. This is normally carried out in a glass system. The chocolate sample is weighed and cut into small pieces before being wrapped in a filter paper, which is in turn placed in a permeable thimble. It is now ready for placing the central part of the extraction system between the flask and the water-cooled condenser. The flask contains the solvent, normally petroleum ether, which is heated on an electric mantle. The boiling ether evaporates and passes through the side arm into the condenser. Here it condenses and runs back into the thimble dissolving the fat. The fat-containing liquid passes through the filter paper and collects in the middle container. Eventually the quantity of liquid builds up until it reaches level A in the siphon (please see Figure 24.31), when it empties back into the flask. In this way the solid particles are retained within the filter paper and the fat is collected in the flask, where the temperature is high enough to evaporate the ether, but not the fat itself.

After about 12 h the top two sections are removed and replaced by the petrol distillation unit. This collects all the petroleum ether and does not let it run back. The fat remains at the bottom of the flask and can be weighed.

This technique measures both free and bound (contained within cocoa or milk particles) fat. When investigating viscosity problems it is sometimes necessary to determine the bound proportion (Chapter 11). An estimate of this can be obtained by first treating the chocolate with a mild solvent for a short period to extract

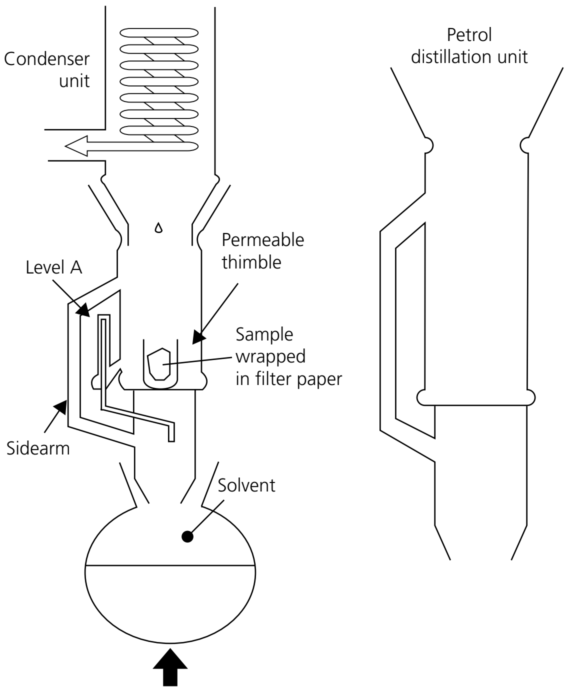


Figure 24.31 Schematic diagram of Soxhlet fat extraction apparatus. Reproduced from Becket (2000).

the easily soluble fat. The more tightly bound proportion is then determined by the standard procedure.

24.3.3 Solid fat content

24.3.3.1 Nuclear magnetic resonance

Two techniques are employed when using nuclear magnetic resonance (NMR) to measure the solid fat content (SFC) of cocoa butter and other fats: pulsed NMR and the continuous scanning method. Both are more reliable when carrying continuous measurements on pure fat systems. When chocolate is being analysed, account must be taken of the other solid components present, for example sugar, milk proteins and so on, which result in reduced sensitivity. When absolute values are required, very strict calibration techniques are needed, especially if a significant amount of water is present together with the fat.

Currently SFC measurements by pulsed NMR are often used. In pulsed NMR, the sample is held in a uniform magnetic field, which causes the protons in it to become polarised and magnetisation to occur. A short radio frequency pulse, at a pre-selected frequency, causes a rotation of this magnetisation vector around an axis normal to the original magnetic field. After the pulse, the longitudinal and transverse components of this rotating, magnetism return to equilibrium over different periods known as relaxation times. Owing to their greater mobility, the relaxation time for molecules in the liquid stage is much shorter than for those in the solid state. It is therefore possible to determine the relative proportions of these two states in the sample.

The solid fat content is expressed as the percentage of the total fat that is measured as being solid. The value depends on which of the two standard methods has been used, and the method should be quoted along with the result. The direct method Cd 16b-93 (AOCS, 1993), ISO 8292 requires calibration with a control containing paraffin/acrylic glass, whereas the indirect method Cd 16-81 (AOCS, 1981) compares measured signals with those coming from a de-crystallised sample. According to Padar (2006), for cocoa butter samples the accuracy of indirect method is higher but more time-consuming than the direct method. The direct method results are available within seconds, but need a correction factor which depends on crystal type and temperature. This causes a systematic bias, which has to be taken into account.

It should be noted that even at room temperature a substantial proportion of the fat phase is still liquid in fat samples, as well as in a normal milk chocolates. The samples must be carefully prepared beforehand, with the fat taken through prescribed temperature cycles to ensure correct crystalisation.

When vegetable fats are used, it is important to know how the chocolate will behave at higher temperatures to be sure of good eating properties. This can be determined by carrying out NMR measurements at a series of temperatures.

24.3.3.2 Differential scanning calorimetry

Not only can differential scanning calorimetry (DSC) measure the amount of solid fat present in a sample, but it can also determine its crystalline state, which is vital to obtain good quality product (see Chapters 7 and 13). DSC enables the relative amounts of each of the crystalline states to be determined. This relies upon the fact that when a crystal melts, large amount of latent heat are taken in (the reverse to solidification). In DSC measuring cell the sample (*note*: the sample weight, approx. 10–20 mg, must be measured with accuracy of ±0.1 mg) is taken relatively quickly through a predetermined temperature range (in the order of 0.5 °C/min; 1 °F/min), and the energy change monitored. Peaks (see Figure 22.32) occur in the temperature ranges corresponding to the crystalline state present. The onset of a peak corresponds to the temperature at which a particular crystal form starts to melt, while the peak maximum corresponds to the temperature at which the rate of melting is greatest. This information can be used to indicate the crystal type. The peak height, position and resolution are strongly dependent upon the scanning speed (rate of temperature change); see Cebula *et al.* (1992).

A common technique used with chocolate is to plunge the sample into liquid nitrogen. Any liquid fat remaining then takes up the very unstable crystal form. When the sample is heated, peaks in the range 28–32 °C (85–90 °F) enable the proportion of the more stable forms to be determined.

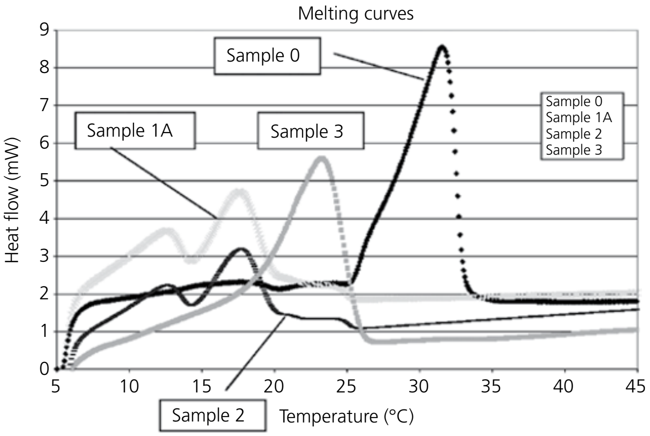


Figure 24.32 DCS plots of milk chocolate samples obtained using different cooling rates (sample 0: control; sample 1A: cooling rate 10 °C/min; sample 2: cooling rate 1 °C/min; sample 3: cooling rate 0.1 °C/min).

24.3.4 Particle size measurement

The original methods employed for determining particle size in milled material, chocolate masses and filling masses, such as the micrometer screw and wet sieving have been largely replaced in the laboratory and/or production areas by laser diffractometry (see also Section 24.2.12). For approximate, fast, on-line measurements however, micrometers are still commonly used, although laser diffractometry does provide more useful and accurate information. Measurements of the particle distribution are more useful than those of the largest particle, which is all that a micrometer can indicate. Traditionally, only the laborious wet sieving approach was available for determining particle size distributions and then only at the larger end of the size spectra. A laser diffractometer can produce the results in about 10 min and is largely independent of the operator. This has helped the manufacturer to optimise both processes and recipes. If fats/oil are used as dispersants, it is possible to run laser diffractometers in laboratory areas located close to the production lines.

Laser diffractometry: The optical components of a laser diffraction particle size instrument are shown in Figure 24.33. Prior to each measurement, the particles from the sample to be measured are dispersed in a liquid for example a special oil or, in certain cases, an organic solvent. This dispersion is aided by ultrasound treatment, which also breaks up agglomerates of particles. The sample is then recirculated through a cell located in the optical path of the laser. This movement prevents particles from sedimenting to the bottom of the cell. Although the dispersed particles are in motion, the laser diffraction pattern of the beam of coherent monochromatic light (laser illumination) is stationery, and contains information on the particle distribution. The laser beam is between 5 and 20 mm diameter, and the image of the diffraction pattern is formed in the focal plane of

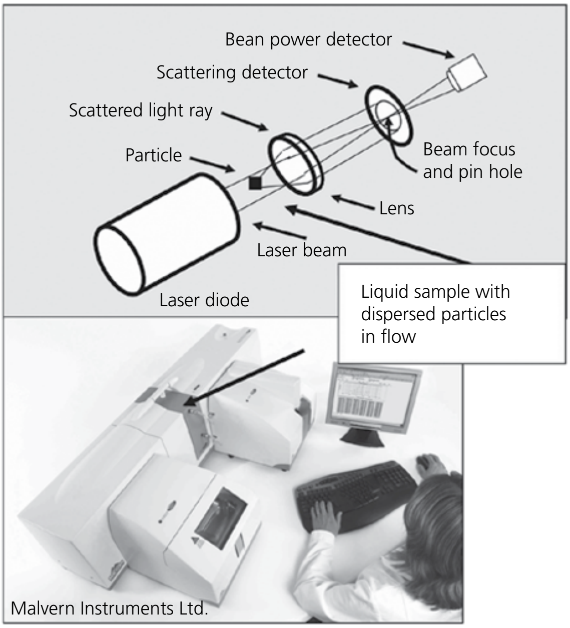


Figure 24.33 Overview of the principle of operation of a laser diffractometer. Reproduced with permission of Mavern Instruments.

the lens and sensed by a photo-diode array (scattered light detector). The intensity of the light that is not scattered is monitored by a beam power detector. The scattering patterns with which to compare the detected signals can be calculated assuming simple Fraunhofer diffraction. The choice of lens determines the size range that can be detected. The model for calculating the particle size distribution is critical for interpretation and estimating errors. These models use an assumed form factor. Often a spherical shape is used, which gives an added uncertainty. For closer monitoring additional camera systems are commercially available. But in all cases it is useful to have a closer look at measurement capabilities and limitations. The structure of the individual particles leads to limitations in the accuracy of the measurement methods. For example differences between particles having the same size, but different shapes are not taken into account. The results are usually presented in table form as volume distribution or number distribution with a statement of the calculated percentage per particle size class and reference to the model used. The particle size is usually plotted logarithmically along the x-axis, see Figure 24.34. Data transmission (e.g. protocol with ASCII characters) is technically possible permitting remote use. Laser diffraction units should be equipped with multi-access levels to allow purpose-optimised operation/modification. In addition such measurement units can be seen as single workstations connected via networks and utilised accordingly. Calibration routines can be run in an automated manner between sites regardless where they are located across the world. The almost unlimited availability of digital particle size data gives the possibility of integrated sampling, for example

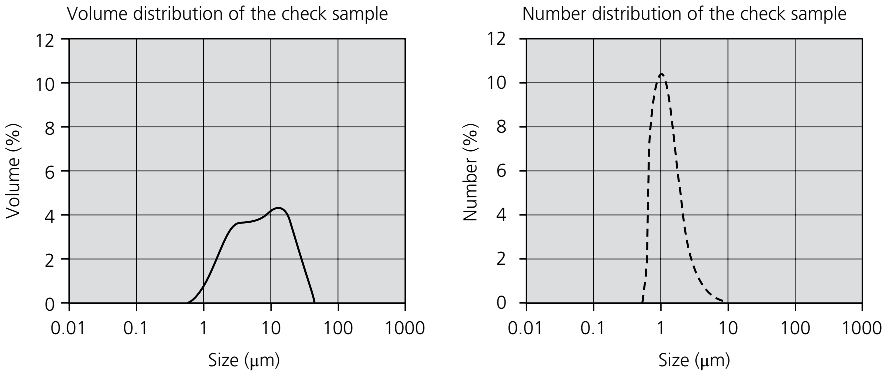


Figure 24.34 Typical particle size distribution for a sample of milled material shown as volume and number distribution curves.

of flakes per refiner, conche and system run time, making automated off-line systems a likely development.

24.3.5 Triglyceride (triacylglycerides) composition (vegetable fat content)

The European Union (EU) chocolate regulations (Chapter 28) limit the types and amounts of vegetable fat that can be added to chocolate and it is therefore important to be able to distinguish between these fats and cocoa butter. Chapter 7 gives further details about the approved raw materials and the properties of the special cocoa butter equivalents (CBEs) that are permitted in chocolate. No other type of CBEs may be used in the EU (legislation elsewhere varies from country to country) and, if the amount of these CBEs exceeds the maximum limit of 5%, the product cannot longer be called chocolate.

The special fats classified as CBEs contain no lauric acid, but possess large amounts of symmetrical and simple unsaturated triglycerides (POP, POS, SOS) and are completely miscible with cocoa butter. Generally, the determination of the triglyceride distribution is made by means of high-temperature gas chromatography (Figures 24.35, 24.36).

As part of the implementation of the EU cocoa regulation, the Joint Research Center (JRC) of the European Commission has over the past few years prepared a data base of triglyceride distributions from hundreds of samples (cocoa butter, CBEs, milk fats) from various geographic regions, as well as from fat mixtures of these in a wide range of proportions. With the aid of existing analytical data, multivariate statistical formulas were established and validated. They are now available for practical use for quantification of cocoa butter, milk fat and CBEs from fat mixtures; no additional fats must be present, however.

Other problems arise from the presence of fats from other sources such as nuts and almonds from filling fats. In addition to the distribution of triglycerides,

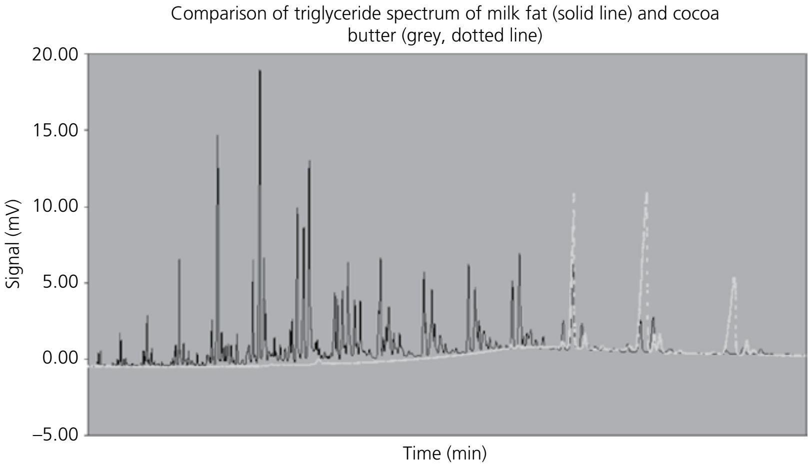


Figure 24.35 Superimposed triglyceride profiles for milk fat and cocoa butter.

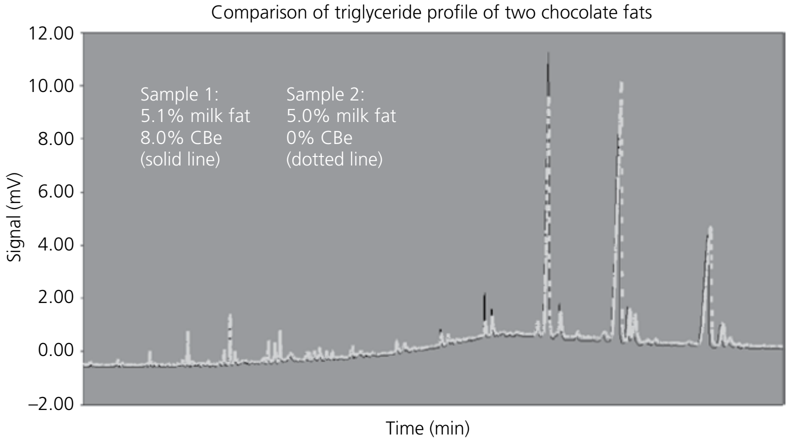


Figure 24.36 Superimposed triglyceride profiles from two fat mixtures. Sample 1 does not comply with Directive 2000/36/EC, Sample 2 is chocolate in compliance with Directive 2000/36/EC.

other complimentary methods exist, for example analysis of the fatty acid distribution (after their hydrolysis from triglycerides and steric esters), tocopherols, sterols and steric esters. When evaluating the data, however, the natural variation in the content of these fatty substances must be always taken into consideration. Existing reference (comparison) data for fats and fat mixtures of known origin and/or known composition are important when evaluating the data from unknown source samples.

24.4 Summary of important analytical procedures in a typical quality assurance laboratory

24.4.1 General

Organisation of sampling, sample storage, sample preparation:

- Sampling technology including random sampling plan and sampling schedule;
- Maintain store of raw materials, semi-finished products, finished products.

24.4.2 Analysis

Organisation of the calibration of laboratory equipment:

- Calibration of burettes (digital),
- Calibration of laboratory balances,
- Calibration of viscometers.

Subject of analysis: general measurements

- pH value;
- Determination of total ash;
- Ash content (conductivity meter);
- Settled and compacted apparent density;
- Colour measurement;
- Flow properties: Determination of viscosity;
- Shrinkage of chocolate by high resolution stress controlled cone/plate system.

Subject of analysis: sensory for raw materials, intermediate products, finished products

- Cut test (cocoa beans);
- Acetone-soluble fraction (lecithin);
- Lipase activity (milk);
- Sensory protocol;
- Triangle test;
- Record complaints for raw materials and intermediate products.

Subject of analysis: sensors for packaging material/finished products, unpackaged

- Robinson test;
- Develop a complaint recording system related to packaging material;
- Set up an archive of quality defects and complaints about packaging materials.

Subject of analysis: visual inspection

- Dirty test of milk powder;
- Set up defect list and defect evaluation table for unpacked products and packaging material;
- Set up defect list and defect evaluation table for unpacked products and MHD (expiry date, minimum durability and best before) for packaged products.

Subject of analysis: water (moisture) content

- Dry matter in a drying cabinet;
- Moist dry matter in a drying cabinet;

- Dry matter in samples containing sugar;
- Brabender moisture (fast method);
- Water activity (A_w value);
- Moisture according to Karl Fischer analysis.

Subject of analysis: fat phase

- Fat content using the Soxhlet method;
- Iodine number;
- Peroxide number;
- Oxidation stability;
- Composition regarding triglycerides;
- Surface fat in milk powder;
- Degree of acidity of milk powder;
- Fat content using NIR;
- Lipase activity;
- Determination of melting point.

Subject of analysis: emulsions

- Stability by doing centrifuge test without/with optical tracking of phase separation;
- Droplet size/distribution, for example fat droplets, by laser diffraction.

Subject of analysis: sugar

- Sucrose and glucose;
- Sucrose (double polarisation).

Subject of analysis: particle size/shape

- Particle size distribution (laser diffraction), In combination with camera system particle shape distribution;
- Fineness determined with a micrometer screw;
- Fineness determined by wet sieving;
- Fineness determined by dry sieving (particle size distribution plot);
- Size determination with hazelnuts (particle size distribution plot);
- Wet sieving of cocoa liquor with organic solvent (particle distribution plot).

Conclusions

This chapter has described some of many analytical tools that are available to the confectionery manufacture. Every company will have its own procedure and instruments, many developed in-house. There is a clear ongoing trend towards more intensive use of digital data for machine and product quality control and a better understanding of processes has helped the user interpret it. Consequently it is increasingly possible to produce more consistent quality products with fewer out of specification issues and improved environmental friendliness. The most important thing is that technology is used correctly to provide the consumer with high-quality safe products.

Acknowledgements

The author would like to thank Mr. I. McFarlane who gave an outline input to this book, especially with regards to the sections on recording flow characteristic, detecting foreign matter and laboratory analysis for moisture measurement, determination of fat content in his chapter on instrumentation in the 3rd edition of this book. Furthermore I would like to thank Stephen Beckett for his support in making novel technical solutions public. Special thanks to Buehler, Uzwil, especially Manuel Hoehener and Dr. Peter Braun, for their contribution and efforts in commercialising the Kraft Foods' invention using refiner supervision by optical means in order to create a feedback system giving fully automated operation. Finally my thanks are given to all supporters of applied infrared technology to evaluate cooling tunnels/refiners at Kraft Foods R&D Munich Inc., the system supplier Infratec GmbH Dresden and operatives at Mondelez International, Loerrach, Germany.

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CHAPTER 25

Food safety in chocolate manufacture and processing

Faith Burndred and Liz Peace

25.1 Introduction

The aim of this chapter is to present the major potential food safety hazards to be considered during chocolate manufacture and use, and to suggest methods of their control. Although it is not intended to be an exhaustive account, it should provide the reader with an overview of the breadth of this subject and of the importance and wide scope of the different food safety controls within the chocolate processing industry.

25.2 The importance of food safety management in chocolate processing

According to ISO (2005), a food safety hazard is a biological, chemical or physical agent in food, or condition of food, with the potential to cause an adverse health effect. In other words, it can be defined as anything related to the food that might cause harm to the consumer. Implementation of a food safety management system and control of such hazards in chocolate processes is essential; the consequences of its failure can be illustrated by a number of serious and high-profile incidents and recalls over recent decades. Such incidents can cause illness, injury, or, in the most severe cases, death to the consumer. Chocolate manufacturing companies must strive to maintain the consumer's trust in their products, as the consequences of a major food safety incident not only affect their own business, but can also have a negative impact on the reputation of the confectionery, and the food industry, as a whole.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

25.3 HACCP and prerequisite programmes

For those readers unfamiliar with the concept, HACCP is the acronym for Hazard Analysis and Critical Control Points, which is a systematic and science-based approach to the identification, assessment and control of food safety hazards. The principles of HACCP have been clearly defined by Codex Alimentarius, and it is considered to be one of the most useful tools for the proactive identification and control of hazards in foods. Prior to the application of a HACCP system, it is essential to have basic prerequisite programmes in place, which include what are commonly referred to as good manufacturing practices (GMP). Therefore prerequisite programmes include, for example, personal hygiene routines, pest management systems and foreign body prevention schemes.

Although this chapter will not describe in detail the principles of a good food safety management system, it is important to note that food safety in chocolate processes should be managed through the implementation of prerequisite programmes and HACCP. It is for this reason that the hazard categorisation used in this chapter to define the different types of food safety hazards follows that used by the HACCP methodology – namely physical, chemical, biological (microbiological) and allergen hazards.

25.4 Physical hazards

Foreign bodies can be defined as matter that is present in a food, but which, whether of intrinsic or extrinsic origin, is undesirable (George, 2004). An intrinsic foreign body is associated with the food itself, for example a nut shell or raisin stalk. An extrinsic foreign body is introduced from external sources and includes matter such as glass, metal, wood, plastic, insects and human hair.

Physical hazards are foreign bodies that are hard and/or sharp. They may cause physical injury, such as cuts to the mouth, throat or digestive system or choking.

The sources of physical hazards during chocolate manufacturing and processing usually fall into one of the following categories:

- Incoming raw materials;
- Processing equipment;
- Failures in prerequisite programmes.

25.4.1 Physical hazards in incoming raw materials

It is important to ensure that all ingredients used in the manufacture of chocolate are received free of foreign materials. Any ingredients derived from raw materials of an agricultural origin, such as cocoa products, nuts or sugar, must have suitable control measures in place during processing by the supplier to remove physical hazards.

A major potential source of foreign materials is unprocessed cocoa beans. The fermented, dried beans may be contaminated by many foreign materials, including stones, wood, metal, glass, fibrous material, loose shells, dust and sand. An essential step in the processing of cocoa beans is cleaning, where various methods are used to separate out the foreign bodies, including air separation, vibration, sieving and magnets. Similar controls are also used for the separation of foreign bodies in nuts.

Further removal of foreign material occurs after the beans have been broken. During winnowing, the shell is separated from the nib, and at this point it is important to remove any other hard residues such as sand and dried pulp remains, as well as the shells.

In addition to the intrinsic hazards present in the incoming raw material crops, it is also possible that the plant, equipment and manufacturing practices used to process the ingredient could contribute extrinsic physical hazards.

It is important to have confidence that the suppliers of such ingredients have effective foreign body management systems in place, both for the intrinsic hazards in the ingredient and for their own manufacturing processes; this can be achieved by audits of the supplier's food safety controls, and the building of a relationship between supplier and chocolate manufacturer.

Incoming raw materials should be adequately protected during transport and storage to ensure that foreign materials such as dirt and wooden splinters from pallets and so on cannot contaminate the material. Metal staples should not be used as part of the ingredient packaging. The condition of incoming ingredients should be checked on delivery and damaged goods rejected.

25.4.2 Physical hazards during processing

Figure 25.1 shows some examples of foreign materials that could inadvertently enter the production process if suitable preventive measures are not in place. These are soft and hard plastic, paper, foil wrapping material, wood, rubber, metal wire and shavings, loose screws, string and threads.

Attention should be paid at the intake and tipping points of ingredients into the chocolate making process to prevent the addition of physical hazards. Operators must be careful during unpacking and tipping of non-bulk ingredients, such as those delivered in paper or plastic sacks, or boxes, to make sure that wrapping materials, string, knives and ingredient scoops do not unintentionally enter the process at this stage. Any entry point of ingredients into the process, such as bulk ingredient delivery points, dry ingredient tipping stations and fat melters, should be designed to minimise the risk of physical hazard entry.

It is common to have additional physical hazard controls in place at such intake points, including in-line filters and magnets for liquid ingredients and sieves for dry ingredients such as milk powder. These controls should be regularly inspected, both for the accumulation of any foreign material and for any damage to this equipment, such as a broken sieve mesh.

Figure 25.1 Some examples of foreign materials. Reproduced with permission of Paul Davies.

The complex nature of the chocolate manufacturing process can lead to further sources of physical contamination. Many items of equipment have moving parts, which can, if problems occur, come into contact with other parts of the equipment and cause metal shavings to enter the process. Examples of such equipment are storage tanks with stirrers, conches, screw feeders, pumps, mixers, temperers and depositors. Other sources of metal contamination include nuts, bolts and other fixings that can wear loose over time and fall into the process, enrober grid wires, which can be prone to breakage, and sieves, which although providing protection against foreign material, can themselves become a source of metal contamination if they break.

Sources of physical contamination are not only metal – problems can also occur through the failure of rubber seals and gaskets, the damage and fraying of conveyor belts and the breakage of plastic moulds, mould carriers and other hard plastic items.

The most effective way to control such contamination is through preventative maintenance – the identification of potential equipment failures and implementation of a regular schedule of inspection and upkeep. Also, prompt reaction to breakages and equipment failures is essential to minimise contamination – there should be, for example, a procedure to deal with mould breakages, whereby the line is stopped, broken moulds removed and replaced, plastic pieces cleared from the area and a number of moulds either side of the breakage removed to prevent mould fragments potentially entering the product. The aim is to ensure that all fragments of mould plastic are recovered from the area.

25.4.3 Physical hazards from failures of prerequisite programmes

The diligent, attentive behaviour of all personnel associated with the production process is essential to minimise the risk of physical contamination of the product. Depending on the nature and scale of the operation, the manufacture and packing of chocolate products can be quite labour intensive, with significant amounts of product handling, for example, the hand packing of assortment boxes. Also production plants can often have areas where the product is exposed to the general environment, such as conveying and wrapping processes. Because of this, there is a risk that foreign material could enter the production process and it is essential that good manufacturing practices are thoroughly applied in the production room. Important procedures are described below.

25.4.3.1 For the factory employees

It is necessary to provide suitable overalls without buttons and ideally only those with inside pockets. In addition effective hair coverage (which may include beards) is required, together with restrictions on the wearing of jewellery, nail varnish and false nails. Loose items must be avoided, other than those essential for the job, for example suitable one-piece pens without lids. Employees must avoid placing loose items, such as pens or tools, on top of processing equipment.

25.4.3.2 In the factory

The use of glass in the production rooms should be minimised and essential glass items protected, for example lighting, and a register should be maintained of glass and hard shatterable plastic items, which must be regularly checked for damage. The use of wood should be very limited, as it is prone to splintering. Wooden pallets should be restricted when possible to the end of the production line, where the product is already wrapped and hence protected.

25.4.3.3 Provision of suitable tools

Cleaning materials should be fit for purpose and designed to minimise the generation of physical hazards – for example brushes should have resin-bonded bristles, cleaning scrapers and shovels should be disposed of if they become damaged. Wire brushes should be avoided. Tools used in the production room, such as knives, scrapers and scoops, should be sturdily constructed and have clearly identified storage locations. Regular checks should be carried out to ensure that they are present and in good condition.

25.4.3.4 Use of suitable containers

Storage containers for ingredients, rework and part processed materials are commonly made of plastic and can be become damaged by regular use. Such containers should be on a system of regular inspection, for example after washing, and damaged tubs should be disposed of.

25.4.3.5 Minimising product exposure

The production process should be enclosed where possible, for example tanks, hoppers, ingredient containers and other vessels should have lids. Where the production line is exposed, the risk of foreign body contamination must be carefully assessed and if necessary, the line should be modified to cover the product. This particularly applies where walkways cross the production line or where there is further processing equipment above the line that could present a physical hazard. Rework must be carefully handled, containers should be lidded and any wrapping materials removed from rework before reprocessing.

25.4.3.6 Care during maintenance and building work

Maintenance procedures should include the protection of exposed food contact surfaces during work, careful cleaning of the area afterwards, and the control of screws, nuts, bolts and so on. Operations that involve the generation of potential foreign materials, such as drilling, should be carried out away from the production line. Buildings should be maintained in a state of good repair, to avoid the risk of flaking paint and other debris. Temporary repairs and "cardboard and tape engineering" should be avoided, or where present, swiftly replaced with a permanent, food-safe solution.

25.4.3.7 Prevention of pests

Chocolate processing equipment is generally dry cleaned, making it difficult to remove all traces of residue. Insects such as cocoa moth and saw-toothed grain beetle are attracted to such residues and can cause infestations. Other ingredients used in confectionery manufacture, for example sugar syrups, are very attractive to insects such as wasps and it is therefore very important to effectively pest-proof the production building and to ensure that external doors are kept closed. In addition it is necessary to minimise residues, quickly clear leaks and spills and to keep waste covered.

25.4.3.8 Staff awareness

A high level of awareness of the factory staff can play an important role in prevention of foreign material contamination. Different means of encouraging such awareness can be used, for example having loose parts boxes in the production room for the collection of stray items (such as nuts and bolts), displaying foreign materials picked up by metal detectors or sieves and setting up feedback notices about the foreign materials returned as consumer complaints.

25.4.4 Equipment to prevent and detect physical hazards

In addition to the methods of control, described in the above sections, it is important to apply foreign body prevention and detection equipment to the production line. A combination of techniques provides the best armoury against the ingress of foreign materials.

These techniques can include sieves and filters, typically at ingredient intake points and other key points in the process, such as at the end of the chocolate making process and importantly, during rework processing. The size of the mesh should be sufficiently small (e.g. 2 mm; 0.1 in) to ensure that significantly sized foreign material fragments cannot pass through it. The sieve mesh should be constructed as sturdily as possible to minimise the likelihood of it breaking; punch-plate styles are particularly robust. Sieves and filters should be subject to regular inspection, to ensure they are still intact and to monitor levels of foreign material present.

Magnets can also afford a defence against ferrous metal contamination. They should be situated in parts of the process downstream from equipment that may be prone to failure; for example in the troughs of enrobers that are subject to gridwire breakages. As with sieves, magnets should be regularly checked to remove build-up of the fine metal dust that is commonly present from the chocolate making process and to check for any unusual levels of metal pieces. These serve as an early warning system for equipment failures or other sources of metal hazards.

Metal detection is an important step of the production process, and is best situated as near to the end of the production process as possible for the optimum detection of metal hazards that may be generated during manufacturing and packing operations. Metal detectors should be carefully specified to suit the production process, in close consultation with the metal detector supplier, to ensure that the most appropriate detector and position in the production line are selected. However it is important to note that metal detectors will not remove all the metal fragments that may be generated by the production process (see also Chapter 24). They have limitations in sensitivity with regard to the metal size and type. Some types of metal such as stainless steel are particularly difficult to detect and long, thin metal fragments of metal may not be detected, depending on the orientation in which they pass through the detector. (George, 2004).

X-ray equipment may be used, particularly when the main hazard to be detected is non-metallic, or for finished products wrapped in metallised packaging.

End of line metal detectors and X-ray equipment are the last line of defence in the process and it is essential that effective upstream foreign body prevention measures are in place.

25.5 Chemical hazards

There are two main sources of chemical contamination during chocolate manufacturing and processing – the intrinsic contamination of incoming raw materials, and contamination that may occur during the production process.

(Allergen hazards are addressed later, in Section 25.7.) At high doses, the exposure to chemical contaminants can cause toxicity to the consumer, for example, acute poisoning from the ingestion of high levels of lead; at lower doses there are generally long-term adverse health consequences that will affect the consumer, such as kidney dysfunction, skeletal damage or reproductive deficiencies when cadmium builds up in the body for many years.

25.5.1 Chemical hazards in incoming ingredients

Raw materials of plant and animal origin are potentially affected by a number of environmental contaminants.

25.5.1.1 Heavy metals

Cadmium is a heavy metal that exists naturally in low concentrations and is absorbed from the soil by many plants, including cocoa beans. Levels of cadmium can vary by growing region, according to the type of soil: soils of volcanic origin, for example, tend to contain higher than average cadmium content. Regulatory limits for cadmium in cocoa products have been, or are being, introduced in a number of countries.

Lead is also widely present in the environment, due to both natural occurrence and human activities, such as the use of leaded petrol. Levels have reduced in food in recent years due to efforts to reduce lead emissions. Raw materials may become contaminated with lead if they are grown, stored or processed under conditions that could introduce larger than typical levels of lead in the food, such as crops grown in soil contaminated from prior use of leaded pesticides. Cocoa mass (liquor) is the principle source of lead in chocolate. As a consequence, lead levels in finished chocolate products tend to be higher in dark than milk chocolates, due to their higher cocoa mass content.

25.5.1.2 Mycotoxins

Mycotoxins are toxic substances produced by specific fungal moulds. Toxigenic fungi occur regularly in food supplies worldwide due to mould infestation of susceptible agricultural product such as grains, nuts and fruits (Murphy *et al.*, 2006). Ochratoxin A (OTA) is the major mycotoxin that threatens cocoa. OTA is produced by several species of *Aspergillus* and has been found to occur essentially between harvest and fermentation of cocoa beans, and under warm, humid transport or storage conditions (Copetti *et al.*, 2014). Good post-harvest practises are essential to prevent mould development and OTA contamination (Codex, 2013). Ochratoxin A can have serious health consequences, including kidney failure, and is classified as a probable human carcinogen by the International Agency for Research on Cancer (IARC). Research on Ochratoxin A levels in cocoa products showed the highest levels concentrated in the shell – hence the efficiency of the winnowing process is important in reducing the levels of contaminant – reducing to much lower levels in other cocoa products and finished chocolate products (Copetti *et al.*, 2014). The lowest levels are found in the fat fraction of cocoa products.

Aflatoxins are generated by a number of species of *Aspergillus*. They are carcinogenic and toxic to the liver (Engel *et al*., 2001). Although most commonly associated with nuts, cereals, rice and dried fruits, Aflatoxin B1 has occasionally been identified in batches of cocoa beans (Doncheva and Dikova, 1992). This research showed levels tending to decrease with each cocoa bean processing step, until they were undetectable in cocoa butter.

25.5.1.3 Pesticides

Pesticides are a group of substances designed to kill pests and to protect crops and stored products. Some pesticides can accumulate in the environment and become increasingly concentrated as they move up the food chain (Engel *et al*., 2001). The type of pesticide used varies by growing region of the cocoa bean. Consignments of West African cocoa have been known to have been rejected due to residues of lindane that was traditionally used to control mirids (sap-sucking insects; Mabbett, 2002).

Methyl bromide has for many years been used to fumigate cocoa beans in storage, particularly as a defence against the cocoa moth, which is a main agent of destruction of stored beans in tropical origin countries. However the use of this chemical has been phased out for environmental reasons to comply with the Montreal Protocol on Substances that deplete the ozone layer.

25.5.1.4 Mineral oils

Cocoa beans are traditionally shipped in bags or sacks, made of woven natural fibres, commonly jute. Jute has previously been impregnated with mineral hydrocarbons, which may subsequently contaminate the cocoa beans. As a consequence, the International Jute Organisation has put a limit of 1250 mg/kg unsaponifiable matter present in jute bags (IJO, 2005). This problem can be avoided by the use of non-toxic vegetable oils for this purpose (Mabbett, 2002).

