Chocolate Science and Technology

Emmanuel Ohene Afoakwa
University of Ghana
Legon – Accra
Ghana

and formerly

Nestlé Product Technology Centre
York
UK
Chocolate Science and Technology
Dedication

This book is dedicated to my dear wife Ellen and our three lovely children, Nana Afra, Maame Agyeiwaa and Kwabena Ohene-Afoakwa (Jnr), whose wisdom, prayers and support have helped me achieve great success in my life.
Chocolate Science and Technology

Emmanuel Ohene Afoakwa
University of Ghana
Legon – Accra
Ghana

and formerly

Nestlé Product Technology Centre
York
UK
## Contents

Preface \hspace{1cm} xi
Acknowledgements \hspace{1cm} xiii
About the author \hspace{1cm} xv

1 **Chocolate production and consumption patterns** \hspace{1cm} 1
   1.1 History of cocoa and chocolate \hspace{1cm} 1
   1.2 World production and consumption of cocoa and chocolate products \hspace{1cm} 2
      1.2.1 World production and consumption of cocoa \hspace{1cm} 2
      1.2.2 World cocoa prices \hspace{1cm} 4
      1.2.3 World consumption of chocolate products \hspace{1cm} 5
      1.2.4 World consumption of premium chocolate products \hspace{1cm} 6
   1.3 Fairtrade cocoa and chocolate in modern confectionery industry \hspace{1cm} 7
      1.3.1 Future of Fairtrade cocoa and confectionery industry \hspace{1cm} 9
   1.4 The concept of this book \hspace{1cm} 10

2 **Cocoa cultivation, bean composition and chocolate flavour precursor formation and character** \hspace{1cm} 12
   2.1 Introduction \hspace{1cm} 12
   2.2 Cocoa cultivation and practices \hspace{1cm} 13
      2.2.1 Cultivation of cocoa \hspace{1cm} 13
      2.2.2 Flowering and pod development \hspace{1cm} 14
      2.2.3 Harvesting and pod opening \hspace{1cm} 16
      2.2.4 Cocoa diseases and pests and their influence on chocolate quality \hspace{1cm} 18
         2.2.4.1 Swollen shoot disease \hspace{1cm} 19
         2.2.4.2 Black pod disease \hspace{1cm} 19
         2.2.4.3 Witches broom disease \hspace{1cm} 20
         2.2.4.4 Pod borers (capsids, cocoa thrips and mealybugs) \hspace{1cm} 20
   2.3 Bean composition and flavour precursor formation \hspace{1cm} 20
      2.3.1 Chemical composition of the bean \hspace{1cm} 20
      2.3.2 Polyphenols and chocolate flavour quality \hspace{1cm} 21
      2.3.3 Effects of proteins and sugars on flavour precursor formation \hspace{1cm} 22
      2.3.4 Microbial succession and enzymatic activities during flavour precursor generation in cocoa fermentation \hspace{1cm} 23
   2.4 Effect of genotype on cocoa bean flavours \hspace{1cm} 26
   2.5 Flavour development during post-harvest treatments of cocoa \hspace{1cm} 27
      2.5.1 Fermentation processes \hspace{1cm} 27
      2.5.2 Drying \hspace{1cm} 30
   2.6 Conclusion \hspace{1cm} 33
3 Industrial chocolate manufacture – processes and factors influencing quality

3.1 Introduction

3.2 Cocoa processing and technology
   3.2.1 Bean selection and quality criteria
   3.2.2 Cleaning, breaking and winnowing
   3.2.3 Sterilisation
   3.2.4 Alkalisation
   3.2.5 Roasting
   3.2.6 Nib grinding and liquor treatment
   3.2.7 Liquor pressing
   3.2.8 Cake grinding (kibbling)
   3.2.9 Cocoa powder production

3.3 Chocolate manufacturing processes
   3.3.1 Mixing
   3.3.2 Refining
   3.3.3 Conching

3.4 Tempering, lipid crystallisation and continuous phase character during chocolate manufacture

3.5 Particle size distribution in chocolate

3.6 Compositional effects on rheological and textural qualities in chocolate
   3.6.1 The role of fats
   3.6.2 The role of sugar
   3.6.3 The role of milk and other dairy components
   3.6.4 The role of surfactants in modern chocolate confectionery

3.7 Moisture and chocolate flow

3.8 Chocolate quality and defects
   3.8.1 Chocolate quality
      3.8.1.1 Rheological measurements of chocolate quality
      3.8.1.2 Sensory evaluation of chocolate quality
   3.8.2 Chocolate defects
      3.8.2.1 Fat bloom
      3.8.2.2 Sugar bloom

3.9 Conclusion and further research

4 The chemistry of flavour development during cocoa processing and chocolate manufacture

4.1 Introduction

4.2 Influence of bean selection on chocolate flavour quality

4.3 Effect of roasting
   4.3.1 Maillard reactions – aldol condensation, polymerisation and cyclisation
   4.3.2 Effects of alkalisation

4.4 Flavour development during chocolate manufacture
   4.4.1 Conching

4.5 Key flavour compounds in milk chocolate
5 Sensory character and flavour perception of chocolates

5.1 Summary and industrial relevance 73
5.2 Introduction 73
5.3 Sensory perception of quality in chocolates 74
  5.3.1 Appearance 75
  5.3.2 Texture 75
  5.3.3 Taste 79
  5.3.4 Flavour and aroma 80
5.4 Sensory assessment of chocolates 80
5.5 Factor influencing chocolate flavour 81
5.6 Flavour release and perception of sweetness in chocolate 82
5.7 Dynamism of flavour perception in chocolate 84
5.8 Retronasal flavour release and perception during chocolate consumption 85
5.9 Measurement of flavour release and intensity in chocolates 87
5.10 Electronic noses and tongues as online sensors for sensory assessment of chocolates 89
5.11 Conclusion 89

6 Nutritional and health benefits of cocoa and chocolate consumption

6.1 Summary and significance 91
6.2 Introduction 91
6.3 Chemistry and composition of cocoa flavonoids 92
6.4 Chocolate types and their major nutritional constituents 94
6.5 Antioxidant properties and their mechanism of action 95
6.6 Effects on endothelial function, blood pressure and cardiovascular system 96
6.7 Effects on insulin sensitivity and carcinogenic properties 98
6.8 Cocoa, chocolate and aphrodisiac properties 99
6.9 Conclusion 100

7 Structure – properties (rheology, texture and melting) relationships in chocolate manufacture

7.1 Summary and industrial relevance 101
7.2 Introduction 102
7.3 Materials and methods 104
  7.3.1 Materials 104
  7.3.2 Preparation of chocolate samples 105
  7.3.3 Determination of particle size distribution 105
  7.3.4 Rheological measurements 105
  7.3.5 Tempering procedure 108
  7.3.6 Texture measurements 109
  7.3.7 Colour measurements of solid dark chocolate 111
  7.3.8 Microstructure analysis 111
## Contents

7.3.9 Determination of melting properties of dark chocolates 111  
7.3.10 Experimental design and statistical analysis 112  

7.4 Results and discussion 112  
7.4.1 Particle size distribution of molten dark chocolate 112  
7.4.2 Rheological properties of molten dark chocolate 115  
7.4.2.1 Casson plastic viscosity 115  
7.4.2.2 Casson yield value 116  
7.4.2.3 Apparent viscosity 118  
7.4.2.4 Yield stress 119  
7.4.2.5 Thixotropy 119  

7.5 Relationships between casson model and ICA recommendations 120  

7.6 Textural properties 123  
7.6.1 Molten dark chocolate 123  
7.6.2 Hardness of tempered dark chocolate 125  
7.6.3 Colour measurements 128  
7.6.4 Relationships between textural properties and appearance of dark chocolate 129  

