Beckett’s Industrial Chocolate
Manufacture and Use
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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 assisted 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 Research 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 and Development 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 Mánuez-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
Contributors

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).
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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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 (Whymer, 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
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
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.

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

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
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 the 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.

References


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.
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 may be 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.
Chapter 2

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

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.
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](image-url) 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.

<table>
<thead>
<tr>
<th>Name of pest or disease</th>
<th>Distribution*</th>
<th>Symptoms or damage</th>
<th>Controlb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black pod rot (<em>Phytophthora</em>)</td>
<td>World wide</td>
<td>Fungal attack of mainly the pods causing them to go brown and rot</td>
<td>Sanitation (removal of infected material). Regular frequent harvesting of pods. Application of fungicides</td>
</tr>
<tr>
<td>Witches’ broom (<em>Moniliophthora perniciosa</em>)</td>
<td>South America, Caribbean</td>
<td>Fungal attack causing extra growths or “brooms” to develop from leaf buds. Can also affect flowers and pods</td>
<td>Pruning and sanitation (removal of infected material). Application of fungicides</td>
</tr>
<tr>
<td>Frosty pod rot, <em>Monilia</em> (<em>Moniliophthora roteri</em>)</td>
<td>Peru, Ecuador, Colombia, Central America including Mexico</td>
<td>Fungal attack of the pods causing them to go brown and rot</td>
<td>Sanitation (removal of infected pods)</td>
</tr>
<tr>
<td>Vascular-streak dieback</td>
<td>South-east Asia, Pacific Islands</td>
<td>A fungal attack causing leaf fall and dying back of stems</td>
<td>Regular pruning of infected material. Cover nurseries to prevent infection of young plants</td>
</tr>
<tr>
<td>Cocoa swollen shoot virus</td>
<td>West Africa</td>
<td>Swelling or thickening of the shoots. The infected tree frequently dies</td>
<td>Eradication of infected trees</td>
</tr>
<tr>
<td>Capsids or mirids</td>
<td>World wide</td>
<td>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.</td>
<td>Application of insecticides</td>
</tr>
<tr>
<td>Cocoa pod borer</td>
<td>South-east Asia and Papua New Guinea</td>
<td>The caterpillar of this moth bores into the pods and affects the development of the beans</td>
<td>Regular frequent harvesting of pods, pruning, application of insecticides</td>
</tr>
</tbody>
</table>

*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.](image)
(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.
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 greish 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,
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 methylxanthenes 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.](image-url)
impacting 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 roadides 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
Chapter 2 looks at the cocoa value chain and the issue of farmer poverty. The price of cocoa is given in US$ or GBE 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
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 10t, 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>
<thead>
<tr>
<th>Month</th>
<th>Actuals or physical market</th>
<th>Futures or Terminal market</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>Buy 1000 t of cocoa at US$ 2000/t</td>
<td>Sell 100 lots at US$ 1950/t for delivery in December</td>
</tr>
<tr>
<td>December</td>
<td>Could have purchased 1000 t at US$ 1900/t</td>
<td>Buy 100 lots @US$ 1850/t to square position</td>
</tr>
<tr>
<td></td>
<td>Assumed loss US$ 100 000</td>
<td>Profit US$ 100 000</td>
</tr>
</tbody>
</table>
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).](image-url)
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.
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.

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

<table>
<thead>
<tr>
<th>Objective of the initiative</th>
<th>Rainforest Alliance</th>
<th>Fairtrade International</th>
<th>UTZ certified</th>
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<tbody>
<tr>
<td>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.</td>
<td>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.</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Inspection and Certification</td>
<td>Third party certification. Third-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.</td>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>
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...
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.

---

### Table 2.4 Composition of cocoa beans.

<table>
<thead>
<tr>
<th>Whole dried cocoa beans (as traded)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>Typical range (%)</td>
</tr>
<tr>
<td>Water/moisture</td>
<td>7.5</td>
</tr>
<tr>
<td>Shell (dry basis)</td>
<td>12.5</td>
</tr>
<tr>
<td>Nib (dry basis)</td>
<td>80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unfermented cocoa beans (dry, fat free)</th>
<th>Fermented cocoa beans (dry, fat free)</th>
<th>mg/g</th>
<th>mg/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total polyphenols</td>
<td></td>
<td>150–200</td>
<td>40–140</td>
</tr>
<tr>
<td>Procyanidins</td>
<td></td>
<td>61</td>
<td>23</td>
</tr>
<tr>
<td>Epicatechin</td>
<td></td>
<td>–</td>
<td>3–16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nib</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (%)</td>
<td>Range (%)</td>
</tr>
<tr>
<td>Water/moisture*</td>
<td>3.7</td>
</tr>
<tr>
<td>Fat (cocoa butter and shell fat)</td>
<td>53.5</td>
</tr>
<tr>
<td>Protein</td>
<td>12.7</td>
</tr>
<tr>
<td>Starch</td>
<td>6.7</td>
</tr>
<tr>
<td>Fibre (crude)</td>
<td>2.5</td>
</tr>
<tr>
<td>Ash</td>
<td>2.9</td>
</tr>
<tr>
<td>Theobromine</td>
<td>1.30</td>
</tr>
<tr>
<td>Caffeine</td>
<td>0.22</td>
</tr>
</tbody>
</table>

* 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.

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.

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

(Continued)
Table 2.5 (Continued)

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

* 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).

<table>
<thead>
<tr>
<th>Description (example of growth/grade)</th>
<th>Bean count</th>
<th>Cocoa bean faults</th>
<th>Foreign material (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCC (Europe) Good fermented, main crop</td>
<td>100/100g</td>
<td>5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5</td>
</tr>
<tr>
<td>FDA/CMAA&lt;sup&gt;d&lt;/sup&gt; (USA) Ghana (main crop)</td>
<td>1000/kg</td>
<td>4&lt;sup&gt;f&lt;/sup&gt;</td>
<td>10</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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.

<sup>b</sup> Max 5% defectives (= mouldy+infested).

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

<sup>d</sup> CMAA specifies that hammy or smoky cocoas are not deliverable.

<sup>f</sup> Maximum amount of mould+infestation is 6% (US FDA defect action levels).

<sup>g</sup> NS = Not specified.
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