25.5.1.5 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are organic compounds, numerous of which are carcinogenic, that are generally a result of the incomplete combustion of organic material. In cocoa bean processing, the drying step has been identified as a potential source of these contaminants, especially certain artificial drying methods. (Misnawi, 2012). Regulatory limits for PAHs in cocoa bean-derived products have been, or are being, introduced in several countries.

25.5.1.6 Chemical hazards in other chocolate-making ingredients

In addition to the hazards described above, relating to cocoa products, chemical hazards in other chocolate making ingredients must also be considered, as these may all end up in the finished product. Other agricultural crops such as those used to produce vegetable oils, sugar or lecithin, may be similarly exposed to environmental contaminants such as heavy metals or to pesticide residues.

Milk products can be derived from raw milk that may contain traces of antibiotics, pesticides and hormones, heavy metals or aflatoxin M1 (Fischer *et al.*, 2011).

To evaluate the likelihood of occurrence of chemical contaminants in incoming ingredients, knowledge on the origin of raw material is important, for example, country of origin, soil type and local climate where relevant as well as the existence and enforcement of regulatory measures. Moreover, information on storage conditions at farm and at supplier level, availability and price of agrochemicals used for ingredients of agricultural origin, as well as the supplier history and confidence level, are all key factors to be analysed when determining which contaminants might occur and at what level. An appropriate monitoring plan for the most relevant contaminants will help develop understanding and build confidence in the supply chain.

25.5.2 Chemical hazards occurring during processing

Contamination of chocolate with chemicals can also occur during manufacture and processing. Cross-contamination linked to the use of chemicals for cleaning confectionery equipment can easily happen. An example is sodium hydroxide solution, which is used to clean equipment such as caramel cookers – to avoid causing contamination; it must be used in the correct concentrations, effectively rinsed off afterwards and properly segregated or stored. Other chemicals, used for treatment of water in heating and cooling systems, or for boiler treatment, may also potentially contaminate the product through inadvertent leakage.

Oils and greases, which are necessary to many items of processing equipment, may potentially cross-contaminate confectionery products. Therefore it is essential that food-grade oils and greases be used where there is any possibility that they may come into contact with food materials.

Other chemicals required for maintenance and upkeep of the production environment, such as paints and sealants, must be of food safe composition when they may come into contact with food. They should be correctly stored and adequate precautions should be taken when using them, including the protection of production lines and ensuring good ventilation.

25.6 Microbiological hazards

25.6.1 Salmonella

The key microbiological hazard during chocolate manufacture and use is *Salmonella*. Although chocolate is a relatively dry product, with a low water activity typically around 0.2–0.4, it is proven that, although it cannot grow in these conditions, *Salmonella* can survive in chocolate products for longer periods of time than in other food matrices; in fact, periods of several years have been reported (Cordier, 1994).

There have been a number of food poisoning outbreaks that have been associated with the presence of *Salmonella* in chocolate, for example the recall of chocolate products in 2006 in the United Kingdom due to contamination with *Salmonella Montevideo* (Harker *et al*., 2013). Food poisoning from chocolate products is often caused by a surprisingly low number of cells. It is hypothesised that the fatty matrix of chocolate actually protects the *Salmonella* cells from the acidic environment of the stomach, allowing them to colonise the lower gastrointestinal tract, producing clinical symptoms (D'Aoust, 1977).

The outbreaks shown in Table 25.1 demonstrate the small number of *Salmonella* that may be sufficient to cause illness in a large number of people, often children. With exporting of chocolate products to other countries now being commonplace, outbreaks could become very widespread in nature.

Symptoms of salmonellosis are diarrhoea, vomiting, fever and abdominal pain, lasting up to seven days. Although rarely so, it can be fatal, with higher mortality rates amongst "high risk" groups – the very young, elderly, and those who are ill, convalescing or with a weakened immune system (Engel *et al*., 2001).

Salmonella may be introduced into the chocolate process through incoming raw materials, or through inadequate hygiene practices at the factory.

25.6.2 Salmonella in raw materials

The primary origin of *Salmonella* is the intestinal tracts and faeces of humans or animals (Engel *et al*., 2001), therefore the raw materials that are most likely to become contaminated are those of an agricultural origin that may have been exposed to such conditions.

25.6.2.1 Cocoa beans

Cocoa beans are a known potential source of *Salmonella*, due to poor hygiene conditions during bean harvesting, fermenting and drying. The pulp and beans are contaminated during and after breaking of the pod by many sources, including hands and tools of harvesters, soil, leaves, re-used wooden containers, insects and animals (Lund *et al*., 2000).

After harvesting, beans undergo a fermentation process, during which a succession of different micro-organisms can be identified. At the start, yeasts are predominant, declining by around the third day in favour of lactic acid bacteria and acetic acid bacteria (see Chapters 2 and 8). The last phase of fermentation favours the development of thermophilic spore-forming bacteria, and the microflora of fermented beans predominantly consists of members of the genus *Bacillus* (Barrile *et al*., 1971). After fermenting, beans are dried, commonly in the sun. During the drying process there may be little environmental control and further microbial contaminants can access the beans. As a consequence of the fermentation and drying processes, raw cocoa beans have high microbial levels and the presence of *Salmonella* is a well recognised hazard (Bell and Kyriakides, 2002).

Table 25.1 Summary of published chocolate outbreaks due to *Salmonella* contamination (compiled from Werber, 2005: CDR-HPA, 2006; Elson, 2006).

Year	Country	Serovar[a]	Vehicle	Source of contamination	CFU/g[b]	No. of affected persons	Age of cases (years)
1970	Sweden	*S. durham*	Chocolate products	Cocoa powder	–	110	53% ≤15
1973 to 1974	USA, Canada	*S. eastbourne*	Chocolate balls from Canada	Cocoa beans	2.5	200	3 (median)
1982	England, Wales	*S. napoli*	Chocolate bars from Italy	Unknown	2–25	272	58% ≤15
1985 to 1986	Canada	*S. nima*	Chocolate coins from Belgium	Unknown	–	–	?
1987	Norway, Finland	*S. typhimurium*	Chocolate products from Norway	Avian contamination speculated	≤1	349	6 (median)
2001 to 2002	Germany, other European countries	*S. Orianenburg*	Two chocolate brands from Germany	Unknown	1.1–2.8	439	15 years (median)
2006	UK	*S. Montevideo*	Chocolate confectionery	Leaking waste water pipe that dripped into milk chocolate crumb during processing	Unknown	37	3 children

[a] Type or strain.

[b] Colony forming units per gram

Roasting of beans or nibs is an essential step in the destruction of *Salmonella* and other vegetative bacteria. It is therefore very important that appropriate controls are applied at the roasting step to ensure that sufficient temperatures and roasting times are achieved and that no under-roasted material can pass into the subsequent process. It is considered that the traditional roasting process, (typically temperatures of 105–150 °C (220–300 °F) for 15 min to 2 h) is sufficient to destroy vegetative micro-organisms, including pathogens such as *Salmonella* (ICMSF, 2000). The most effective process in reducing microbial levels is one that combines a steam pretreatment, or "debacterisation" step; lower thermal death rates can be expected from a dry roasting process. Roasting processes should be validated to ensure that they are capable of inactivating expected levels of *Salmonella*.

A recent trend is the consumption of "raw chocolate", which is typically not exposed to temperatures exceeding 42 °C during processing. Due to the lack of a validated heat treatment step, there is concern that such products may present a health hazard from *Salmonella*. (National Confectioners Association's Chocolate Council, 2011).

After the roasting step, there are no further processing stages in the manufacture of chocolate products that will effectively destroy *Salmonella*, as the low water activity and high fat content lead to significantly increased heat resistance of *Salmonella* in the chocolate matrix (Cordier, 1994). Temperatures of 70–80 °C (158–176 °F) attained during milling, refining or conching are not sufficient to destroy small numbers of *Salmonella* (Lund et al., 2000; Krapf and Gantenbein-Demarchi, 2009). Therefore hygienic processes and working practices are essential as preventive measures to avoid *Salmonella* cross-contamination.

Correct hygienic zoning of the cocoa bean process is required to ensure that there is no possibility of cross contamination from the raw beans to subsequent, post-roasting steps. Raw bean storage and handling areas must be well segregated. Personnel and equipment should be dedicated to these areas and movement between the raw bean and post-roasting departments must be minimised. Hygiene barriers between these areas must be robust, incorporating shoe and overall changing for workers and complete separation of the buildings and equipment. The airflow as well as personnel and vehicle movement must be designed to prevent any chance of the ingress of raw cocoa bean dust into the post-roasting process. Air, including that used for cooling the beans after roasting, must not be drawn from the environment in which raw beans are present (Bell and Kyriakides, 2002). All air introduced directly into products or in an exposed product environment should be suitably filtered (IOCCC, 1991).

25.6.2.2 Other raw materials

The hazard of *Salmonella* must also be controlled during the production processes of other sensitive chocolate ingredients. Milk powder has been implicated in a large number of Salmonellosis outbreaks (Bell and Kyriakides, 2002) and heat treatment and cross-contamination controls in the milk powder manufacturing process must be strictly followed. Similarly to cocoa beans, raw nuts may become contaminated with *Salmonella*; in 2009 a major recall in the United States linked to peanut butter demonstrated the impact of such issues on the industry (Carr, 2010). As with cocoa beans, the roasting step and preventing post-process contamination are essential controls. The presence of *Salmonella* has also been linked to other common confectionery raw materials, including egg products, flours and starches, lecithin and coconut (Cordier, 1994).

Although *Salmonella* is the main organism of concern for chocolate manufacturers, it is also important that all raw materials are assessed during HACCP studies for other microbiological hazards – for example freeze-dried fruits used as inclusions in chocolate products could be at risk of contamination by viruses or other enteric pathogens.

Careful supplier selection and auditing is important to ensure that incoming ingredients will be microbiologically safe for use in the chocolate making process, particularly because the microbiological safety of the chocolate products relies entirely on the use of safe ingredients and the control of cross contamination during processing and packing. Regular risk-based microbiological monitoring of incoming raw materials should be carried out. Ingredients should be inspected on arrival to ensure they are in good condition, with no damage or signs of pest activity.

25.6.3 Prevention of microbiological contamination during processing

In addition to the incoming cocoa beans and other raw materials, it is important to consider the other possible sources of microbiological contamination, including *Salmonella*, in the chocolate process.

Once again, good manufacturing practices are imperative in the prevention of *Salmonella*. All employees, visitors and contractors should strictly follow basic personal hygiene rules. These must include thorough hand washing and drying, removal of jewellery, prevention of hand to mouth contact (e.g. prohibition of eating in the production room), provision of appropriate work wear, pre-employment medical screening of food handlers who may be carriers of micro-organisms capable of causing food-borne diseases and reporting of cases of sickness and diarrhoea by workers, with exclusion from food handling duties until clearance is given.

Pest management is important to prevent potential pathogen-carrying pests such as birds, insects and rodents from entering the food production area. This includes ensuring that buildings are pest proofed with no unscreened windows or gaps below doors, keeping the interior and exterior of the premises tidy and clear of waste and spillages that will attract pests, and employing an effective pest control system of baits and traps for early detection.

Rework must be hygienically collected, carefully stored in clean, dry, covered containers or closed bags and kept in suitable storage areas. Its condition should be assessed before use to ensure there has been no possibility of contamination.

Waste must also be hygienically collected and stored in covered containers or bags designated for waste use only, and its disposal must be controlled to prevent cross-contamination from external to internal areas.

Movements of people and vehicles between production and non-production areas must be minimised to prevent cross-contamination from external areas.

25.6.4 Water control and cleaning practices

A key element in the prevention of *Salmonella* in chocolate processes is the minimisation and control of water.

Cleaning procedures used in chocolate manufacturing and processing are normally focussed towards dry cleaning wherever possible. Dry cleaning procedures include manual scraping, brushing and vacuum cleaning. Use of water should be minimised but, where it is absolutely necessary, equipment must be designed for this purpose, with surfaces that can be easily and quickly dried and visual inspection possible after cleaning. Cleaning tools should be dedicated for food contact surfaces – normally through a clear colour coding system – to ensure that equipment used to clean the floor does not come into contact with that used to clean the production line.

Linked to this, hygienic design of equipment is an important factor – ensuring that the “cleanability” of processing equipment is considered during its design, minimising complex surfaces, avoiding hollow bodies, allowing full access for people and tools during cleaning and easy dismantling and reassembling of the equipment where necessary. Walls and floors should be well constructed, smooth and impervious and capable of being easily cleaned. Storage tanks and hoppers should be covered and plant layout should be carefully assessed, ensuring that pipes, cables or other installations that may collect dirt, leak, cause condensation or otherwise contaminate the product are not located above uncovered product flow. Condensates from cold water pipes, refrigerator coils and cooling tunnels can introduce water into an otherwise dry environment. Cool surfaces in warm areas should be insulated and the temperature of coolers should be correctly set for the throughput of the production line and thereby minimise risk of condensation (IOCCC, 1993). Hygienic design of the process must also be revisited in the event of any changes to the process, product or environment.

Water leaks are also a potential source of contamination. Much of the equipment used during chocolate processing is kept warm by water jacket systems, for example to maintain pipeline temperatures, tempering zones and storage tank jacket temperatures. This can lead to the risk of corrosion and micro leaks, especially in older installations. The water circulates through the system, often with relatively slow flow and only low levels of replenishment with fresh water. This can be compounded in older processing facilities where changes to production lines and water circuits over the years can lead to complex circuitry and the possibility of dead-ends containing stagnant water.

The growth of pathogens, particularly in association with biofilms inside the pipework, is a possibility and should be controlled. Biofilms containing sulphite-reducing bacteria may also lead to the development of leaks, which could allow water to contact the products. Systems should be closed to prevent ingress of nutrients into the water. Circuit diagrams of water systems should be available and any dead legs eliminated. Suitable sampling points should be installed, with regular testing of microbiological water quality, and prompt action in the event of abnormal results. Action can include treatment with chlorine based biocides (though great care should be taken with mild steel pipes, as this can lead to corrosion) draining and flushing out of the water system and, in the worst case, replacement of sections of pipework.

Water used as an ingredient or for cleaning must be of potable quality. Steam in contact with food or food surfaces must be food-grade quality (IOCCC, 1991).

25.6.5 Microbiological monitoring

A well designed monitoring programme for the environment and product is essential to verify the effectiveness of microbiological controls and to serve as an early warning system in the event of contamination.

A sampling plan must be devised to regularly test for both *Salmonella* and for suitable hygiene indicators, such as Enterobacteriaceae. It is important that sampling programmes include vulnerable points on the line, such as processes with high levels of human handling, areas of recent building work or maintenance, rework and equipment where wet cleaning is necessary. Samples should not only be taken of "clean" finished product, more meaningful samples are where residue accumulates on and around the production line. Examples include inside the walls of vessels, build-up on sieve meshes, on catch trays and ledges of the plant, on rollers that drive conveyor belts, on food contact cleaning tools and from debris collected inside food-contact vacuum cleaners. Samples should not only be taken according to a regular plan but should include investigative samples taken according to the condition of the production line on the day or taken during cleaning when the line is open and more exposed for effective sampling. Management of data and evaluation of trends over time can help to identify the development of problems before they can influence product safety.

25.6.6 *Escherichia coli* 0157:H7 and other verocytotoxin-producing *E. coli*

The survival of *Escherichia coli 0157:H7* and other verocytotoxin-producing *E. coli* (VTEC) has not been fully established in chocolate and confectionery products, unlike *Salmonella*. However, a study has proven that these pathogens can also survive for similar periods of time to *Salmonella* in artificially contaminated chocolate and confectionery products (Baylis *et al.*, 2004). Based on current knowledge, control measures established in factories to control *Salmonella* are also appropriate to control these pathogens.

25.7 Allergen hazards

A food allergy is a food hypersensitivity involving the immunological mechanism. Food allergy is known to affect 5–7% of children, reducing to 1–2% of adults. Coeliac disease, another important food hypersensitivity to gluten-containing cereals such as wheat or barley, is estimated to affect up to 1% of the population in the United Kingdom. The clinical symptoms of food allergies, which can be triggered by very small quantities of the offending food, range from mild discomfort to severe or life-threatening reactions, requiring immediate medical treatment. Common symptoms are quite varied, and include respiratory (e.g. asthma), gastrointestinal (e.g. vomiting) and skin reactions (e.g. eczema and hives; IFST, 2013).

The presence of unlabelled/hidden allergenic foods is therefore a major food safety hazard faced by the confectionery industry. There have been a number of recalls of confectionery products in recent years due to the presence of inadequately labelled allergens in the product. With food allergen labelling legislation with regards to ingredients now in force in many parts of the world, the thorough management of allergenic ingredients and prevention of cross-contact in chocolate processes is essential.

The majority of allergic reactions and cases of food hypersensitivity are triggered by the following foods and ingredients, as listed in the Codex General Standard for the Labelling of Prepackaged Foods (Codex, 1985):

- Peanuts and peanut products;
- Tree-nuts and nut products (Hazelnut, Almond, Walnut, Cashew, Pecan nut, Brazil nut, Pistachio nut, Macadamia nut and Queensland nut and products thereof);
- Milk and milk products (including lactose);
- Eggs and egg products;
- Soya beans and products of thereof;
- Cereals containing gluten; that is wheat, rye, barley, oats, spelt or their hybridised strains and products of these;
- Fish and fish products;
- Crustacea and products of these;
- Sulfite in concentrations of 10 mg/kg or more.

In some countries, there are additional allergens that are particularly prevalent amongst their population. For example, in the European Union, celery, mustard, sesame seeds, lupin, molluscs and products thereof are additional allergens that must appear on food labels (EU, 2011).

Table 25.2 Potential sources of allergens into the production process.

Potential direct source of allergens into a product	**Potential indirect sources of allergens into a product (cross-contact)**		
Materials used to make the product	Equipment used to make the product	Raw material storage and handling	Other shared resources
Ingredients	Shared production line	Storage areas	People
Rework	Shared process equipment, e.g. mixers	Transport	Cleaning equipment
Processing aids	Pipelines and storage tanks	Ingredient handling, e.g. scoops	Maintenance tools
Packaging	Shared wrapping machinery	Rework and semi-finished product containers	Air handling

The confectionery industry faces challenges with allergen management, as the first six types of allergen in the above list are commonly used in the manufacture of confectionery products.

When determining allergen management programmes in confectionery factories, it is important to consider the various routes by which allergens may be present in the finished product. Table 25.2 shows the potential sources of allergens into the production process.

25.7.1 Allergens as ingredients

These are the easiest to consider, as they are primary ingredients of the product and should be well known, such as milk used in the manufacture of milk chocolate, lecithin if derived from soya, peanuts or tree-nuts used as inclusions, for example in moulded tablets and wheat gluten found in wafers or biscuit inclusions. However, it is fundamentally important to find out information about the ingredient's composition and the supplier's process, as there may be minor components of an ingredient that may contain a major allergen, or cross-contact due to shared production lines, equipment or transport used by the supplier. This information needs to be carefully assessed, to understand the hazard it presents to the finished product – will it require labelling, or is it possible for the supplier to apply further controls to exclude the allergen.

Another important consideration is rework – it has to be considered as an ingredient of the finished product, and all sources of rework, and potential allergens contained within it, must be known. Rework should ideally be reused back into the same product (Chapter 17). If this is not feasible, it must not contribute additional unlabelled ingredients, especially unlabelled major allergenic foods from ingredients, additives or processing aids into the product in which it is used.

25.7.2 Allergens from cross-contacts at the factory

Due to the diverse range of confectionery products manufactured, their frequency of change and new product development, coupled with the economic necessity for flexible production lines, it is quite common for a production line to manufacture a number of different products. Compounding this problem is the difficulty in thoroughly cleaning confectionery lines – in fact, as already discussed, dry cleaning is the normal method to minimise microbiological risk, but this naturally leads to some levels of residue remaining on the line. All this leads to the necessity to very carefully consider the allergen hazards across the full portfolio of products made on the same production line, as residues can easily remain in the equipment on changeover from one product to another. This is particularly the case for ingredients of a particulate nature, such as peanuts and tree-nuts, where particles or dust of the ingredient are not homogeneously distributed and may collect and later dislodge from hidden areas of the process.

Additional allergen cross contacts must also be considered within the factory environment as a whole – if an allergenic ingredient is used on a production line in only one part of the factory, there may be still be possibility that cross-contact can occur through the use of shared materials and tools. Examples of this include plastic containers use to store or transport rework or semi-finished products, cleaning tools and materials used for food contact such as ingredient scoops, or maintenance tools. Also cross-contacts must be considered for shared items of processing equipment – for example mixers that may be used for different products or processes.

Allergen assessment in the factory must be extremely thorough and systematic to ensure that the full range of ingredients, products, processes and procedures are considered in the factory, and all possible allergen sources are identified.

25.7.3 Control measures

For each allergen hazard identified, it is essential that an effective control measure is in place. For allergens present as an ingredient, the control is the clear labelling of the ingredient on the packaging. For minor ingredients that contain an allergen that otherwise would not be present in the ingredients list, it is good practice to consider whether it is feasible to replace the ingredient with one that has similar functionality, but that does not present an allergen hazard.

For allergens present as potential traces in the finished product due to cross contact, precautionary labelling of the finished product should be the last resort, in order to offer the allergic consumer the widest possible choice of available products. First, other means of controls should be evaluated, for example using dedicated processing equipment, or a dedicated colour coding system for storage containers to segregate products that contain allergens. Any such system must be thoroughly implemented through careful training to ensure full understanding and compliance and be regularly checked to ensure it is being adhered to.

For shared lines and equipment, cleaning is a possibility, but it must be ensured that cleaning is fully effective and validated, can be consistently performed to the same standard, will not leave levels of residues that will present an allergen hazard in the subsequent product and can be fully visually inspected after the clean is complete. For many complex confectionery processes, especially those that are dry-cleaned, this can be very difficult to achieve.

Sequencing of production runs is another option, so that there is follow on of the allergen-containing products, hence reducing the number of major allergen cleans required.

Where labelling of the allergen as an ingredient or via a precautionary warning is necessary, it is imperative that the labelling is done clearly and legibly on the wrapper. This can be a challenge for confectionery, especially for small products where there is minimal room on the wrapper, or where the information may need to be presented in a number of languages. The packaging needs to be carefully designed to ensure that the consumer can easily find this critical food safety information. When the wrapping material is being changed it is of great importance to ensure that the allergen information is thoroughly checked and is verified to be correct before use on finished product. Also, systems must be in place in the factory for product changeovers, to ensure that the correct packaging material with its correct labelling is always in use.

Conclusions

This chapter has presented an outline of the different categories of food safety hazards that must be considered during the manufacture and processing of chocolate. It is hoped that this has given the reader a general overview of the different hazards, and their potential sources, that must be considered, and also some ideas on control measures.

All food safety hazards should be carefully evaluated for each product and manufacturing process through the HACCP approach, including good manufacturing practice programmes, to ensure that such hazards are effectively controlled, enabling the confectionery industry to continue to produce safe and pleasurable products.

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CHAPTER 26

Packaging

Carl E. Jones

26.1 Introduction

This chapter starts by looking at the different types of chocolate products and how they are packaged. The chapter covers foil and paper, twist wrap and flow wrap formats in addition to outlining carton overwrapping, carton board and corrugated board. The various main packaging materials are reviewed as to their particular beneficial properties and where they should be used, before moving on to sustainability and portion control.

26.2 Confectionery types

26.2.1 Moulded chocolate tablets and bars

For many years, moulded chocolate bars remained relatively unchanged with minimal barrier protection required from the packaging. However, with the use of "inclusions" such as cereals and nuts (e.g. crisped rice, hazelnuts), the protection required from the packaging has increased.

Traditional chocolate bars utilised tinfoil and paper-band over wrap packaging; today, aluminium foil has replaced tinfoil (Figure 26.1) with some formats employing a full cover paper or paperboard envelope-style overwrap. The typical thickness of aluminium foil for bars without inclusions is 10 µm (0.39×10^{-3} in) whereas, for bars with inclusions that may damage the foil, it should be thicker [12–14 µm (0.47×10^{-3} to 0.55×10^{-3} in)]. Improved barrier protection against infestation, odours and water vapour can be provided by the application of heat-sealable coatings or polyethylene (PE) linings.

In the United Kingdom and some other countries around the world, flow wrap packaging for tablets has largely replaced foil and paper packaging (Figure 26.2). Faster wrapping speeds, lower cost packaging materials and reduced labour have encouraged the use of flow wrap formats. In addition, in many countries flow wrap packaging is seen as modern while foil and paper is seen as outdated. However, foil and board packages are used for premium tablet formats.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett, Mark S. Fowler and Gregory R. Ziegler.

Figure 26.1 Tablets in foil and paper and foil and board formats.

Modern flow wrap equipment with very precise pack cut-off/repeat lengths (±0.1 mm) has largely removed the need for cardboard inserts in the pack to prevent tablet breakage and/or keep the tablet stable should the tablet become broken.

Twelve to 36 tablets are typically packed into a box known as an outer (in some countries known as an inner) or display box (Figure 26.3). These outers are placed into a corrugated case for transportation. Microflute corrugated outers and display boxes have become very common in West European countries in recent years. Fully printed boxes, made with E, F and N flute (see Section 26.4.2) provide additional strength and in many circumstances eliminate the need for corrugated shipping cases. Tablets laid on edge generally provide the strongest stacking configuration, allowing for lower-strength and therefore lower-cost outers.

26.2.2 Chocolate countlines

The "countline" is the core of the large-scale chocolate business in many countries. It is typically an enrobed irregular shaped product in contrast to the uniform shape of a tablet. Flow wrap packaging formats dominate the countline market.

Figure 26.2 Tablets flow-wrap format.

Figure 26.3 Shelf ready display box.

The flow wrap (Figure 26.4) can provide barrier protection for the product or hold a number of pre-wrapped products (multi-pack). Varying the structure of the film can modify the barrier properties of the package to prevent ingress of moisture vapour, gases, odours and light, or to prevent the loss of flavour.

White chocolate does not contain the anti-oxidants present in milk and dark chocolate and therefore requires packaging with light barrier properties such as metallised films to prevent light-induced oxidative rancidity. In addition, countlines containing nuts can find shelf life extended by light-excluding packaging.

The outer packaging and shipping case packaging for countlines is essentially the same as that for moulded tablets; however, in most cases countlines are laid flat in the box and are very often in display boxes. Because flow wrap countlines have extended end seals and tend to have large amounts of trapped air within the wrapper, more free space may be required inside the outer box compared to moulded tablets. This means that distribution costs can be higher. However, modern high-speed flow wrap equipment can be fitted with air reduction systems to minimise the size of the outer box.

Figure 26.4 Countlines flow-wrap format.

26.2.3 Bulk chocolate

Although most bulk chocolate is now transported in liquid tankers, an appreciable market still exists for block or pelleted chocolate. In both cases, the preferred packaging method is PE-lined multi-ply paper sacks containing, say, 5 × 5 kg (11 Ib) blocks or an equivalent weight of pellets, flakes and so on. To maintain stability it is advisable to ensure that the outer paper ply is treated to prevent it slipping. It is advisable to place a PE sheet between the transportation pallet and the sacks to reduce any possibility of moisture or taint from the wood affecting the product. Liquid chocolate can be poured into a case, generally corrugated board, lined with a PE bag. When the chocolate has set, the bag and chocolate can easily be removed and is very stable for transportation.

26.2.4 Boxed chocolates

The variety of containers for boxed chocolates appears to be almost infinite, ranging from rigid handmade boxes with plinth bases, metal feet and tasselled lids (Figure 26.5) to machine-erected single- or double-wall cartons. In markets where the cost of labour is low, hand-erected pre-glued cartons are often used either in single- or double-wall format. Hand-erected cartons offer greater flexibility in box format than machine-erected cartons, as multiple change-parts for the erecting machine are not required; in addition, machine downtime is avoided. The materials used range from flock paper or chipboard to metallised or film laminated cartonboard. Rigid plastic can be used, to give a clear container that shows off brightly foiled sweets to best advantage. Alternatively, thin film in the form of a window can be combined with cartonboard to give the same effect.

The use of recycled boards for chocolate boxes is not recommended without a functional barrier sealing the product from any contaminants that may migrate from the board. Due to the taint potential of chocolate, it is recommended to use chemical pulp paperboard, for example solid bleached sulfite (see Section 26.4.2), for chocolate boxes without a functional barrier between the board and the chocolate. Mechanically produced boards, for example coated chromo board can

Figure 26.5 Chocolate boxes, rigid formats.

Figure 26.6 Chocolate box VFT format.

also be used for chocolate boxes; however, over time, there is a greater potential for odour generation from naturally occurring components in the board, such as aldehydes and ketones.

In contrast to the multitude of the outer container forms, the inner fitments of chocolate boxes vary relatively little from box to box. Plastic vacuum formed trays (VFTs) have almost completely replaced heat-formed glassine cups (Figure 26.6) which were once universally used to hold individual sweets. In order to address environmental concerns, biopolymer trays are finding their way in to some markets. Plastic and biopolymer trays are produced by heating the plastic or biopolymer to soften the sheet, which is then drawn by vacuum into a metal mould of the desired shape, with an individual cavity for each sweet. Plastic trays can be made from one of several different polymers in a variety of colours ranging from crystal clear to silver or metallised gold. They can be made to reproduce the appearance of a layer of paper cups or designed to give extra protection to particularly vulnerable centres. They can also be built up below the flatter sweets by the inclusion of a "step" so that the whole layer appears to be of uniform height.

Other items that may be incorporated in the internal packaging of a box of chocolates are wave-embossed glassine or a greaseproof sheet to provide cushioning and prevent crushing of the sweets. Glassine-lined cellulose wadding can perform a similar function, perhaps more attractively, although more expensively. Corrugated glassine pads are commonly found in chocolate boxes, with corrugated plastic sheets providing a cheaper alternative.

Some nutty sweets, such as pralines or coconut clusters, exude fat to such an extent that this can permeate glassine or cellulose layers. These may therefore require a sheet of impermeable film to prevent staining of the box itself. An alternative method of restraining fat exudation is to foil wrap these individual sweets. In addition to protecting the packaging from the sweet and, in some markets with extreme climates, providing a last protective barrier to the sweet, foil is frequently used on individual sweets purely for decorative purposes.

The principle means of protecting boxed chocolates from the atmosphere, and incidentally the box itself from scuffing and marking, is a film overwrap. This can take the form of cellulose or plastic film (predominately bi-oriented polypropylene; BOPP). Polypropylene has largely replaced cellulose due to the limited numbers of suppliers and high cost of cellulose. This overwrap format employs a heat-sealed overlap along the base and heat-sealed envelope folds at the ends (Figure 26.7). While offering good protection to the sweets inside, envelop sealed overwrap formats rarely provide a 100% seal due to the number of folds in the ends. To offer easy opening of the overwrap, self-adhesive tear tape is normally applied to the film on the wrapping machine.

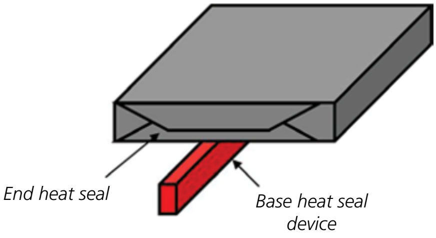


Figure 26.7 Carton overwrap envelope format.

Heat induced shrink-wrap film using either polyvinylchloride (PVC) or PE film provide an alternative to the envelope style overwrap. However, environmental concerns have reduced the use of PVC in recent years and dust build-up due to static of PE shrink films has led to an increase in the use of BOPP shrink films. These films produce a smooth, flat, tight surface whereas the envelope style wrap tends to leave gentle undulations and ripples in the film surface.

Converting standard chocolate boxes to seasonal use can be performed by the addition of a printed paper or film band with a seasonal theme, which can be removed from unsold stock after the festival. The same objective can be achieved by the use of self-adhesive stickers, for example heart-shaped for St. Valentine's Day. Such stickers can be made of a wide variety of materials, ranging from high-gloss paper to crystal-clear polyester and polypropylene.

When boxes of chocolates are combined together in an outer, a conscious decision must be taken as to whether they should travel flat or on edge. If there is any likelihood of a large soft-centred sweet coming under pressure, it is often better to pack the carton on edge so that the thermoformed tray can relieve the pressure, provided it is made sufficiently strong to do so. In addition, in a double layer box (common in the UK), the tray should be designed so that the upper layer can be turned round to place a small sweet over a large one in the bottom layer. In other respects, the construction of the outers and cases is similar to bars or countlines.

26.2.5 Twist wrapping

Brightly wrapped twist-wrapped chocolates (Figure 26.8) have been a major part of the confectionery scene for many years. The basic materials used have become more sophisticated and the machinery faster. Materials used still include aluminium foil (backed or un-backed, plain silver or coloured) and film (tinted,

Figure 26.8 Twist wrap.

clear or printed). The foil is applied separately as an under-strip or it can be laminated to the film as a centre strip with the foil just reaching the twist areas. The foil also allows film that does not naturally have dead-fold properties to retain a twist, allowing non-twist grade films to be used.

Twist wrap applications continue to use regenerated cellulose film (RCF); however, it has become less and less common due to its high cost and the reduction in producers of RCF. However, to date, no other film has been able to offer the feel, clarity and sparkle of RCF, especially when the film is tinted in the master batch (coloured film is used as opposed to film where the surface is printed to produce a solid colour).

Twist-grade metallised paper and films such as PVC, bi-axially oriented polyethylene terephthalate (BOPET) and polypropylene (either Cast PP or BOPP) are increasingly being used to add an extra dimension to the variety of wraps in an assortment. The addition of pattern-applied cold seal adhesive in the twist area has become more common in recent years, enabling films to be used that would not normally retain a twist. In addition, cold seal adhesive has also been used to create a fin seal closure along the base of the sweet. This increases the barrier protection properties, especially when used in combination with cold seal in the twist areas. New biomaterials such as PLA (produced from cereal starch) have also been used for confectionery twist wraps.

The most common form of twist wrap is the "double-end fantail" known as a double twist (Figure 26.8). A popular alternative is a combination of twist at one end and folds at the other, giving a sachet style wrap often referred to as a bomb wrap (Figure 26.9). This is particularly effective with fruit designs, for

Figure 26.9 Twist wrap bomb format.

instance for strawberry creams, where the body represents the sweet and the fantail the leaves.

Because the attraction of a twist-wrapped assortment lies in its bright, glossy and colourful packaging, the container from which it is sold is often transparent or has a clear window. For many years, twist-wrapped chocolates were sold from screw-topped returnable glass jars but, in line with the modern trend to non-returnability, these have generally been replaced by clear PVC, polypropylene (PP) or polyethylene terephthalate (PET) containers. The glass jar in recent years has found itself supplanted by PET due to PET's glass-like visual clarity and ability to be moulded in to a variety of shapes, resulting in the container often finding a secondary usage in the home.

Weigh-out retailer and consumer packages traditionally comprised brightly printed round tins, with the finish and quality of print and design making up for the loss of visibility. Metallised materials such as cartonboard laminated with metallised film or plastic containers have replaced tinplate in many applications due to the high cost of tinplate containers.

Twist-wrapped chocolate sweets also lend themselves to packaging in printed film bags, generally with display windows, produced on vertical form–fill–seal machines. BOPP, PE or BOPET usually in laminated forms are the most commonly found bag formats for twist-wrapped chocolates.

26.2.6 Easter eggs and other seasonal chocolate novelties

Traditionally, Easter eggs and other seasonal novelties, such as Easter rabbits, Father Christmas, chocolate bells and so on, have been foil wrapped, taking advantage of the ability of foil to follow irregular contours and to be smoothed into shape, as well as its decorative appeal when printed.

Foiling Easter eggs is relatively simple, either by hand or by machine, but the designing of a piece of foil to go round an Easter rabbit (Figure 26.10) requires the skill of a specialist to ensure that all the features on the foil match up with those of the chocolate figure. One method to achieve this is lining the mould with the foil. However, the usual method is to produce the figure first and then foil it, relying on the skill of the foiler to apply the properly designed foil accurately. Machinery is available to foil simple shapes and, where appropriate, to attach cords for hanging from Christmas trees (Figure 26.11).

Unfoiled chocolate novelties can be wrapped in clear or part-printed film to show off the quality of the product where there is a short shelf life and good storage conditions. Care must be taken to ensure that conditions encouraging chocolate bloom are avoided, for example direct sunlight. Strip-metallised films are frequently used for this purpose as they are good barriers and highly decorative. They make good bags, but of course cannot be used to "foil", as they have no dead-fold characteristics (i.e. cannot retain their folded shape).