7.7 Microstructural properties of molten dark chocolate 131  

7.8 Melting properties of dark chocolate 133  
7.8.1 Effects of particle size distribution 135  
7.8.2 Effects of fat content 141  
7.8.3 Effects of lecithin 142  

7.9 Relationships between rheological, textural and melting properties of dark chocolate 144  

7.10 Conclusion 153  

8 Tempering behaviour during chocolate manufacture: effects of varying product matrices 155  
8.1 Summary and industrial relevance 155  
8.2 Introduction 156  
8.3 Materials and methods 157  
8.3.1 Materials 157  
8.3.2 Tempering procedure 158  
8.3.3 Determination of particle size distribution 158  
8.3.4 Experimental design and statistical analysis 160  
8.4 Results and discussion 161  
8.4.1 Particle size distribution of dark chocolates 161  
8.4.2 Effect of particle size distribution on tempering behaviour 165  
8.4.3 Effect of fat content on tempering behaviour 169  
8.5 Conclusion 172  

9 Tempering and fat crystallisation effects on chocolate quality 174  
9.1 Summary and industrial relevance 174  
9.2 Introduction 174  
9.3 Materials and methods 175  
9.3.1 Materials 175  
9.3.2 Determination of particle size distribution 176
Contents

9.3.3 Tempering experiment 176
9.3.4 Texture measurements 177
9.3.5 Colour and gloss measurements 177
9.3.6 Image acquisition and capture 177
9.3.7 Determination of melting properties 178
9.3.8 Microstructural determinations 178
9.3.9 Scanning electron microscopy 178
9.3.10 Experimental design and statistical analysis 179

9.4 Results and discussion 179
9.4.1 Particle size distribution of dark chocolates 179
9.4.2 Fat crystallisation behaviours during tempering of dark chocolate 179
9.4.3 Effect of temper regime and PSD on mechanical properties 181
9.4.4 Effect of temper regime and PSD on colour and gloss 182
9.4.5 Effect of temper regime and PSD on melting properties 185
  9.4.5.1 Effects of temper regime 185
  9.4.5.2 Effects of particle size distribution 187
  9.4.5.3 Thermal behaviours and ratio of sugar/fat melting enthalpies in products 188
  9.4.5.4 Effect of temper regime on product image 190
9.4.6 Effect of temper regime on microstructure 190
9.4.7 Effect of temper regime on scanning electron microstructure 193

9.5 Conclusion 197

10 Fat bloom formation and development in chocolates 198
10.1 Summary and industrial relevance 198
10.2 Introduction 198
10.3 Materials and methods 200
  10.3.1 Materials 200
  10.3.2 Determination of particle size distribution 200
  10.3.3 Tempering experiment 200
  10.3.4 Texture measurements 201
  10.3.5 Surface colour and gloss measurements 201
  10.3.6 Determination of melting properties 201
  10.3.7 Microstructural determinations 202
  10.3.8 Experimental design and statistical analysis 202
10.4 Results and discussion 202
  10.4.1 Particle size distribution of dark chocolates 202
  10.4.2 Changes in textural properties during blooming 203
  10.4.3 Changes in appearance (surface whiteness and gloss) during blooming 204
  10.4.4 Changes in melting behaviour during blooming 207
  10.4.5 Changes in microstructure during blooming 208
10.5 Conclusion 212
11 Matrix effects on flavour volatiles character and release in chocolates 215

11.1 Summary and industrial relevance 215
11.2 Introduction 215
11.3 Materials and methods 216
  11.3.1 Materials 216
  11.3.2 Tempering procedure 217
  11.3.3 Determination of particle size distribution 217
  11.3.4 Quantification of flavour volatiles by gas chromatography 218
  11.3.5 Gas chromatography–olfactometry analytical conditions 218
  11.3.6 Experimental design and statistical analysis 218
11.4 Results and discussion 219
  11.4.1 Particle size distribution of dark chocolates 219
  11.4.2 Characterisation of flavour compounds in dark chocolates 219
  11.4.3 Effects of particle size distribution on flavour volatile release 222
  11.4.4 Effects of fat content on flavour volatile release 225
  11.4.5 Relating flavour volatiles release to PSD and fat content: product spaces 227
11.5 Conclusion 228

12 Conclusions and industrial applications 230

12.1 Conclusions: Structure–properties relationships in chocolate manufacture 230
12.2 Conclusions: Tempering behaviour from response surface methodology 231
12.3 Conclusions: Effects of tempering and fat crystallisation on microstructure and physical properties 232
12.4 Conclusions: FAT bloom formation and development with undertempering 233
12.5 Conclusions: Flavour volatiles and matrix effects related to variations in PSD and FAT content 233
12.6 Industrial relevance and applications of research findings in this book 234
12.7 Recommendations for further research studies 235

References 236
Appendix 1. Abbreviations used and their meanings 254
Appendix 2. Abbreviations, acronyms and websites of organisations related to cocoa and chocolate industry 255
Appendix 3. Glossary of chocolate terminologies 256
Index 259

The colour plate section (‘Photographs showing chocolate manufacture from cocoa seedling to final product’) follows page 16
The character of chocolate not only originates in flavour precursors present in cocoa beans but are generated during post-harvest treatments and transformed into desirable odour notes in the manufacturing processes. Complex biochemical modifications of cocoa bean constituents are further altered by thermal reactions in roasting and conching, and in alkalisation. However, less well understood is the extent to which the inherent bean constituents from the cocoa genotype, environmental factors, and post-harvest treatments and processing technologies affect flavour formation and the final flavour quality. This book provides scientific and technological accounts of all these issues as well as for the various biological and genetic factors that modulate variations in flavour formation in cocoa and chocolate. It explains the chemistry of Maillard reactions that leads to flavour development during cocoa processing and chocolate manufacture, using chemical equations and specific technical examples. With the increase of speciality niche products in the modern chocolate confectionery industry, a better understanding of these factors could have significant commercial implications.

Chocolate as a complex emulsion is a luxury food that during consumption evokes a range of stimuli that activate pleasure centres of the human brain. Central to chocolate quality is an appropriate melting behaviour that ensures products are solid at ambient temperature but melt on ingestion to undergo dissolution in oral saliva, with a final assessment of texture after phase inversion. During manufacture, several factors play important roles in shaping chocolate’s rheological behaviour, textural properties, melting characteristics and sensory perception, but the science and technologies involved are poorly understood. With opportunities for improvements in quality possible through improved and more transparent supply chain management, plant breeding strategies and new product development associated with Fairtrade and the development of niche/premium quality products, there is a need for greater understanding of the variables as well as the science and technologies employed.

This book provides detailed, reviewed explanation of the scientific and technological basis of the various chocolate manufacturing processes used in the modern confectionery industry. Using the latest research, it also provides scientific answers to many of the frequently asked questions on process improvements, quality control, quality assurance, and the production of low-fat chocolates and niche/premium products. The ideas and explanations provided in this book evolved from my doctorate research on chocolate technology, and contain findings that impact on quality assurance processes and new product development techniques with significance for cost reduction and improved product quality. The chapters cover the entirety of the science and technology of chocolate manufacture – from cocoa production through manufacturing processes to nutrition and health benefits of chocolate consumption.

It is hoped that this book will be a valuable resource for academic and research institutions around the world, and as a training manual on cocoa processing, chocolate technology and the science of chocolate manufacture. It is aimed at confectionery and chocolate scientists
in industry and academia, general practicing food scientists and technologists, and food engineers. The chapters on research developments are intended to help generate ideas for new research activities relating to process improvements, product quality control and assurance, as well as development of new niche/premium chocolate products.