A wide variety of containers is available for presentation of foiled eggs and figures. The most usual are either some form of open windowed carton or clear

Figure 26.10 Foil wrap hollow figure format.

Figure 26.11 Foil novelties with string.

plastic vacuum-formed “clam-shell” type containers within a carton frame. Eggs were traditionally sold in eggcups, printed beakers, wicker or plastic nests and baskets; however, in recent years, price sensitivity and environmental sustainability have seen the reduced usage of this type of container in many markets. In the United Kingdom, many standard Easter egg formats use 100% recyclable packaging; however, luxury eggs still use plastics with no recycling stream available.

There is no doubt that the most likely cause of damage to Easter eggs and novelties is poorly designed packaging. The most attractive cartons are useless if they cannot protect their contents from the rigours of the distribution chain, and it is often necessary to affect a compromise between design and strength. High-quality boards can enable designs that were formerly impracticable to be used, but at a cost.

It is always advisable to carry out carriage tests on new packaging materials and/or formats. The tests are designed as far as possible to reproduce the normal hazards of distribution, but with Easter eggs and novelties, this becomes essential. It is also critical that such tests are carried out using exactly the materials that will be used in bulk manufacture and that these materials are clearly specified and checked. There have been many cases where cartons have been made of different boards when printed from those supplied in plain form for testing.

26.2.7 Shelf ready/retail ready packaging

Recent developments have seen the growing demand from retailers for “shelf ready” or “retail ready” packaging, that is packaging that will go from transit to shelf with the minimum amount of labour and time (Figure 26.3). Therefore, transit cases have become more expensive in order to decorate the case more elaborately, while enabling the contents to be placed on the retail shelf with minimum effort and fuss.

Corrugated and cartonboard cases have become more complex with tear-off lids and/or multiple-piece construction allowing a lid or hood to be removed easily without the aid of cutting blades. Usually this leaves a tray holding the contents, which can easily be placed on the shelf, thereby significantly reducing the labour time required to fill the shelf.

Although shelf ready/retail ready packaging is an added cost for the manufacturer of the goods (increased decoration/printing, complexity and materials that are more robust), these transit formats offer increased potential to display the brand image to its best advantage. In addition, these fully decorated transit cases become more easily identifiable in the back of store, minimising shelf out of stock situations and maximising sales opportunities.

The full benefits of shelf ready packaging can only truly be achieved when the packaging provides:

1 Easy identification – locate in back of store and on shelf;
2 Easy opening – tool free, minimum time;

3 Easy to place on shelf – stable, maintains shape when opened;
4 Easy shopper interaction – clear link between primary and secondary packaging, easy product removal from the secondary packaging.
5 Easy disposal – tool free, minimum interaction, space saving.

26.3 Flow wrap machinery and sealing

Flow wrapping is carried out as follows: The flow wrapper operates as a horizontal form-fill-seal machine. It forms a continuous tube of packaging film by producing a longitudinal seal (often referred to as a fin seal) along the base of the pack. Product is pushed into the tubes for a set distance. The tube containing the product is then sealed (end seals) and cut to a predetermined length. The key to an effective flow wrap operation at high speed is a well designed and built "folding box" or "folding plate" (figure 26.13).

The end seals may be heat sealed by the application of pressure and heat from rotating predominantly metal jaws for a pre-determined time. For heat sealing the main wrapper typically consists of a lamination such as 10–12 μm (0.39–0.47 × 10^{-3} in) PET and 25–30 μm (0.98–0.1.18 × 10^{-3} in) cast polypropylene (CPP; metallised or non-metallised), with the CPP as the heat seal layer. In addition mono-web co-extruded BOPP film can be used on its own for heat seal applications. However the available sealing layer thickness is often only ≈ 1 μm (0.039 × 10^{-3} in) thick and, therefore, the sealing jaw set-up and maintenance must be perfect to produce consistently tight seals. The end seals may be cold sealed by the application of pressure alone when cold seal adhesive is employed. The sealing surface of the rotating jaws may now be a softer material such as Kevlar or rubber. The softer surfaces of these materials even-out any irregularities in the film to produce improved seal integrity.

Where higher barriers are required (e.g. to oxygen, moisture or odours) or high visual impact, several layers of different films are laminated together (usually by the printer) with adhesive. The lamination process typically involves solvent-based adhesives. However, there has been a gradual move towards solvent-less adhesives, which produce a weaker bond in the lamination but also

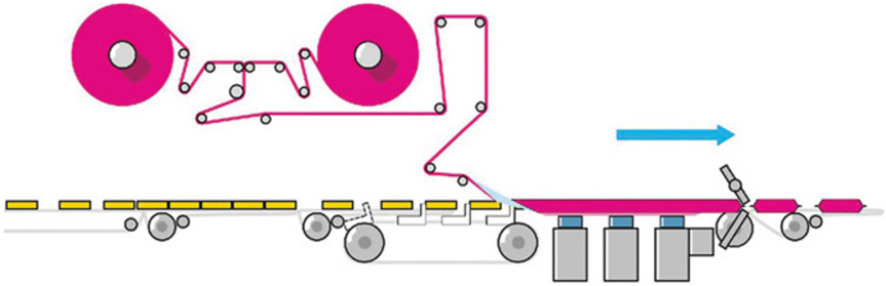


Figure 26.12 Schematic illustration of a flow wrapping line.

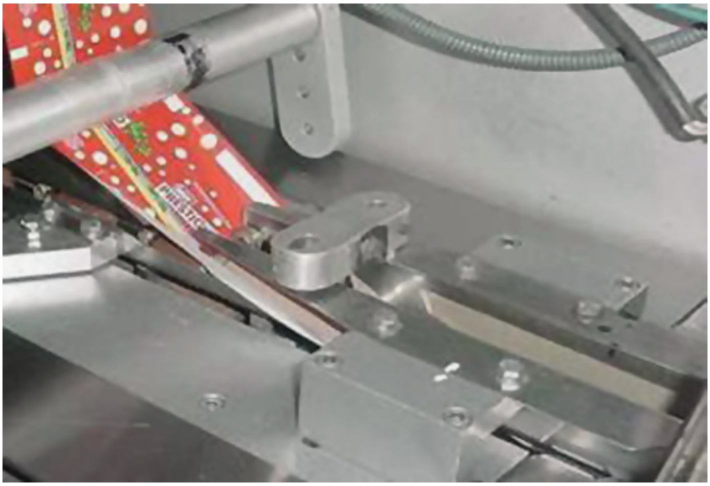


Figure 26.13 Flow wrap folding box.

produce a softer feel to the finished pack. Extrusion lamination using LDPE as the adhesive is also used; however, these structures are more commonly found in the cereal bar category providing a little added puncture resistance.

As discussed, a typical structure for a high-quality impact laminate film could be BOPET/adhesive/CPP whereby the print is sandwiched between the adhesive and PET, giving a high gloss surface. In this structure, the heat seal is provided by the internal layer of CPP that has a lower melting point than the external layer of PET. In addition, a thicker sealing layer is used compared to a coated film or mono-web BOPP to guarantee maximum seal integrity and high sealing bond strength.

Standard heat seal films on horizontal flow wrap machines run at up to 30 m/min (98 ft/min). Low temperature sealing (LTS) or broad sealing range (BSR) films are proven to run at 70–80 m/min (230–262 ft/min). However, some suppliers state their films run at up to 100 m/min (328 ft/min). LTS/BSR films attract a premium price and have therefore found limited use compared with cold seal adhesive films. LTS/BRS films are not recommended for vertical pillow pack machines due to their initial weak bond strength (seal required to carry a load immediately after sealing and before the seal has cooled).

Cold seal films work by applying a blend of natural rubber latex and synthetic polymer-based adhesive onto the internal edges of the film to be sealed. These are then pressed together on the wrapping machine at high speed (see Section 26.4.5). Cold seal films are typically used for horizontal flow wrap operations where high-speed wrapping is required. Vertical pillow-pack operations rarely use cold seal films due to the low-speed equipment and the premium price incurred for cold seal structures. Although synthetic cold seal adhesives have been developed and proven over recent years, their use in replacing natural rubber latex has proven slow due to additional on-costs.

26.4 Materials

26.4.1 Aluminium foil

Aluminium foil provides the best barrier available in a flexible format to water vapour, gas transmission and odour. Aluminium is generally defined as a fully annealed, soft temper metal of 99–99.5% purity, the remaining percentage being made up of silicon and iron with traces of other elements. Recent developments have reduced the percentage of aluminium by incorporating manganese to give added strength (so-called "special alloys").

The thickness can be 5–20 µm ($0.20–0.79 \times 10^{-3}$ in), but generally range within 6.5–17.0 µm ($0.25–0.67 \times 10^{-3}$ in) for confectionery purposes. Cost reduction has resulted in special alloys, rolled thinner on more efficient modern plant; so that, for example, 8 µm (0.31×10^{-3} in) foil can be obtained that is stronger than the old 9–10 µm ($0.35–0.39 \times 10^{-3}$ in) foil and, in some cases, than the traditional 12 µm (0.47×10^{-3} in). Thinner gauges of foil are rolled double, giving the characteristic shiny and matt sides that appeal to artists and designers in different ways – some prefer the bright side for display value, whereas others regard the matt face as conveying discreet quality.

For bar and tablet wrapping, foil can be specified in several forms, plain unbacked with or without embossing, backed with or without embossing or coated with or without embossing. In most cases, un-backed foil is used with the embossed versions providing additional decoration along with a slight increase in rigidity for transport through the wrapping machine. When added strength and crease resistance are required, for example when nuts protrude from the back of a bar, it may be necessary to laminate the foil to other materials.

The most popular backing material is paper because it is strong, easily printed and relatively inexpensive. Depending on the end use and whether it is laminated to the outside or inside of the foil, there is a wide choice of paper forms available, for example sulfite tissue, kraft (usually bleached) and glassine, with an equally wide range of adhesives, such as dextrin, polyethylene, wax and hot melt. A widely used combination, for example, is foil: 7 µm (0.28×10^{-3} in)/wax: 3 gsm (0.0098 oz/ft^2)/tissue paper: 20 gsm (0.0655 oz/ft^2) [gsm = grams per square metre].

In addition to adding strength to the foil, lamination [e.g. to 20 gsm (0.0655 oz/ft^2) tissue paper] can provide a cost reduction in material when compared to using higher gauge foils such as 17 µm (0.67×10^{-3} in).

Plastic films are used where extra barrier properties and puncture resistance are required and occasionally to provide a high gloss finish. In this instance, it is important to balance the relative gauges of material so that the "spring" of the film does not overcome the desirable dead fold properties of the foil. An example of such a structure is 9 µm (0.35×10^{-3} in) aluminium foil laminated to 12 µm (0.47×10^{-3} in) BOPP.

In general, the thinner the gauge of foil the more minute pinholes can be expected, for example 7 μm (0.28×10^{-3} in) foil will have more pinholes than 20 μm (0.79×10^{-3} in) foil. When foil is coated, usually with vinyl or PE in order to make it heat sealable, this has the additional effect of filling in the pinholes. Although research has shown that most pinholes have very little effect on the barrier properties of foil, such filling can only be beneficial.

Provided all traces of residual rolling oils (which could go rancid under certain conditions) are removed, unconverted foil is perhaps the material least likely to taint a sensitive product such as chocolate. Converted foil (i.e. foil converted by printing, coating or laminating) can create odour problems because of the coatings and adhesives as well as the printing inks. Therefore, it is important that full taint and residual solvent tests be carried out before such material is used.

Foil is most attractive when printed. All major printing processes, particularly gravure and flexography, can do this and foil is frequently over-lacquered with transparent colours to make full use of its metallic visual properties.

26.4.2 Paper and board

These are materials produced from the natural cellulose fibres found in trees. The production process broadly consists of taking the wood apart by pulping and subsequently re-joining the fibres, without their own binding materials, as an engineered matrix designed to perform a specific function. This pulping can be done chemically whereby the organic binding material holding the fibres together is dissolved away (e.g. solid bleached sulfite with all layers being chemical pulp; see Table 26.1). Alternatively, pulping can be done physically whereby the wood is "mechanically" broken up and the binding material washed away by water (e.g. coated chromo board with a centre layer of mechanical pulp; see Table 26.2). The former method produces strong, expensive paper or board with minimal odour and taint potential and is ideal for direct chocolate contact. The latter method produces relatively weak, cheaper material, which is perfectly adequate for many purposes, but can also produce tainting of chocolate due to the production of hexanal over time.

Table 26.1 Structure of solid bleached sulfite board.

Component	Thickness (g/m^2)	Proportion (%)
White coating	20	6.7
Bleached cellulose: white covering	40	13.3
Bleached cellulose: white middle	200	66.7
Bleached cellulose: white back	40	13.3
Total	300	100

Table 26.2 Structure of coated chromoboard.

Component	Thickness (g/m^2)	Proportion (%)
White coating	20	5.0
Bleached cellulose: white covering	60	15.0
Mechanical wood pulp: middle later cream	260	65.0
Bleached cellulose: white back	55	13.8
Pigment preparation	5	1.2
Total	400	100

The finished slurry is dried out in sheet form and passed through rollers to make paper or built-up in layers to make board. The layers can be of different qualities, making a multilayer sandwich by including different materials, such as reclaimed waste paper and pure fibres. If the board or paper is to be printed, it normally has a top layer of good-quality bleached fibres plus a coating of china clay-containing pigment such as titanium dioxide and possibly an optical brightening agent. This is known as coated paper or board, and many different types and qualities are available.

Different chemical techniques can produce glassine, in which the fibres are completely destroyed, giving a very high degree of resistance to oil and grease in the final product, but making the paper relatively weak. Glassine can be formed into rudimentary shapes by heat and pressure, producing, for example, paper cups into which chocolates can be placed or into which very fatty product such as noisette can be directly deposited. Glassine is frequently used laminated to board, in order to protect it from fat penetration and staining. It can also be incorporated in a non-heat sealed wrap to stop fat migration from chocolate bars in hot climates. Glassine in corrugated form is also in widespread use, ranging from sincor (wave-embossed) to single- and double-faced fluted material to provide cushioning inside boxed chocolates.

Similar cushioning, but of rather coarser quality, can be achieved by using corrugate made from greaseproof or vegetable parchment. The latter is produced by the action of concentrated sulfuric acid on wood pulp, giving greater strength along with grease resistance.

In many instances, cartonboard outers are packed into shipping cases for distribution, particularly where rail or sea transportation is involved, and here corrugated board is used. No other material offers corrugated board's unique combination of product protection, stacking strength, printability, lightweight and relatively low cost.

In general, corrugate board is made of two plies of liner material separated by a layer of fluting or corrugating medium. The fluting is formed from the flat material by huge meshed rollers: glue is applied to the tips of the fluting and the liners are then stuck on. Usually this is done on one long machine, which also prints the finished material and cuts it into the appropriate shape for the finished

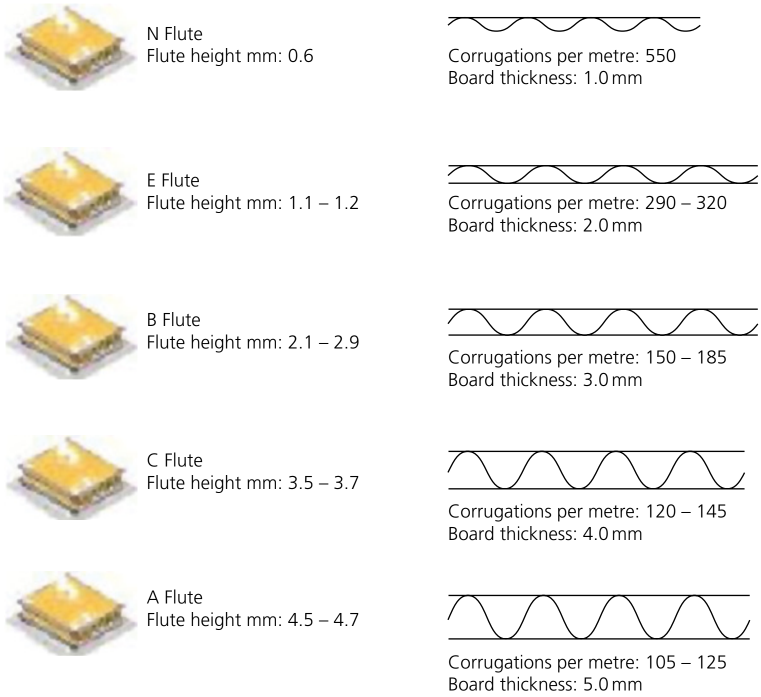


Figure 26.14 Common flute grades.

case. The type of corrugate is described by the number of flutes per centimetre or foot. The most widely used version is B-flute, which has some 1.7 flutes/cm (52 flutes/ft). For smaller boxes where a finer material and more decorative surface are required, E-flute, with 3.2 flutes/cm (98 flutes/ft), is often used; even finer "microflute" such as F- and N-flute are now also available. The most common flute grades are shown in Figure 26.14.

Depending on the use to which the finished box is put, many different qualities of material can be used for the liners, ranging from heavy-duty kraft down to glassine or greaseproof. The liners also have different characteristics: colour natural, white top, mottled, fully bleached, printability (e.g. clay coated) and barrier (e.g. PE laminate).

Kraft liners (virgin fibre-based):
- Typically 70% virgin soft wood fibres and 30% recycled fibres;

Test liners (recycling-based liners):
- Typically 100% recycled fibres;

Test liners are divided into different classifications:
- Test liner 2 Corrugated factory recovered paper,
- Test liner 3 Supermarket recovered paper,
- Chip: the cheapest test liner grade based on urban recycled fibres.

When deciding which combination of liner and fluting to use, the first question to be asked must be: does the corrugated box take the load or does the product

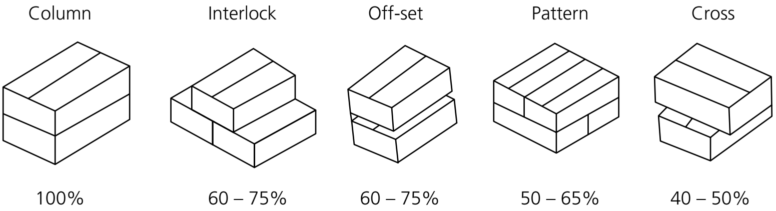


Figure 26.15 Relative strength of different stacking patterns.

inside the box take the load? Most of the corrugated case strength is in the corners and the majority of the fluting should be in the vertical position to maximise case strength. Column stacking in the pallet provides maximum load strength, however, this produces an unstable load. Therefore, pattern stacking is commonly used with cases interlocking to produce a stable load in transit. An approximate guide to the relative stacking strengths is shown in Figure 26.15.

The traditional method of printing is an integral part of the process of corrugate manufacture, which is followed by creasing and slotting. This results in a poor quality of reproduction by modern standards. Changeable information can be applied at the last moment using the actual corrugating equipment.

High-quality print methods such as rotogravure or offset lithography can be applied to single-web paper or board, but not to formed corrugate because they would break down its structure. There is an increasing tendency to preprint the outer liner before it is formed into corrugate. This enables the use of more sophisticated printing, giving much better decoration, and illustrations can be achieved by the use of halftones. One advantage of micro-flute is that it can be printed directly to give high-quality graphics.

26.4.3 Regenerated cellulose film

Until the late 1970s and 1980s regenerated cellulose film (RCF) dominated the flexible packaging field. Like paper and board it is made from wood pulp, although generally of a higher quality: a high proportion comes from eucalyptus grown especially for the purpose. A chemical process is used in which, as in papermaking, individual fibres are put into solution. Instead of being spread out in layers, they are then chemically regenerated and passed through a slot to form a transparent film. Glycerol and various glycols are used as plasticisers to add flexibility to the film.

In its natural state RCF has few characteristic properties other than transparency, flexibility, dead-fold and the ability to form a barrier to oxygen, provided it is dry. It cannot be sealed and it is very susceptible to moisture, expanding or contracting with changes in atmospheric humidity. In order to make RCF a practicable proposition it has to be coated. Initially it was made heat sealable and given some barrier properties by the application of a nitrocellulose coating. This material (MS) is perfectly adequate for most confectionery purposes. Where extra protection is required, a polyvinylidene chloride (PVdC) coating is used and the film is then characterised as MXXT, with the suffix "S" for solvent applied or "A" for aqueous dispersion coated. Although it is more effective and avoids the problem of disposal of residual solvents, the reactivity of RCF to moisture makes the aqueous method of coating much more difficult. MXXT films generally have more sparkle than MS and more resistance to abrasion.

Other coatings or treatments can be used to make RCF permeable to some gases and not to others. This enables the atmosphere inside to be controlled to a certain extent for the benefit of some products. It can also be made extra flexible (PF) for twist wrapping, supplied uncoated where moisture pick-up is not a problem (e.g. most chocolate-covered sweets) and can be coloured either intrinsically or in the coating.

Coated RCF is an ideal film for automatic packaging because it is not subject to structural alteration as a result of temperature; however, it cannot be thermoformed. It offers a combination of rigidity with elasticity – it will stretch before it breaks – and it avoids problems associated with static electricity (such as attracting dirt and upsetting wrapping machines). It's tensile and burst strengths are good; a tear, once made, propagates easily, but this is actually an advantage when a tear strip is required. The heat-seal temperature is not critical, as coated film has a relatively wide sealing range. It can be obtained in various thicknesses and, in general, the thicker the film, the stronger it is; barrier properties, however, do not vary with overall thickness since the coating weight (expressed in gsm equivalent units) remains the same. RCF, unlike most plastic films, is biodegradable so it appeals to environmentalists.

On the debit side, RCF, even when coated, does not have the shelf life of plastic materials. It requires carefully controlled storage conditions, but even so will deteriorate with time. As with paper and board packaging, it is essential to place the RCF in the packaging hall at least 24 h before use to allow the material to equilibrate with the atmosphere in the room to prevent curling of the material.

NatureFlex™ cellulose films have been specifically developed for enhanced compostable performance that is certified to EU (EN13432), US (ASTM D6-400) and Australian (AS4736) norms.

In recent years, RCF production has been deemed environmentally un-friendly due to some of the chemicals used in its manufacture. Therefore, the number of producers of RCF is now very limited, which has in turn led to the film becoming expensive in comparison to plastic films.

26.4.4 Plastic films

Despite all its properties, plastics films for flexible packaging have largely supplanted RCF. PVdC, used to coat RCF, is itself a plastic and can be obtained in film form, as well as in coating form. The range of plastics materials available for packaging is very wide and increasing, however this chapter is confined to those that play a significant part in the packaging of chocolate products.

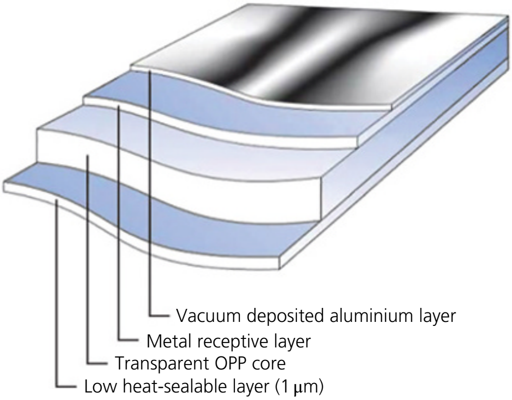
26.4.4.1 Polypropylene

The plastic that has had perhaps the greatest impact on the packaging of confectionery is polypropylene (PP), although in most applications this is co-extruded in three or more layers (see Figure 26.16) and bi-axially oriented (BOPP) whereby the extruded film is stretched in both the transverse and machine direction. This is a close cousin of polyethylene; both are polyolefins derived from ethylene, but PP has an even wider range of applications. As a packaging film it can be made very thin, down to 10 μm (0.39×10^{-3} in); but, due to the film's desire to stretch, it is not commonly used for printing below 15 μm (0.59×10^{-3} in). However, in the United States, central impression flexographic print presses are used to print BOPP below 15 μm (0.59×10^{-3} in). It is the least dense commonly used plastic material, so it is very light; the combination of these characteristics gives very high yields. (Yield is the area of material contained in a given weight, generally expressed as m^2/kg or in^2/lb.) It can be coated with other materials or co-extruded with them to give any combination of properties required in a package. It runs well on automatic packaging lines, having a low coefficient of friction with metal, and it has a wider sealing range than its competitors, provided the machinery has adequate heater controls where heat sealing is employed.

For heat-sealing purposes, it should be note that, in BOPP structures, the sealing layer is very thin typically ~1 μm (0.039×10^{-3} in) with the core layer not readily wanting to heat seal to itself (Figure 26.16). CPP is co-extruded in the same way as BOPP but without the bi-axial stretching process; therefore, the sealing layer in the co-extrusion is thicker and provides greater opportunity to produce tight heat seals.

In its clear form, PP has largely captured the boxed chocolate market, and most confectionery bags are now made from BOPP or laminates incorporating BOPP or CPP. PP can be used to make thermoformed trays, although these are more difficult to form, more rigid and less user friendly then the un-plasticised PVC versions. On the other hand, blown PP shrink film, although rather more difficult to handle, gives more protection than PVC.

Figure 26.16 BOPP structure metallised format.



BOPP has dominated the market in recent years for flow wrapped chocolate tablets and countlines in cavitated, solid white or metallised forms, in mono-web and laminated formats. However, the PP that has shown the most rapid growth worldwide is white opaque (cavitated) PP whereby the core layer of a co-extruded film (typically three to seven layers) contains air pockets. As well as being light, thus giving a high yield, it is relatively rigid and crisp, and it can be made either with high or low sheen to look like paper. Perhaps its biggest advantage for use with chocolate-coated products is that it eliminates optical staining (when wet or greasy marks show through), a constant problem with paper, glassine and transparent film.

The film can be white with a pearl-like colour, where the outer layers are transparent, or "super white", where the outer layers are coloured white providing a deep white and glossy surface for printing. Development work is continuing and several manufacturers have reduced density even further while increasing opacity and stiffness, without impairing the barrier properties of the cavitated material.

Other structures used include solid white BOPP for a more rigid feel, metallised transparent BOPP for added moisture, oxygen and light barrier and laminated films such as metallised BOPP/PET for high barrier and quality feel, particularly for heat seal applications. In recent years, metallised cavitated OPP has become available due to its higher yield over transparent solid metallised film and therefore potential lower cost per square metre. Metallised films are often used for their ability to retard light induced rancidity, for example with white chocolate, thus extending shelf life. It also minimises optical staining or "show through". In many ways, metallised films are superior to aluminium foil, which they closely resemble, but none has the same dead-fold properties, so they are primarily used on horizontal flow wrap and vertical bagging equipment.

Where moisture barrier is the key criteria for product shelf life, for example chocolate-coated wafers, then metallised polypropylene has been the material of choice either in mono-web form for cold seal applications or in laminates for both cold and heat seal applications. It must be noted that, in simple laminations, the metallised layer provides the majority of the moisture barrier. The addition of a transparent BOPET to a metallised BOPP for example will add almost no additional barrier to the structure. In the example shown in Table 26.3, the daily water vapour transmission rate (WVTR) of the metallised BOPP is 0.8 g/m^2 (0.052 g/100 in^2) at 38 °C (100 °F) and 90% relative humidity (RH. The addition of BOPET with a daily WVTR of 40 g/m^2 (2.6 g/100 in^2) has almost no impact on the total barrier property of the laminate, changing the theoretical daily WVTR to 0.78 g/m^2 (0.050 g/100 in^2).

Today, metallised cast polypropylene films (met.CPP) can match the barrier properties of standard met.BOPP films. A thicker sealing layer and superior flow properties (caulking) under heat compared to met.BOPP has meant met.CPP has become popular in hot humid climates for heat seal applications, especially for flow wrap operations.

Table 26.3 Example of the calculation of daily water vapour transmission rate (WVTR) of a two ply laminated structure.

	Structure	WVTR (g/m^2)	Contribution to WVTR in laminate		
Material 1	15 μm metBOPP	0.8	1/0.8	1.25	
Material 2	12 μm BOPET	40.0	1/40.0	0.025	
				1.275	1/1.275
Total WVTR Material 1 + 2					0.78

Note: The same theoretical calculation can be used to determine oxygen permeability of laminated materials.

Advances in surface layer technology in addition to improved vacuum and plasma metallisation deposition have meant very high barrier materials can now be produced. Whereas in the past a standard metallised BOPP would be expected to have a daily WVTR of $\leq 0.8\,\text{g/m}^2$ ($0.052\,\text{g/100 in}^2$) at 38 °C (100 °F) and 90%RH, metallised films are now available with WVTR figures of $<0.3\,\text{g/m}^2\text{/day}$ ($0.019\,\text{g/100 in.}^2\text{/day}$) at 38 °C (100 °F) and 90% RH allowing the replacement of aluminium for some applications.

26.4.4.2 Polyester

The other plastic film that has achieved relatively widespread acceptance in confectionery packaging is polyethylene terephthalate (polyester) in coextruded bi-oriented format (BOPET, often referred to as just PET), which is very strong and clear. Its co-extruded structure is very similar to that of BOPP (Figure 26.16), but with a higher melting point and reduced capacity for stretching. It does not tear easily, and it is resistant to abrasion as well as to oils and fats. It is a fairly good barrier to moisture vapour and gas, and thus to taints. In addition, in its transparent state it also offers some barrier to ultraviolet light.

Although for packaging purposes it can be obtained commercially down to 10 μm (0.39×10^{-3} in) in thickness, polyester is still an expensive material. As a packaging material for chocolate and confectionery, it is probably most widely used in its transparent form in sandwich printed laminates due to its heat resistance, high gloss and its ability to be printed at 12 and 10 μm (0.47 and 0.39×10^{-3} in). Unlike polypropylene, polyester is not used in a cavitated form. Heat seal versions of PET film are available; however, once again, the sealing layer (as with BOPP) tends to be very thin at around 1 μm (0.039×10^{-3} in).

26.4.4.3 Polyethylene

Polyethylene was the first major synthetic material to find a place in packaging and it is still the most widely used. The most outstanding characteristics of its commonest low-density and linear low-density forms are low cost, flexibility, moisture protection, heat sealability and versatility. It can be made with a "memory" so that it can be induced to shrink or stretch and remain shrunk or stretched or revert to its original form. It can be used as a coating, as a film, as an adhesive or in solid form.

On the other hand, polyethylene is not a good barrier to gas or taint and it is not easy to seal on its own. Its surface is non-polar, so treatment with flame or corona discharge is necessary before it can be printed or induced to accept adhesive. Care must also be taken to ensure that polyethylene coatings or laminates are odour-free.

As a film, its principal uses are where toughness rather than clarity is required, for example as a stretch film for pallets or trays of heavy items. It can also be used as a barrier film on pallets. As a coating, it adds toughness, a moisture barrier and heat sealing to other materials such as paper and aluminium foil. In its opaque white form, it can be used to coat poor-quality grey board (partially derived from reconstituted waste paper and board) and give it a high-quality finish. As an adhesive, it can be used to laminate disparate materials and additionally provide a moisture and fat barrier where these materials are deficient in such properties.

26.4.4.4 Polyvinyl chloride

Polyvinyl chloride (PVC) is most commonly used where clarity and sparkle are required in a film, rather than strength, for example for shrink-wrapping fancy boxes. It has good resistance to oils and fats, but its water vapour permeability is relatively high. Where protection against moisture is important, for example if a chocolate box to be overwrapped contains wafer-based sweets, a form of polypropylene shrink film would be preferable. PVC for use with food should be un-plasticised to minimise the possibility of taint or migration from the packaging into the product.

Much thicker PVC has been used in thermoformed trays for packing chocolate assortments in some countries. As with RCF, PVC in recent years has suffered from constant criticism because of its chlorine content, which is seen as being environmentally unfriendly. Other concerns have also been raised with regard to vinyl chloride monomer and the type of plasticisers and stabilisers used; as a result, PVC use in food packaging is diminishing.

In some parts of the world, the old glassine cups are again being used. There is little doubt that the great saving in labour resulting from the use of thermoformed trays to locate and protect sweets in predetermined formation will ensure most manufacturers continue using thermoformed trays. In the United States, polystyrene (PS) is widely used for the manufacture of these trays. However, residual styrene monomer in the tray can lead to tainting of the chocolate, leaving the consumer with an acrid taste.

26.4.5 Cold seal

A revolution in flow wrap packaging has come about through combining films with special properties and cold seal adhesives based on natural rubber latex combined with synthetic polymers. In principle, the latex component creates adhesive to adhesive bonding while the synthetic polymer sticks the adhesive to the film substrate. The ratio of latex to polymer in a cold seal formulation should vary according to the film substrate to which it is to be applied. A white BOPP film for example may require a lower synthetic polymer content compared to a metallised BOPP due to the film's higher surface energy; therefore, a cold seal for a metallised film may contain less latex reducing the adhesive to adhesive bond strength.

The great advantage of cold seal is that the three main parameters governing the sealing process (pressure, dwell time and temperature) are reduced, with heat not being required at all. Without the necessity to control temperature, which is critical with plastic films, the only restraints to wrapping speed are mechanical. In addition, as heat is not required, the possibility of damage to chocolate products during machine stoppages is eliminated. Other benefits include reduced energy usage and wear on the sealing mechanism in addition to eliminating potential harm to operators and engineers from heated sealing jaws.

Cold seal adhesive should always be applied in a pattern on the inner surface of the film (see Figure 26.17) whether the film is a surface printed mono-web structure or a sandwich printed laminate film (print between two layers of film). Chocolate is capable of picking cold seal off the film when in direct contact; therefore, the pattern of cold seal must allow for the minimum possible contact between chocolate and cold seal adhesive.

Surface printed cold seal films employ "release lacquers" which should be applied as a smooth continuous layer at 1.5–2.0 g/m^2 (0.0049–0.0065 oz/ft^2) over the whole surface of the printed side of the film to prevent the inner layer of the film adhering to the outer layer of the film in the reel (known as blocking). Polyamide or nitrocellulose-modified polyamide is commonly used for such lacquers. Hot humid conditions may require special lacquers at higher coating weights to ensure good release in the long term.

Sandwich printed laminated cold seal films typically use a release laminate layer whereby the outer surface of the external layer of film is not receptive to the cold seal adhesive on the underside of the internal layer of film. In most cases, an outer homo-polymer layer in a BOPP co-extruded film generates the release property.

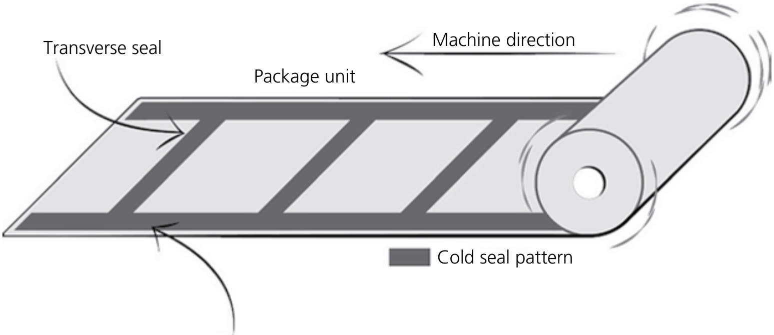


Figure 26.17 Pattern of cold seal application on a packaging film.

Cold seal adhesive films must be considered as a complete system whereby the substrate, ink, cold seal and release lacquer/layer must be compatible. Cold seal adhesive films theoretically have unlimited running speeds with countlines typically running 300–600 packs/min, although speeds up to 800 packs/min are known for smaller size countlines and moulded products.

Typical dry coating weight of cold seal adhesive is 3.5–5.0 g/m^2 (0.0115–0.0164 oz/ft^2). Synthetic cold seal adhesives are now available eliminating the use of natural rubber latex. Synthetic cold seals tend to require a lower coating weight typically 2–3 g/m^2 (0.0065–0.0098 oz/ft^2) to achieve the same bond strength as latex based cold seal. However, sealing bond strength should not be viewed as an indicator of seal integrity, that is a sufficient quantity should be applied to ensure flow (caulking) of the adhesive to ensure tight seals. At the time of writing, synthetic cold seal adhesive was not widely used due to the limited formulations available and significant on-cost compared to latex-based cold seal.

It is important to ensure that any inks used for overprinting or in-line marking (for example ink jet "best before" information) adhere to the release lacquer or release laminate sufficiently. The correct ink formulation must be determined when changing from a heat seal substrate to a cold seal substrate to prevent easy removal by rubbing off of the "best before" information.

Cold seal adhesive can be difficult to see, especially on white film; this can lead to difficulties in setting up the wrapping machine or in checking the presence and correct positioning of the cold seal in the sealing areas. Adding colour (generally light pink or blue) to the adhesive can overcome this problem.

Care must be taken when considering how to transport and store cold seal reels of film. Extreme cold within a reel of cold seal film prevents the formation of a good seal – should the internal temperature of a reel of film reach freezing point or just above, the sealing properties of the film will deaden, causing seal failure; the deadening is often reversible by reheating the film.

Tough plastic materials and cold seal have developed in parallel with the growing sophistication and availability of microprocessor-controlled wrapping machines. Together they have, in effect, removed the bottleneck frequently caused by the packaging element in an integrated production line and, at the same time, they have reduced operator supervision. The use of cold seal means that wrapping machines can speed up or slow down, giving an instant response to availability of product. This applies whether they are wrapping naked bars straight from an enrober or moulding plant, or collations of wrapped bars from a number of primary wrapping machines. At speeds of 200+ per minute, automatic feed systems and automatic boxing are essential, as is the automatic splicing when changing to a new reel of film. This avoids the need to stop the wrapping machine to renew the wrapping material.

26.4.6 Biopolymers

In recent years, both industry and consumers have become increasingly aware of the need for sustainability in many aspects of life, including the use of packaging materials. Conventional plastics are made from oil and gas feedstock that are both finite resources and subject to many price fluctuations. Plastics produced from oil and gas can take many years to break down once their useful life has finished. In addition, the availability and use of landfill waste sites has become less acceptable. Therefore, recent years have seen the development and commercialisation of a wide variety of renewable biopolymers for packaging.

Renewable resources for packaging can be broken down in to four main categories: starch-based, polyhydroxy (alkanoates/butyrates)/polyesters, polylactic acid (PLA) and cellulose-based (See Table 26.4).

In addition to cellulose film (see Section 26.4.3), two of the main renewable packaging materials used for chocolate are PLA and Plantic™.

26.4.6.1 Polylactic Acid

PLA is produced from cereal starch. PLA NatureWorks™ produced by Cargill uses cornstarch and the manufacturing process produces aliphatic polyesters, which can be used for flexible films and rigid packaging. Various trials are currently (2015) being performed using PLA NatureWorks™ for twist wrap applications with chocolate confectionery.

Bi-orientation of PLA films produces properties that include high stiffness, high transparency and gloss, good dead fold and twistability, in addition to printability. The rigidity of the film gives it a metallic sound similar to polystyrene when manipulated that can sound noisy. While PLA can provide good barrier properties to odours and resistance to oils and grease, the barrier to moisture and oxygen is limited.

Supporters of PLA state the material is carbon neutral, coming from carbon-absorbing plants, and therefore reduces the emission of greenhouse gases compared to petro-chemical produced packaging. In addition, when incinerated, PLA will not produce toxic gases. While PLA is compostable, critics state this only applies to industrial composting systems that are continually fed digestive

Table 26.4 Renewable packaging categories.

Category	Manufacturers
Starch-based	Plantic Technologies Ltd Biopar (Biop) MaterBi (Novamont) Bioplast (Biotec) IBEK Verpackungs GmbH
Polyhydroxy(alkanoates/butyrates)/polyesters	Biopol, PHA (Metabolix) Nodax, PHA (P + G/Kaneka) Sorona, polytrimethylene terephthalate (DuPont)
Polylactic acid	NatureWorks Hycail
Cellulose-based	NatureFlex (Innovia Films) Biograde (FKuR/IBEK Verpackungs GmbH)

microbes at a temperature of 60 °C (140 °F). In addition, opponents claim PLA must not enter the recycling stream of petro-chemical based plastics.

26.4.6.2 Plantic™

Plantic™ is produced from cornstarch which is modified with the inclusion of ingredients such as plasticisers and processing aids and extruded. At the time of writing (2015), the application for chocolate packaging was for vacuum formed trays (VFTs) for chocolate assortment boxes.

Properties of Plantic™ material in VFT format include rigid feel, static resistance, easily heat formable and dissolves completely in warm/hot water. Moisture content control and vacuum forming process control are critical in producing VFTs. In addition, storage conditions of the finished product are important as the material will pick up and lose moisture as the ambient climate changes, which can lead to the material becoming brittle.

26.5 Sustainability

Sustainability has become a major topic and focus area for all food manufacturers and packaging producers. Responsible food producers should ensure all packaging placed on the market is optimised in terms of environmental performance using recognised cradle to grave life cycle analysis (LCA) tools. According to ISO 18602:2013:

> "packaging optimization is the process for the achievement of a minimum adequate weight and volume for meeting the necessary requirements of primary, secondary and transport packaging, when performance and user/consumer acceptability remain unchanged or adequate to reduce the impact of packaging on the environment".

When developed well, packaging makes a valuable contribution to economic, environmental and social sustainability through protecting products, preventing waste and enabling efficient business conduct. Attempts to reduce packaging impacts should only be pursued if they maintain or reduce the overall impacts of the final packed product – a recent study indicated as much as 10 times more energy goes into producing the food contained within the packaging than the actual packaging. Therefore, light-weighting and down-gauging exercises are sustainability meaningless if product waste is increased. To contribute positively to the sustainability of a product, the packaging and product should be designed holistically to optimise the overall environmental performance.

Recycled materials should only be used where there is a clear environmental benefit and where appropriate. For example, much is made of the use of recycled cartonboard; however, there is currently little evidence that the use of recycled board constitutes an environmental advantage due to the lower mechanical properties and potential food safety issues compared to virgin board.

Many terms are used to justify sustainability; however, in many cases the incorrect use or understanding of these terms leads to much confusion. The following sections give a number of definitions for terms commonly related to packaging and sustainability.

26.5.1 Biodegradable

Materials that are capable of undergoing decomposition into carbon dioxide (CO_2), methane, water, inorganic compounds and/or biomass, in which the predominant mechanism of degradation is the enzymatic action of microorganisms (bacteria, fungi, algae). Note methane is 25 times worse than CO_2 as a greenhouse gas. There is no evidence to date that biodegradability confers an environmental benefit and, indeed, biodegradability does not solve the litter problem – biological degradation without the required conditions (microorganisms, temperature, humidity) is very slow and can last for several years.

26.5.2 Compostable

Biodegradable materials which biodegrade in ways which meet the conditions of international standards such as EN 13432, ISO 17088, ASTM 6400. Compostability certification states the conditions and time constraints under which the composting should occur, as well as criteria to be met in terms of material composition, disintegration, ultimate biodegradability (weight loss), compost quality and recognisability (labelling).

26.5.3 Renewable resources

A renewable resource should meet all of the following requirements:

1. Be composed of biomass which can be continuously regenerated within a given time frame.
2. Be replenished at a rate that is equal to or greater than the rate of depletion.
3. Come from sources that are managed in accordance with the principles of sustainable development.
4. Have a verifiable traceability system is in place (definition from the draft amendment to ISO 14021).

26.5.4 Bioplastics

The term bioplastics is a rather loose term that includes different types of plastics and two aspects of bioplastics are frequently confused:

1. *Composition*: a plastic made from renewable resources;
2. *End of life*: a biodegradable or compostable plastic;

Composition and end of life are independent aspects. A biobased plastic from renewable resources is not necessarily biodegradable. Furthermore, biodegradable plastics are not always made from renewable resources. Traditional petroleum based plastics can be biodegradable.

26.5.5 Recyclability

For a packaging item to qualify as recyclable it must meet three criteria according to ISO 14021:

1. Collection, sorting and delivery systems to transfer the used packaging from the source to the recycling facility are conveniently available to a reasonable proportion of consumers of the packaged product.
2. Recycling facilities are available to accommodate the collected packaging materials.
3. The packaging for which the claim is made is being collected and recycled.

The fact that a packaging item is made out of one single material is thus not sufficient to claim recyclability.

26.5.6 Recycled content

Two types of recycled materials qualify as recycled content according to ISO 14021/US FTC:

1. Post-consumer material: material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product, which can no longer be used for its intended purpose. This includes returns of material from the distribution chain that generated it.
2. Pre-consumer material: material diverted from the waste stream during a manufacturing process. Excluded is reutilisation of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

26.6 Portion control

Chocolate confectionery can be generally high in one or more of the health-sensitive nutrients, specifically fats and added sugars, and therefore high in energy content. It is widely accepted that excessive intake of energy dense foods, saturated fatty acids, sodium and added sugars may negatively affect health and have to be taken in moderation. Balance is the key to healthy eating; therefore, chocolate in moderation can be part of a healthy diet.

The serving size used on the pack nutrition label may or may not be according to the discretion of the food manufacturer, depending on legislation of the country where the food is being sold. For example, in the Americas, Brazil, Canada, Mexico and United States, guidelines exist on reference amounts for nutrition labelling. However, in Europe, each manufacturer can select a serving size that it considers most appropriate for a specific type of food for nutrition labelling. Nonetheless, the Association of the Chocolate, Biscuits and Confectionery Industries of the European Union (CAOBISCO) has established reference quantities for labelling of Guideline Daily Amounts, in anticipation of future European Union regulations on serving size information in nutrition labelling.

Serving sizes to encourage responsible consumption have come to the fore in recent years with terms such as “portion control” and “portion guidance” being widely used. Reduced product size is one way to achieve portion control/guidance. However, an alternative is the introduction of reclose packaging solutions on multi-portion packs.

26.6.1 Tablets/blocks

Chocolate tablets and blocks are often segmented with one or more segments being a single serving (see Figure 26.18). Aluminium foil and paper label formats provide a natural reclose feature. However, an increasing number of mainstream tablets have moved to flow wrap packaging formats with no natural reclose feature. With the move to flow wrap packaging more inventive methods of reclose have been developed, many of which have been patented (e.g. cold seal adhesive easy open and reclose features; see Figure 26.19) and transverse label opening and reclosing.

Chocolate countline products sold in bars, sticks, minis or other individually packed formats are typically uncut or unsegmented, with the entire product being one serving (see Figure 26.20). Methods to achieve portion control/guidance for countlines include several pieces in the same flow wrap (bar pre-cut in pieces), segmented bars or bars with clear indentation for intuitive portioning. Twist to reclose has become one of the easiest solutions to achieve reclose for these formats (see Figure 26.21).

26.6.2 Nibbles

These are small pieces of “bite sized” confectionery and may be chocolates with filling, ingredients or solid chocolate, individually unwrapped and often sold in bags. A number of patented reclose solutions have appeared in recent years.

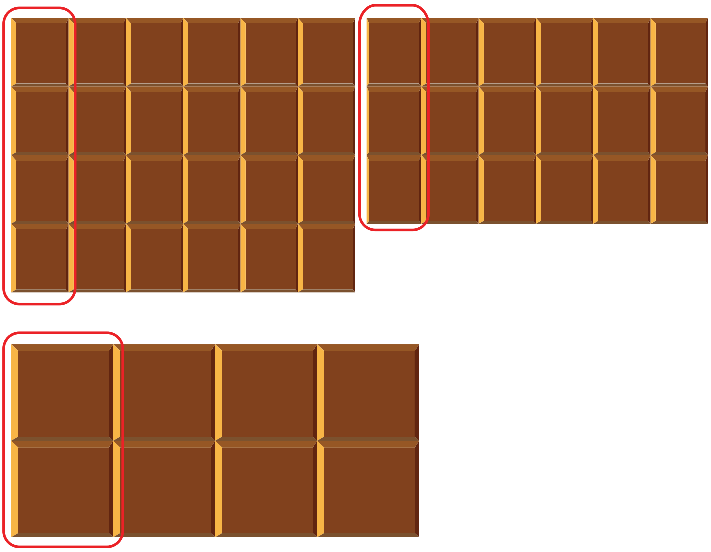


Figure 26.18 Chocolate tablet portions.

Figure 26.19 Cold seal easy open and reclose.

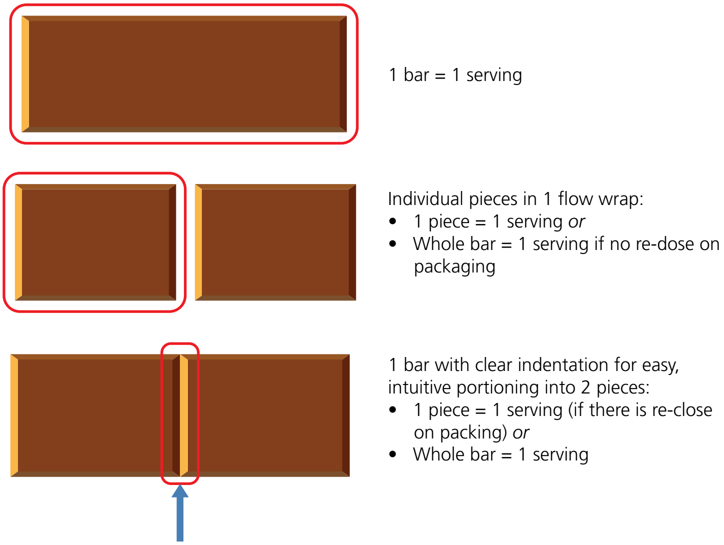


Figure 26.20 Portion control for countlines.

However, the two most common solutions for reclose are still the self-adhesive label (see Figure 26.22) and the zipper system.

In summary, three guiding principles for effective portion control and guidance with packaging are:

1. Communicate a responsible message in a way that consumers can relate to.
2. The design to be intuitive and engaging, decreasing waste without adding complexity.
3. See packaging as part of a system, that is product and packaging must be designed together to deliver effective portion control.

Figure 26.21 Countlines, twist to reclose.

Figure 26.22 Reclose using self-adhesive label.

26.7 Quality control and environmental criteria

26.7.1 Quality control

When it comes to food safety, “Declarations of Compliance” should be provided by the supplier of packaging materials intended for direct food contact confirming good manufacturing practice (GMP) have been adhered to. For example, the GMP part of European regulation 2023/2006 sets out the requirement for all suppliers to provide clear declarations of the suitability of their product for direct food contact.

The integration of high-speed production lines would not be possible without full electronic control of what is basically a series of mechanical operations. It also depends heavily on the quality of the packaging materials, and here such factors as print and sealant registration, particularly where the photoelectric cell (PEC) register mark is concerned, stretch, slip and accuracy of slitting must be controlled to a much higher degree than before and monitored by the end user. This control of quality can involve a multiplicity of tests to be carried out before materials reach the production line. If agreement on standards can be reached with suppliers, it should be possible for the supplier to carry out the bulk of the testing, with only spot checks being carried out by the user. Nevertheless, a well-equipped packaging laboratory should be capable of carrying out at least the following tests:

- Seal strength, tensile strength, burst strength;
- Coefficient of friction;
- Moisture vapour resistance;
- Detection of residual solvents, for example by gas liquid chromatography;
- Taint, using a panel of tasters (see Section 23.12.4);
- Print stability and resistance to abrasion;
- Scannability of bar codes.

Chocolate is particularly sensitive to external taint and it is essential that every precaution be taken to exclude it. Most modern flexible materials are fairly good barriers to taint and can be made very good by coating with PVdC or acrylic, laminating or metallising. The quality of seal is important: where the package is not sealed, external taint sources must be eliminated.

Although the manufacturer has little control over the environment after the product has left the factory, there are many potential sources of taint during manufacturing operations. These include residual solvents, or other likely contaminants in wrapping materials, resulting from incomplete drying or oxidation of printing inks and varnishes, including sealants. Print can "offset" onto the inside of a reel, or indeed any printed materials and come into direct contact with chocolate. Incorrectly applied coatings or laminates, such as PE, can also be the cause of taint.

In addition to its role in protecting its contents from the hazards of climate and distribution, packaging is also instrumental in persuading the consumer to buy. It is therefore well worth taking pains to get it right.

26.7.2 Environmental issues

All packaging must now take into account environmental criteria. Fundamentally, this means using the minimum amount of material consistent with the requirements of the product, but in some markets there are prejudices against specific materials, which must also be taken into account. Such materials include PVC (primarily because it is perceived as contributing towards acid rain and releasing dioxin when burned) and aluminium because of environmental damage allegedly caused during its manufacture and the original extraction of bauxite.

Although there are few legal restrictions on the use of such materials, consumer objections expressed through the retail trade may necessitate the use of alternative materials, such as polyester and PP, for vacuum-formed trays or wrapping chocolate blocks. Where laminates are concerned it is wise to ensure that the different layers can be recycled together or easily separated for recycling, but the use of mono-materials is generally to be recommended from an environmental standpoint.

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CHAPTER 27

The global chocolate confectionery market

Jonathan Thomas

27.1 Background

Chocolate forms an integral part of the global confectionery industry and is widely eaten in most parts of the world. It represents one of the world's most popular forms of snack and is widely recognised as an affordable indulgence on the part of consumers. It appeals to both sexes and to all parts of the age spectrum, as well as being strongly associated with some of the world's leading holidays and festivals. The significance of chocolate and cocoa powder can be further illustrated by its presence in the manufacture of certain other popular foods, examples of which include biscuits, ice cream, dairy desserts and hot beverages.

The earliest references to cocoa and/or chocolate date back thousands of years to what is now Latin America. The beans of the cacao tree (the scientific name for which is *Theobroma cacao*) were roasted and ground to form a spicy chocolate beverage called "xocolatl" in civilisations such as the Mayans and the Aztecs. During these times, cocoa beans were also used as a form of currency, owing to the widespread belief that they were gifts from Quetzalcoatl, the god of wisdom. Chocolate was first imported to Europe following the Spanish conquest of the Aztecs.

It was during the first half of the nineteenth century that products featuring chocolate started to emerge and some of the now-familiar names within the chocolate industry first began to establish themselves. Developments in early technology enabled many forms of confectionery to be manufactured on a larger scale and the availability of glucose and condensed milk made possible the development of boiled sweets, toffees and fudges. The rapid expansion of urban populations throughout Europe, coupled with rising income levels, led to the establishment of a network of retailers in factory towns such as Birmingham in the UK, where Cadbury was born.

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

It was during the nineteenth century that methods were developed in Western European countries such as France, Switzerland and the Netherlands to manufacture chocolate products as they are known today. New techniques and approaches were developed which affected chocolate manufacture and in turn led to the creation of products such as milk and moulded chocolate. The world's first milk chocolate bar was launched in Switzerland in 1875, while Cadbury launched its first milk chocolate bar in the UK more than 20 years later, as the nineteenth century was coming to an end. It was made from ingredients such as milk paste, cocoa butter and sugar but, by the company's own admission, it was too coarse and dry to gain widespread popularity.

The first two decades of the new century saw the launch of some of the now-familiar chocolate brands – for example, Cadbury introduced Dairy Milk in 1905, followed by Bournville in 1908 and Milk Tray in 1915. In the USA, meanwhile, the Hershey's Kiss brand from Hershey made its debut in 1907. With the appearance of these brands, the chocolate confectionery market started to develop, as a result of which consumption increased in parts of the world such as Europe, North America and the former British dominions. During World War II, in several Allied countries the special virtues of confectionery were recognised by its inclusion in food rationing schemes. Meanwhile the American and British armies introduced confectionery products to many other countries in the world.

From a promotional perspective, advertising within the chocolate industry started to take off in the years leading up to World War II – one of the pioneers in this area was Cadbury, whose iconic "glass and a half" message first appeared in the 1920s. Chocolate manufacturers were also at the forefront of developing better welfare and development opportunities for employees, partly as a result of the strong religious and philanthropic beliefs of some of the company founders. Notable examples included Cadbury and Rowntree in the UK, as well as Hershey in the USA.

The post-war period witnessed a period of significant expansion for the chocolate industry in many parts of the developed world, as well as the appearance of the first television adverts. With greater quantities of chocolate being exported and manufacturing bases being established in overseas countries, the industry became steadily more global in nature. At the same time, consumption in parts of the world such as Western Europe and North America rose significantly as income levels rose and diets became more varied.

More recently, growth in consumption has begun to level off throughout the developed world. Reasons for this include greater competition from other forms of snacks, health concerns over chocolate's sugar and fat content and, from time to time, adverse economic circumstances. Faced with this situation, many of the world's leading chocolate suppliers have been looking towards developing regions for growth, with countries such as Russia, China, India and Brazil being notable examples.

Table 27.1 Chocolate brands carrying Fairtrade status. Source: Leatherhead Food Research (2011, 2013).

Brand	Manufacturer	Year of Fairtrade conversion
Green and Black's	Mondelez International	1994
Cadbury's Dairy Milk	Mondelez International	2009
KitKat (four-finger)	Nestlé	2010
Maltesers	Mars	2011
KitKat (two-finger)	Nestlé	2012

In recent years, the chocolate industry has also made something of a return to its philanthropic roots by seeking better conditions for those employed in cocoa production. This was first addressed by UK and European firms during the early part of the twentieth century – more recently this concern for the livelihoods of cocoa farmers and workers in key growing regions such as Africa and Latin America has been reflected in a greater usage of cocoa carrying some form of certification. Many leading chocolate suppliers now work in partnership with the various certification bodies, in order to secure a sustainable and environmentally friendly future for the cocoa industry (see Chapter 2).

This trend has been evidenced by the conversion of several leading brands to Fairtrade status (Table 27.1). One of the pioneers in this sector was Green and Black's (which is now part of Mondelez International) in 1994, and it has since been joined by the likes of Cadbury's Dairy Milk, Maltesers and KitKat. In addition to chocolate confectionery, other products such as cocoa powder have also gained accreditation.

As can be seen from Table 27.1, multinational chocolate suppliers such as Mondelez International, Nestlé and Mars all now own brands carrying Fairtrade accreditation. The possibility exists that more will enter into the category in the future; assuming supplies of Fairtrade cocoa can be assured.

From a regulatory standpoint, chocolate confectionery is usually defined as containing cocoa and its derivatives, as well as milk, sugar and many other ingredients. The chocolate industry is a major user of many types of agricultural products, owing to the wide range of different flavours, tastes and textures – examples of the latter include dried fruits, nuts (e.g. hazelnuts, peanuts and macadamia nuts) and coconut.

27.2 The global chocolate market

In 2012, the global confectionery market was valued at US$ 190bn. The chocolate sector accounted for US$ 105bn of this, having grown by an estimated 25% in value terms during the years since 2007. The remainder of the global confectionery market is made up of sugar confectionery and chewing gum, which were worth US$ 59bn and US$ 26bn respectively in 2012. The importance of the chocolate sector is further illustrated by the fact that it typically accounts for up to 60% of all new product activity taking place within the confectionery industry every year.

Growth within the chocolate sector held up fairly well during the global economic downturn that followed the banking crisis in 2008, despite its effect on consumer spending and the rising price of raw materials such as cocoa. Chocolate has also faced severe criticism from some quarters, most notably the health lobby – this trend has been especially apparent in markets such as the UK and the USA, where the role of sugar in rising obesity rates has come under particular scrutiny. Within the chocolate market itself, recent growth has been highest in certain sectors – notable examples have included Fairtrade chocolate (which has benefited from the aforementioned extension of a number of major brands into the category) and single-origin products, both of which tend to be priced at the higher end of the market.

In regional terms, growth in demand for chocolate has come from the less developed parts of the world. Although developed regions and countries accounted for almost 60% of global sales in 2012, annual growth in these places has averaged just 3% lately. In contrast, the chocolate market in parts of the world such as Asia and Latin America has grown by around 11% in recent years, driven by rising consumer incomes and the greater availability of western-style chocolate products. Brazil, for example, is the third largest confectionery market in the world. Within the next few years, the share of the global chocolate market taken by the Asian region in value terms is forecast to increase to around 20%, as countries such as China and India assume growing significance.

In value terms, chocolate accounts for a leading 55% of the global confectionery market, ahead of sugar confectionery (31%) and chewing gum (14%). The situation is rather different by volume. However, in this instance, chocolate's share of the global market drops to 35%, trailing sugar confectionery (57%). The reason for this apparent discrepancy is that chocolate is frequently sold at a higher price than many forms of sugar confectionery, and the share taken by more expensive products is therefore more significant.

In many of the world's poorer countries, chocolate remains unaffordable for large sections of society. As a result, sugar confectionery products such as boiled sweets and mints are the preferred choice of snack, and consumer penetration levels for chocolate remain on the low side. The same is true for countries in warmer climates, where chocolate may be prone to melting. In contrast, consumption of chocolate outweighs sugar confectionery in many of the Western European countries, such as UK, Germany and France.

27.3 Industry supply

The global chocolate market is contested by a large number of companies, ranging from multinational food groups to small, artisanal chocolate producers. The bulk of the international market, however, is controlled by a select few global operators, which are present in most of the world's regions and countries.

Not only do these suppliers benefit from considerable economies of scale as far as manufacturing is concerned, but they are also able to devote sizeable budgets to research and development activity.

Compared with the sugar confectionery industry, the chocolate market is relatively concentrated, with the top five suppliers accounting for almost 60% of global sales in value terms. This is mainly because the sugar confectionery category comprises a wider selection of products (ranging from boiled sweets to mints, fruit chews, toffees, caramels, lollipops, gums and jellies), while in poorer countries such as India, many forms of sugar confectionery are sold through informal retail channels, of which street markets are one notable example.

Concentration within the global chocolate industry has increased as the new millennium has progressed. Much of this has occurred as a result of manufacturers seeking to increase their presence in high-growth markets in the developing countries, as well as to counter the buying power of the major food retailers. Some of the largest mergers and acquisitions to have taken place within the confectionery industry of late include Kraft's £ 11.5bn purchase of Cadbury in 2010 (which in turn created the global snacks giant Mondelez International) and the US$ 23bn acquisition of Wrigley by Mars Inc. two years earlier.

The merger between the former Kraft and Cadbury businesses created a new leader within the world chocolate confectionery market. Mondelez now accounts for 16% of global sales, ahead of closest rivals Mars (15%) and Nestlé (13%). Also worthy of note are Ferrero and Hershey, each of which account for 7% of global chocolate confectionery sales (Table 27.2).

Prior to its acquisition by Kraft, Cadbury occupied a particularly strong position within chocolate markets such as the UK, Ireland, Australia, New Zealand and South Africa. It is also leader of the growing Indian chocolate market, where it accounts for 70% of sales. Kraft's strength prior to the merger with Cadbury lay mainly in European markets (where its Milka brand continues to represent one of the region's largest varieties of chocolate blocks and tablets), while the company also accounts for almost one-third of chocolate sales in Brazil.

Table 27.2 Shares of the global chocolate confectionery market (% value), 2013. Source: Leatherhead Food Research (2011, 2013).

Company	% value
Mondelez International	16
Mars	15
Nestlé	13
Ferrero	7
Hershey	7
Others	42
Total	100

Second-placed Mars accounts for 25% of the chocolate market in the USA and represents the largest western-based supplier within the growing Chinese sector. It is particularly strong in the countlines sector worldwide, as a result of brands such as Snickers, Mars bar, Twix and Milky Way. Nestlé, on the other hand, has a more modest presence in both the USA and Chinese chocolate markets, although its brands are widespread throughout regions such as Europe and Australasia, and it also accounts for almost one-quarter of the large Brazilian market (this figures rises to 40% if its acquisition of Garoto in 2002 is included).

Hershey ranks as a global player, but its geographical footprint has tended to lag behind rivals such as Mars. Although it leads the USA chocolate market with over 40% of sales, it has yet to establish a major presence in the European region. Ferrero, meanwhile, has traditionally been strongest at the premium end of the chocolate market, following the success of brands such as Ferrero Rocher. Compared with its aforementioned rivals, Ferrero's share of main sectors such as countlines and chocolate blocks and tablets is rather more limited.

Branded products account for the vast majority of sales within the global chocolate market, with the share taken by own-label varieties estimated to be worth less than 5%. Although the switch to cheaper groceries observed during the post-2008 economic difficulties has increased demand for own-label foods, this trend has been less evident within the chocolate category compared with other areas of the food industry. Nevertheless, quality levels continue to improve within the own-label chocolate sector, with many food retailers having started to offer more premium products focusing on areas such as organic, Fairtrade and single-origin chocolate.

Returning to the branded sector, many of the market's bestsellers have a long and distinguished heritage within the industry – for instance, Cadbury's Dairy Milk range first appeared early in the twentieth century, while Mars launched Snickers and Rowntree launched KitKat in the 1930s. Consequently, the market's leading brands tend to command a high degree of loyalty amongst consumers and continue to account for a sizeable percentage of sales. This is frequently reflected in new product activity by the leading suppliers – instead of developing completely new brands (which can involve significant costs in terms of timescale and research and development), many manufacturers prefer to extend existing chocolate brands, via strategies such as new flavour variants or packaging formats.

27.4 Global production and consumption of chocolate

The world's largest producer of chocolate confectionery is the USA, where domestic output amounted to approximately 1.9 million tonnes in 2012 (Table 27.3). This is perhaps to be expected, given that many of the world's leading suppliers operate manufacturing facilities in the country. Despite the fact that chocolate multinationals have been targeting developing economies for

Table 27.3 The world's leading chocolate producer countries by volume (×1000 tonnes), 2008–2012. Source: Leatherhead Food Research (2011, 2013).

Country	2008	2012
USA	1600	1900
Germany	975	1025
Brazil	505	550
Russia	470	525
UK	500	515
France	245	250
Italy	215	240
Canada	210	220
Poland	160	200
Japan	210	215

manufacturing purposes in recent years, domestic chocolate production within the USA increased by almost 19% between 2008 and 2012 – Mars, for example, opened its first new chocolate factory in its home market for more than 30 years during the first quarter of 2014.

Other major chocolate producers include European countries such as Germany, Russia and the UK, as well as Brazil. Many multinationals have opened new facilities in Russia, in order to take advantage of the local growth in demand for western-style premium chocolate. In Brazil, meanwhile, chocolate output has risen by almost 10% in the years since 2008, and the country now ranks as the world's third largest chocolate producer. Looking further ahead, it is possible that chocolate manufacture may undergo further expansion in Asia, Latin America and parts of the Middle East as the industry goes ever more global.

With volume sales worth in excess of 1.72 million tonnes, the USA also has the world's largest market for chocolate confectionery at present (Table 27.4). Although consumption has grown by less than 1% in the years since 2008, volume sales of chocolate remain considerable in the USA. Almost two-thirds (67%) of USA adults purchase chocolate on a regular basis, a figure which rises to 90% for the country's children and teenagers.

Germany and the UK have Western Europe's largest markets for chocolate confectionery, with volume sales worth 670 000 and 595 000 tonnes respectively in 2012. However, both markets are large and mature, as a result of which neither has performed especially well of late: in Germany, for example, consumption declined by almost 8% between 2008 and 2012, mainly as a result of the contraction in consumer spending. Further east, Russian consumption of chocolate confectionery amounted to 850 000 tonnes in 2012, a figure which has risen by 21.4% since 2008. Following this growth, Russia now represents the world's second largest chocolate confectionery market in volume terms.

Table 27.4 The world's leading chocolate confectionery markets by volume and value, 2008–2012. Source: Leatherhead Food Research (2011, 2013).

Country	Volume (×1000 tonnes)		Value (US$m)	
	2008	2012	2008	2012
USA	1680	1725	16 850	17 500
Russia	700	845	6150	7370
Germany	725	670	5900	5700
UK	580	595	6665	6900
Brazil	470	495	4150	4550
France	417	415	3220	3200
Japan	240	255	4795	5150
Italy	235	240	4415	4855
Poland	230	235	1310	1375
Canada	220	225	1650	1725

Besides Russia, growth in chocolate consumption has also been evident in Brazil, which is Latin America's largest market by some distance. In 2012, the Brazilian market was worth 495 000 tonnes, having risen by 5.3% in the years since 2008. Elsewhere, volume sales of chocolate confectionery are currently worth 210 000 tonnes in the developing Indian market and, if present trends continue, the country is set to break into the global top ten at some point in the next few years.

By value, sales of chocolate are also highest in the USA, where the market was worth US$ 17.5bn in 2012. This figure has increased by a very modest 3.9% compared with 2008, when market value was worth US$ 16.85bn. Other significant markets for chocolate confectionery in value terms during 2012 included Russia (worth US$ 7.37bn), the UK (worth US$ 6.9bn) and Germany (worth US$ 5.7bn). In many instances, growth in market value has been driven by the trend towards more premium forms of chocolate, as well as higher prices at the retail level.

In per capita terms, consumption of chocolate confectionery is highest amongst Western European countries. Table 27.5 lists the world's top ten chocolate consuming nations – as can be seen, per capita consumption of chocolate is highest in Switzerland, at almost 12 kg. This figure decreases to nearly 10 kg in Ireland and 9.5 kg in the UK. Generally speaking, per capita consumption of chocolate tends to be higher in Europe's more northerly countries.

Outside Europe, per capita consumption is highest in Canada, at 6.4 kg. The country ranks ahead of its southern neighbour by some distance, where 5.5 kg of chocolate is eaten by the average consumer in the USA every year. While per capita levels are also relatively high in both Australia (5.9 kg) and New Zealand (4.8 kg), they lie well below the global average in many less developed economies. The average Indian consumer, for example, eats just 170 g of chocolate per annum, and in China it is even lower at around 100 g.

Table 27.5 The world's leading chocolate consumers in per capita terms (kg), 2012. Source: Leatherhead Food Research (2011, 2013).

Country	Per capita (kg)
Switzerland	11.9
Ireland	9.9
UK	9.5
Austria	8.8
Belgium	8.3
Germany	8.2
Norway	8.0
Denmark	7.5
Canada	6.4
France	6.3

27.5 Reasons for eating confectionery

Confectionery is eaten throughout the world for a variety of reasons, of which gaining pleasure and enjoyment is probably paramount. In most instances, products such as chocolate and sweets represent an affordable treat for adults and children alike, which is why consumer penetration rates tend to be on the high side. Although large quantities of chocolate are bought on impulse, other factors can and do influence purchasing. These reasons are now examined in more detail.

Chocolate has traditionally been viewed as an impulse purchase, most frequently for immediate consumption as a snack. Despite growth in other areas, impulse buying still accounts for a sizeable percentage of purchases within the world chocolate market. It is for this reason that so-called "convenience" channels (e.g. smaller-sized grocery outlets) remain such a strong feature of the market. In the UK, for example, a survey by Shoppercentric (2011) found that chocolate was the third most popular impulse purchase (behind sweets and cakes) amongst shoppers, with 65% of respondents claiming to buy chocolate in this way because "*they fancied it*".

The widespread popularity of chocolate as a snack can be further illustrated by the results of research carried out by Nielsen (2014) into the global snacking market during 2013. This research – which valued the global snack foods category at US$ 347bn – found that chocolate was the world's favourite form of snack. According to a poll of 30 000 consumers spread across 60 countries carried out by Nielsen, a leading 15% stated that chocolate was their favourite snack, ahead of yoghurt and bread/sandwiches.

The same study found that almost two-thirds (64%) of consumers had eaten chocolate within the last 30 days, which was marginally higher than the corresponding figure for fresh fruit (62%). By region, chocolate was the second most frequently consumed snack amongst Europeans (trailing only fruit), while it also occupied second position in the USA (behind potato crisps), in Latin America (behind yoghurt) and in the Middle East and Africa (behind fresh fruit). The same study found that chocolate was consumed as a snack slightly more often amongst women, at 68% of all respondents. This figure decreased to 61% for male consumers.

Confectionery such as chocolate also represents a popular form of gift, reflecting emotions such as affection, gratitude, hospitality or even remorse. Much of this is skewed towards certain times of year, when chocolate sales are on the high side – notable examples in many western markets include Christmas, Easter, Valentine's Day and, increasingly, Halloween. Chocolate is virtually synonymous with Easter and (to a slightly lesser extent) Christmas in many parts of the world, when gifts are traditionally exchanged. In the UK, sales of boxed chocolates during Easter, Valentine's Day and Mother's Day are worth over £ 100 m (US$ 150 m) per year.

Easter is arguably the most significant season within the global chocolate market, despite the fact that it has yet to catch on in parts of the world such as China. In contrast, it is well-established across large parts of Europe, as well as in the USA, where the Easter period accounts for over a third of seasonal chocolate sales. Another significant market for Easter chocolate is Brazil, where Easter eggs account for around 20% of the country's chocolate market, and over 100 million are eaten every year. This figure falls slightly, to around 80 million Easter eggs, in the UK.

Chocolate eggs (both shell and filled varieties) remain the mainstay of the Easter confectionery market, both in Brazil and elsewhere. Sales appear to have held up well during the recession – in the UK, for example, the market for chocolate eggs grew by 5.5% to more than £ 300 m during 2013. Consumers also display an increasing appetite for Easter-themed novelties and shapes in markets such as the UK. Traditionally, one of the best examples has been Gold Bunny from Lindt and Sprüngli, but competition is increasing from rival companies. The Malteaster Bunny from Mars, for example, was launched in the UK in 2009 and is now worth almost £ 17 m per annum.

The Christmas period accounts for a sizeable percentage of sales of boxed chocolates in many parts of the world. In the UK, for example, November and December respectively account for 24% and 45% of sales of boxed chocolates during the course of a typical year, while chocolate assortments sold over Christmas accounts for up to one-fifth of the total French chocolate confectionery market. The Christmas chocolate market also encompasses seasonal novelties (e.g. tree decorations and advent calendars), as well as products geared towards children. Mintel estimates that between 15% and 20% of all Christmas chocolate confectionery products launched per year are targeted at this age group.