It is my vision that this book will inspire African food industries in their quest for adding value to the many raw materials that are produced within the continent, especially cocoa.
Acknowledgements

I wish to express my sincere gratitude and thanks to my parents – late Mr Joseph Ohene Afoakwa (Esq.) and Mrs Margaret Afoakwa – for ensuring I obtained the best education in spite of the numerous challenges they faced in some periods of their lives. Their profound love, prayers, support and advice strengthened me from my childhood, giving birth to the many dreams and aspirations which have all become realities in my life today. I am also grateful to the government of Ghana and to all cocoa farmers in Ghana whose toil and sweat funded my education through the Ghana Cocoa Board Scholarship Scheme, which I earned all throughout my secondary education, and without which I could not have remained in school and secured a place at university. I am indeed indebted to you all.

My gratitude and appreciation also goes to the Management of Nestlé Product Technology Centre (York, UK) for providing the funding and support for my training in chocolate technology at the Nestlé Product Technology Centre, York, and also to Dr Alistair Paterson, Centre for Food Quality, University of Strathclyde, Glasgow, UK, Mr Mark Fowler, Head of Applied Science Department of Nestlé Product Technology Centre (York, UK) and Dr Steve Beckett (retired confectionery expert) for their support, encouragement, patience and friendliness during the period of my doctoral training in York. Many thanks also go to Joselio Vieira, Angela Ryan, John Rasburn, Peter Cooke, Philip Gonus, Angel Manéz, Jan Kuendigar, Ramana Sundara and Sylvia Coquerel of Nestlé Product Technology Centre, York, and to Dr Jeremy Hargreaves (Nestlé Head Office, Vevey, Switzerland) whose advice, guidance and support enhanced my understanding into the science and technology of chocolates.

My sincere thanks also go to the many friends and colleagues around the world who have mentored, encouraged and inspired me in various ways throughout my career including Professor Samuel Sefa-Dedeh, Professor George Sodah Ayernor, Professor Ebenezer Asibey-Berko, Professor Anna Larney, Dr Esther Sakyi-Dawson, Dr Kwaku Tano-Debrah, Dr Agnes Simpson Budu, Dr William Bruce Owusu and Dr George Annon, all of the Department of Nutrition and Food Science, University of Ghana, Legon – Accra, Ghana; Professor Demetre Labadarios (formerly of Stellenbosch University) and Executive Director of Knowledge Systems, Human Sciences Research Council in Cape Town, South Africa; Professor Ruth Oniang’o, Founder and Editor-in-Chief of the African Journal of Food, Agriculture, Nutrition and Development (AJFAND), Nairobi, Kenya; Dr Linley Chiwona-Karlton of the Swedish University of Agricultural Sciences, Uppsala, Sweden; Mr George Ekow Hayford, Quality Assurance and Regulatory Affairs Manager for Nestlé Central West African Region; Dr Gene White, Dr Janey Thornton, Mrs Barbara Belmont, Ms Penny McConnell, Mr Paul Alberghine and Mrs Mary Owens of the Global Child Nutrition Foundation, Washington, DC, USA.

Finally, my profound appreciation and love goes to my siblings Sammy, Juliana, and Regina for their prayers and support throughout my education, and again to my dear wife
Ellen and our lovely children Cita, Nana Afra, Maame Agyeiwaa and Kwabena Ohene-Afoakwa (Jnr) for supporting me and most importantly providing the much needed love, encouragement and affection that strengthened me throughout my career. We all have very good memories of the beautiful cities of London, York and Glasgow, the Nestlé Rowntree Factory and the Nestlé Product Technology Centre in York, UK.
About the author

Emmanuel Ohene Afoakwa, BSc (Hons), MPhil (Ghana), PhD (Strathclyde, UK) in Food Technology, holds Postgraduate Certificates in International Food Laws and Regulations from the Michigan State University, East Lansing, Michigan, USA, and Food Quality Management Systems from the Wageningen University, Wageningen, the Netherlands. He is a member of several professional bodies and has authored and co-authored 112 publications (including 52 peer-reviewed journal publications, 4 books and 56 conference presentations with published abstracts) in food science and technology. As a technical consultant to many multinational food industries in sub-Saharan Africa, he has vast experience in food technology and translates his research findings through process and product development into industrial productions. He spent 3 years training and conducting active research into chocolate manufacture at the Nestlé Product Technology Centre in York, UK, where he acquired various skills and knowledge into the science and technology of chocolate. He has several research and review publications on chocolate science and technology in peer-reviewed journals and has presented several papers on chocolate technology at international conferences around the world including the Annual Meeting of Food Technologists (IFT) in USA, World Congress of Food Science and Technology (IUFoST Bi-annual Congresses) in France and China, and the ZDS Chocolate Technology International Congress by ZDS Solingen in Cologne, Germany. Presently, he is a Senior Lecturer at the Department of Nutrition and Food Science, University of Ghana, Legon – Accra, Ghana, where he has worked for over 12 years, teaching and conducting research into the areas of beverage (chocolate and sugar) science and technology, food chemistry and thermal processing of foods.
1 Chocolate production and consumption patterns

1.1 HISTORY OF COCOA AND CHOCOLATE

The term ‘cocoa’ is a corruption of the word ‘cacao’ that is taken directly from Mayan and Aztec languages. Chocolate is derived from cocoa beans, central to the fruit of cocoa tree, *Theobroma cacao*, which is indigenous to South America and believed to have originated from the Amazon and Orinoco valleys. *Theobroma* (food of the gods) are of the family Sterculiaceae with four principal types: Criollo, about 5% of world cocoa production; and the more common Forastero, with smaller, flatter and purple beans; Nacional with fine flavour, grown in Ecuador. The fourth variety, Trinitario, a more disease-resistant hybrid of Criollo and Forastero is regarded as a flavour bean (Fowler, 1999). *Theobroma cacao* grows between tropics of Cancer and Capricorn, with varieties originating in forest areas of South America. Forastero – basic cocoa, grows mainly in Brazil and West Africa, whilst flavour cocoas are largely hybrids and are cultivated in Central and South America. Aztecs in Mexico cultivated cocoa from South America, via Caribbean islands, and Hernandos Cortés, a Spanish, took cocoa to Spain as a beverage and to Spanish Guinea as a crop. The Spanish not only took cocoa to Europe but also introduced the crop into Fernando Po in the seventeenth century, and thus laid the foundation of the future economies of many West African countries. Currently, West Africa produces more than 70% of world cocoa (Awua, 2002; Amoye, 2006; International Cocoa Organisation, ICCO, 2008).

The use of cocoa beans dates back at least 1400 years (Rössner, 1997), when Aztecs and Incas used the beans as currency for trading or to produce the so-called chocolatl, a drink made by roasting and grinding cocoa nibs, mashing with water, often adding other ingredients such as vanilla, spices or honey. In the 1520s, the drink was introduced into Spain (Minifie, 1989) although Coe and Coe (1996) emphasised that the European arrivals in the new world, including Christopher Columbus and Herman Cortes, were unimpressed with the Mayan beverage, sweetening it with honey. Nevertheless, the conquistadors familiarised the chocolate beverage throughout Europe, and being expensive, it was initially reserved for consumption by the highest social classes, and only in the seventeenth century that the consumption of chocolate spread through Europe.

As the consumption of chocolate became more and more widespread during the eighteenth century, the Spanish monopoly on the production of cocoa soon became untenable and plantations were soon established by the Italians, Dutch and Portuguese. At this point, chocolate was still consumed in liquid form and was mainly sold as pressed blocks of a grainy mass to be dissolved in water or milk to form a foamy chocolate drink. The mass production of these chocolate blocks also began in the eighteenth century when the British Fry family founded the first chocolate factory in 1728, using hydraulic equipment to grind
the cocoa beans. The first US factory was built by Dr James Baker outside Boston a few decades later, and in 1778 the Frenchman Doret built the first automated machine for grinding cocoa beans. The production of cocoa and chocolate was truly revolutionised by Coenraad Van Houten in 1828 by the invention of a cocoa press, which succeeded in separating cocoa solids from cocoa butter. The resulting defatted cocoa powder was much easier to dissolve in water and other liquids and paved the way, in 1848, for the invention of the first real ‘eating chocolate’, produced from the addition of cocoa butter and sugar to cocoa liquor (Dhoedt, 2008).