Halloween has traditionally been an important time of year as far as the USA chocolate market is concerned – in 2013, for example, chocolate accounted for over 70% of all consumer expenditure on confectionery during the Halloween period. Data from the National Confectioners Association indicates that USA spending on chocolate during Halloween in 2013 grew by over 5% to US$ 2.2bn. Across the Atlantic, sales of chocolate during Halloween are also rising sharply in Western European countries such as the UK and Ireland. The UK market for Halloween-themed food and drinks is now worth over £ 300 m per year, with chocolate treat packs one of the best performing sectors.

In both Europe and North America, snack-sized chocolate bars are especially popular at this time of year, owing to their suitability for giving to “trick or treaters”. The growing significance of Halloween within the UK chocolate market is further illustrated by new product activity from major confectionery manufacturers such as Cadbury/Mondelez International. Its range now includes the Screme Egg, a version of the Crème Egg brand, which features green-coloured “goo” instead of the usual yellow.

Another occasion during which consumption of chocolate is becoming increasingly significant is what is usually termed as the “big night in”. As the economic situation worsened in regions such as Europe and the USA, greater numbers of people became less inclined to go out socialising, largely on the grounds of cost. Instead, many turned towards staying in with their friends and family, making use of home entertainment and sharing food and drinks in the process.

With its indulgent nature, chocolate is ideally placed to capitalise on this trend. One effect has been the growth in demand for bite-sized chocolate confectionery products, which are usually packaged in formats geared towards sharing, such as bags and pouches. The UK market for bite-sized chocolate, for example, was valued by Mars at £ 550 m in 2013, up by around 40% from the previous year. Many leading manufacturers have extended their chocolate brands into this sector, thereby further driving market growth – examples include Mars, Milky Way and Twix from Mars, as well as Aero from Nestlé, Cadbury’s Twirl and Flake from Mondelez International.

Despite the fact that some research has linked chocolate consumption with health, this has yet to become a leading reason for purchasing chocolate. Although the science community as a whole remains to be convinced that chocolate possesses significant nutritional benefits, the last decade has seen products coming to market which have been positioned on various health platforms – examples include weight management, anti-ageing and heart health. Chocolate manufacturers have even made references to these health qualities in the marketing of their products, although the prevailing regulatory situation means that very few make specific claims.

A recent example was the study carried out by the University of California in San Diego (2012), the results of which were published in the March 2012 issue of *Archives of Internal Medicine*. The research – which focused upon the eating habits of more than 1000 healthy men and women in the USA – found that people who ate chocolate on a more frequent basis had a lower body mass index (BMI) than those whose consumption levels were lower. It was suggested by the researchers that this may be due to the fact that chocolate contains antioxidants, as well as other ingredients that might promote weight loss (see Chapter 22).

More specifically, much of the research carried out in this area has focused upon the health benefits of polyphenols (which are antioxidants and have been shown by studies to improve blood flow), which are found in cocoa. As a result, the link between products with high cocoa levels (such as dark chocolate) and reduced likelihood of cardiovascular disease has been well to the fore within the industry, as illustrated by the launch of the CocoaVia brand by Mars in 2003. Although this was largely unsuccessful and the original range later withdrawn, consumer awareness of the role dark chocolate could potentially play in improving heart health continues to rise.

It is chiefly for this reason that consumption of dark chocolate has grown in parts of the world, often at the expense of more traditional milk chocolate confectionery. In the USA, for example, the percentage of adult consumers who expressed a preference for dark chocolate (rather than milk) rose from 33% to 35% in 2012, according to data from Mintel. Much of this is for health reasons – research from the same source found that over 70% of all USA chocolate consumers felt that dark chocolate is healthier.

Elsewhere, dark chocolate is now the preferred variety for almost a quarter (23%) of UK consumers, with consumption especially high amongst the older age groups. Demand for dark chocolate is also growing in several European markets at present, examples of which include Ireland, Italy, Denmark, Sweden, Finland and the Benelux countries. As is the case in the UK and the USA, much of this is due to its healthier image.

Chocolate's role as far as nutrition is concerned is described in more detail in Chapter 22.

27.6 The marketing of confectionery

Chocolate and confectionery marketing have come a long way since the early days of the industry, when press and outdoor advertising were usually the favoured ways for manufacturers to communicate with their consumers. One notable example from the UK was Cadbury, which commissioned a local artist named Cecil Aldin to illustrate posters and press advertisements for its chocolate during the early part of the nineteenth century. The images created for these early forms of promotion became iconic and were widespread throughout the UK.

How chocolate is marketed depends very much upon the company concerned. For example, global multinationals whose brands and products are sold in large quantities devote considerable sums for advertising and promotional purposes, reaching out to their consumers through a variety of different mediums. On the other hand, small artisanal chocolate producers tend to specialise in certain niches of the market, since they do not enjoy the same financial strengths or economies of scale employed by their larger counterparts. As such, these small producers firms tend to compete in sectors such as organic and Fairtrade chocolate, where it is easier to differentiate their products from mass-produced brands.

Advertising budgets within the chocolate industry appear to have held up despite the worldwide economic downturn. Hershey, for example, spent an estimated US$ 580 m on advertising and promotional activity in 2013, a figure which equates to approximately 8% of its sales. These figures compare with US$ 108 m (equivalent to 2% of sales) in 2006. Elsewhere amongst the global giants, for example, Mars spent almost US$ 87 m advertising its Snickers brand in its home USA market during 2012. Many of the chocolate industry's television adverts in particular have become extremely well-known and well-remembered over the years, examples of which have included the "*Work, rest and play*" campaign for the Mars bar and, more recently, Cadbury's drumming gorilla.

Chocolate manufacturers are also making increasing use of new technologies to advertise and promote their brands. One of the most significant examples of this trend is the way social media now features in the marketing strategies of the market's leading suppliers. These companies have been embracing new ways to reach out to their consumer base, and social media has come to represent an increasingly important element within the marketing mix.

To illustrate the extent to which social media can shape marketing strategy, it is worth recollecting the fact that Cadbury UK brought back the Wispa brand in 2007 in the wake of a social media campaign. The brand had been delisted in 2003 two decades after it was first introduced, but returned following an online petition which included Facebook and MySpace. Similar campaigns have since been undertaken for other discontinued chocolate and grocery brands, but thus far Wispa remains the most significant example of this trend.

At the time of writing, Nestlé's KitKat brand is the most popular with social media users, with approximately 23.5 million "likes". This figure compares with around 19 million for Ferrero Rocher, 12.4 million for Hershey's Reese's Peanut Butter Cups and 12 million for M&Ms. The top 10 chocolate brands as far as Facebook "likes" are concerned are listed in Table 27.6.

The majority of the most well-liked chocolate brands on Facebook belong to the industry's leading suppliers, which is perhaps a reflection of their widespread popularity across large parts of the world. In addition to the examples mentioned above, Mondelez International owns brands such as Crème Egg (2.7 million "likes") and Wispa (2 million "likes"), while additional chocolate brands from Mars include Milky Way (2.3 million "likes") and Galaxy (2.1 million "likes").

Table 27.6 Top 10 chocolate brands on social media, June 2014. Source: Leatherhead Food Research (2011, 2013).

Brand (company)	Number of Facebook "likes" (million)
KitKat (Nestlé)	23.5
Ferrero Rocher (Ferrero)	19.0
Reese's Peanut Butter Cups (Hershey)	12.4
M&Ms (Mars)	12.0
Snickers (Mars)	10.9
Cadbury Dairy Milk (Mondelez International)	9.2
Milka (Mondelez International)	8.2
Twix (Mars)	8.2
Hershey's (Hershey)	6.3
Toblerone (Mondelez International)	3.6

Social media has also been utilised by manufacturers of chocolate confectionery in order to develop new flavour variations for their products – for example, Nestlé UK and Ireland recently ran a campaign called "Choose a Champion" for its KitKat Chunky brand, which made heavy use of social media. Consumers voted *Mint* as the flavour they would most like to see introduced, ahead of *Chocolate Fudge*. This trend of using social media for developing new flavour variants has also been evident within other sectors of the food industry, one example of which is potato crisps. It has been suggested by social media experts that engaging with consumers in product development in this way encourages a greater sense of involvement on their part and can in turn strengthen brand loyalty.

Another favourite marketing tactic of chocolate manufacturers is to extend their brands with different formats. One of the best examples of this strategy has been the success of the twist-wrap assortments sector, as evidenced by the Miniature Heroes and Celebrations brands from Mondelez International and Mars respectively. These consist of assortments of miniature versions of popular countlines. As is the case with new flavour varieties, the purpose of introducing new formats of established brands is to create additional demand for the product in question. Although some of these new flavours and formats establish themselves as successful long-term products in their own right, others are marketed as limited editions to encourage purchasing during the limited period that they will be available.

Brand extension into other sectors of the food and drinks industry has also featured in the marketing of chocolate products. Since many of the world's leading chocolate brands are well-known and widely recognised by consumers, they are appearing in ever greater numbers in related categories such as biscuits, cakes, ice cream, dairy desserts and flavoured milk drinks. This marketing strategy holds the advantage for manufacturers of tapping into and building upon existing loyalty for established brands, rather than devoting time and money into creating new ones.

Price is another crucial component of the marketing mix. As far as pricing strategy is concerned, most of the world's leading chocolate confectionery manufacturers cater towards all ends of the income spectrum, although it is perhaps significant to note that chocolate sales tend to lag in less affluent countries where income levels are lower than the world average. Meanwhile, since chocolate is frequently perceived as an indulgence, certain products – most notably chocolate blocks/tablets and boxed assortments – tend to command more premium prices and, as such, are purchased less frequently. At the other end of the spectrum, the post-2008 squeeze on consumer spending increased the appeal of own-label chocolate in some quarters.

In recent years, the pricing strategy of chocolate manufacturers has been heavily influenced by the rising cost of raw materials. The ingredients most affected by this have generally been cocoa (the cost of which stood at over US$ 3100 per tonne as of June 2014), as well as sugar and milk powder. Some industry suppliers have been reluctant to pass these costs on the consumer in the form of raised prices at the retail level. Instead, portion sizes have been decreased in order to protect margins. According to chocolate manufacturers, this strategy has the added advantage of assisting consumers with their calorie intake and therefore helps to combat rising obesity levels.

As alluded to already, the global chocolate industry can be segmented into mass-produced products, which are sold in large quantities by the world's leading manufacturers, and the output of smaller artisanal operators, whose production levels tend to be much lower. These latter firms tend to specialise in certain market niches – examples have included organic and Fairtrade chocolate, as well as so-called "origin" chocolate, whereby much is made in the marketing of the provenance of the cocoa beans. Typically, these are sourced from parts of the world which carry a strong association with cocoa, and therefore command a premium price (Chapter 18).

In order to cater to their wide consumer base, multinational chocolate suppliers utilise a wide variety of retail channels to sell their products. In western markets such as the UK and the USA, chocolate purchasing has typically been heavily skewed towards smaller convenience stores, including what in the former market are referred to as the CTN (Confectioner, Tobacconist and Newsagent). These have traditionally been ideally suited towards impulse purchases of chocolate confectionery – for example, a UK survey carried out in 2002 by the Office of Fair Trading found that confectionery accounted for 15% of sales within an average CTN.

In recent years, however, the number of independent CTNs within the UK retail industry has fallen sharply. As a result, supermarkets and larger food retailers now account for an ever growing share of chocolate confectionery sales, with these channels having made particular headway in sectors such as multipacks and boxed chocolates, that is chocolate products not purchased for immediate consumption. One example of the importance of supermarkets as far as chocolate purchasing is concerned has been the decision by Tesco (the UK's largest supermarket) to remove confectionery from its checkouts, in a bid to encourage healthier eating. The company carried this move out within its larger stores in the 1990s and announced that its smaller stores would follow suit during the course of 2014.

Large food retailers such as supermarkets and hypermarkets also account for a growing share of chocolate purchases in other Western European countries such as France and Germany, as well as in the USA and Australia. In Europe, hard discount chains such as Aldi and Lidl represent an increasingly significant feature of the chocolate industry. In less well-developed countries, more informal retail channels still account for a sizeable percentage of sales – examples include vendors and street stalls.

Also worthy of mention is the possibility of the internet assuming an increasing share of global sales of chocolate. In the UK, for example, data from the Institute of Grocery Distribution valued the country's online grocery market at £ 6.5bn in 2013. Although this still accounts for less than 4% of the UK's total food and grocery market, the sector is projected to more than double by the year 2018. Online sales of chocolate and confectionery are reported to be rising in the UK, and it seems highly possible that the chocolate sector may contribute towards some of this growth at least.

27.7 The regulatory position

At the international level, cocoa and chocolate products are governed by the Codex Alimentarius series of standards (see also Chapter 28 for a discussion of standards). These aim to provide a high level of consumer protection and fair practice as far as the global trade of food and agricultural products is concerned. These standards are overseen by the Codex Alimentarius Commission, an intergovernmental body jointly sponsored by the Food and Agriculture Organisation and the World Health Organization.

The Codex standards for chocolate products were last revised in 2003 and are listed in Table 27.7. As can be seen, these cover constituent ingredients for products such as chocolate and white chocolate, and determine recommended levels of cocoa butter, cocoa solids and milk fat. It seems unlikely that the Codex committee will wish to revisit the standards in the near future since the path to obtaining the existing agreement was long and difficult.

As is the case with other foods, confectionery and chocolate products must comply with national labelling legislation. This varies according to country and region – in the UK, for example, the respective legislation is described in the

Table 27.7 Extract from Codex standards for chocolate products (Codex Alimentarius, 2003).

Products	**Constituents (%)**				
	Cocoa butter	**Fat-free cocoa solids**	**Total cocoa solids**	**Milk fat**	**Total milk solids**
Chocolate	≥18	≥14	≥35		
Milk chocolate		≥2.5	≥25	≥2.5 or 3.5	≥12 or 14
Family milk chocolate		≥2.5	≥20	≥5	≥20
White chocolate	≥20			≥2.5 or 3.5	≥14

Notes:

1 "Milk solids" refers to the addition of milk ingredients in their natural proportions except that milk fat may be added or removed.

2 Where two figures are shown (e.g. ≥2.5 or 3.5 for milk fat in milk chocolate), this indicates that agreement could not be reached and that the authorities in the country where the product is marketed are free to determine which standard shall apply.

3 The table above is an extract from the Codex standards which are far more comprehensive, covering 14 types of chocolate other than those listed above. Readers with an interest in such matters are advised to consult the original document (see References for details).

Food Labelling Regulations. Although a full explanation of these is outside the scope of this chapter, they require pre-packed foods to carry a label showing the name of the food itself, as well as a list of its ingredients and their quantity, and other information such as the name and address of the manufacturer and any special conditions of use.

At the European level, the European Union (EU) Directive relating to cocoa and chocolate products for human consumption was passed at the turn of the millennium in 2000, and later amended slightly in 2008. Under the terms of the original piece of legislation, products which are labelled as chocolate – examples of which include milk chocolate, family milk chocolate, filled chocolate, white chocolate and powdered chocolate – are required to meet certain compositional standards. For certain types of chocolate, this Directive determines the minimum percentage of cocoa butter which can be used, while it also permits the use of vegetable fats, assuming this does not exceed 5% of the end product and is clearly stated on the label.

In most EU countries, the Directive states that "milk chocolate" must contain at least 25% cocoa solids and a minimum of 14% milk solids. In the UK and Ireland, however, "milk chocolate" can be made with a minimum 20% for both cocoa solids and milk solids. This is permitted to be sold in other EU member states, although it must be labelled as "family milk chocolate". Elsewhere in the EU, some chocolate products sold in Belgium carry the AMBAO certification mark, which states that no non-cocoa vegetable fats or artificial additives have been used in the manufacturing process.

Moving to the USA, labelling of chocolate confectionery falls under the jurisdiction of the country's Food and Drug Administration (FDA). From this organisation a guidance document is available, which specifically states when the use of the term "chocolate" (rather than "chocolate flavouring") can be used on a label. According to the same document, the label of a non-standardised food which contains no artificial flavour or natural flavour derived from a source other than cacao beans can also be regarded as "chocolate". This is assuming the product meets one of the following two conditions:

- The product bears as its only source of chocolate flavouring an ingredient which complies with one of the standards of identity for cacao products;
- The product is flavoured with cocoa and the food is one that consumers have long recognised as containing cocoa as the characterising chocolate flavouring ingredient and is one that consumers do not expect to contain a chocolate ingredient.

The FDA supplies a standard of identity for many different varieties of chocolate and chocolate ingredients. These are divided into the following types: chocolate liquor, sweet chocolate, milk chocolate, buttermilk chocolate, skim milk chocolate, mixed dairy product chocolate, bittersweet chocolate and white chocolate. For each of these, the FDA lays down requirements regarding the formulation of the chocolate itself (e.g. milk and sugar content), as well as restrictions regarding what ingredients may be added to the product.

In addition to the varieties mentioned above, the FDA also permits certain food products which consumers might reasonably expect to be either chocolate flavoured or made with chocolate to carry the label "chocolate". Typical examples include chocolate milk, chocolate cake, chocolate pudding and chocolate biscuits/cookies.

At the time of writing, FDA regulations do not include a standard of identity for dark chocolate. This is despite the fact that similar standards exist for both milk and white chocolate, the latter of which came into effect during 2002 following extensive pressure from the Chocolate Manufacturers Association. The fact that dark chocolate is not as yet covered by FDA standards has led to petitioning, on the basis that products may carry the label "dark chocolate" even though they do not use real dark chocolate ingredients. Such products, it has been alleged, are likely to be made from vegetable fats such as palm oil, which may in turn mislead consumers over their supposed health benefits.

Similar classifications exist in Canada, where administration and enforcement of food labelling is carried out by the Canadian Food Inspection Agency. As is the case in the USA, chocolate products are segmented into categories such as milk chocolate, sweet chocolate, white chocolate and bittersweet chocolate, all of which carry stipulations regarding the quantity of key ingredients which must be used. However, the Canadian regulatory situation differs from its USA neighbour, in that cocoa butter substitutes are not permitted in the manufacture of chocolate confectionery. Canadian regulations also prohibit the use of certain artificial sweeteners in chocolate, examples of which include aspartame, sucralose and sorbitol.

In Japan, the regulation of chocolate confectionery has been the responsibility of the Japanese Fair Trade Commission since the early 1970s. This organisation classifies six types of "chocolate materials", which are used in the manufacture of four varieties of "chocolate products". The chocolate materials, according to the Commission, include the following types: pure chocolate material, pure milk chocolate material, chocolate material, milk chocolate material, quasi-chocolate material and quasi-milk chocolate material. Each of these materials is required to contain specific percentages of key ingredients such as cocoa, milk and so on. Chocolate products as defined by the Commission include chocolate, chocolate sweet, quasi chocolate and quasi chocolate sweet.

Elsewhere in the Asia-Pacific region, food labelling in the Australasian countries is governed by Food Standards Australia New Zealand, which describes itself as a bi-Government agency and administers the Food Standards Code for both countries. As far as chocolate is concerned, the Australia New Zealand Food Standards Code defines it as "a confectionery product characterised by the presence of cocoa bean derivatives". Furthermore, the product must be prepared from a minimum of 200 g per kg of cocoa bean derivatives and must contain no more than 50 g per kg of edible oils, other than cocoa butter or dairy fats.

Conclusions

Arguably the greatest challenge facing the world's chocolate industry is the pressure it is currently facing from the healthy eating trend. This has been one of the main underlying reasons why growth rates in consumption have tailed off in parts of the world, while health concerns from consumers have also resulted in many of the industry's leading players reformulating their chocolate confectionery products to lower calories, as well as sugar and saturated fat levels.

It seems unlikely that the pressure upon the industry to help address escalating obesity rates will abate any time soon. In the UK, for instance, Mondelez International, Mars and Nestlé were signatories to a Government pledge to cut five billion calories from the nation's diet in 2012. This target is likely to come under strong scrutiny from the media and the health lobby, although it does provide an example of how seriously chocolate confectionery manufacturers are taking their responsibility to help people eat more healthily.

Although chocolate producers have been extremely active as far as product reformulation is concerned, it is questionable how much further action is possible on their part. Reductions in sugar usually have profound implications on chocolate confectionery products in terms of both taste and texture, while manufacturers are also hampered by the fact that global demand for reduced-sugar and/or sugar-free chocolate remains extremely limited. Thus far, the latter market remains a niche sector in most parts of the world, a situation unlikely to change at any time soon.

Given that further reformulation along health grounds appears to be unfeasible and not accepted by consumers, chocolate producers have instead been opting for portion control as a way of countering accusations that they are indirectly partly responsible for the obesity crisis. As an example of this trend, several of the world's most well-known brands have undergone some kind of shrinkage in terms of size, thereby reducing the amount of calories consumed. This is one of the current goals of world leader Mondelez International – its website states that the company aims to increase the number of individually-wrapped products that are 200 calories or less in its portfolio, to help consumers manage calorific intake and be mindful of portions.

Related to the healthy eating trend is the growing consumer demand for more natural ingredients, largely at the expense of artificial additives. Although this has been much more apparent within the sugar confectionery sector (as evidenced by the recent new product activity from the likes of Haribo and Nestlé), there are implications for chocolate confectionery manufacturers. The prospects for chocolate products marketed as containing only natural flavours, for example, would appear to be favourable, while artificial and/or synthetic colours are also falling out of favour in confectionery manufacture. The trend towards natural food ingredients may also result in the appearance of more chocolate products sweetened with steviol glycosides, although their usage has to date been largely skewed towards other sectors, for example soft drinks.

From a consumer perspective, the chocolate industry also faces significant challenges in terms of maintaining its share of grocery expenditure. In western markets such as Western Europe and North America, frequency of purchase for the confectionery sector has for the most part declined over the last decade, with people more inclined to trade up to more premium products which are not bought quite so regularly. However, the recent development of the bite-sized chocolate confectionery sector in countries such as the UK serves as a good example of how innovation within the industry can maintain consumer interest, seek out new opportunities and take advantage of wider social trends, such as the tendency of people not to stay in more frequently.

On a related note, growth rates for the consumption of chocolate confectionery are expected to remain higher across the developing world, as rising disposable income levels in emerging economies enable greater frequency of purchase. Perhaps the most important demographic trend in less developed markets such as China and India is large-scale migration of consumers to urban areas – for example, India's urban population is expected to soar from 340 million in 2008 to 590 million by 2030, and this consumer base is likely to account for a steadily growing share of food expenditure. Future growth in demand in parts of the world such as these are also likely to be driven by development of the retail industry, which is expected to result in higher numbers of modern outlets and hence greater availability of chocolate confectionery.

Also worthy of note is the changing way that chocolate and other forms of confectionery are being marketed and/or promoted. It is thought that this trend will shape the chocolate confectionery market in the future, especially given the advent of social media and its usage amongst younger consumers in particular. While the importance of more traditional forms of advertising and marketing is not expected to diminish, manufacturers are likely to use social media more often to attempt to engender a greater relationship with their consumers, especially to help maintain brand share.

In summary, the chocolate sector is expected to retain its position as the largest within the global confectionery market, at least in value terms. The global consumer base for products such as countlines, moulded chocolate bars and tablets and chocolate gifts is expected to remain large, with high penetration levels existing in most parts of the world. On the supply side of the industry, further consolidation cannot be ruled out, given the high cost of raw materials and production and the ongoing pressure on margins.

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CHAPTER 28

Legal aspects of chocolate manufacture

Richard Wood

28.1 Introduction

Although the first bars of chocolate were commercially introduced in the early 1800s, it remained over a century before the development of standards for such products began. Initially, the establishment of standards for an Industry which is heavily reliant on innovation had been considered inappropriate since it could prevent manufacturers from taking advantage of the latest technological developments. In the absence of standards, it was therefore vital that manufacturers nonetheless maintained the quality of their products. Since food law and regulation is designed to protect consumers and provide for fair trade practices, and the perceived quality of chocolate is important to consumers, it was inevitable that the composition and labelling of chocolate products would become regulated. This chapter provides information on international standards and legal requirements in the major chocolate-consuming markets.

28.2 International standards – the Codex Alimentarius

The Codex Alimentarius Commission was jointly established by two specialised agencies of the United Nations – the Food and Agricultural Organization (FAO) and the World Health Organization (WHO) – in 1961. Before the Codex Alimentarius was established, governments were setting divergent food standards, which could be seen as barriers to international trade. Harmonised standards would facilitate international trade in food. One of the first expert committees to be established was the Codex Committee on Cocoa and Chocolate Products, which held its first meeting in Switzerland in 1963. Although meeting annually during the 1960s, it began to meet less frequently during the 1970s due to inability to reach agreement. The most contentious point – which would not be resolved by the Codex Committee until it had also been addressed by the

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Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

(then) European Economic Community – concerned the use of vegetable fats other than cocoa butter.

Today there are 187 countries, plus the European Union, participating in Codex work. Member countries may choose to accept Codex Standards in full or with specified deviations, or to permit imports of products complying with the Codex Standard.

Of particular relevance to the functioning of Codex is the World Trade Organization (WTO), which today has 164 member countries. In accepting the WTO Agreement, member countries agree to be bound by multi-lateral trade agreements, including the Agreement on Sanitary and Phytosanitary Measures (SPS) and the Agreement on Technical Barriers to Trade (TBT). The SPS Agreement requires member countries to base their standards on international standards, guidelines or recommendations such as those established by the Codex Alimentarius Commission. Codex texts are implicitly targeted in the TBT Agreement since the setting and use of international standards is encouraged.

The first Codex Standards for Cocoa and Chocolate Products were established in 1981, although an amendment to allow use of vegetable fats other than cocoa butter was not included until 2003 after four decades of discussion. Negotiations had been complicated by the continued political opposition of cocoa-producing countries to any proposal which appeared likely to result in a reduction in cocoa butter use and the differences in chocolate manufacturing in developed markets where addition of vegetable fats was considered by some to be adulteration.

28.2.1 Cocoa products

Codex Standards are established for the following cocoa products.

28.2.1.1 Cocoa butter

Cocoa butter is the fat obtained from cocoa beans with the following characteristics:

- Free fatty acid content (expressed as oleic acid): not more than 1.75% m/m (percentage mass/mass basis).
- Unsaponifiable matter: not more than 0.7% m/m, except in the case of press cocoa butter which shall not be more than 0.35% m/m.

28.2.1.2 Cocoa mass

Cocoa mass or cocoa/chocolate liquor is the product obtained from cocoa nib, which is obtained from cocoa beans of merchantable quality which have been cleaned and freed from shells as thoroughly as is technically possible with/without roasting, and with/without removal or addition of any of its constituents. It contains 47–60% m/m cocoa butter. The cocoa shell and germ content must not be more than 5% m/m calculated on the fat-free dry matter or not more than 1.75% calculated on an alkali free basis (for cocoa shell only).

Table 28.1 Composition of cocoa powder and dry mixtures of cocoa and sugars.

Cocoa powders only		**Cocoa butter content (as a minimum cocoa powder content on a dry matter basis)**		
		≥20% m/m	**≥10% m/m but < 20% m/m**	**<10% m/m**
		Cocoa powder	**Fat-reduced cocoa powder**	**Highly fat reduced cocoa powder**
Cocoa powder content in dry mixtures	Not <25% m/m	Sweetened cocoa, or sweetened cocoa powder, or drinking chocolate	Sweetened cocoa, fat-reduced, or sweetened cocoa powder, fat-reduced, or fat-reduced drinking chocolate	Sweetened cocoa, highly fat-reduced or sweetened cocoa powder, highly fat-reduced or highly fat-reduced drinking chocolate
	Not <20% m/m	Sweetened cocoa, or sweetened cocoa powder, or drinking chocolate	Sweetened cocoa mix, fat-reduced, or sweetened mixture with cocoa, fat-reduced:	Sweetened cocoa mix, highly fat-reduced or sweetened mixture with cocoa, highly fat-reduced
	<20% m/m	Sweetened cocoa-flavoured mix	Sweetened cocoa-flavoured mix, fat-reduced	Sweetened cocoa-flavoured mix, highly fat-reduced

28.2.1.3 Cocoa cake

Cocoa cake is the product obtained by partial or complete removal of fat from cocoa nib or cocoa mass. The cocoa shell and germ content must not be more than 5% m/m calculated on the fat-free dry matter or not more than 4.5% calculated on an alkali free basis (for cocoa shell only).

28.2.1.4 Cocoa powder

Cocoa powder, fat-reduced cocoa powder and highly fat-reduced cocoa powder are the products obtained from cocoa cake transformed into powder (Table 28.1).

28.2.2 Chocolate products

Chocolate products are obtained from cocoa materials which may be combined with milk products, sugars and/or sweeteners and other permitted additives. Other edible foodstuffs, excluding added flour and starch (except for chocolate a la taza and chocolate familiar a la taza) and animal fats other than milk fat, may be added to form various chocolate products. These combined additions are limited to 40% of the total weight of the finished product.

The addition of vegetable fats other than cocoa butter must not exceed 5% of the finished product, after deduction of the total weight of any other added edible foodstuffs, without reducing the minimum contents of cocoa materials.

Where required by the authorities having jurisdiction, the nature of the vegetable fats permitted for this purpose may be prescribed in applicable legislation.

Natural and nature-identical flavourings, except those which imitate natural chocolate or milk flavours, may be added in accordance with good manufacturing practice. Vanillin and ethylvanillin may be used to a maximum of 1 g/kg (singly or in combination).

A reference to "milk solids" refers to the addition of milk ingredients in their natural proportions, except that milk fat may be added or removed.

28.2.2.1 Chocolate

Chocolate (in some regions also named bittersweet chocolate, semi-sweet chocolate, dark chocolate or "chocolat fondant") is the product containing, on a dry matter basis, not less than 35% total cocoa solids, of which not less than 18% shall be cocoa butter and not less than 14% fat-free cocoa solids. Chocolate a la taza contains a maximum of 8% m/m flour and/or starch from wheat, maize or rice.

28.2.2.2 Sweet chocolate

The product containing, on a dry matter basis, not less than 30% total cocoa solids, of which at least 18% shall be cocoa butter and at least 12% fat-free cocoa solids. Chocolate familiar a la taza contains a maximum of 18% m/m flour and/or starch from wheat, maize or rice.

28.2.2.3 Couverture chocolate

The product containing, on a dry matter basis, not less than 35% total cocoa solids of which not less than 31% shall be cocoa butter and not less than 2.5% of fat-free cocoa solids.

28.2.2.4 Milk chocolate

The product containing, on a dry matter basis, not less than 25% cocoa solids (including a minimum of 2.5% fat-free cocoa solids) and a specified minimum of milk solids between 12% and 14% (including a minimum of milk fat between 2.5% and 3.5%). The minimum content for milk solids and milk fat shall be applied by the authority having jurisdiction in accordance with applicable legislation. Where required by the competent authority, a minimum content of cocoa butter plus milk fat may also be set.

28.2.2.5 Family milk chocolate

The product containing, on a dry matter basis, not less than 20% cocoa solids (including a minimum of 2.5% fat-free cocoa solids) and not less than 20% milk solids (including a minimum of 5% milk fat). Where required by the competent authority, a minimum content of cocoa butter plus milk fat may also be set.

28.2.2.6 Milk chocolate couverture

The product containing, on a dry matter basis, not less than 25% cocoa solids (including a minimum of 2.5% non-fat cocoa solids) and not less than 14% milk solids (including a minimum of 3.5% milk fat) and a total fat of not less than 31%.

28.2.2.7 White chocolate

The product containing, on a dry matter basis, not less than 20% cocoa butter and not less than 14% milk solids (including a minimum milk fat in the range 2.5–3.5% as applied by the authority having jurisdiction in accordance with applicable legislation). Where required by the competent authority, a minimum content of cocoa butter plus milk fat may also be set.

28.2.2.8 Gianduja chocolate

"Gianduja" (or one of the derivatives of the word "Gianduja") chocolate is the product obtained, first, from chocolate having a minimum total dry cocoa solids content of 32%, including a minimum dry non-fat cocoa solids content of 8% and, second, from finely ground hazelnuts such that the product contains not less than 20% and not more than 40% of hazelnuts.

The following may be added:

- Milk and/or dry milk solids obtained by evaporation, in such proportion that the finished product does not contain more than 5% dry milk solids;
- Almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

28.2.2.9 Gianduja milk chocolate

"Gianduja" (or one of the derivatives of the word "Gianduja") milk chocolate is the product obtained, firstly, from milk chocolate having a minimum dry milk solids content of 10% and, secondly, from finely ground hazelnuts such that the product contains not less than 15% and not more than 40% of hazelnuts. The following may be added: almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product. Where required by the competent authority, a minimum content of cocoa butter plus milk fat may also be set.

28.2.2.10 Chocolate vermicelli/Chocolate flakes

Cocoa products obtained by a mixing, extrusion and hardening technique which gives unique, crisp textural properties to the products. Vermicelli are presented in the form of short, cylindrical grains and flakes in the form of small flat pieces.

Chocolate vermicelli/chocolate flakes contain, on a dry matter basis, not less than 32% total cocoa solids, of which at least 12% shall be cocoa butter and 14% fat-free cocoa solids.

Milk chocolate vermicelli/milk chocolate flakes contain, on a dry matter basis, not less than 20% cocoa solids (including a minimum of 2.5% fat-free cocoa solids) and not less than 12% milk solids (including a minimum of 3% milk fat). Where required by the competent authority, a minimum content of cocoa butter plus milk fat may also be set.

28.2.2.11 Chocolate para mesa

Unrefined chocolate in which the grain size of sugars is larger than 70 microns. It shall contain, on a dry matter basis, not less than 20% total cocoa solids (including a minimum of 11% cocoa butter and a minimum of 9% fat-free cocoa solids).

28.2.2.12 Semi-bitter chocolate para mesa

The product containing, on a dry matter basis, not less than 30% total cocoa solids (including a minimum of 15% cocoa butter and a minimum of 14% fat-free cocoa solids).

28.2.2.13 Bitter chocolate para mesa

The product containing, on a dry matter basis, not less than 40% total cocoa solid (including a minimum of 22% cocoa butter and a minimum of 18% fat-free cocoa solids).

28.2.2.14 Filled chocolate

A product covered by a coating of one or more of the chocolates defined above with exception of chocolate a la taza, chocolate familiar a la taza and chocolate para mesa, the centre of which is clearly distinct, through its composition, from the external coating. Filled chocolate does not include flour confectionery, pastry, biscuit or ice cream products. The chocolate part of the coating must make up at least 25% of the total weight of the product concerned. If the centre part of the product is made up of a component or components for which a separate Codex Standard exists, the component(s) must comply with the applicable standard.

28.2.2.15 A chocolate or praline

The product in a single mouthful size, where the amount of the chocolate component shall not be less than 25% of the total weight of the product. The product shall consist of either filled chocolate or a single or combination of the chocolates as defined above, with exception of chocolate a la taza, chocolate familiar a la taza and chocolate para mesa.

28.3 European standards

European Union (EU) legislation is applicable in the 31 participating states of the European Economic Area: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom. In addition, the Swiss Confederation has provisions based upon European legislation, by virtue of its association agreement with the EU.

The first European Directive on Cocoa and Chocolate Products (73/241/EEC) was adopted in 1973, although partial agreement on the use of vegetable fats other than cocoa butter was not achieved until 1980. Beyond the fundamental issue of whether or not to permit vegetable fats, there had been no suitable method of analysis to determine the presence of "cocoa butter equivalents" (CBEs) – fats that had similar properties to cocoa butter, nor could agreement be found on the use of other types of vegetable fat. The use of vegetable fats was left to Member State discretion, and thus imports were subject to importing country legislation, hence a barrier to trade.

A comprehensive review of EU compositional standards in the 1990s would lead to a solution. At this point in history, seven countries permitted vegetable fats: Austria, Denmark, Finland, Ireland, Portugal, Sweden and the United Kingdom. Five countries did not permit vegetable fats: Belgium, France, Luxembourg, Netherlands and Spain. Three countries did not permit vegetable fats but desired to do so: Germany, Greece and Italy. The breakthrough was:

- The realisation of "non-permitting" countries that they were putting their own manufacturers at an economic disadvantage compared with "permitting" countries which had been freely exporting products to the rest of the EU;
- The limitation of CBE use to a maximum of 5%, to limit any impact on African, Caribbean and Pacific cocoa-producing countries;
- The introduction of a label statement "contains vegetable fats in addition to cocoa butter" to adequately inform consumers.

After 27 years, Directive 2000/36/EC on Cocoa and Chocolate Products was finally introduced in the year 2000, the key provisions of which are included in this chapter. Six years later, on the basis of a study by the European Commission, it appeared that the revised Directive had not made a large impact on the use of vegetable fats since manufacturers in traditional "non-permitting" countries would continue not to use them.