In the UK in 1847, Joseph Fry was the first to produce a plain eating chocolate bar, made possible by introduction of cocoa butter as an ingredient (Beckett, 2000). Demand for cocoa then sharply increased, and chocolate processing became mechanised with development of cocoa presses for production of cocoa butter and cocoa powder by Van Houten in 1828, and milk chocolate in 1876 by Daniel Peters, who had the idea of adding milk powder – an invention of Henri Nestlé, a decade earlier. This was followed by the invention of the conching machine in 1880 by Rudolphe Lindt, from where chocolate came to take on the fine taste and creamy texture we now associate with good-quality chocolate. It was still very much an exclusive product, however, and it was not until 1900 when the price of chocolate’s two main ingredients, cocoa and sugar, dropped considerably that chocolate became accessible to the middle class. By the 1930s and 1940s, new and cheaper supplies of raw materials and more efficient production processes had emerged at the cutting-edge of innovation with fast-manufacturing technologies and new marketing techniques through research and development by many companies in Europe and the United States, making chocolate affordable for the wider populace. Chocolate confectionery is now ubiquitous with consumption averaging 8.0 kg/person per annum in many European countries (Nuttall & Hart, 1999; Whitefield, 2005; ICCO, 2008).

1.2 WORLD PRODUCTION AND CONSUMPTION OF COCOA AND CHOCOLATE PRODUCTS

1.2.1 World production and consumption of cocoa

*Theobroma cacao* originated in the Amazon Basin and optimal conditions for growth are 20–30°C (68–86°F), 1500–2500 mm of annual rainfall and 2000 hours of sunshine per year. Table 1.1 shows that density of production is centred within West Africa, accounting for approximately 71% of world cocoa production in 2005–2006 growing season. West African countries are ideal in climatic terms for growing cocoa as a cash crop. However, as a consequence, natural or man-made problems have potentially a disproportionately large impact on cocoa trade. Small holders of West Africa have dominated world production since the 1930s. In 1980s, emergence of Malaysia and Indonesia gave more balanced geographical spread of production.

However, a period of low prices wiped out Malaysia as a major producer and Brazil as a major exporter, increasing share of production of West Africa. In 2005–2006, 71% of world cocoa came from Africa: Côte d’Ivoire, 37.8%; Ghana, 19.9% (ICCO, 2008).

In 2006–2007, world production of cocoa beans dropped by almost 9% from the previous season to 3.4 million tonnes, mainly as a consequence of unfavourable weather conditions in many cocoa-producing areas. West Africa, the main cocoa-producing region, was hit by a severe harmattan and its inherent dry weather, which lasted from the end of 2006 to
Table 1.1  World cocoa production between 2004 and 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>World total</td>
<td>3379 (100%)</td>
<td>3724 (100%)</td>
<td>3400 (100%)</td>
</tr>
<tr>
<td>Africa</td>
<td>2375 (70.3%)</td>
<td>2642 (71.0%)</td>
<td>2392 (70.4%)</td>
</tr>
<tr>
<td>Americas</td>
<td>445 (13.2%)</td>
<td>446 (12.0%)</td>
<td>411 (12.1%)</td>
</tr>
<tr>
<td>Asia and Oceania</td>
<td>559 (16.5%)</td>
<td>636 (17.1%)</td>
<td>597 (17.5%)</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>1286 (38.1%)</td>
<td>1408 (37.8%)</td>
<td>1292 (38.0%)</td>
</tr>
<tr>
<td>Ghana</td>
<td>599 (17.8%)</td>
<td>740 (19.9%)</td>
<td>614 (18.1%)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>460</td>
<td>530</td>
<td>490</td>
</tr>
<tr>
<td>Nigeria</td>
<td>200</td>
<td>200</td>
<td>190</td>
</tr>
<tr>
<td>Cameroon</td>
<td>104</td>
<td>166</td>
<td>129</td>
</tr>
<tr>
<td>Brazil</td>
<td>171</td>
<td>162</td>
<td>126</td>
</tr>
<tr>
<td>Ecuador</td>
<td>116</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>48</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>31</td>
<td>42</td>
<td>47</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses represent percentage (%) of annual production. Totals and differences may differ due to rounding. Source: ICCO (2008).

February 2007, had a strong negative impact on production. In Asia and South America, El Niño-related weather conditions developed in September 2006 and continued until the beginning of 2007. Cocoa production in the two major producing countries was severely hit in 2006–2007.

Production in Ghana declined by 17% from the previous season to 614 000 tonnes, resulting mainly from a very poor mid-crop. In Côte d’Ivoire, cocoa output reached 1 292 000 tonnes, down by 116 000 tonnes from the 2005–2006 season. As in Ghana, the second harvest of the season proved very disappointing, as the trees did not recover from the poor level of soil moisture and lack of rainfall, which lasted until February 2007, causing many developing pods to shrivel. The statistical picture for the mid-crop in Côte d’Ivoire could have been worse. Indeed, the 2007–2008 main crop experienced an early and strong start at the end of August – almost 100 000 tonnes of cocoa beans reached Ivorian ports in September 2007. These cocoa beans were statistically counted as part of the 2006–2007 mid-crop and, consequently, enhanced the production figures of the 2006–2007 cocoa season, while in fact, they were part of the 2007–2008 main crop (ICCO, 2008).

Cocoa consumption, as measured by grindings, increased by 2.5% from the 2005–2006 season to 3 608 000 tonnes in 2006–2007 (Table 1.2). Despite a relative slowdown during that season, the cocoa market was characterised over the last 5 years by a sustained demand for cocoa, rising by 3.8% per annum (based on a 3-year moving average) (ICCO, 2008). It was supported by a strong demand for cocoa butter to rebuild stocks, as well as by rising chocolate consumption in emerging and newly industrialised markets, and changes in chocolate consumption behaviour in mature markets towards higher cocoa content chocolate products.

At the regional level, developments were heterogeneous in 2006–2007, with grindings rising by around 6% in Europe to 1 540 000 tonnes and to 514 000 tonnes in Africa (Table 1.2). Meanwhile, they remained at almost the same level, at 699 000 tonnes in Asia and Oceania and declined by 3% in the Americas to 853 000 tonnes. Processors located in Germany and Ghana contributed to almost half of the increase in world grindings, reflecting
Table 1.2  World consumption/grinding of cocoa beans between 2004 and 2007

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>1379 (41.4%)</td>
<td>1456 (41.4%)</td>
<td>1540 (42.7%)</td>
</tr>
<tr>
<td>Germany</td>
<td>235</td>
<td>306</td>
<td>357</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>460</td>
<td>455</td>
<td>465</td>
</tr>
<tr>
<td>Others</td>
<td>684</td>
<td>695</td>
<td>719</td>
</tr>
<tr>
<td>Africa</td>
<td>501 (14.9%)</td>
<td>485 (13.8%)</td>
<td>514 (14.3%)</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>364</td>
<td>336</td>
<td>336</td>
</tr>
<tr>
<td>Others</td>
<td>137</td>
<td>149</td>
<td>179</td>
</tr>
<tr>
<td>Americas</td>
<td>853 (25.4%)</td>
<td>881 (25.0%)</td>
<td>853 (23.7%)</td>
</tr>
<tr>
<td>The United States</td>
<td>419</td>
<td>432</td>
<td>418</td>
</tr>
<tr>
<td>Brazil</td>
<td>209</td>
<td>223</td>
<td>224</td>
</tr>
<tr>
<td>Others</td>
<td>225</td>
<td>226</td>
<td>212</td>
</tr>
<tr>
<td>Asia and Oceania</td>
<td>622 (18.5%)</td>
<td>698 (19.8%)</td>
<td>699 (19.4%)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>115</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Malaysia</td>
<td>249</td>
<td>267</td>
<td>270</td>
</tr>
<tr>
<td>Others</td>
<td>258</td>
<td>291</td>
<td>289</td>
</tr>
<tr>
<td>World total</td>
<td>3354</td>
<td>3520</td>
<td>3608</td>
</tr>
<tr>
<td>Origin</td>
<td>1262</td>
<td>1293</td>
<td>1325</td>
</tr>
<tr>
<td></td>
<td>(37.6%)</td>
<td>(36.8%)</td>
<td>(36.7%)</td>
</tr>
</tbody>
</table>

Note: Figures in parentheses represent percentage (%) of annual consumption/grinding. Total and difference may differ due to rounding. Source: ICCO (2008).

the installation of additional capacities in these countries. The Netherlands and the United States remained the major cocoa processing countries, each with grindings of more than 400 000 tonnes during the year.

The ICCO (2008) reported that the average consumption of cocoa beans in the world is 0.55 kg/person. Europeans consume most at 1.81 kg/person, followed by Americans (1.38 kg/person), with people of Africa and Asia/Oceania consuming only 0.14 and 0.11 kg/person, respectively. Belgium/Luxembourg had the highest per capita consumption of cocoa beans with 5.97 kg/person, followed by Switzerland (5.28 kg/person), France (3.90 kg/person), Germany (3.76 kg/person) and the UK (3.72 kg/person). Others include United States (2.72 kg/person), Slovenia (2.66 kg/person), Australia (2.65 kg/person), Croatia (2.14 kg/person), Japan (1.29 kg/person), Russia (1.24 kg/person), Brazil (0.53 kg/person), Côte d’Ivoire (0.49 kg/person), Ghana (0.47 kg/person) and China (0.03 kg/person).

1.2.2 World cocoa prices

World cocoa prices have been increasingly fluctuating since the fallout period between 1999 and 2000 when it reached a lowest of about US$940 per tonne. Prices of the beans increased drastically to about US$1850 in 2002, after which regular fluctuations of US$1550 and 1850 were recorded between 2002 and 2007. Average international cocoa prices, as measured by the ICCO daily price, increased in 2006–2007 from the previous cocoa year by 19% to US$1854 per tonne. The large production deficit in the 2006–2007 cocoa season had been the main factor leading to this development in the market (ICCO, 2008). Other bullish factors included the position in the futures markets of cocoa processors and chocolate manufacturers,
having below average forward fixed price coverage, and the weakening US dollar against
other major currencies.

The highest price level of the season was reached on 6 July 2007, when prices climbed to
£1140 on the London terminal market and US$2144 in New York, their highest levels since
2003. However, the strong increase in recorded prices induced some nervousness among
market participants and, at such relatively high prices, the markets were rendered vulnerable
to profit-taking. In the second week of July, the cocoa futures markets witnessed a strong
adjustment, and after a short-lived recovery, the markets again retreated until the fourth week
of August.

Notably, within the first quarter of 2009, cocoa prices were stabilised both in the London
and New York markets, and the beans were sold around US$2300–2400 per tonne. However,
in May–June 2009, prices were averaging between US$2500 and 2600 per tonne in the interna-
tional market. Surprisingly, between July and December 2009, prices of cocoa increased
sharply from US$2600 in July to US$3500 per tonne in December on both London and
New York terminal markets, and this trend in prices apparently will continue to rise in the
ensuing year. It is noteworthy that cocoa production continues to be the major agricultural
mainstay of the economies of Ghana and La Côte d’Ivoire, representing over 60% of their
revenue generation from the agricultural sector; therefore, any price fluctuations would affect
the stabilities of these economies.

1.2.3 World consumption of chocolate products

The international global sale of chocolate was estimated at US$74 billion in 2006, an increase
of 5% since 2005, and the Western European region accounts for an estimated 45% of global
chocolate sales in volume sales. Figures for consumption of chocolate products in 2006
(Fig. 1.1) revealed Switzerland as the leader in chocolate consumption at 9.9 kg/person
with Austria at 9.3 kg/person, Norway (8.5 kg/person), Ireland (8.4 kg/person), Germany
(8.2 kg/person) and the UK (7.9 kg/person). No African country comes close (International
Confectionery Association, 2007). Consumption of chocolate is highest within Western
Europe in per capita terms, where household penetration is high and whose consumers eat
chocolate several times during an average week. Per capita consumption levels tend to be
highest in the more northerly European countries or those with a strong chocolate heritage –
major examples include Switzerland, the UK, Belgium, Germany and Ireland.

In recent years, the consumer base has also become more sophisticated, with more people
in regions such as the United States and Europe coming to regard themselves as connoisseurs
of chocolate. This has led to rising demand for a wide variety of more upmarket ingredients,
as well as products made from beans sourced from countries such as Ghana, Ecuador and
Venezuela. On a geographical basis, sales are heavily skewed towards Europe and North
America, which is to be expected since consumers in these regions are generally more affluent
compared with other parts of the world. However, evidence exists that consumers are turning
to premium varieties of chocolate with greater frequency elsewhere, notably in parts of the
Far East such as Japan, South Korea and Thailand, as well as in Australasia. Some leading
chocolate suppliers are now believed to be targeting developing economies such as China and
Russia, which suggests a potential market for premium chocolate in these parts of the world.

Much of the recent growth in the market has resulted from the entrance of many of the
world’s leading chocolate suppliers, as a result of which levels of new product development
have been high. For example, up to 1500 new products have now been launched in the sec-
tor since 2002, with more manufacturers striving to develop a strong portfolio of premium
chocolate ranges. Many are now collaborating more heavily with artisanal chocolate producers to develop premium lines.

Demand for dark chocolate is increasing and currently accounts for 8–10% of global chocolate tablet sales. In 2006 it was reported that 33% of chocolate products launched were dark chocolate confectionery and US dark chocolate consumption increased at about 9% per annum over the period 2001–2005. Popularity of dark chocolate relates to research findings on positive impact of cocoa and chocolate on cardiovascular health.

1.2.4 World consumption of premium chocolate products

Premium chocolate represents a fast-growing and dynamic market in many parts of the world, with global sales having risen by over 18% within the last year. Sales and consumer

![Fig. 1.1 Per capita consumption of chocolate confectionery by country. Source: International Confectionery Association (2007).](image-url)
awareness are both growing for a variety of reasons – these include wider availability of premium chocolate at the retail level and high levels of new product activity. Additionally, more consumers are becoming attracted to dark chocolate on account of its health benefits, while ethical concerns have increased demand for organic and Fairtrade chocolate, all of which tend to be positioned at the premium end of the market. At present, sales of premium chocolate are heavily skewed towards the European and North American regions, which together accounted for almost 98% of global value in 2007. This is mainly because consumers are generally more affluent in these parts of the world and purchasing power is therefore higher, as well as many leading suppliers of premium chocolate are headquartered either in the United States or in Europe, the latter of which boasts of a long-standing chocolate manufacturing heritage. However, sales of premium chocolate are now developing in other parts of the world, with a more affluent urban consumer base emerging in countries such as Russia and China.