28.3.1 Names and definitions

28.3.1.1 Cocoa butter

The fat obtained from cocoa beans or parts of cocoa beans with the following characteristics:

- Free fatty acid content (expressed as oleic acid): not more than 1.75%;
- Unsaponifiable matter (determined using petroleum ether): not more than 0.5%, except in the case of press cocoa butter, where it shall not be more than 0.35%.

28.3.1.2 Cocoa powder, cocoa

The product obtained by converting into powder cocoa beans which have been cleaned, shelled and roasted, and which contains not less than 20% cocoa butter, calculated according to the weight of the dry matter and not more than 9% water.

28.3.1.3 Fat-reduced cocoa, fat-reduced cocoa powder

Cocoa powder containing less than 20% cocoa butter, calculated according to the weight of the dry matter.

28.3.1.4 Powdered chocolate, chocolate in powder

The product consisting of a mixture of cocoa powder and sugars, containing not less than 32% cocoa powder.

28.3.1.5 Drinking chocolate, sweetened cocoa, sweetened cocoa powder

The product consisting of a mixture of cocoa powder and sugars, containing not less than 25% cocoa powder; these names shall be accompanied by the term "fat-reduced" in the case where the product is fat-reduced as defined above.

28.3.1.6 Chocolate

The product obtained from cocoa products and sugars which contains not less than 35% total dry cocoa solids, including not less than 18% cocoa butter and not less than 14% of dry non-fat cocoa solids; however, where this name is supplemented by the words:

- "Vermicelli" or "flakes": the product presented in the form of granules or flakes must contain not less than 32% total dry cocoa solids, including not less than 12% cocoa butter and not less than 14% of dry non-fat cocoa solids;
- "Couverture": the product must contain not less than 35% total dry cocoa solids, including not less than 31% cocoa butter and not less than 2.5% of dry non-fat cocoa solids, and where this is further supplemented by information or descriptions relating to quality criteria, not less than 16% dry non-fat cocoa solids;
- "Gianduja" (or one of the derivatives of the word "gianduja") nut chocolate: the product must be obtained firstly from chocolate having a minimum total dry cocoa solids content of 32% including a minimum dry non-fat cocoa solids content of 8%, and secondly from finely ground hazelnuts in such quantities that 100 g of the product contain not less than 20 g and not more than 40 g of hazelnuts. The following may be added:
  - milk and/or dry milk solids obtained by evaporation, in such proportion that the finished product does not contain more than 5% dry milk solids;
  - almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

Supplementary information or descriptions relating to quality criteria may be provided where the product, other than couverture chocolate (refer to requirements provided above), contains not less than 43% total dry cocoa solids, including not less than 26% cocoa butter.

28.3.1.7 Milk chocolate

The product obtained from cocoa products, sugars and milk or milk products which contains:

- Not less than 25% total dry cocoa solids;
- Not less than 14% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat;
- Not less than 2.5% dry non-fat cocoa solids;
- Not less than 3.5% milk fat;
- Not less than 25% total fat (cocoa butter and milk fat).

However, where this name is supplemented by the words:

- “Vermicelli” or “flakes”: the product presented in the form of granules or flakes must contain not less than 20% total dry cocoa solids, not less than 12% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat, and not less than 12% total fat (cocoa butter and milk fat);
- “Couverture”: the product must have a minimum total fat (cocoa butter and milk fat) content of 31%;
- “Gianduja” (or one of the derivatives of the word “gianduja”) nut milk chocolate: the product must be obtained firstly from milk chocolate having a minimum content of 10% of dry milk solids, obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream or from partly or wholly dehydrated cream, butter or milk fat and secondly from finely ground hazelnuts, in such quantities that 100 g of the product contain not less than 15 g and not more than 40 g of hazelnuts. Almonds, hazelnuts and other nut varieties may also be added, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

Supplementary information or descriptions relating to quality criteria may be provided where, the product contains not less than 30% total dry cocoa solids and not less than 18% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat, including not less than 4.5% milk fat.

Where the word “milk” is replaced by:

- “Double cream”, in Switzerland only: the product must have a minimum milk fat content of 10%;
- “Cream”: the product must have a minimum milk fat content of 5.5%;
- “Skimmed milk”: the product must have a milk fat content not greater than 1%.

28.3.1.8 Family milk chocolate

The product obtained from cocoa products, sugars and milk or milk products and which contains:

- Not less than 20% total dry cocoa solids;
- Not less than 20% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat;
- Not less than 2.5% dry non-fat cocoa solids;
- Not less than 5% milk fat;
- Not less than 25% total fat (cocoa butter and milk fat).

In the United Kingdom, Ireland and Malta the name “milk chocolate” may be used to designate family milk chocolate on condition that the term is accompanied by an indication of the amount of dry milk solids, in the form “milk solids: … % minimum”.

28.3.1.9 White chocolate

The product obtained from cocoa butter, milk or milk products and sugars which contains not less than 20% cocoa butter and not less than 14% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream or from partly or wholly dehydrated cream, butter or milk fat, of which not less than 3.5% is milk fat.

28.3.1.10 Filled chocolate, chocolate with … filling, chocolate with … centre

The filled product, the outer part of which consists of one of chocolate, milk chocolate, family milk chocolate and white chocolate. The designations do not apply to products, the inside of which consists of bakery products, pastry, biscuit or edible ice. The outer chocolate portion of products bearing one of these names shall constitute not less than 25% of the total weight of the product.

28.3.1.11 Chocolate a la taza

The product obtained from cocoa products, sugars, and flour or starch from wheat, rice or maize, which contains not less than 35% total dry cocoa solids, including not less than 18% cocoa butter and not less than 14% dry non-fat cocoa solids, and not more than 8% flour or starch.

28.3.1.12 Chocolate familiar a la taza

The product obtained from cocoa products, sugars, and flour or starch from wheat, rice or maize, which contains not less than 30% total dry cocoa solids, including not less than 18% cocoa butter and not less than 12% dry non-fat cocoa solids, and not more than 18% flour or starch.

28.3.1.13 A chocolate or a praline

The product in single-mouthful size, consisting of:

- Filled chocolate;
- A single chocolate or a combination or a mixture of chocolate, milk chocolate, family milk chocolate or white chocolate and other edible substances, provided that chocolate constitutes not less than 25%.

28.3.2 Optional ingredients

Other edible substances, such as nuts, fruits, biscuits, coffee, etc, may be added to chocolate products up to 40% of the total weight of the finished product. However the addition of animal fats and their preparations not deriving solely from milk is prohibited. The use of flours, granular or powdered starch is also prohibited, with the exception of chocolate a la taza.

Only those flavourings which do not mimic the taste of chocolate or of milk fat may be added to chocolate products.

28.3.3 Calculation of minimum amounts

For the minimum cocoa solids, the method of calculation imposed by the repealed Directive 73/241/EEC continues to be applied. The total dry cocoa solids content is calculated on the “noble” part of the product – that is “after the weight of the additions … has been deducted”.

The minimum milk solids comes from the partial or total dehydration of whole milk, semi- or full-skimmed milk, cream, partly or wholly dehydrated cream, butter or milk fat. Hence substances remaining after milk fat or water has been removed should be in their natural proportions. Whey powder or derivatives such as permeates and protein fractions are excluded from the definition and are optional ingredients. Optional ingredients cannot be combined to reconstitute an ingredient, which could then be used to fulfil the milk solids requirement.

Lactose, together with other mono- and disaccharides, should be considered as being among the sugars.

28.3.4 Use of vegetable fats other than cocoa butter

Specified vegetable fats may be used in chocolate, to a maximum of 5%. The calculation is based on the sum of the compulsory ingredients: cocoa solids (+ milk solids) + sugars + vegetable fats and excludes optional ingredients. This point is particularly important for gianduja chocolate and chocolate a la taza.

The vegetable fats are, singly or in blends, cocoa butter equivalents (CBEs) and must comply with the following criteria:

- They are non-lauric vegetable fats, which are rich in symmetrical monounsaturated triglycerides of the type Palmitic-Oleic-Palmitic, Palmitic-Oleic-Stearic and Stearic-Oleic-Stearic acids.

- They are miscible in any proportion with cocoa butter, and are compatible with its physical properties (melting point and crystallisation temperature, melting rate, need for tempering phase).
- They are obtained only by the processes of refining and/or fractionation, which excludes enzymatic modification of the triglyceride structure.

In conformity with the above criteria, the following vegetable fats, obtained from the plants listed below, may be used:

- Illipe, Borneo tallow or Tengkawang (*Shorea* spp.);
- Palm-oil (*Elaeis guineensis*, *Elaeis olifera*);
- Sal (*Shorea robusta*);
- Shea (*Butyrospermum parkii*);
- Kokum gurgi (*Garcinia indica*);
- Mango kernel (*Mangifera indica*).

European countries may allow the use of coconut oil in chocolate used for the manufacture of ice cream and similar frozen products.

28.3.5 Industry initiatives

Swiss-based manufacturers of chocolate have played a major role in development of the art and technology of chocolate. To safeguard the reputation for quality Swiss chocolate, CHOCOSUISSE – Union de Fabricants Suisses de Chocolat (Association of Swiss Chocolate Manufacturers) – took steps in the 1970s to protect Swiss chocolatiers by trademarking, in the European Union, the United States and Canada, the terms “Swiss” and “Switzerland”, together with relevant symbols such as the Swiss flag (CHOCOSUISSE, 2001).

CHOPRABISCO – l’Association Royale Belge des Industries du Chocolat, de la Praline, du Biscuit et de la Confiserie (Royal Belgian Association of Chocolate, Pralines, Biscuit and Confectionery Industries) – introduced the “Belgian Chocolate Code”. Belgian chocolate must meet specific ingredient requirements, and refining and moulding must occur in Belgium. Chocolate that is not made entirely in Belgium should be labeled “Made with Belgian chocolate”.

28.3.6 Chocolate cigarettes

Council Recommendation 2003/54/EC on the prevention of smoking and on initiatives to improve tobacco control calls on Member States to prohibit “the sale of sweets and toys intended for children and manufactured with the clear intention that the product and/or packaging would resemble in appearance a type of tobacco product”.

28.4 United States of America

Title 21 of the Code of Federal Regulations Part 163 lays down the following standards for cocoa and chocolate products:

28.4.1 Breakfast cocoa

The food prepared by pulverising the material remaining after part of the cocoa fat has been removed from ground cocoa nibs. Breakfast cocoa contains not less than 22% by weight of cocoa fat.

28.4.2 Cocoa/medium fat cocoa

The food prepared by pulverizing the material remaining after part of the cocoa fat has been removed from ground cocoa nibs. The cocoa fat content is less than 22%, but not less than 10% by weight.

28.4.3 Low fat cocoa

The food prepared by pulverising the material remaining after part of the cocoa fat has been removed from ground cocoa nibs. The cocoa fat content is less than 10% by weight.

28.4.4 Chocolate liquor

The solid or semi-plastic food prepared by finely grinding cocoa nibs. The fat content of the food may be adjusted by adding one or more of cocoa fat and cocoas to the cocoa nibs. Chocolate liquor contains not less than 50% nor more than 60% by weight of cocoa fat.

28.4.5 Sweet chocolate

The solid or semi-plastic food prepared by intimately mixing and grinding chocolate liquor with one or more optional nutritive carbohydrate sweeteners, and may contain specified optional ingredients. Sweet chocolate contains not less than 15% by weight of chocolate liquor, as calculated by subtracting from the weight of the chocolate liquor used the weight of the cocoa fat therein and the weights therein of any alkali, neutralising, and seasoning ingredients, and multiplying the remainder by 2.2, dividing the result by the weight of the finished sweet chocolate, and multiplying the quotient by 100. The finished sweet chocolate contains less than 12% by weight of total milk solids based on specified dairy ingredients, exclusive of any added sweetener or other dairy derived ingredient that is added beyond that amount that is normally present in the specified dairy ingredient. Semisweet chocolate or bittersweet chocolate is sweet chocolate that contains not less than 35% by weight of chocolate liquor.

The use of flavourings that imitate the flavour of chocolate, milk or butter is prohibited.

28.4.6 Milk chocolate

The solid or semi-plastic food prepared by intimately mixing and grinding chocolate liquor with one or more optional dairy ingredients and one or more optional nutritive carbohydrate sweeteners and may contain one or more specified other optional ingredients. Milk chocolate contains not less than 10% by weight of chocolate liquor, as calculated by subtracting from the weight of the chocolate liquor used the weight of cocoa fat therein and the weights of alkali, neutralizing and seasoning ingredients, multiplying the remainder by 2.2, dividing the result by the weight of the finished milk chocolate and multiplying the quotient by 100. The finished milk chocolate contains not less than 3.39% by weight of milk fat and not less than 12% by weight of total milk solids based on the specified dairy ingredients, exclusive of any added sweetener or other dairy-derived ingredient that is added beyond that amount that is normally present in the specified dairy ingredient.

Optional dairy ingredients:

- Cream, milk fat, butter;
- Milk, concentrated milk, evaporated milk, sweetened condensed milk, dried milk;
- Skim milk, concentrated skim milk, evaporated skim milk, sweetened condensed skim milk, non-fat dry milk.

The use of flavourings that imitate the flavour of chocolate, milk or butter is prohibited.

28.4.7 Buttermilk chocolate

The food that conforms to the standard for milk chocolate except that the optional dairy ingredients are limited to sweet cream buttermilk, concentrated sweet cream buttermilk, dried sweet cream buttermilk and any combination of these.

28.4.8 Skim milk chocolate

The food that conforms to the standard for milk chocolate, except that the optional dairy ingredients are limited to skim milk, evaporated skim milk, concentrated skim milk, sweetened condensed skim milk, non-fat dry milk and any combination of these; and the finished skim milk chocolate contains less than 3.39% by weight of milk fat and not less than 12% by weight of skim milk solids based on the specified dairy ingredients, exclusive of any added sweetener or other dairy-derived ingredient that is added beyond that amount that is normally present in the specified dairy ingredient.

28.4.9 White chocolate

The solid or semi-plastic food prepared by intimately mixing and grinding cocoa fat with one or more optional dairy ingredients and one or more optional nutritive carbohydrate sweeteners. White chocolate contains not less than 20% by weight of cocoa fat as calculated by subtracting from the weight of the total fat the weight of the milk fat, dividing the result by the weight of the finished white chocolate and multiplying the quotient by 100. The finished white chocolate contains not less than 3.5% by weight of milk fat and not less than 14% by weight of total milk solids, calculated by using only specified dairy ingredients and not more than 55% by weight nutritive carbohydrate sweetener.

It must be free from colours. The use of flavourings that imitate the flavour of chocolate, milk or butter is prohibited.

28.4.10 Use of vegetable fats other than cocoa butter

Standards are prescribed for "sweet cocoa and vegetable fat coating", "sweet chocolate and vegetable fat coating" and "milk chocolate and vegetable fat coating". In October 2006, the United States Food and Drug Administration was petitioned by Industry (including the Chocolate Manufacturers Association) to allow the use of vegetable fats other than cocoa butter in chocolate products. The petition was unsuccessful.

28.5 Canada

The Food and Drug Regulations, Part B, Division 4, concern cocoa and chocolate products and lay down the following definitions.

28.5.1 Cocoa powder

The product that is obtained by pulverising the remaining material from partially defatted cocoa liquor by mechanical means and contains not less than 10% cocoa butter.

28.5.2 Low fat cocoa powder

The product that is obtained by pulverising the remaining material from partially defatted cocoa liquor by mechanical means and contains less than 10% cocoa butter.

28.5.3 Cocoa liquor, unsweetened chocolate, bitter chocolate

The product obtained from the mechanical disintegration of the cocoa nib with or without removal or addition of any of its constituents and contains not less than 50% cocoa butter.

28.5.4 Chocolate, bittersweet chocolate, semi-sweet chocolate, dark chocolate

One or more of cocoa liquor, cocoa butter and cocoa powder combined with a sweetening ingredient. The product contains not less than 35% total cocoa solids, of which not less than 18% is cocoa butter and not less than 14% is fat-free cocoa solids.

28.5.5 Sweet chocolate

One or more of cocoa liquor, cocoa butter and cocoa powder combined with a sweetening ingredient. The product contains not less than 30% total cocoa solids, of which 18% is cocoa butter and 12% is fat-free cocoa solids.

28.5.6 Milk chocolate

One or more of cocoa liquor, cocoa butter and cocoa powder combined with a sweetening ingredient. The product contains not less than:

- 25% total cocoa solids, of which not less than 15% is cocoa butter and not less than 2.5% is fat-free cocoa solids;
- 12% total milk solids from milk ingredients;
- 3.39% milk fat.

It may contain less than 5% whey or whey products.

28.5.7 White chocolate

Contains the following combined together:

- Not less than 20% cocoa butter;
- Not less than 14% total milk solids from milk ingredients;
- Not less than 3.5% milk fat.

It may contain less than 5% whey or whey products.

28.6 BRIC markets

The emerging economies of Brazil, Russia, India and China represent opportunity for chocolate manufacturers, although Russia is already a significant consumer. Table 28.2 summarises the requirements in these countries.

28.7 Use of additives

A restricted number of additives may be used in chocolate products. It is always necessary to check the legislation in the markets where the products will be sold.

In respect of emulsifiers, the following are commonly employed:

- Sunflower or soya lecithin (321), in accordance with good manufacturing practice;
- Ammonium phosphatides (442), to a maximum of 10 g/kg;
- Polyglycerol polyricinoleate (476), to a maximum of 5 g/kg.

In the United States, the total amount of emulsifiers must not exceed 1% in sweet chocolate and milk chocolate and 1.5% in white chocolate. In Canada, the total amount of emulsifiers must not exceed 1.5% in all types of chocolate.

The use of sweeteners is often questioned given that standards often define chocolate products as mixtures of cocoa products and sugars or nutritive carbohydrate sweeteners. In Europe, the Standing Committee on the Food Chain and Animal Health has confirmed that the use of sweeteners such as polyols is possible in no-added-sugar products, provided these are labelled "with sweetener". In the United States, products containing sweeteners could not be called by the standardised name.

Table 28.2 Legislation in BRIC markets.

		Cocoa products			Milk products			Total fat (from cocoa fat and milk fat) (%)	Vegetable fats other than cocoa butter
		Cocoa solids (%)	Cocoa butter (%)	Fat-free cocoa solids (%)	Milk solids (%)	Milk fat (%)	Fat-free milk solids (%)		
Milk chocolate	Brazil	≥25							No restriction
	Russia	≥25		≥2.5	≥12	≥2.5		≥25	Not authorised
	India			≥2.5		≥2	≥10.5	≥25	Not authorised
	China	≥25		≥2.5	≥12	≥2.5			≤5%
White chocolate	Brazil		≥20						No restriction
	Russia		≥20		≥14	≥3.5			Not authorised
	India					≥2	≥10.5	≥25	Not authorised
	China		≥20						≤5%
Other chocolates	Brazil	≥25							No restriction
	Russia	≥40	≥20						Not authorised
	"Dark chocolate"	≥55	≥33						
	"Bitter chocolate"		50–58						
	"Unsweetened chocolate"								
	India			≥12				≥25	Not authorised
	"Plain chocolate"								
	China	≥30	≥18	≥12					≤5%
	"Black chocolate"								

28.8 Labelling

Labelling must be easy to understand, the printing must be clearly legible and the printing inks must be indelible. This is particularly important with regard to dates and/or batch codes which are generally printed onto each package on the production line. The information must be easily visible. This means that a consumer should not have to hunt for information.

With due consideration to the labelling provisions in major chocolate-consuming markets, and as a general rule, the information below must appear on chocolate products:

28.8.1 Legal name

Names are normally prescribed for chocolate products. The name used must give a clear description of what the product is, and to allow it to be distinguished from other products. Brand names, trademarks and fancy names cannot be substituted for the legal name as they do not inform the purchaser as to the true nature of the product.

28.8.2 List of ingredients

The list of ingredients must be headed or preceded by the heading "Ingredients".

Ingredients must be listed in descending order of weight, this being determined at the time of use. This is known as the point where the ingredients are put into the "mixing bowl". For the purposes of ingredient list calculation, the weight of dehydrated or concentrated ingredients may normally, if desired, be determined by rehydration factors.

Allergens must always be labelled. For details, refer to Chapter 25.

The declaration of each additive relates to the function that it is fulfilling in the finished product. Additives used in food are normally declared by their category name followed either by the specific name or INS/E-number.

28.8.3 The quantity of certain ingredients ("quantitative ingredients declaration")

An indication of the quantity of certain ingredients is required where these are:

- Mentioned in the name of the food;
- Emphasised;
- Essential to characterise the food.

For example, the amount of almonds in a "white chocolate with almonds". Information normally appears either beside the name of the food or in the ingredients list as a percentage.

Note that in Europe, the cocoa solids content of chocolate products must be provided in the form "Cocoa solids: … % minimum". This requirement does not apply to filled chocolates and pralines.

28.8.4 Date of minimum durability and special storage conditions

An indication of shelf life, typically in the format "Best Before", followed by the date, together with any specific storage conditions necessary to achieve that shelf life, such as "Store in a cool and dry place".

28.8.5 Batch code

Products must generally carry a batch code (lot mark) to aid traceability in the event of a problem. Date codes showing at least a day and month (in that order) may sometimes be used instead of batch codes. However, much traceability will be lost if the date code is only changed monthly rather than daily.

28.8.6 Business name and address

The name and address of the manufacturer, packer or seller.

28.8.7 Place of origin

The place of origin must always be given if its omission could mislead the purchaser about the true origin of the product.

28.8.8 Net quantity or weight

With the exception of the United States, the quantity is provided in metric units. A minimum height may be prescribed for the quantity declaration. In Europe, the "e-mark" may be applied to indicate that products are packed in accordance with the "average system".

28.8.9 Nutrition information

Nutrition labelling was traditionally applied only where a nutrition or health claim was made. Governments are increasing favouring mandatory nutrition labelling as one of the tools to help halt rising levels of obesity. Labelling includes the typical amounts of energy expressed in kJ and/or kcal, protein, carbohydrate, sugars, fat, saturated fat, sodium or salt, and dietary fibre – per 100 g and/or per serving. Front of pack labelling, which includes the percentage of the Guideline Daily Amount (Daily Value) may additionally be applied to help consumers make informed choices. Consumer and health promotion groups consider that such labelling schemes should also be colour-coded.

Conclusions

Legislation is complex and changes happen slowly only after protracted negotiations. Standards can be a barrier to innovation and many confectionery products are therefore made with substitute products – compounds – which are not subject to compositional standards (Chapter 19). Future legislative developments will be driven by the need to reduce intakes of sugar and saturated fat, such as the regulation of sweeteners or novel ingredients with no history of safe use.

Further reading

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CHAPTER 29

Intellectual property: Protecting products and processes

Patrick J. Couzens

29.1 Introduction

The history of chocolate making is full of creativity and invention, from the very first chocolate tablet to the wide variety of chocolate products, brands and processes we have today. These creations of the human mind can be owned, and the owner may be able to stop other people using them. This is called *intellectual property* and the associated legal rights are *intellectual property rights*. Intellectual property is usually divided into two categories: (i) industrial property, which includes patents, trade marks and industrial designs and (ii) copyright, which includes literary and artistic works. Intellectual property is an asset and can be bought, sold or licensed just like any other property. The main types of intellectual property are listed in Table 29.1.

Although the concepts of intellectual property are fairly straightforward, the details can be complex. This chapter aims to provide an overview of the subject for chocolate manufacturers, but it is important to seek competent professional legal advice to answer specific questions. Infringing other people's rights or missing an opportunity to protect your idea could weaken or even destroy your business.

The laws governing intellectual property vary around the world, but for members of the World Trade Organisation (WTO; around 160 countries) the minimum level of protection is defined by the TRIPS agreement (Agreement on Trade-related Aspects of Intellectual Property Rights; WTO, 1994).

29.2 Patents

29.2.1 What is a patent?

A patent is an exclusive right, granted by a State, to an invention. A patent allows the owner of the patent to stop others from making, using or selling the invention without their permission. Patents only last for a limited period,

Beckett's Industrial Chocolate Manufacture and Use, Fifth Edition. Edited by Stephen T. Beckett,
Mark S. Fowler and Gregory R. Ziegler.

Table 29.1 Summary of the main types of intellectual property.

Type	Description	Normal duration	Advantages	Disadvantages
Patents	Patents are used to protect solutions to technical problems – known as inventions. A patent is a monopoly granted by a government in exchange for sharing knowledge. They are known as "Utility Patents" in the USA	20 years from filing	Clearly defined protection for technical developments Most useful for "visible" inventions such as new ingredients, products or packs	Releases know-how Less useful for "hidden" inventions such as new processing methods
Utility models	Similar to a patent but with less stringent requirements. Primarily used for mechanical innovations. Only available in certain countries, for example Austria, Germany, France, Spain, Russia, China and Japan. A similar right in Australia is called an "Innovation Patent"	Usually between 7 and 10 years, but varies from country to country	Cheaper and quicker to obtain than a patent Particularly suited for "minor" improvements to existing products	No detailed examination at filing, so there is a risk that the Utility Model will turn out to be invalid when you go to court to try and enforce it
Trade secrets	Trade secrets are information that companies keep secret to give them an advantage over their competitors. A well-known example is the recipe for COCA-COLA®	Until it is no longer a secret	No fees to pay Useful for protecting production "know-how"	Unlikely to work for long periods Competitors may have the same idea and patent it
Trade marks	A trade mark is a badge of origin showing who makes a product. Words, logos, signs, shapes, colours or pieces of music can be registered as trade marks	Potentially lasts for ever if it continues to be used	Long duration of protection	With only a trade mark to protect your product it may be copied by a competitor as long as they do not use your trade mark
Industrial designs	New designs with "individual character" can be registered to protect the way something looks. For example a new shape for a chocolate assortment box. Called "Design Patents" in the USA	Up to 25 years, but varies from country to country	The product itself need not be new as long as its visual appearance is new	Only protects the look of something, not its technical function
Copyright	Copyright protects original literary, dramatic, musical and artistic works. Equipment instruction manuals and engineering drawings can all be protected by copyright	The rules are complex but copyright normally extends for a number of years after the author's death	Automatic protection, no registration required	Does not protect an idea, only its "fixed form", e.g. how it is written down

typically 20 years if the owner continues to pay the required fees. The idea behind a patent system is that, without patents, inventors would keep their inventions secret for fear that their competitors would copy them. This secrecy would prevent others from building on the earlier knowledge and so the scientific knowledge and technology of society would not advance. In exchange for granting a patent, the State requires that the invention be fully disclosed so that other people can learn from the invention and, once the patent has expired, can use the invention. The extent to which the present international patent system balances the needs of business with those of society is a contentious topic, which is outside the scope of this chapter.

In order to be patentable an invention must be:

Novel. Novel is another word for new. To be considered novel the invention must not be publicly available anywhere in the world, in any form, before the patent application is filed. A common way in which an invention becomes public is if it is described in a journal or at a conference. However, showing members of the public an inventive product with no restrictions will usually also disclose it. This is why it is often advisable to file a patent before performing market research on an inventive chocolate product. Once the invention is disclosed it is no longer novel and so cannot then be patented. If someone could have analysed your product and found what was new about it, then the invention is considered disclosed even if no-one actually analysed it.

Some countries, such as the United States, Canada, Australia and Japan, allow a grace period between an inventor disclosing their invention and filing the patent. In these countries, even if the inventor discloses their invention, it will still be considered new if the inventor files a patent application within a certain time. The conditions vary; some disclosures can only benefit from a grace period in the country where the disclosure happened. The grace period is usually six months or one year. However, many chocolate businesses are global, and so to obtain patents in a wide range of countries it is important to keep your invention secret before filing the patent. For example, there is no grace period for European Patents (apart from in a few very limited situations).

In general, if two people invent the same thing and both apply for patents, then it is the person who filed their patent on the earlier date who will be granted a patent. It is therefore important not to delay unnecessarily in getting your invention filed at the patent office. In the United States there used to be a *first to invent* system rather than this *first to file* system, but that changed in 2013.

Inventive. Patents are granted for solutions to technical problems. The solution to a problem is considered inventive if, when compared with what is already known, it would not be obvious to someone skilled in the relevant technical area. Patent offices have developed different standard approaches to test for inventiveness, but it is not an entirely objective decision. If you develop something new, and it is not simply a trivial modification, then it might be worth discussing with your patent advisor whether to file a patent application.

Capable of industrial application. "Industry" is used in a very wide sense here and it is unlikely that inventions related to chocolate manufacture and use (on any scale) would not be considered industrially applicable.

Not excluded. There are a number of things which are not patentable in most countries. For example:

- Diagnostic, therapeutic and surgical methods for the treatment of humans or animals;
- Plants and animals other than micro-organisms, and essentially biological processes for the production of plants or animals (e.g. breeding plants through crossing and selecting in the traditional manner).

Although plant varieties cannot be patented, there is another form of intellectual property to protect new varieties of plants called Plant Breeders' Rights. These rights could be used, for example, to protect a particular variety of disease-resistant cocoa plant obtained by crossing and selecting. However, the detailed situation is complex and varies around the world so it is important to seek professional advice.

Patents are generally intended to cover products or processes with new technical or functional aspects; patents are therefore concerned with, for example, how things work, what they do, how they do it, what they are made of or how they are made. There is a misconception that patents are only for "groundbreaking" inventions. In fact, the vast majority of patents are for incremental improvements in known technology.

29.2.2 International protection

Patents are territorial rights, so, for example, a patent granted just in the United Kingdom (UK) would not stop someone using the invention in Japan (although it would stop someone importing the product of the invention into the UK). Even if your business operates only in one country, you should think carefully about whether you might want to file patents abroad. Your business might grow in the future, or you might want to make money by licensing your patent to a company in another country.

If you wanted a patent in many foreign countries it would be difficult to make a separate application in each country. Fortunately there is a system to help you. Around 150 countries have signed up to a treaty called the Patent Co-operation Treaty (PCT). As long as you are a resident or a national of one of the PCT countries you can file a single international patent application and designate any of the member countries. This is equivalent to filing the patent in each of the countries individually, but much more convenient. There is no such thing as an international patent however. Each designated country will have to examine the patent individually and decide whether or not to grant it.

It is generally cheaper to use the PCT route if you know you will want protection in more than five countries.

When one patent application results in several patents in many different countries, all of the patents and applications associated with the original patent application are called the *patent family*. However, exactly what is covered by the final granted patent in each country may vary, for example due to changes made during examination at the different offices.

There are a few regional patent offices which can grant patents for member states of that region. Examples are the African Regional Intellectual Property Organisation (ARIPO) and the European Patent Office (EPO). The EPO is able to search, examine and grant patents in a single procedure for the 38 states which have signed the European Patent Convention. These include some non-European Union states such as Switzerland. There may soon be a new type of patent in Europe called a Unitary Patent which will be obtained via the EPO for most European Union countries. The idea is that once your European patent application is granted you will be able to choose whether the patent becomes a series of individual national patents in the EPO member countries you select; a Unitary Patent where a single patent covers most European Union (EU) countries; or a Unitary Patent with individual patents for any European Patent Convention countries which do not participate in the new system. It may be cheaper and simpler to choose to have one Unitary Patent rather than many national patents. However, at time of writing, the 2016 referendum in the UK to leave the EU has made the future of the Unitary Patent system uncertain.

Some countries have laws which prevent you from filing the first application for a patent family abroad. The restrictions aim to protect national security, but even with a patent relating to chocolate it can be important to file in the correct country (or get the appropriate permission). It can be complicated knowing what is considered “abroad”; as the chocolate industry becomes more international, even medium-sized manufacturers may be based in one country, perform research in a second country, and have inventors who are resident in a third country. If in doubt, seek professional advice.

29.2.3 The life of a patent family

As was described earlier, in order to be granted a patent your invention must be novel. This makes the date of filing important as, when determining novelty, the invention in your patent will be judged against anything published before that date. Fortunately, after you file a patent application in one country you can file applications for the same invention in other countries up to twelve months later and they will be treated as if they were all filed on the original date. An international treaty dating from 1883 called the Paris Convention governs this. The date of filing the first application is called the “priority date”.

There are many different permutations in the way you can file the individual patents in a patent family. A typical sequence for a UK company is shown in

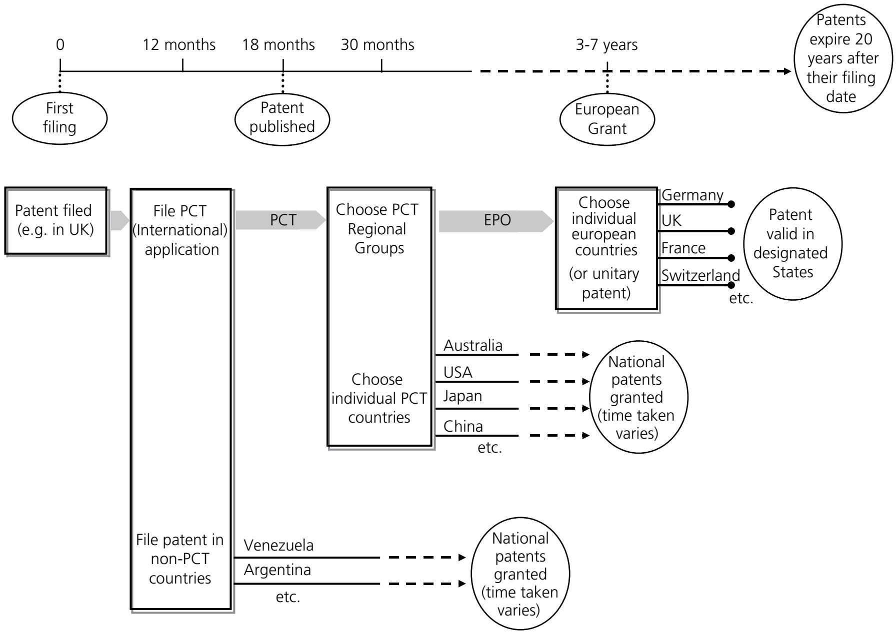


Figure 29.1 Typical timetable for patenting an invention in a number of countries using the PCT system.

Figure 29.1 but a legal advisor such as a patent attorney (see Section 29.10) will be able to advise you on the best approach for your particular situation and the exact timings. For example you might suspect that competitors are likely to copy your invention in a certain country and so you want to be in a position to take action against them as soon as possible (see Section 29.9) by establishing rights in that country.

Obtaining the grant of a patent takes time. Patent offices around the world are under pressure to examine patents more quickly, but it is likely to take several years for a patent to be granted. The patent office examiners enter into a dialogue about whether the invention is patentable, and changes may be required before they agree to grant the patent (or decide to refuse it). You will need to employ local representatives (patent agents) to deal with the different patent offices. Information on the admitted representatives may be obtained directly from the national IP offices. The patent attorney you employ to draft and file your application will usually be able to arrange and manage agents to act on your behalf in the different countries.

Patent applications are sometimes divided, the original application becoming two different applications covering different inventions. The patent office may require this, for example if they consider that your application contains multiple inventions which are not technically related, or the applicant may do this through choice. There are a number of reasons why an applicant might want to divide their application, but one is to obtain a rapid grant of those claims that the patent office readily accepts, and so have a patent that can be enforced. The applicant can then take the time to pursue the other claims in the divisional application.

In some countries people have the opportunity to submit observations on the patentability of your invention during the examination phase, and they may be able to present arguments about why your patent should not have been granted. For example, in Europe, an opposition can be filed against a patent, but this must be done within nine months of the publication of the grant. If your patent is opposed it may take several years before the opposition procedure is complete. The United States has a similar system called "Post Grant Review", although the fees for this are much higher than for an opposition at the European Patent Office.

29.2.4 The cost of a patent

How much a patent family will cost depends on a number of factors, the most important being how many countries you file the patent in and for how many years you maintain the patent. The costs can be split into the official fees paid to patent offices, the fees paid to patent professionals and other fees such as translations. The official fees continue through the life of the patent; starting with filing and search fees, then examination fees, grant fees, fees for publication and renewal fees. If you follow a sequence such as shown in Figure 29.1 and file at just one patent office initially, the majority of the cost in the first year will be the professional fee paid to a patent attorney for writing the patent. It is not strictly necessary to employ a patent attorney to write the patent, you could write the patent yourself, but a mistake in the patent text could render your patent useless, so it is generally money well spent. The patent attorney's fees will depend on the length and complexity of the patent so it is difficult to generalise. However, the preparation and initial filing of a straightforward patent application might cost € 4000–8000. Filing the patent on an international basis 12 months after the first filing may cost a further € 4000–6000 depending on how much additional material needs to be included in the application.