In spite of recent growth, premium varieties still account for less than 10% of the global chocolate market. This figure rises to around 12% for Europe, and at 32%, it is especially high in Switzerland. The premium sector accounted for almost 18% of the US retail chocolate market in 2007, although this figure is forecast to increase to around a quarter by 2011. From a consumer’s standpoint, purchasers of premium chocolate are increasingly no longer confined to the higher income groups, as a result of which the sector is encroaching on the mainstream chocolate market. With the consumer base continuing to widen, the premium chocolate sector is increasingly coming to mirror trends observed recently in markets such as wine and coffee. More people are now becoming more knowledgeable about specific cocoa varieties and their origins. As the premium chocolate market has grown, more of the leading multinational confectionery suppliers have been developing their products ranges in this area. This has mainly been done via acquisition or collaboration with specialist suppliers. Many companies have also increased levels of new product activity, launching new lines in sectors such as dark, single-origin, organic and Fairtrade chocolate.

1.3 FAIRTRADE COCOA AND CHOCOLATE IN MODERN CONFECTIONERY INDUSTRY

Fairtrade is a trading partnership that aims for sustainable development of excluded and disadvantaged producers, seeking greater equity in international trade by offering better trading conditions, and securing the rights of marginalised producers and workers – especially in the South. Fairtrade Labelling Organizations (FLO) backed by consumers are actively engaged in supporting producers, raising awareness and campaigning for changes in rules and practices of conventional international trade, with regulated terms of trade that ensure that farmers and workers in the poorest countries in the world are adequately protected and can build a more sustainable future (Fairtrade Federation, 1999; EFTA, 2005; FLO, 2006).

The concept of ‘Fairtrade’ has existed since the early 1960s, founded by a group of importers and non-profit retailers in the wealthy, northern European countries and small-scale producers in developing countries. The aim was fighting against low market prices and high dependence on brokers, a more direct type of trade with the European market. Conventional trading relations between the South and the North were believed unfair and unsustainable. Its goal is to tackle poverty in developing countries through trade, and its pragmatic approach is central to its success. However, diversity in the movement, its lack
of structure and economies of production scale were impediments to sustainability. Thus, since the early 1990s, the Fairtrade movement has become more organised and is now growing rapidly with about US$200 million annually in sales (Brown, 1993; Kilian et al., 2006). Fairtrade models that use a broad definition of farmer benefits have been widely studied (Dankers, 2003; Parrish et al., 2005; Shreck, 2005; Jaffee, 2007), and find Fairtrade approaches beneficial to smallholder development. Other studies, which focus on the income effects of higher prices to farmers (LeClair, 2002; Maseland & de Vaal, 2002; Lindsey, 2003; Zehner, 2003), tend to conclude in favour of free trade approaches. Harmonisation of definitions, increased professionalism and emphasis on quality assurance, direct marketing through multiple retailers and establishment of working relations with mainstream businesses to enable economies of scale, have secured steady growth of Fairtrade, coupled with consumer demand for ethical products.

Viewed positively, globalisation of world trade, currently totalling £3.5 trillion per annum, has helped lift 400 million people out of poverty in tiger economies of East Asia and elsewhere (Geographical, 2004). However, although international trade is a powerful redistributor of global wealth, it brings problems such as imbalance of economic power between producers, with wages at subsistence and below in developing countries, compared with retailers and distributors making profits in the supply chain in the developed world (Denny & Elliott, 2003). Fairtrade means better livelihoods for cocoa farmers by modernising farming with productivity improvements, introduction of systems of good practices and improvements in living and working conditions, guaranteeing a minimum price, perhaps more significantly often shortening the value chain in order to return greater revenue. Codes of good practices, containing guidelines for sustainable production, mean farmers benefit from better access for Fairtrade cocoa and chocolate products. This meets new requirements from consumers as demand for Fairtrade cocoa and chocolate products increases. Consumers of Fairtrade cocoa and chocolate products have now value systems that demand products which provide a decent living for farmers, are produced in a socially acceptable way, minimise harm to the environment and which are safe and healthy to enjoy (FLO, 2005). Delivering such products is in the interest of farmers, cocoa processors, traders/exporters and chocolate manufacturers. Benefits resulting to farmers and other stakeholders in the chain delivering ‘Fairtrade cocoa’ are enhanced livelihoods for farmers, improved market access and sustainable increases in production and consumption.

Currently in 2009, over 1.5 million people in developing countries benefit from sales of Fairtrade cocoa in 20 national markets across Europe, North America, Japan and Mexico. The Fairtrade mark appears on a range of cocoa and chocolate products including confectionery, sauces, hot drinks, snack bars and biscuits. This product range grows progressively and standards for new categories are introduced on a regular basis. Since 1997, UK retail sales of Fairtrade cocoa-certified products have grown on average at 50% per annum and currently worth about €300 million. The current dilemmas of marketing Fairtrade goods in mainstream distribution channels can perhaps be best understood in the context of the ‘ethical consumer’ movement (Carrigan & Attalla, 2001; Harrison et al., 2005). ‘Ethical consumerism’ is a seductive concept because it suggests the transformative power of individual choice and action. It is also a message of inclusion – all consumers can, through the simple act of choosing one good in preference to another, create positive social and/or environmental change. A rise of ‘ethical consumerism’ has been documented, with systematic influences on global chocolate trade. Consumer values have shifted from pragmatic, price and value-driven imperatives to a new focus on ethical values and stories behind products (Low & Davenport, 2007; Poelman et al., 2007).
1.3.1 Future of Fairtrade cocoa and confectionery industry

Despite the unprecedented ‘mainstream’ respectability achieved by the Fairtrade cocoa market over the past decade, it is considered as counterhegemonic act of resistance (Shreck, 2005), which seems to be struggling with its relationship to the larger global market. Although the Fairtrade concept is successfully moving from a marginal niche to the mainstream market, there are several factors that present limitations to the potential of this strategy for bringing about lasting social change. First, the structure of international trade (as governed by the World Trade Organization, WTO, and free trade agreements), within which Fairtrade initiatives operate, is not necessarily favourable to the continuous growth of the Fairtrade market. For instance, differentiation of commodities according to how they are produced is contradictory to the WTO’s mission of eliminating barriers to trade. Therefore, explicit commitments to supporting Fairtrade efforts are likely to be found unacceptable by the WTO. Another barrier to market-based resistance stems from the very same enthusiasm that contributes to the growth of alternative trade in the first place. Research suggests that consumers and retailers are beginning to suffer from ‘label fatigue’ as the multiplication of competing certification schemes becomes overwhelming and the differentiation between labels becomes confusing and even questionable (Watkins, 1998; Jaffee et al., 2004). A final limitation of this form of resistance for fostering any transformative change is the producers’ weak understanding of the Fairtrade market, the initiative more generally, and their role as Fairtrade ‘partners’ (Shreck, 2005).

Most multinational ‘specialty’ chocolate processing companies produce premium brands to provide increased incomes and opportunities for farmers, given the premium prices they pay for the special qualities of cocoa they buy. However, this makes the assumption that the value chain used by the multinationals to source their products returns the value to the producers. As shareholder-driven organisations, it is questionable whether it would be in their interest to adopt models that may lead to a perceived reduction in the free market efficiency of their value chains. Despite the concerns expressed that paying premium prices encourages more supply, they complain that the Fairtrade system is too small to supply their needs for high-quality beans. For instance, Nestlé, ADM and Cargill alone directly process over 500 000 tonnes of cocoa beans annually, many times over the quantity accounted for by FLO-registered production. Therefore, even a significant increase in production by Fairtrade growers would have little impact on the conventional cocoa markets, especially since Fairtrade cocoa does not attach any ‘improved quality’ criteria to its production. What would attract these multinational ‘specialty’ chocolate manufacturing companies to Fairtrade cocoa would be the adoption of ‘total quality’ practices, using improved harvesting, fermentation and drying methods to enhance both the physical and flavour quality characteristics, to cater for their special or premium brands. Post-harvest processes such as fermentation and drying have been reported to have strong influence on final cocoa and chocolate flavour qualities (Kattenberg & Kemming, 1993; Clapperton et al., 1994; Afoakwa et al., 2007a; Beckett, 2009).

Sustainability of the rapid growth of Fairtrade cocoa industry could be seen from a broader perspective than ‘fairness’ alone; indeed, it could be assumed to encompass both ‘fairness’ and ‘total quality’. The adoption of sustainable Fairtrade cocoa supply chain would be to provide a mechanism for traceability and efficiency in producing ‘total quality’ produce that conforms to principles of sustainable development, delivered with emphasis on social, environmental, yield and quality factors, which would therefore continue to command premium prices.
1.4 THE CONCEPT OF THIS BOOK

The cocoa and chocolate industry is undergoing dynamic change in the nature of the demand for chocolate. The trends towards niche or premium chocolate products have engendered not only new challenges but also opportunities for all participants in the sector. Until recently, the general perception was that consumption of chocolate in Europe and the United States would begin to stagnate, as these major chocolate markets were reaching saturation. However, consumption behaviour across these mature markets has recently experienced major change, with the increasing appeal of premium chocolate, including organic, Fairtrade, single-origin, reduced sugar and dark and high cocoa content chocolate. Indeed, the confectionery market has increasingly been characterised by consumer demand for taste, convenience and health, and products addressing ethical and environmental concerns.

New product developments and ‘functional foods’ with wholesome ingredients (foods that provide health benefits beyond basic nutrition) have played an important role in the upward trend of the confectionery market. In recent times, many research activities have increasingly been conducted on the health and nutritional benefits of cocoa and chocolate. The findings indicate that flavonoids in cocoa may decrease low-density lipoprotein (‘bad’ cholesterol) oxidation, helping to prevent cardiovascular diseases. In addition, cocoa’s high content in antioxidants has been proved to reduce the risk of cancer. The demand for dark and high cocoa content chocolate, in particular, has surged in response to these positive findings.

The chocolate industry has demonstrated a strong ability to meet these challenges and to benefit from the new opportunities brought about through changing consumer demand. Companies traditionally known for milk chocolate products have been introducing new dark and high cocoa content chocolate products. The global dark chocolate market is now estimated to represent between 5 and 10% of the total market for chocolate tablets (the others being plain milk, plain white and filled chocolate tablets), with a higher share in continental Europe than in the United States and the UK. Similarly, the certified organic and Fairtrade chocolate markets have been booming, increasing at double-digit rates.

The advent of increased demand for chocolate has impacted significantly on the demand for cocoa beans in terms of both quantity and quality. While the chocolate industry has responded proactively to this development, the need for cocoa producers to have further information on this issue was brought to the fore. Such information would provide cocoa-producing countries with a better basis for formulating and implementing policies and programmes regarding cocoa production. One of the main challenges facing producing countries, to enhance their revenues from cocoa, is to meet the changing face of consumer demand. As a result of these increasing chocolate consumption trends, the cocoa processing and chocolate manufacturing industry faces an enormous challenge of meeting the demand and quality criteria expected by the consuming populations. This has to be marched vigorously by increasing production capacities of chocolate manufacturing industries, which also require a great deal of understanding of the science and technology of chocolate.

As chocolate manufacturing is complex and requires numerous technological operations and the addition of a range of ingredients to achieve products of suitable physical and chemical attributes, appearance and taste parameters with prespecified ranges, understanding the science of its manufacturing and the technological processes that can result in the expected product quality is paramount. Additionally, chocolate processing differs due to historical development within a producing company and geographical locations in which products are sold and therefore requires the necessary expertise to achieve the required quality attributes,
rheological characteristics, flavour development and thus sensory perception that are needed to satisfy a specified consuming population.

This book is therefore a mediator in bringing modern scientific and technological knowledge and understanding of the processes involved in cocoa processing and chocolate manufacturing to all who are engaged in the business of learning, making, consuming and using cocoa and chocolate products.
Cocoa cultivation, bean composition and chocolate flavour precursor formation and character

2.1 INTRODUCTION

The principal varieties of the cocoa tree *Theobroma cacao* (family Sterculiaceae) are *Criollo*, rarely grown because of disease susceptibility; *Nacional* with fine flavour, grown in Ecuador; *Forastero* from the Amazonas region; and *Trinitario*, a hybrid of *Forastero* and *Criollo*. *Forastero* varieties form most of the ‘bulk’ or ‘basic’ cocoa market. World annual cocoa bean production is approximately 3.5 million metric tonnes and major producers are the Ivory Coast, Ghana, Indonesia, Brazil, Nigeria, Cameroon and Ecuador. There are also a number of smaller producers, particularly of ‘fine’ cocoa, which forms less than 5% of world trade (Coe & Coe, 1996; Awua, 2002; Schwan & Wheals, 2004; Amoye, 2006).

Cocoa consumption has possible health benefits with specific claims recently identified and studied (Erdman *et al*., 2000; Wollgast & Anklam, 2000b; Weisburger, 2001; Tapiero *et al*., 2002; Steinburg *et al*., 2003; Gu *et al*., 2006; Miller *et al*., 2006). Cocoa beans and derived products are rich in antioxidants – including catechins, epicatechin and procyanidins – polyphenols similar to those found in wine, vegetables and tea (Kim & Keeney, 1984; Yamagishi *et al*., 2001; Carnesecchia *et al*., 2002; Hatano *et al*., 2002; Kris-Etherton & Keen, 2002; Tapiero *et al*., 2002; Engler *et al*., 2004; Grassi *et al*., 2005; Lamuela-Raventos *et al*., 2005; Buijsse *et al*., 2006; Gu *et al*., 2006; Hermann *et al*., 2006; Afoakwa *et al*., 2007a). These contribute as precursors to flavour formation in cocoa and chocolate (Misnawi *et al*., 2003; Counet *et al*., 2004; Kyi *et al*., 2005).

Chocolate has a distinctive flavour character, with specific notes related to bean genotype, growing conditions and processing factors (Clapperton, 1994; Beckett, 2003; Whitefield, 2005). Fermentation is a key processing stage that causes the death of the bean and facilitates removal of the pulp and subsequent drying. During this stage, there is initiation of flavour precursor formation and colour development, and a significant reduction in bitterness.

The chemistry of cocoa beans in fermentations is still under study (Buyukpamukcu *et al*., 2001; Luna *et al*., 2002; Misnawi *et al*., 2003; Schwan & Wheals, 2004; Kyi *et al*., 2005) as are contributions from roasting and alkalisation (Gill *et al*., 1984; Jinap & Dimick, 1991; Oberparlaiter & Ziegleder, 1997; Dimick & Hoskin, 1999; Stark *et al*., 2005; Granvogl *et al*., 2006; Ramli *et al*., 2006; Reineccius, 2006; Stark *et al*., 2006a) and conching (Pontillon, 1995; Plumas *et al*., 1996; Beckett, 2000; Awua, 2002; Reineccius, 2006). Key flavour compounds in chocolate have been identified (Cerny & Grosch, 1994; Cerny & Fay, 1995; Schnermann & Schieberle, 1997; Schieberle & Pfanner, 1999; Counet *et al*., 2002; Taylor, 2002; Taylor & Roberts, 2004; Reineccius, 2006; Afoakwa *et al*., 2008a). However, the biochemical and chemical processes leading to chocolate flavour formation and development, and their relationships to the final character and perceptions of quality are not fully understood.
This chapter discusses cocoa cultivation practices, bean composition and the biochemistry of flavour precursor formation and character in cocoa resulting from the inherent chemical composition of the bean, genotypic variation in bean origin and fermentation processes, and suggests the types of flavour precursors formed and their overall achieved characters.