By filing a PCT international application you can delay the moment when you need to choose the full list of countries for your patent family until about two and a half years after your first filing. This is a significant moment in terms of setting current and future levels of expenditure. The costs mount up significantly thereafter, depending on the number of countries in which you wish to protect the patent. Costs can easily reach € 80 000 over the first five years. Some countries will require the text to be translated which adds cost. Once a patent is granted you need to pay renewal fees in each country to maintain the patent. These fees generally increase with the age of the patent, the logic being that if you are continuing to maintain a patent it must be generating commercial revenue and so the various governments want their share. If you are a private inventor, or work for a very small "start-up" company, you will probably need to obtain external funding within the first few years to finance your patent. Be sure to at least have a Confidential Disclosure Agreement with the other party (see Section 29.6), but preferably file your patent before approaching potential industrial partners with your invention.

29.2.5 Where to find patents

Patents are an important source of technical information along with reference books and journals. In recent years it has become much easier to access patents from the major countries of the world as they are available on the internet free of charge. The European Patent Office has a searchable database called *esp@cenet*® which gives free access to around 80 million patent documents from around the world. The *Espacenet*® database has patent family information, telling you if similar patents have been claimed in other countries, and legal status information about published patents from over 72 countries and regions of the world. In most cases it is possible to view the actual patent text, or at least text from an equivalent patent from the same family.

There are also commercial databases and search engines for which you have to pay a fee. These can provide extra information and more advanced search and analysis tools. Examples include *Derwent World Patents Index*®, *Thomson Innovation*®, *Innography*®, *PatBase*® and *ORBIT* but a web search will find other competing options. There are also companies and organisations you can pay to perform searches for you, an example being the Swiss Federal Institute of Intellectual Property. A professional search is certainly recommended if you are making a critical decision based on the search. If you are concerned about whether your new product launch might infringe someone else's patent then you should consult a patent professional such as a patent attorney for advice.

29.2.6 How to read a patent

When you first look at a patent it can seem unintelligible, almost as if it were deliberately written to be unreasonably repetitive and awkward. However, once you understand how a patent is structured and what information is found in the different sections it all becomes clearer. The language used can also be confusing, with some words in patents having a very particular meaning, which can be different from the way the word is used in everyday conversation. I will attempt to give some pointers to help you if you are new to reading patents.

The way a patent is structured is broadly similar between different countries, although the order of the different sections and the terms used may vary.

When you first see a patent, do not try and read all of it from beginning to end. Start by looking at the front page, then read the claims and look at the drawings (if there are any). That will give you an overview of what the patent is about before you start to read it in more detail. You may already be able to decide that it is not relevant.

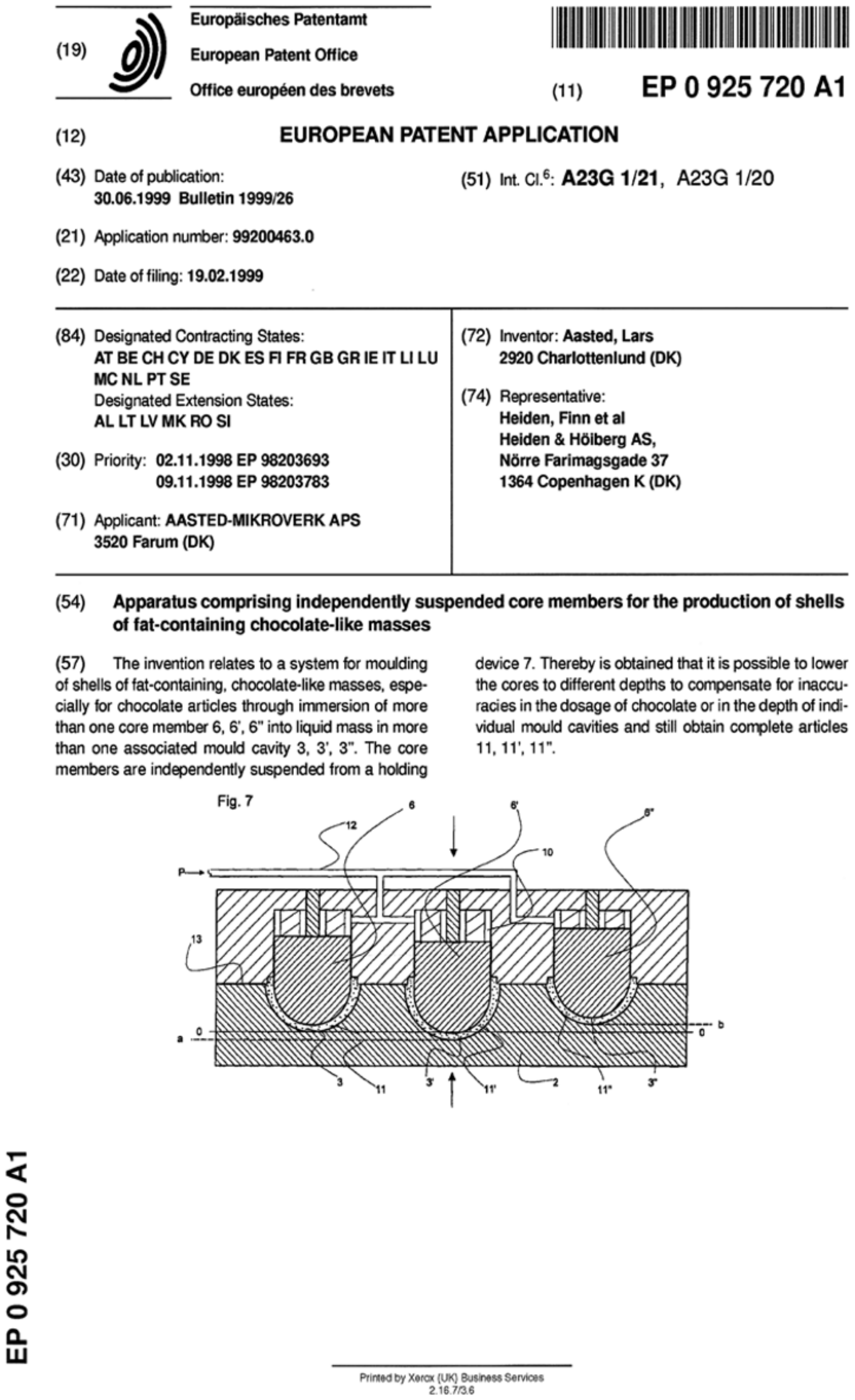
Think about why you are reading the patent before you start. If you want to know if the patent could stop you from doing something, then concentrate on the claims, comparing what you plan to do with what it says in the claims. Use the rest of the patent to help you understand what the claims mean. You will also need to establish whether the patent has been granted in the relevant country and is still in force. Many of the commercial patent search programs will summarise this information for you for the whole patent family. However, apparently "dead" patents might still be able to be restored, or there may be other relevant rights; if it is important, seek professional advice.

If you have recently made an invention and are reading a published patent to check whether your invention is novel, then the whole patent is relevant. It does not matter if the patent has been granted or has expired. If your invention has already been described in a patent (or any other publication) then it is not novel.

Front Page. A reproduction of a European Patent front page is shown in Figure 29.2, downloaded from the *Espacenet®* service of the European Patent Office. Each item of information is marked by a number in brackets. These numbers are called "INID codes" (internationally agreed numbers for the identification of bibliographic data) and because these numbers are consistent in every country, they allow you to identify important information from a patent even if you do not understand the language it is printed in. For example the title of the invention is marked (54).

The patent number (11) is at the top right of the page. The first two letters, "EP", mean that it is a European Patent, this is followed by a number to identify the patent and then there is a code such as A1 or B1. The patent in Figure 29.2 has A1 after the number. The "A" means that this version of the European Patent is an application. You might want to look on a database such as *Espacenet®* to see if there is the granted version (which in fact there is for the patent in Figure 29.2) and this will have a "B" after the number. The granted version may be quite different from the version that was originally filed. Since 2001 the United States Patent Office has also adopted "B" to signify a granted patent, but different countries use different codes in their patent numbers and these have changed over the years, so it is worth checking the exact meaning of the codes on the appropriate patent office website.

The filing date (22) is towards the top of the page on the left hand side. This date is important because generally patents are only valid for 20 years after the filing date. (There are some exceptions to this, particularly for pharmaceutical patents, so if it is critical seek advice.) For this patent there is another important date, the "priority date" (30). This is printed below the filing date and for the patent in Figure 29.2 there are two priority dates. Most likely these correspond to different material within the patent. The priority date is the date of an earlier patent filing (or in this case, two filings) from which this patent "claims priority"



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 925 720 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
30.06.1999 Bulletin 1999/26

(51) Int. Cl.^{6}: **A23G 1/21**, A23G 1/20

(21) Application number: **99200463.0**

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(30) Priority: **02.11.1998 EP 98203693**
09.11.1998 EP 98203783

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(54) **Apparatus comprising independently suspended core members for the production of shells of fat-containing chocolate-like masses**

(57) The invention relates to a system for moulding of shells of fat-containing, chocolate-like masses, especially for chocolate articles through immersion of more than one core member 6, 6', 6" into liquid mass in more than one associated mould cavity 3, 3', 3". The core members are independently suspended from a holding device 7. Thereby is obtained that it is possible to lower the cores to different depths to compensate for inaccuracies in the dosage of chocolate or in the depth of individual mould cavities and still obtain complete articles 11, 11', 11".

Fig. 7

EP 0 925 720 A1

Printed by Xerox (UK) Business Services
2.16.7/3.6

Figure 29.2 Example of a front page from a European patent application (downloaded from the *Espacenet* service of the European Patent Office).

(see Section 29.2.3). When the patent office examines the patent to see if the invention is new, they will normally only consider publications earlier than the priority date for that material.

The names of the inventors (72) and the name of the applicant (71) are also printed on the front page. Generally the applicant is a company, and if the patent concerns chocolate you may well recognise them as a competitor or supplier. The applicant listed on the patent may not own the patent now as they might have sold it to another company. On United States patents the name of the company is not always given, but looking at other patents in the patent family may reveal another patent where the company is named.

The patent's title may help you understand what the patent is about, but they can be quite general such as "Confectionery Item". There may also be an abstract and a reproduction of one of the drawings from the patent on the front page.

Claims. The claims are very important as they define exactly what the patent protects. The claims in US and European patents are towards the end of the patent. They take the form of a numbered list of paragraphs headed by text such as "Claims" or "What is claimed is". The rules require that each claim is a single sentence, so if the claims are long they can be difficult to read. You may find it helpful to mentally insert the words "What is claimed is" before each claim when reading them.

When reading claims it can also be helpful to break them into sections. Sometimes the patent writer has done this for you, as in the granted version of the patent whose front page is shown in Figure 29.2. The first two claims of that patent EP 0 925 720 B1 are reproduced below:

1. *A system for the production of shells of fat-containing, chocolate-like masses, in particular for chocolate articles,*
   comprising more than one mould cavity (3, 3′, 3″) to receive the mass (5, 5′, 5″),
   more than one core member (6, 6′, 6″) to be immersed into the mass,
   characterized in that *the core members are independently suspended from a holding device (7).*
2. *A system according to claim 1, comprising means adapted to guide a vertical travel of the independently suspended core members (6, 6′, 6″) in relation to the holding device (7).*

(The numbers in brackets in the claims refer to numbered items in the drawings, found elsewhere in the patent.)

Make a note of any key words to check exactly what they mean in this patent. Do not assume you know what they mean as they may have been defined in a special way earlier in the patent. For example, the term *chocolate* may not be restricted to what can legally be labelled as chocolate. For these claims you might also want to check the meaning of *chocolate-like mass* and *independently suspended.*

When used in patent claims, the word "comprising" has a very specific meaning. Under most patent laws it means that the claim covers all the elements listed, but does not exclude additional unnamed elements. In the above example, the claim covers a system with *more than one mould cavity* and with *more than one core member*, but the system could also have additional components.

The contrasting term would be "consisting of". This gives the claim more limited scope and if it had been used in the above example in place of "comprising" it would mean that the claimed system could have *more than one mould cavity* and *more than one core member*, but nothing else.

Another type of phrase with special significance is used to separate two parts of a claim. Examples of such separating phrases include "wherein" or, in the example above, "characterised in that". In Europe, the words before "characterised in that" describe what was already known and the words after "characterised in that" describe the improvement that the invention brings. In this case the improvement is that *the core members are independently suspended from a holding device*. This two-part structure for claims is common in European patents.

The second claim in the example refers back to the first claim using the words "according to claim 1". This is known as a *dependent claim*, in contrast to claim 1 which is an *independent claim*. Dependent claims are always narrower in scope than the independent claim they are based on. They provide a "fall-back" position to a more specific claim in case the patent examiner does not allow the broader independent claim. Having a narrower claim may also be useful when suing someone for infringement in court; the more closely your claim relates to what the other person is doing, the harder it is for them to argue that their actions fall outside your claim.

The differences between the scope of two claims in the same application may be quite subtle, but there will be differences. If you initially think two claims cover exactly the same things just in different words then this should act as a warning that you have not understood them properly. Claim interpretation is complex, and may take years of study and experience to master. Legal decisions over the years have established specific meanings for some words and structures in claims which are not at all obvious. As a non-specialist reading a patent, your aim should be to get a general understanding of what the patent covers but know when to seek help.

Main text. The main text is split into sections and it is worth flicking through the patent to see where they start and end. Sometimes the different sections are indicated with titles which is helpful to the reader. The first section will describe what was generally known about this subject at the date the patent was written. This can provide a useful review of the technology in the area, but remember that the patent was written to convince the patent office that this specific idea is new and inventive over what has gone before rather than to provide a totally objective review of the wider technology area.

Generally the text will then go on to explain what the problem is that the patent sets out to solve, why this invention is needed and why the previous technology was unsatisfactory. The word "surprisingly" is often used to emphasise the point that the invention is not obvious. There will be a short paragraph summarising the invention, which is often very similar to the first few claims.

The text then describes the invention in more detail. This part of the text may be headed “Description”. Patent writers have two conflicting aims when writing the description. They need to set out in detail the invention for which they claim a patent, but they would prefer not to disclose information which won’t be protected by the patent, that is, which is not covered by the claims.

Patent writers need to explain the invention sufficiently well for a skilled person to be able to reproduce it. As explained earlier, in return for granting a patent, a State expects the technology in the patent to be disclosed to the public. If the patent office decides that the disclosure is insufficient, they won’t grant the patent. In the United States there is also a requirement to disclose the best way you know of carrying out the invention. This is called the “best mode”. Bear in mind that the owner of the patent may have improved the invention since writing the patent and describing the “best mode”.

One of the things that makes patents difficult to read is the inclusion of huge lists describing different options for the invention. For example, after saying that sugar should be used in a recipe, there may be a whole paragraph listing suitable sugars. When first reading the patent it is best to ignore those lists and come back to them when you need specific information. Similarly the patent description will often contain a whole series of seemingly repetitive ranges such as, “the reaction time should be between 1 and 100 minutes, preferably between 20 and 80 minutes, more preferably between 40 and 60 minutes.” These may be repeated in the claims and like nearly everything in a patent they are included for a purpose. One reason for describing many options for the different aspects of the invention is to try and prevent a competitor later filing a patent for an improvement based on selecting a particularly beneficial option you did not describe. Another reason is that during examination the patent office may refuse some of the claims or may require the patentee to limit their claims to a narrower range. By this examination stage the patentee cannot introduce new material to the patent, so there has to be a basis in the description for anything added to the claims, hence the large amount of “back up” material found in some patent descriptions.

The description may also explain the meaning of key words and expressions. For example, if the term “chocolate-like masses” appears in the claims, you might see a phrase such as, “chocolate-like masses are suspensions of non-fat particles, such as sugar, milk powders and cocoa solids in a liquid fat phase”. However, the terms in the claims are supposed to be clear without any further definition. For many countries in the European Patent system it is only the claims which are translated, so it is important that the claims are “self-explanatory”.

Figures. Not all patents have figures or diagrams, but when they do they can be very helpful in understanding how the invention works. The figures have numbers on rather than text labels so you need to read the description to find

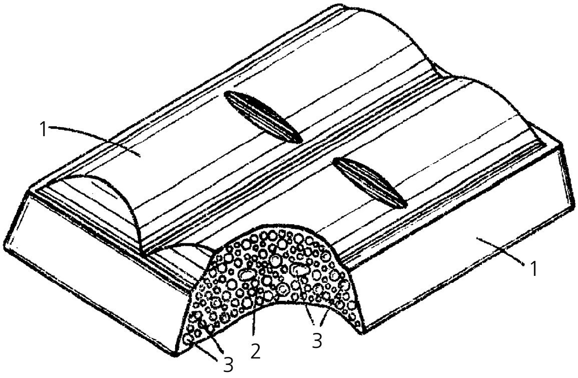

Figure 29.3 Example of a figure taken from GB 459 582, a Rowntree and Co. Ltd patent for aerated chocolate filed in 1935 (downloaded from the *Espacenet*® service of the European Patent Office).

out to what the numbers refer. This is done so that the drawings do not need to be altered when the patent is translated into different languages. These reference numbers will often appear in the claims. You may find it helpful to spend a few minutes adding labels to the figures before trying to understand them. An example of a patent figure is shown in Figure 29.3. To show that patenting inventions concerning chocolate is not new, the example is taken from a patent for aerated chocolate dating from the 1930s.

Examples. Many practical chocolate technologists find the examples the easiest part of the patent to understand. They are often in the form of recipes or process instructions, perhaps with measurements of the end-product to demonstrate the advantages of the invention. Not all patents have examples, but when they do it is important to realise that the patent claims probably cover more than just what is written in the examples or drawn in the figures. All the products described in the examples might be cakes, but that doesn't necessarily mean that the patent is restricted to cakes. To find out what is covered you need to read the claims!

29.3 Trade marks

Trade marks are signs that distinguish the goods or services of one company from another. For many companies a trade mark is a precious asset and can be worth millions of pounds. Probably the most valuable piece of intellectual property in the world today is the trade mark COCA-COLA®. It has been said that if all of the company's buildings, vehicles, factories and equipment were destroyed, Coca-Cola Inc. would emerge from the ruins and rebuild itself provided that the trade mark survived.

A trade mark has to be distinctive, and not likely to be confused with someone else's prior trade mark. A trade mark also has to be capable of being represented graphically, but this is not as limiting as you might first think. Words and logos are the most common trade marks, but colours, three dimensional shapes and even scents and sounds have been registered as trade marks. (The smell of fresh cut grass was registered in Europe as a trade mark for tennis balls, but this is very unusual.) Trade marks capture the essence of brands and the energy, investment and know-how that goes into them. They play a very important role in the marketing of chocolate products and are often fought over. There have been well-publicised disputes in the UK between Cadbury (owned by Mondelēz International), who opposed Nestlé's trade mark application for the three dimensional shape of the KIT KAT® chocolate wafer product, and Nestlé, who opposed Cadbury's application for a particular shade of purple as a trade mark for chocolate.

If you are thinking up a word to use as a trade mark for a new product, the strongest protection is obtained from fanciful, invented words with no previous connection with that type of product. The SNICKERS® confectionery bar is believed to have been named after one of the Mars family's favourite horses. Your trade mark cannot be a sign that merely describes the goods that you offer. For example, the word *Dark* could not be a trade mark for a new dark chocolate product as it is descriptive. In between these two extremes there is a range of possibilities, decreasing in level of protection as the words become less arbitrary and more descriptive. The same applies for other signs such as shapes. The shape of a strawberry is unlikely to be accepted as a trade mark for a strawberry-flavoured product, although it might be an acceptable trade mark for hair care products. Trade marks are registered for a specific class of goods. A three-dimensional trademark is not allowed to be a shape required to obtain a technical result as this would give protection which goes beyond simply indicating the origin of the product. Other intellectual property rights such as patents are available for protecting technical aspects of products.

There are a number of other restrictions on what can be used as a trade mark. Trade marks cannot be misleading, for example *sugar sweet* would not be allowed for a chocolate sweetened with artificial sweetener and they cannot designate the place of origin or mislead the public about the place of origin. There are also marks which are prohibited. You must not register a trade mark which resembles certain official emblems such as the symbol of the Olympic Rings and trade marks should not include profane language or include obscene visuals.

After selecting a trade mark it is important to search to see if anyone else has the same or a similar trade mark. Trade Mark agents can assist with this, but it is possible to search the trade marks register yourself and this may be a good starting point. However, it is advisable to pay for a professional search before filing an application as the fee is not refunded if the application is refused. If the trade mark is to be used internationally, it is also good idea to check that the word does not have unintended or vulgar meanings in other languages.

In a few countries the legal rights to a trade mark are established simply by using it. However, it is generally advisable to register your trade mark as it makes it easier to enforce your rights, and in many countries this is essential. Like patents, trade marks are territorial rights and so need to be established in individual countries. There is no such thing as an international trade mark, but as with patents there is a system to simplify the registration of a trade mark in multiple countries. This is known as the Madrid system. Once you have filed an application to register a trade mark in your own country you apply for an International Trade Mark to be registered with the World International Property Organisation (WIPO). You specify the countries where you want trade mark rights (who must be members of the Madrid Union) and the application is equivalent to applying in each of the countries individually. Within the European Union there are both national trade marks and EU trade marks. EU trade marks cover all the member countries of the EU.

Details of the registration process vary, but generally the trade mark office will check that the trade mark complies with the rules and has the required distinctive character. However, even if a trade mark lacks distinctive character it may still be possible to register it if you can prove that the public exclusively associates the mark with your product. This is called *acquired distinctiveness* (or *secondary meaning* in the USA) and typically applies to well-established products.

29.3.1 Maintaining trade mark rights

Trade mark rights may be lost over time if the trade mark is not used. For example, in the UK a person can apply to have your trade mark removed from the register if it has not been used for a period of five years. The registration of a trade mark must be renewed, for example a EU trade mark must be renewed every 10 years with payment of a fee.

Incorrect use of trade marks can lead to a loss of protection if they start to become a generic description. The word *margarine* was originally a trade name, but now it is a generic term for a wide range of butter substitutes. Trade marks are adjectives which should be followed by a noun – for example a box of FERRERO ROCHER® *chocolates*. Companies should use their trade marks correctly and also insist on other people doing the same. In order to prevent a trade mark becoming generic, the owners of the trade mark often contact publications that appear to be using the trade mark incorrectly and ask them to use the trade mark properly. It can seem petty, but legally it is important for the trade mark holder to show that they are attempting to prevent the mark becoming the generic term for the product.

It is advisable to use trade marks consistently and be cautious of making changes such as altering the typeface; this helps to emphasise that the term is a trade mark and not just another word. One way of identifying that a word is being used in a trademark sense is to use the symbol TM after it. If the trade mark is registered, then you can use RTM or ®. In some countries it is an offence to use the RTM or ® symbol for an unregistered trade mark.

29.3.2 Unfair competition and "passing off"

The laws of unfair competition provide some protection against a competitor confusing the public into thinking that their activities are associated with your business, even without a registered trade mark or any other IP right. However, this area of law is complicated and there are major differences between countries. The biggest differences stem from whether the country is a "Common Law" or "Civil Law" jurisdiction. Most common law jurisdictions descend from the English legal system and include countries such as the UK (except Scotland), the Republic of Ireland, the United States (except Louisiana), Canada (except Quebec), Australia, New Zealand and Malaysia. India and South Africa also have forms of common law. Continental Europe and much of the rest of the world use the civil law system. In a common law jurisdiction much of the law derives from previous judgements by judges hearing real cases, whereas in civil law countries the main emphasis is on the legal codes such as the French Napoleonic code and much less weight is given to judicial precedent.

The law of "passing off" arises in common law countries. To sue for "passing off" in England you need to prove that:

- Your products have acquired a goodwill or reputation in the market and are known by some distinguishing feature;
- The other party is doing something to confuse the public into believing that the products they sell originate from you;
- You have suffered damage (including damage to your reputation) as a result.

However, it can be very difficult and expensive to prove "passing off". One advantage of registering a trade mark is that it is generally easier to prove infringement of a registered trade mark than "passing off" of an unregistered mark. Once again, this is an area where you should seek professional advice.

29.4 Designs

Designs are concerned with the appearance of a product rather than its function. In chocolate confectionery, the design protection is commonly used for packaging, for example the shape and appearance of an assortment box, but it can also be used to protect the shape of chocolate products themselves. Once again the situation varies around the world, but generally, to be protectable, a design must be new and have individual character. To have individual character the overall impression conveyed must differ from that conveyed by previous designs.

In the European Community there is a two tier protection system:

- The Unregistered Community Design (UCD);
- The Registered Community Design (RCD).

An Unregistered Community Design gives automatic protection for your design for three years after you made the design public. It has the advantage that you do not need to file any applications, but the major drawback is that the protection can be difficult to enforce. A UCD gives the right to prevent the commercial use of the design only if the use results from intentional copying.

A Registered Community Design gives you exclusive rights over the use of that design. An RCD initially has a life of five years, but it can be renewed in five-year blocks up to a maximum of 25 years. You can register your design and keep it undisclosed for up to 30 months for an additional fee. There is a grace period which allows you to market your product for up to a year before applying for a Registered Community Design, but it is generally safer to register as soon as possible. A major advantage of having a registered right is that it is easier to prove infringement.

It is worth considering designs and trade marks together when looking at protection options. It might be possible to protect a distinctive and novel product shape as a three dimensional trade mark which could provide a valuable alternative to design registration, potentially giving protection indefinitely.

The equivalent protection in the United States to registered designs is the "Design Patent". Like registered designs, a United States Design Patent is concerned with appearance not function (the patents dealing with function in the United States are called "Utility Patents"). A difference between European Registered Community Designs and United States Design Patents is that for a Design Patent you must show that your design is not just new, but is also not obvious. Whether a design is non-obvious is not always clear, and may lead to differences of interpretation.

29.5 Copyright

Internationally, copyright is of huge economic value, covering such things as books, drawings (including engineering drawings), paintings, music, film, TV, radio and, in many countries, computer software. It is important however to realise that copyright does not protect ideas. If you have written down a great idea for a new chocolate product, your written words (the expression of the idea) will be protected by copyright, but the idea itself is not protected.

The main international agreement concerning copyright is the Berne Convention. Most of the major countries in the world are parties to the Berne convention, so generally copyright protection is international. The Berne convention requires that each member country gives citizens of other countries at least the same degree of copyright protection that it gives to its own citizens, and also the convention imposes minimum standards of protection. The duration of copyright protection must be at least for the life of the author plus 50 years (for all except photographic and cinematographic works), but some countries and regions such as the European Union allow longer protection.

Copyright protection is automatic as soon as there is a record in any form of what has been created. It is useful to mark copyright material with the international copyright symbol © followed by the name of the copyright owner and year of publication. This is not essential for Berne Convention countries, but it is an advisable and simple step to take. In the United States there is an official register for copyright works, but copyright is not dependent on registration. However, United States law strongly encourages registration by providing additional benefits to copyright owners who register. It can be useful to be able to prove when you created your copyright material, for example if someone accuses you of copying their later work. Some people send themselves copies by registered post, which they leave unopened to be able to prove a date on which the work existed, or deposit their work with banks or solicitors.

For chocolate manufacturers, copyright is mostly used for protecting the text and graphics on pack, as well as marketing and advertising literature. It can be a valuable tool in tackling counterfeit goods. Chocolate manufacturers need to be aware of other people's copyright and make sure they do not infringe it. For example, adding music to your training or promotional video requires permission from the copyright owner of the music. When buying copyrighted material it is important to be clear exactly what rights you own. For example, you might purchase a painting to hang in your office reception area, but you may not necessarily own the right to reproduce the painting in publicity material. Similarly, when commissioning on-pack art work and photographs it is important to make sure you own or have licensed the rights you need to use the material and that you keep a record of any restrictions on further use. Damages of many millions of dollars have been awarded in some cases when copyright was not respected.

29.6 Contracts and agreements

Contracts are important tools for managing intellectual property. A contract is a "promise" or an "agreement" that is enforced or recognised by the law. Companies generally cannot work in isolation, they need to deal and co-operate with other companies and organisations. A good relationship clearly involves trust, for example between a manufacturer and a supplier, but legal contracts provide security and set out what each party has agreed to do or not to do. The law governing contracts varies from country to country, but contracts may be implied by the relationship between the two parties, they may be agreed orally or they may be agreed in writing. Agreeing a contract in writing is normally the best policy, as it avoids doubt and is easier to enforce than an oral contract.

A common contract is the confidential disclosure agreement (CDA), sometimes referred to as a non-disclosure agreement (NDA). These agreements are valuable when you want to disclose confidential information or trade secrets but need to make sure the information doesn't become public. For example, you may have developed a new chocolate product and would like to discuss with an equipment supplier what machines they would propose for its manufacture.

In order to obtain good advice you need to explain your product in some detail, and the supplier in turn needs to share technical information about their process equipment. A CDA allows you to have open and useful discussions, but gives some legal security that the information won't be passed on to competitors. The wording of a typical NDA is given on the UK Intellectual Property Office website (UK IPO, 2011a) but this is just an example and may not fit your specific circumstances, in particular it is written for English law.

Confidential disclosure agreements should be used with care. Once a secret has been made public you cannot get it back, and suing the other party for breaching the CDA may not provide you with much recompense and can be difficult to do in practice. It is important to find a good balance between sharing information with a business partner in order to work efficiently and keeping your secrets secure.

Written agreements can be used to prove that information has been passed under confidentiality. This can be important for patent applications, as the invention of the patent must not be disclosed to the public before the patent is filed and a competitor might try to invalidate your patent on the basis that you disclosed the invention to someone with no requirement for confidentiality. The safest policy is to file the patent before telling anyone else about it, but in practice you may need other parties to help test the idea or build prototypes before you can finish writing the patent. Consumer research is a particularly dangerous area. It may be possible to agree confidentiality with a small group of consumers, but large-scale quantitative tests, or tests where the consumer takes the product away with them would not normally maintain confidentiality, so the patent should be filed first.

There are a number of other common types of contract. "Trials Agreements" or "Development Agreements" may be used when two parties have the possibility of developing new intellectual property together. The agreement sets out who will own any new intellectual property generated. It is much easier to agree this in advance than to wait until the new discovery has been made and then start discussing who owns it.

Some speciality materials, particularly biological materials, are supplied under a Material Transfer Agreement (MTA). The MTA sets out how the materials may be used, for example by limiting the applications the sample can be put to or by preventing the receiving party from analysing the material. MTAs may also assign intellectual property rights in inventions made using these materials to the supplier.

"Licence agreements" allow others to use your intellectual property, typically for a fee. Licenses can be for registered rights such as patents, but also for confidential intellectual property such as trade secrets. The licence agreement sets out what the licensee is allowed to do and any terms and conditions applying to this use.

"Exclusivity agreements" typically agree that an ingredient or product will only be sold to one customer. These may be agreed as part of commercial negotiations involving both price and volume. The customer needs to decide whether having exclusive access to this ingredient or product will bring sufficient economic return to justify the price and conditions being asked for. Laws aimed at protecting consumers and encouraging competition may set limits on the extent or duration of exclusivity agreements.

"Contracts of employment" are used to agree such things such as wages, hours of work and notice periods between a company and its employees. They may also explicitly state that the employee must keep his employer's information confidential, during and after employment. Employment contracts also commonly assign the ownership of any intellectual property that the employee may invent to their employer. Some employment contracts contain restrictive covenants which prevent an employee taking a job with a competitor. As with all legal contracts, professional advice is required to ensure such covenants are valid. For example in common law countries, the principle of "restraint of trade" means that a person is entitled to undertake a lawful trade when and where he wishes. Any restrictive covenant has to be shown to be reasonable for both parties (and the public). Often, restrictive covenants are agreed in return for extra payment and are limited in duration. In most countries there are laws which govern the duties and responsibilities of employees and employers in addition to those written in an employment contract (see Section 29.7).

Contracts are often established between companies and organisations that are based in different countries. Written contracts will usually state under which country's law they should be interpreted. A change in legal jurisdiction can make a significant difference to the way the contract will be interpreted, especially moving between "Civil Law" and "Common Law" countries (see Section 29.3.2). This is another area where professional legal advice is likely to be required.

29.7 Trade secrets

Trade secrets are information that companies keep secret to give them an advantage over their competitors. The formula for the COCA-COLA® beverage is famous for being protected by a trade secret. The recipe is supposedly a closely guarded secret kept in a bank vault. More common examples of information that may be kept as a trade secret include customer identities and preferences, supplier lists, the prices paid for goods, marketing strategies, company finances and manufacturing processes.

Keeping your important information secret has advantages over other types of protection such as patents as there are no fees to pay and the protection does not run out after a fixed number of years. The major disadvantage however, is the practical difficulty of keeping the information secret. You need to take great care to keep the secret and be sure that everyone involved does the same.

It may seem surprising, but in a large organisation, it requires excellent communication to keep a secret.

Another risk with the strategy of keeping a technical invention secret is that someone may independently have the same idea and decide to file a patent. Despite the fact that you have known this idea for a long time, the knowledge was not made public so they will be entitled to the patent.

In chocolate manufacture, secrets are best used to protect technical insights and understanding, process settings and in some cases the process itself. Clearly, if competitors can analyse your product and determine what ingredients were used and how the product was made, there is no point trying to keep that information as a trade secret. One approach for keeping recipes and processes secret when working with co-manufacturers is to use different companies to produce different parts of the product. For example, a fat blend could be made by one company, while the milk components are made by a second. All the components are then combined in yet another location. This avoids sharing the knowledge of the overall process, but is likely to add cost.

It makes sense to control who visits your factory and to avoid showing secret aspects of your process to those who do not need to see them. Visitors may not intend to pass on confidential information, but may do so inadvertently. Asking visitors to sign a secrecy agreement helps to remind them of their obligations. Some companies take great care not to allow any outsiders into their factories. Processing equipment is delivered to the door of the factory, and the supplier is not involved in the installation and may not even know exactly what the equipment is being used for, or whether further modifications are being made after delivery. This approach is not one to be taken lightly, as you lose the benefit of the supplier's expertise in specifying and maintaining the equipment and may limit your options regarding warranty. A good trusting relationship with your suppliers can be very valuable.

Most countries have laws to protect confidential information. This is required under the terms of the TRIPS agreement (WTO, 1994). The exact legal position and terminology varies from country to country, but there are three common factors. To be protected, information must:

- Be secret (not generally known to the public);
- Have commercial value because it is secret;
- Have been subject to reasonable steps to keep it secret.

An example of "reasonable steps" is the shredding of confidential information. Although, with a great amount of effort, someone might be able to piece together the shredded material and discover your secrets, you would be considered to have taken reasonable steps to protect your confidential information.

Legal obligations of confidentiality are not always as a result of a contract. Confidentiality may be expressly stated, but it can also be implied. In many countries certain relationships are presumed to be confidential, such as between a husband and wife, or a solicitor and client.

Employees are likely to be exposed to a company's Trade Secrets and of course they may move jobs from time to time. Employment contracts were described earlier (Section 29.6) and these generally expressly oblige the employee not to divulge the secrets of their employer, during and possibly after employment. National laws often require an employee not to do anything against the interests of their employer during their employment and not to disclose confidential information even after their employment has ended. It can be a complicated issue however, as the distinction between the ex-employee's personal technical skills and the "know how" of the ex-employer are not always clear.

29.8 Defensive publication

The opposite strategy to keeping something secret is to deliberately publish it. Although not strictly a form of intellectual property, this can be a valuable protection tool. By publishing details of a technical invention you prevent other people who subsequently have the same idea from patenting it. Your publication becomes prior art and means that any later patent application for the same invention is not novel. Publishing can be an appropriate tactic if you do not want to spend money on a patent, perhaps because the technology is useful but will not generate significant revenue, or because it would be expensive to enforce when patented. By publishing you ensure that your future options will not be blocked by someone else's patent. However, a decision to publish should be carefully considered because the publication effectively prevents you from obtaining a patent in the future if you change your mind.

The content of a publication made for this purpose is typically similar to the content of a patent. It needs to give enough details to explain how the invention can be put into practice, or "enabled". Although in principle any publicly available disclosure should prevent a later patent for the same invention, in practice you may want the publication to be readily found by patent examiners. There are companies which offer journals and online databases specifically for publications of this type, such as *Research Disclosure* and *IP.com*. Publications may be made anonymously if you do not want competitors to be aware of what you are working on.

29.9 Strategy

To be effective, companies should have a plan of how they intend to use intellectual property to reach their long-term aims. The intellectual property strategy is an integral part of the overall business and innovation strategy of the company. IP strategy can be considered on a number of levels; from the top level – how IP fits with the overall business, to the lower level – how and where to protect an individual idea or development. The strategic approach chosen at each level should be aligned.

29.9.1 High-level strategy

A fundamental point for an organisation to consider is, what do we want to use intellectual property for? Some companies aim to make money from the intellectual property directly, for example by creating or buying intellectual property specifically to license and sell to others. This can be coupled with other services, such as a development firm who sells a license for their technology, helps to install it and often provides continuing support to their customers. There are also companies who enforce patent rights against accused infringers in an attempt to collect licensing fees but do not manufacture products or supply services themselves. Such companies are known by their detractors as “patent trolls”.

The most common approach by companies in the chocolate industry is to use IP primarily to protect the products and services they sell against copying by competitors. If your product has an advantage that none of your competitors can offer, then you can increase your profits by selling more and/or being able to charge a higher price. That advantage could be technical, perhaps protected by a patent, or it could be due to the strength of your brand and the quality that consumers associate with the brand, perhaps protected by a trade mark. Similarly, protecting a process which provides greater efficiency or lower cost provides a commercial advantage.

Generally, intellectual property rights are expensive to obtain, maintain and defend. It therefore makes sense to have a strategy to identify the countries where you will try to obtain rights. This should be aligned not just with your current business, but also with your future plans. Patents can last for 20 years, but there is only a limited time after the first filing when you can file the same invention in other countries. Ideally you would file in any country where you expect to be doing significant business during the lifetime of the patent and where there is an effective patent system (or there is expected to be an effective system soon). As well as the countries where you manufacture or have significant sales, you might want to consider obtaining protection in major countries where your competitors operate, particularly protection via patents. This can provide an opportunity to make commercial deals with your competitors such as licensing, but you also might want to avoid competitors becoming strong through exploiting your innovations in a market where you do not operate and then using that strength to compete against you with other products in your home market. However, the choice of where to obtain IP rights must be balanced against cost, and based on a realistic assessment of future opportunities and threats. For a small company it may make sense to concentrate IP protection solely in the home market. Even large companies typically do not have patent protection in every country where they operate. The choices need to be thought through and established as a component of the high-level strategy, but not to be inflexible if unusual situations arise or the business environment changes.

Another high-level strategy is to decide to concentrate on ensuring you are not blocked by other people's IP rights (i.e. you have "freedom to operate") but not aim to build a significant IP portfolio of your own. Small, specialist chocolate makers commonly choose this approach, limiting their own IP to the trade marks which identify their business and perhaps their main products. People have been making chocolate confectionery for a long time, so the basic technologies are no longer covered by patents. Many companies do not try to obtain a competitive advantage by developing their own improved technology, they prefer to buy equipment and ingredients from suppliers, effectively using the same technology as many of their competitors. They may compete strongly in other areas such as quality, price or specialisation. There are different ways of protecting competitive advantage than just IP. Having a production or distribution system that others cannot easily replicate, or simply being fast may provide protection. For a company that constantly changes their products and engages consumers by always offering something new, filing IP for each new product may not make sense. By the time the rights are granted the company will be making something else.

With a strategy of not building your own IP, defensive publications can be used to prevent others from filing patents which block you (see Section 29.8). It is also advisable to keep systematic records of the products you sell and the recipes used to make them. These could be useful in proving "prior use", for example if a competitor later files a patent covering that product. Some companies choose not to file their own IP, but keep their inventions secret. As discussed in Section 29.7, there are risks associated with this strategy that need to be carefully considered.

High-level strategies are often combinations of the approaches described above. It may make sense to own IP in one strategic area of the business, but aim to use publicly available technologies in another. Once the strategy is defined, decisions such as whether to patent an invention, or whether to compromise on IP rights for the sake of concluding a contract, become clearer.

29.9.2 Innovation strategy and IP

There have been some successful innovations that were made more or less by chance, but generally companies need a strategy to maximise their chance of making profitable innovations. It is important not only to be aware of your own strengths but also to be aware of the strengths of your competitors, both in terms of technical strengths and patents. It is not normally wise to invest development effort in an area that your competitors already control through market position and patents. You might be better advised to look for an opportunity where you have the chance of building a sustainable competitive advantage using appropriate protection tools.

Patent landscaping is a technique used to analyse patenting opportunities and threats in a particular technology or business area. A set of relevant patents are identified by a patent search (see Section 29.2.5), then categorised, either by software or manually using experts, and plotted graphically to help analyse the situation. Software packages are available which analyse a mass of patent, business and literature data, extracting information automatically from the text and presenting analyses of the data graphically, for example grouping similar concepts together. Commercial database and search tools (see Section 29.2.5) often have analytical functions built in, such as the *ThemeScape*® mapping tool in *Thomson Innovation*® and there are also "stand-alone" analysis tools available such as INTELLIXIR. To analyse a group of patents you might choose to plot the assignees (owners) of the patents against different aspects of a technology to see where different companies are filing patents. Landscaping can also be used to study the technological evolution of a particular field, detect emerging technologies and perhaps identify a related technology you have overlooked.

Patent landscaping is a helpful tool, for example to check whether a proposed development direction makes sense or to get an overview of a competitor's patent portfolio, but it does not make strategic choices for you. When planning where to direct R&D efforts to generate valuable IP, patent landscaping needs to be combined with an understanding of your technical and business capabilities and, most importantly, what your customers would want to buy. Just because there are no patents in an area does not mean it makes commercial sense to start R&D activities there.

It is important to realise that being patentable does not mean that something will make you money. A large proportion of filed patents are never commercialised. The Institute of Patentees and Inventors estimates that the success rate of getting patented ideas to the market is only 2% (IPI, 2014). As ideas move from paper concepts, through small-scale prototypes, to pilot plant trials and then to industrial trials there is a series of selections to find the most promising ideas, with only a small number of ideas moving on to the next stage. These selections can be made on the basis of business insight, consumer research, preliminary costings or even the personal taste of the managing director. At the early stages of development there is a high chance of failure, especially if it is a technology new to the whole industry. However, this is also the stage where you have the best chance of securing broad patent coverage. As the development continues and successfully passes the selection stages the uncertainty reduces and the probability of success increases. A company aiming to compete in the market for many years would expect to have a mixture of developments at different stages of maturity.

29.9.3 IP strategies for individual developments

For an individual idea or development you need to consider carefully what advantage it brings. This is the heart of what you want to protect and ideally you would like to protect every way of achieving this advantage and so gain the broadest protection. You should consider the full range of protection tools, not just patents, and use them in combination where appropriate. Consider in which countries you need protection. If you have a top-level strategy governing the countries where you file patents and trade marks, is it appropriate for this development? Often the choice of countries is delayed as long as possible when filing patents, for example using a filing sequence as shown in Figure 29.1. This allows more time for the business opportunities of the invention to be assessed. However, it may be important to obtain rights quickly in some countries, for example to take action against competitors who are likely to launch infringing products (see Section 29.10). You should discuss the most appropriate way of achieving this with your IP attorney.

As a fictitious example of the points to consider, imagine you have invented an ingredient combination "Floatium" that when added to chocolate makes the chocolate lighter than air so that it floats like a helium balloon. You would review the protection tools available and decide that keeping this invention secret is not an option, as once the product is on the market the key ingredients will need to be declared on the ingredient list. So patenting seems to offer the best protection.

Your first thought might be to quickly patent a chocolate with just that particular ingredient combination. However, on reflection you realise that there are other useful things you could protect. You talk to your colleagues in the laboratory (they are bound by their employment contract to secrecy) and they point out that other similar ingredients might have the same effect. So, in parallel with the development of the main Floatium ingredients, the lab team dedicate a small amount of time to testing their ideas and establish a family of Floatium ingredients. These ingredients work in the same way, although they are not as effective as the original combination. You therefore file a patent for a lighter than air chocolate comprising the Floatium family of ingredients. To support the product claims, you add examples showing how to manufacture the lighter than air chocolate with a representative selection of the ingredient combinations. You add claims for the manufacturing process. By taking some time to check what else might work you have been able to broaden the claims and avoid a competitor readily being able to modify your ingredient combinations and so launch a product with the same benefit to consumers. Competitors may work around your patent eventually, but it will take time, during which period your product can become established on the market.

The Floatium ingredient combinations might have many other applications, not just in different foods, but in areas such as transport. Currently you do not have the resources or expertise to explore this. In the patent you also include claims for the Floatium ingredient combinations themselves and their use to make objects float in the air. By being first into a new technology area you have the best opportunity to obtain broad protection. Other people may subsequently solve the problems associated with further uses of Floatium and then patent their new products and processes. However, they will not be able to manufacture or sell products containing Floatium without your permission, as long as your patent for the Floatium ingredient combinations is in force. Patents are a right to exclude others, they do not necessarily allow you to use your invention. A patent which prevents the use of later patents is sometimes called an "umbrella patent". You may be able to make money from the "umbrella patent" through licensing it to the owners of the later patents, or agree a cross-license if you want to use their later patents.

You decide to file your patents in all the countries where you currently have sales and manufacturing. You also choose to file in China as you see a great potential for the product there. The new product does not fit with any of your existing brands so you decide to trade mark the name FLOAT-O-CHOC as well as a distinctive logo ready to use in a major advertising campaign. The product requires special packaging to stop the chocolates floating away when the pack is open. A packaging tray with attractive tabs each in the shape of the brand logo is developed to hold the sweets in place, so you file a design registration to protect the appearance of the pack. You register the designs and trade marks in the same countries as the patents, with appropriate modifications of the trade marks to suit the different languages. You enter into a partnership with an ingredient manufacturer to produce "Floatium" on your behalf, using a non-disclosure agreement for initial discussions and then agreeing a contract setting out the terms of your business partnership and protecting any confidential information exchanged. You realise that you will not be able to supply and distribute the product in China, so you licence the relevant IP to a local manufacturer who will produce the product and pay you a royalty. In this way you have combined available protection tools to prevent others from freely copying the advantages your idea brings.

Development work continues on FLOAT-O-CHOC, with particular emphasis on optimising production efficiency and reducing cost. A new class of cheaper ingredient is identified that can be made to have the same desirable properties as "Floatium" by ingenious processing of the chocolate. This new processing method and ingredient are then patented, six years after the original patents were filed. When the original patents expire, competitors will be free to produce their own versions of the float-in-the-air product using Floatium. However, the later patents still protect the new cheaper ingredient for another six years, maintaining some competitive advantage. As the development continues, a number of machine modifications are found to improve the manufacturing efficiency, but it is decided to keep these as trade secrets.

Given the high cost of developing new products and processes and bringing them to market, it is important that you can sustain your competitive advantage for as long as possible. For those interested in exploring IP strategy in more detail, many books have been written on the topic such as Barrett *et al.* (2008), Blaxill (2009), Harrison and Sullivan (2011) and Knight (2013).

29.10 Enforcement

It is up to the owner of intellectual property to enforce their rights. Rights are enforced through the courts, or in some countries the relevant Intellectual Property Office. However, you may be able to resolve your dispute without taking any legal action, and this is generally cheaper. If you suspect someone is using your protected intellectual property rights without permission (infringing) you should take professional advice immediately. Do not contact the other person before seeking advice as your communication could be construed as an unjustified threat and might be illegal. Similarly if you are threatened with legal action you also need to take professional advice. Such contacts are not always bad news – it is possible that you might be able to reach a profitable commercial arrangement with the other party.

It is advisable to monitor the marketplace by checking the press, trade publications and the web for companies using your intellectual property without authorisation, as well as monitoring products being offered for sale. In the case of trade marks, you should also make sure no one tries to protect an identical or similar trade mark to yours. This may be done by setting up alerts on trade mark databases, or by employing a professional trade mark watching service. If you discover a competitor has applied to register, or has registered, a mark that is similar or identical to your own, you can oppose or cancel the trade mark registration.

Border control officers have the power to take action against goods suspected of infringing certain intellectual property rights. If you believe that imported goods are infringing your IP rights, you can request that the border control authorities detain the goods. You must file an application for action and provide a description of the goods that is accurate enough to enable the goods to be intercepted. You must also be able to show that you hold the IP rights that you think are being infringed. Although border control officers can detain suspicious items on their own initiative, the probability that they will find infringing items substantially increases if the rights holder files an application for customs action.

In order to take legal action you need to have rights. Some IP rights can be obtained more quickly than others, so if you suspect that a competitor is likely to copy your product in a certain country this may influence your strategy. Trade mark registration is faster than getting a patent granted for example, and may be more straightforward to enforce at customs. In countries where Utility Models rights are available for your invention (see Table 29.1) these provide a potential basis for an infringement action more quickly than waiting for a full patent to be granted. Patents may give some provisional protection as soon as they are published, the details vary from country to country. It could therefore be advisable to request early publication and fulfil any other requirements necessary to obtain this provisional protection. Generally, any damages obtainable once the patent is granted will be calculated back to the date the patent was published. In all these situations, professional advice is required.

Insurance is available for all kinds of intellectual property rights to provide for the costs of litigation. For example, there are insurance policies which would cover you in the event that you needed to enforce your patent by launching an infringement action. Such policies are generally more suited to small companies who would otherwise not have the financial strength to enforce their rights.

29.11 How to find help

In some countries it may be technically possible to represent yourself or your employer without professional help, but IP law is complicated and a small mistake could leave you with no protection for your potentially valuable idea. Unless you are very sure of your competence it is advisable to seek legal or other professional advice, as the cost of not using a qualified professional could easily exceed their fees. Larger chocolate manufacturing companies may have in-house lawyers and intellectual property specialists, but smaller organisations will need to find external help. The UK Intellectual Property Office publishes a booklet to help choose the right IP adviser (UKIPO, 2011b). Make sure the person you employ is appropriately qualified, for example a qualified legal professional, patent attorney or trade mark attorney. Qualifications differ between countries, but a quick web search should indicate the appropriate qualifications for representing clients. In the copyright and related areas, lawyers and/or one of the trade associations may be helpful. As in any profession, qualifications set the basic standard, but abilities and experience in a particular area may vary. It can be useful to seek recommendations from contacts in the industry before choosing a representative.

When working with a patent attorney to draft a patent you should try and provide them with as much relevant material as possible. If the information you provide is well organised, the patent attorney can then easily select what they need to draft the application. Points to consider include a description of the problem which the invention solves; full details of the invention including examples, things that are essential for it to work, and any experimental data and drawings, as well as relevant background information and any earlier publications you are aware of. It is also advisable to explain the commercial relevance of the invention and how it will be used. This helps the patent attorney draft appropriate patent claims to protect your business. The patent attorney will usually send you a draft to comment on. If you do not understand what the patent attorney has written, then ask – it may be wrong. Similarly, if an important aspect you hoped to cover is not mentioned in the draft, then say so. The patent attorney probably knows less about the technical area than you, and by working together you can improve the quality of the application and the chances of being able to enforce the patent.

Obtaining protection for your intellectual property can be expensive, and patent costs increase with time. Lone inventors and start-up companies usually need to find financial backers, and the ideal time to approach these is in the first year after filing the patent. The filed patent makes it difficult for others to steal your idea and shows that you are serious. After the first year the costs start to escalate. Government funding may be available for start-up companies but some forms of help can have “strings attached”. For example, you may have to share some of your profits or set up a business within a defined geographical area. There are also firms known as Invention Promoters who offer to help evaluate, develop and market your idea, usually for a large fee. Be very careful about using the services of such companies, or you may find you have made a costly mistake.

Conversations with professional advisers such as patent attorneys, solicitors or patent office staff are usually confidential as these professions have a legal duty of confidentiality, but make sure you have an appropriate confidentiality agreement before disclosing your idea to anyone else. Even with professional advisors it is worth checking that they do actually owe you a legal duty of confidentiality!

Conclusions

This chapter provides an introduction to intellectual property, together with some pointers to help you find more information. The four key points to remember are:

1. An idea may be patentable, but that doesn’t mean that it has any commercial value.
2. Obtain competent professional legal advice in good time and certainly before disclosing your “great idea” to people not bound by confidentiality.
3. You need to consider a range of protection tools, not just patents.
4. Infringing other people’s rights or missing an opportunity to protect your new product could weaken or even destroy your business.

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Appendix: Useful web addresses

Web addresses can change, but the following list was correct at time of writing. If the address has changed, the new address should be possible to find by using an internet search engine.

- United Kingdom Intellectual Property Office: www.ipo.gov.uk
- European Patent Office: www.epo.org
- United States Patent and Trademark Office: www.uspto.gov
- World Intellectual Property Organisation: www.wipo.int
- European Patent Office searchable database *Espacenet:* www.epo.org/searching/free/espacenet.html
- European Union Intellectual Property Office: euipo.europa.eu
- The Swiss Federal Institute of Intellectual Property: www.ige.ch
- Japan Patent Office: www.jpo.go.jp
- The Chartered Institute of Patent Attorneys (a UK professional body): www.cipa.org.uk
- Institute of Professional Representatives before the European Patent Office: www.patentepi.com
- The Institute of Trade Mark Attorneys (a UK professional body): www.itma.org.uk

CHAPTER 30

Future trends

Stephen T. Beckett

"According to the old adage, there is nothing new under the sun. There is, however, an infinity of possible variations on any one theme, and it is to the divergent conceptions of the chocolatier, confectioner, food chemist, packaging and mechanical experts that the industry owes its multitude of interesting product". So wrote C. Trevor Williams (1964) in his book on *Chocolate and Confectionery* over 50 years ago. This to a certain extent is still true today and will continue to be so. However, before trying to predict future developments, it is interesting to read how this past author thought the art of chocolate-making would develop and then to compare this with the current situation.

30.1 Past predictions

Three areas of development were reviewed by Trevor Williams (1964): new materials, package design and novel processing.

30.1.1 New materials

The hydrogenation of fats was once thought to open up new fields for the chocolatier with regard to texture and bloom resistance. This was surpassed by the widespread development of cocoa butter equivalents and substitutes, as partial or total replacers for cocoa butter in compounds and some chocolate markets (see Chapter 7). More recently (Mori, 1990; Talbot, 2009), the use of tempering, bloom retarding and lower calorie fats and the development of enzyme interesterification to produce some of the components of cocoa butter from new oil sources are just two of the many new ingredient types and processes with great potential for the future. New legislation (see Chapter 28) in many countries has limited their use in products labelled chocolate and it is only in markets like Japan that it is possible to see their true potential. Health concerns over *trans* fats

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has also led food scientists to develop alternative fats to replace the original hydrogenated ones, which will still give products with the correct texture and shelf-life (Talbot, 2006).

Some plastics and whey concentrates were regarded as possible alternative new ingredients. Although the former have yet to be developed the latter, as whey- or lactose-derived substances, are in fact incorporated in many chocolates, particularly in continental Europe. Their wide variety and importance has led to Chapter 5 in this edition being rewritten and updated.

The public's perception of the food value, or harmful effects of certain products, was considered a problem for the future of the industry. Over 50 years ago the need for the industry to educate the public was noted. How much more so is this true today! Natural "healthy" products such as soya, groundnut, sunflower seed oils, pectins and yeasts were considered as possible additions. The present health-food trend is certainly an important one, with many developments in the field of "functional foods", that is ones with positive health benefits. During past 30 years a large amount of work has been carried out which has shown the very positive health effects of eating cocoa (see Chapter 22). A major problem for the manufacturer is that an ingredient, which has a positive image one week, can be regarded as unhealthy the following week. Even more strangely an additive which is beneficial in one market would be difficult to sell in others, whilst some products with good nutritional properties are still regarded as being junk food by the media.

Also included in William's list was the possibility for alternative sugars. Dextron in particular was noted. Although this has not found a major application in the confectionery industry, the development of new sweeteners has been a major part of present research within the sugar/sweeteners industry (see Chapter 4) and the ideal low calorie sucrose replacer that is free from laxative effects is probably yet to be fully developed. There is also a current media campaign in some countries to reduce overall sugar intake, claiming that it is more unhealthy than fat.

30.1.2 Packaging

A possible future prediction was the use of an edible moisture-proof film, sprayed on confectionery to eliminate the necessity of wrapping media. This appears to be totally impractical, however, as packaging is designed to protect the product from dirt and physical damage. This necessitates the packaging material being removed to take dirt with it. It also often needs to be relatively bulky so as to withstand knocks.

The importance of the correct use of colour, packaging design and symbolic devices to denote different manufacturing houses are as important today as they were in the past. The development of new machines means that the range and quality of packaging has changed rapidly. The increase in the speed of these machines and the growth in importance of large super/hypermarket outlets have led to a rapid growth of packaged countline goods. Trevor Williams noted that in the 1960s 80% of the chocolates and confectionery produced in the USA was packaged as countline goods. This trend has since continued in other markets.

In recent years the influence of the environmental movement has tended to lead to a reduction in the amount and thickness of the packaging material used, coupled with a preference for the use of degradable or recyclable packaging materials where possible. Some materials are now available, particularly for boxed chocolates, which will in fact degrade with moisture over a relatively short timescale.

30.1.3 Processing

Probably as a result of the influence of Mosimann (1963), ultrasonics was considered likely to find a major role within the confectionery industry. It was thought to be able to take part in the emulsification, particle comminution and conching of chocolate. At present the use of ultrasonics as a solid fat monitor appears to be the most commercially viable application (see Chapter 15).

30.2 Present position

This section looks at some of the developments which have taken place over the past 50 years and which were not reviewed above.

30.2.1 Materials

The source and quality of the basic raw material of all chocolate, cocoa has been changing dramatically over the period. The Ivory Coast has become by a long way the dominant supplier of cocoa to Europe, whilst owing to cocoa disease Brazil has changed from being a major exporter of beans to having to import some cocoa products. Sustainable and ethical sources of cocoa are becoming increasingly important to the industry (see Chapter 2) as are varieties with distinctive flavours.

Each cocoa origin provides its individual flavour, and thus the overall flavour of some chocolate is changed as new sources and types of beans are introduced. It is interesting to note that at least four authors have stressed the importance of obtaining high-quality properly fermented and dried beans, also noting that processing is at present unable to overcome any defects. It is, therefore, of great concern to many manufacturers that changes in the source of cocoa should not lead to a deterioration in quality.

One of the main areas of development of new ingredients has been in the low calorie or sugar-free markets. New sugar substitutes (see Chapter 4) are not the only area being developed. By adding a long chain, difficult to digest, fatty acid with two smaller chain fatty acids it has been possible to produce triglycerides with only 4 cal/g compared with the normal 9 cal/g and with adequate crystal structure. Commercial fats such as “Caprenin” and “Salatrim” have led to many new products entering the marketplace, even if currently they are largely incompatible with cocoa butter (Talbot 2009).

Other fats have also been developed for specific purposes. One Japanese product produces a "chocolate" which bends like rubber, whilst several fat manufacturers sell fats which improve heat resistance by dramatically reducing bloom formation. Many of these are, however, only legally permitted in a few markets. Emulsifiers, such as fractionated lecithins are now widely available, whilst others such as PGPR (see Chapter 11) are permitted in most markets. A large percentage of lecithin was obtained from soya, some of which is obtained from genetically modified crops. With the European customer's demand for GM-free ingredients, this has led to the manufacture of lecithin from soya from new sources, or from new crops such as sunflower, or to develop alternative emulsifiers.

30.2.2 Processing

Here many changes have occurred in the field of roasting, with the roasting of whole beans often being replaced by nib or even cocoa mass roasting. The thin-film or batch devices developed to do the latter have also been used to reduce conching times and/or change the flavour of the chocolate. The conches themselves have tended to become bigger, while the use of the long conche has almost disappeared altogether (Bolenz, 2014).

Overall there has been a movement amongst the larger manufacturers towards large-volume processing lines, which are operated as far as possible in a continuous manner. The installation of advanced computer control and instrumentation has also resulted in a vast reduction in the man-hours required per tonne of chocolate produced (see Chapter 24). The processing of the vast majority of the world's cocoa is carried out by about half a dozen companies and there are increasingly fewer factories actually making chocolate, although probably an increasing number using it. This was emphasised by Jeffery (1997) who said that "in the United States there are perhaps only 15–20 makers and literally hundreds of companies 'adding value' to it in producing an enormous variety of confections". In this edition a new chapter has been added which looks at the problems and advantages of this type of artisan company (see Chapter 18).

Many of the more recent innovations have, in fact, been concerned with chocolate usage, for example to make it into a mesh or to convert a standard moulding line to produce filled product without the complexity of a full shell moulding plant. It is interesting to note that the ideas behind two of the latter, that is "single-shot" depositing and the frozen cone/plunger method, originated more than 40 years ago but have only more recently become widely available as commercially built plants. This has been very much helped by the greatly improved process control techniques which are now available (see Chapter 24) and which are playing a vital role in the industry today.

30.3 Possible future trends

Predicting the future is always very risky, as unforeseen circumstances can totally change the course of events. For example, an incurable disease in cocoa could destroy the industry, whilst the consumption of chocolate might suddenly increase many-fold. One can of course extrapolate present trends in the belief that at least some of them will continue.

It was noted above that large manufacturers are installing larger and faster machinery. These firms have captured a substantial proportion of the market and their products are known internationally. At the same time small specialist firms, normally retailing their own goods, appear to be flourishing in many countries. It is likely that this will continue, with an even greater polarisation into the two types of manufacturers. The use of large machinery makes it impossible for the chocolatier to fully develop the potential of each individual type of bean. Thus, although there may be a variety of “house” flavours, it will be left to the smaller manufacturer to exploit the full range of possible chocolate flavours. It may also be that eventually the chocolate assortment box will be primarily produced by this type of firm, with bars, countlines and so on composing the chief market of the major international manufacturers.

The increasing difference between the two types of manufacture is also likely to be reflected in the two types of chocolate, namely “real” chocolate and coatings. Whilst it seems likely that legislation will remain strict for the former, the latter is likely to extend in its range of constituents and quality. The range of other fats and techniques for their manufacture will enable better products to be made. At the other end of the market, work on chocolate flavour will probably continue with the discovery of several hundred new contributing compounds. The probability is very low, however, of finding an economical alternative which cannot easily be distinguished from cocoa.

In his look at chocolate making into the next millennium, Jeffery (1997) regarded low-fat and low-calorie products as being particularly important. He noted that old ideas, such as the Cadbury (1976) one of using sugar rather than fat as the continuous phase of chocolate, might be revived. Currently, however, the target of having a low-calorie product, with a texture and flavour equivalent to that of normal chocolate, with no laxative or other side effects, has not been achieved on a large industrial scale. Many experimental products are, however, much nearer this goal than they were 10 years ago.

As traditional markets have tended to remain fairly static in size, the search for new markets will continue. As many of these are in hotter developing countries, the developments in heat-resistant chocolate, like the Hershey Desert Bar (which incorporates water and egg white), are likely to continue. There is also the Japanese approach of making chocolate softer from the refrigerator or freezer to increase summer sales. The former communist states in Eastern Europe are also providing new markets for the large multi-national chocolate companies. Here it is perhaps a two-way exchange, with the newer processes being introduced into these countries to make their traditional confectionery products, which might then be introduced to new markets.

In addition to new markets, chocolate is increasingly being used as a component of other food products, such as frozen desserts, mousses, ice creams and so on. This field is likely to expand. The general liking of the public for chocolate frequently means that the chocolate variant is the biggest seller.

An increase in engineering capability has in the past been reflected by larger machines, for example 2.5 m (8.2 ft) roll refiners, 10 t conches or larger and more sophisticated machinery such as the cocoa mass treatment machines. This increase in machine size may have now reached its limit but, as was noted earlier, improved process control has already played a major role and is likely to develop further. Automatic online instrumentation, neural networks, computer management and expert systems are likely to find increasing roles within the confectionery industry within the next few years. In addition, it should also be remembered that processes which have failed to operate satisfactorily in the past may have done so because the degree of engineering skill then available did not meet the required standard. New developments in materials, machines and process control may mean that old ideas are worth another consideration. Perhaps, for example, the jetmill/ultrasonic system of Mosimann (see Chapter 15) may be viable in some circumstances.

Research and development workers in almost every industry are frequently dispirited when the novel methods which operated satisfactorily in the laboratory or pilot scale area fail to do so under the more stringent conditions of the production line. Little progress will be made, however, unless the industry is prepared to take the financially great risk of trying very different machines and processes. The introduction of new processing technology is likely to prove of benefit both to the confectionery industry and to the many consumers of chocolate throughout the world.

The last two decades have seen the increasing use of online sales for higher-value products. It is particularly applicable to short shelf-life products or niche market ones such as special cocoa chocolates. The ability to personalise a box of products coupled with the formation of chocolate-tasting clubs means that this type of sales are likely to increase.

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Glossary

Alkalisation: A treatment used during the making of cocoa powder to give particles better suspension properties when they are used in a drink, alter the flavour and colour (commonly known as the Dutching process).

Amorphous: Not having a distinct crystalline form.

Bloom: Fat or sugar on the surface of chocolate giving a white sheen or sometimes individual white blobs.

Cacao: ***Theobroma cacao*** is the botanical name of the cocoa tree. Also used to refer to unprocessed cocoa and matter relating to the growing of cocoa.

Chocolate liquor: Another name for cocoa mass, used in United States.

Chocolate mass: May refer to either cocoa mass or partially processed chocolate.

Coatings: See "compounds" and "couverture".

Cocoa: Traditionally the manufactured powder used for drinks or food manufacture. Often refers to the commodity (fermented beans in bulk).

Cocoa butter: Fat pressed, expelled or extracted from the centre (kernels or nib) of cocoa beans.

Cocoa butter equivalent (CBE): Vegetable fats which are totally compatible with cocoa butter and can be mixed with it in any proportion.

Cocoa butter replacers (CBR): Vegetable fats of a non lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can be used to replace most of the cocoa butter in coating applications and can be used with some cocoa mass.

Cocoa butter substitutes (CBS): Vegetable fats of a lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can only be used with cocoa powder due to their low compatibility with cocoa butter.

Cocoa liquor: Another name for cocoa mass.

Cocoa mass: Cocoa nib ground finely to give a liquid above 35 °C (95 °F).

Cocoa nib: Cocoa beans with the shell removed.

Cocoa powder: Cocoa nib with some of the fat removed and ground into a powder.

Cold forming: A technology to make chocolate shells, or other shapes, wherein an exact amount of liquid chocolate is put into a cavity and a plunger at a

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temperature of less than 0 °C (32 °F) applies pressure to distribute and partially set the mass, so that it holds its shape.

Compounds: Materials that are similar to chocolate but do not meet the legal definition of chocolate, usually because they contain vegetable fats other than cocoa butter

Conche: A machine in which the chocolate is kept under agitation, so that the flavour is developed and the chocolate becomes liquid. Sometimes used for machines which treat cocoa mass to remove volatile components.

Chocolatl: Drink made from crushed cocoa beans developed by the Aztecs.

Countline: Item of confectionery sold and consumed as an individual unit, for example Mars bar.

Couverture: Usually refers to a high fat (i.e. over 31% cocoa butter), normally high-quality chocolate which gives high gloss and good snap. In the United Kingdom and the United States also refers to biscuit coating chocolate, which often contains non-cocoa vegetable fats.

Crumb: Intermediate material in the milk chocolate making process, composed of dehydrated milk, sugar and usually cocoa mass.

Dietetic chocolate: "Chocolate" made for people with special dietary requirements, for example lactose intolerance, diabetes.

Dutching process: See "alkalisation".

Emulsifier: A substance used to stabilise emulsions. In chocolate they function as surface active agents to lower the viscosity of liquid chocolate.

Enrober: Machine for coating sweet centres with chocolate, by pouring molten chocolate over them.

Fermentation: A process between harvesting and drying of cocoa beans which develops the cocoa flavour precursors. The beans are heaped together and the surrounding pulp undergoes a microbial fermentation. The resulting heat and acid cause bean death and a series of chemical changes in the nib.

Flavanol: A polyphenolic, water soluble plant pigment with antioxidant properties that maybe beneficial to health.

Husk: The wall of the cocoa pod which contains the fresh cocoa beans. Often incorrectly translated as the shell round the nib or kernel.

Lauric fat: A fat that contains lauric fatty acid (a saturated 12-carbon chain fatty acid), for example coconut oil, palm kernel oil.

Lecithin: Class of organic compounds similar to fats but with molecules containing nitrogen and phosphorus. Used in chocolate as a surface-active agent to improve its flow properties.

Lipid: Generic term for oils, fats and waxes.

Methylxanthine: See theobromine.

Microniser: Device for the radiant heating of cocoa beans so as to loosen the shell.

Milk fat replacer: A vegetable fat used to replace milk fat in chocolate.

Non-Newtonian liquid: A liquid whose viscosity varies according to the rate at which it is stirred (sheared).

Origin liquor or mass: Cocoa mass manufactured in the country of origin of the beans.

Outer: Box containing a number of retail units.

Panning: A method of coating a centre by building up layers of chocolate or other material carried out within a rotating pan or other device.

Plastic viscosity: Relates to the amount of energy required to keep a non-Newtonian liquid moving once it has started to move (see also yield value).

Polymorphism: The existence of the same substance in more than two different crystalline forms.

Polyphenol: An organic chemical found in cocoa beans and other fruits and vegetables. They have a molecular structure based on phenol units. These chemicals potentially have health benefits.

Precrystallisation: A method of producing a small percentage of crystals of the correct form within the chocolate, for example as occurs in a temperer.

Refiner: Roll mill, often with five rolls, used to grind solid chocolate ingredients. In some countries it also refers to machines for changing the flavour of cocoa mass. This is not used in this context in this book.

Rework: Substandard or waste material of food grade that can be recovered and reused.

Temperer: A machine for cooling/heating chocolate to form stable fat crystals, that is to achieve a glossy surface and avoid development of bloom.

***Theobroma*:** Biological name for the group of trees in which cocoa *(T. cacao)* is classified. It is derived from Greek and translates to “food of the gods”.

Theobromine: A methylxanthine found in cocoa, similar to caffeine, which has a mild stimulatory effect.

Viscosity: A measure of a liquid’s resistance to flow, that is how fluid it is. See “plastic viscosity” and “yield value”.

Winnowing: The separation of a light material from a denser one by blowing air over them. In the case of cocoa, the shell is blown away from the cocoa nib and collected separately.

Yield value: Relates to the amount of energy required to start a non-Newtonian liquid moving (see also plastic viscosity).

Useful physical constants

Thermal conductivity

Ingredient	State/temp.range	W/m°C (SI unit)	BTU/h ft°F (IMP unit)	Source
Cocoa mass	60°C (140°F)	0.21	0.123	[a]
Cocoa butter	Liquid 43°C (110°F)	0.12	0.07	[b]
Chocolate	40°C (104°F)	0.26	0.15	[c]
	35°C (95°F)	0.26	0.15	[c]
	30°C (86°F)	0.27	0.16	[c]
	27°C (80°F)	0.28	0.16	[c]
	15°C° (60°F)	0.22	0.13	[c]

[a] Measurement complicated by the long crystallization process and the associated heat of crystallization.

Sources:
[a] A. Dodson (1975) *Thermal Conductivity of Foods*. BFMIRA,Leatherhead, UK
[b] *The Manufacturing Confectioner.* August 1991.P.43.
[c] S.M. Clegg (2001) *Thermal Conductivity of Chocolate:* Summary Report Scientific & Technical Note 203, Leatherhead Food International. July 2001.

Specific heat

Ingredient	State/temp.range	J/kg°C (SI unit)	BTU/lbs°F (IMP unit)	Source
Cocoa butter	Solid/15–21°C (60–70°F)	2010	0.48	[a]
	Liquid/32–82°C (90–180°F)	2090	0.50	[a]
Chocolate	Liquid/solid 15–40°C (60–120°F)	1590	0.38	[a]
	Liquid/40–60°C (104–140°F)	1670	0.40	
Cocoa mass	Solid/4–25°C (39–77°F)	1970	0.47	
	Liquid/30–59°C (86–131°F)	1420	0.34	

Source: [a] *The Manufacturing Confectioner,* August 1991.p.43

Latent heat

Ingredient	J/g (SI unit)	BTU/lbs (IMP unit)
Cocoa butter	157	67.6
Dark chocolate	46	20.0
Milk chocolate	44	19.0

Source: J. Chevaley *et al.* (1970) A study of the physical properties of chocolate. *Reviews in international chocolate* **25** (Jan.) 4.

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ERH

Ingredient	Moisture content (%)	a_w range	ERH (%)
Chocolate	0.1–0.5	0.4	35–40

Source: The Manufacturing Confectioner, January 1987,p. 65.

Density

Ingredient	State/temp.range	g/cm^3 (SI unit)	lb/ft^3 (IMP unit)
Cocoa butter	Solid/15°C (59°F)	0.96–0.99	60
	Liquid	0.88–0.90	55
Chocolate	Solid	1.3	80
	Liquid/40°C (104°F)	1.2	76
Cocoa mass	Solid	1.1	68

Source: The manufacturing confectioner, July 1969,p. 49.

Flash point of Cocoa butter (with 1 % free fatty acid (FFA)) is 315°C (600°F). It will however be lower if more FFA or solvent extracted butter is present. (Rossell. J.B.(1998) Leatherhead Food RA, private communication.)

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