2.2 COCOA CULTIVATION AND PRACTICES

2.2.1 Cultivation of cocoa

Cocoa cultivation requires an appropriate climate that is mostly found within the area bounded by the Tropics of Cancer and Capricorn. The majority of the world’s cocoa is grown as small or large plantations within 10° North and South of the equator, and best suited for sea level up to a maximum of about 1000 m, although most of the world’s cocoa grows at an altitude of less than 300 m. Cultivation requires temperatures generally within 18–32°C (65–90°F) and rainfall well distributed across the year, with a range between 1000 and 4000 mm (40–160 in.) per year, but preferably between 1500 and 2500 mm (60 and 100 in.).

During cultivation, cocoa prefers high humidity, typically ranging between 70–80% during the day and 90–100% at night. Cocoa trees are usually planted to achieve a final density of 600–1200 trees/ha (1500–3000 trees/acre) and intercropped with food crops (Fig. 2.1). Due to the fragility of the cocoa trees during the early stages of growth, they are mostly protected from strong winds using food crops; for instance, plantain trees are used as wind shield on plantations in Ghana. The trees grow well on most soil but preferably well-aerated soils with good drainage and a pH of neutral to slightly acidic (5.0–7.5), and pest and diseases carefully controlled (Fowler, 1999). Cocoa trees used to grow to a height of approximately 10 m tall at maturity, preferably under the shades of other trees. However, modern breeding methods have led to the development of trees to a standard of approximately 3 m tall to allow for easy harvesting.

Fig. 2.1 Cocoa plantation showing young trees intercropped with food crops (plantain). See Colour Plate No. 2.
2.2.2 Flowering and pod development

The emergence of the bud through the bark of the tree marks the beginning of the cocoa bean development. This takes about 30 days from its histological beginnings to its culmination on the bark surface, and within hours of its emergence, the bud matures, sepals split and the flower continues to mature during the first night following the budding. On the next morning after budding, the flower is fully opened (Fig. 2.2) and the anthers release their pollens.

If not pollinated and fertilised on this day by insects, the flowers continue to abscission on the following day. It is interesting to note that a single healthy cocoa tree produces about 20 000–100 000 flowers yearly but only 1–5% of these get pollinated and develop into pods.

Once successfully pollinated and fertilised, the various stages of embryo and ovule growth continue, the pods reaching maximum size after about 75 days following pollination. The pods then mature for another 65 days, making a total of about 140 days after pollination (Fig. 2.3). The fruits are then allowed to ripen for about 10 days and the pods are harvested. The matured cocoa fruits measure between 100 and 350 mm (4 and 14 in.) long and have a wet weight of approximately 200 g to approximately 1 kg (Mossu, 1992).

A key determinant of properly ripened cocoa fruit is the external appearance. There are considerable variations in the shape, colour and surface texture of the pods depending on genotype (Figs 2.4–2.6). The ripening is visible as changes in the colours of the external pod walls occur and the nature of colour changes is dictated by the genotype of cocoa involved. However, cocoa fruit ripening is generally thought of to be from green or purple to varied shades of red, orange or yellow depending on genotype. The composition of the internal content, comprising the bean and pulp, is extensively discussed in the next section, with emphasis on the bean composition and its influence on chocolate flavour precursor formation and development.

Fig. 2.2 Flowering of cocoa tree during growth. See Colour Plate No. 3.
Fig. 2.3  Mature Amelonado-type cocoa trees bearing unripe pods.

Fig. 2.4  Unharvested West African Forastero (Amelanodo) cocoa fruits.
2.2.3 Harvesting and pod opening

Harvesting of cocoa fruits involves the removal of pods from the trees and the extraction of the beans and pulp from the interior of the pod. While the ripening process occurs in a 7- to 10-day period, the pods can safely be left on the trees for up to 2 weeks before harvesting. Thus, a 3-week window exists during which the cocoa may be considered fit to harvest. There are two concerns that dictate how quickly the harvest is completed – potential for pod diseases and the possibility of bean germination in the pod, if delayed for too long.
During harvesting, a knife or cutlass is normally used to remove the pod from the tree, but there exists a special long-handled tool for removing pods which are higher up the tree (Fig. 2.7).

After removing the pods from the trees, they may be gathered into heaps (Fig. 2.8) and opened immediately or allowed to sit for a few days before opening, a technique known as pod storage, which has been reported to have significant beneficial effects on the flavour quality of the bean during subsequent fermentation and processing. Much of this depends on
2.2.4 Cocoa diseases and pests and their influence on chocolate quality

The cocoa tree is susceptible to a number of diseases and pests that affect the yield of pods from the trees. Due to their versatility in infesting other pods, it is recommended that all diseased pods be harvested with the healthy ones and then separated for destruction. The cocoa pod diseases and pests are as described.
2.2.4.1 Swollen shoot disease

This is a viral disease affecting cocoa and is spread by small whitish insects known as mealy bugs. The pods assume a roundish shape and also diminish in size, causing a drastic reduction in yield from infested trees. Control measures involve cutting down infected trees and adjoining trees and burning them completely. There is, however, no evidence that this disease has any adverse effect on the quality of fruits of the cocoa tree or on the quality of the products after fermentation. This is because a full investigation on these has not been conducted and would be dangerous to assume that no evidence exists.

2.2.4.2 Black pod disease

This disease is characterised by browning, blackening and rotting of cocoa pods and beans. It is caused by the fungi *Phytophthera palmivora* and *Phytophthora megakarya*, the latter being more aggressive and destructive. These fungi attack every portion of the cocoa tree and are controlled by good cultural practices by the removal of infected pods and by spraying with approved fungicides. Their rate of infestation could be reduced by reducing the humidity and by increased aeration on the cocoa farm.

The pods harvested from infected trees may be used with the healthy pods, if the fungal attack has not penetrated the pod walls, hence the beans would be unaffected. If, however, harvesting is delayed and attack is severe, there is some evidence (Awua, 2002) that the free sugars of the pulp are utilised by the fungus, giving rise to a dry pulp similar to that of an unripe pod. If such pods occur in quantity, fermentation is impaired and a product of poor quality results.
2.2.4.3 Witches broom disease

This disease is caused by the fungus *Marasmius perniciosus* and is indigenous to South America. It has, however, spread to surrounding cocoa-growing countries and has caused considerable damage to cocoa trees in Brazil and Trinidad and Tobago. It is characterised by abnormal tufted vegetative growth on the trees at the expense of pod formation. Unless the cocoa pod is almost ripened when attacked, the infection destroys the diseased pods and renders them useless. The infected trees are controlled by spraying with fungicides. However, this disease is absent in the West African cocoa-growing region.

2.2.4.4 Pod borers (capsids, cocoa thrips and mealybugs)

Several insect pests such the capsids and moths feed on young shoots and pods of the cocoa tree. They damage the young soft tissues of the trees by piercing the young shoots with their mouth parts, injecting poisonous saliva and then sucking out the fluid food from the wound, causing the death of the young trees. These infections could be controlled by the application of the recommended insecticides and by leaving a reasonable amount of shade between the young trees. None of these insect pests have been reported to have any direct influence on the quality of manufactured chocolate products. However, it is feared that large-scale insecticide-spraying exercises used in their control may have result in taints in the prepared products. These control techniques may also increase the pesticide levels in the fermented and dried cocoa beans, and may pose problems of high, unacceptable pesticide doses on the international markets. It is therefore recommended that cocoa with these infections is controlled under supervision by agricultural extension officers.

2.3 BEAN COMPOSITION AND FLAVOUR PRECURSOR FORMATION

2.3.1 Chemical composition of the bean

The shell (testa) represents 10–14% dry weight of the cocoa bean, while the kernel or cotyledon is made up of most of the remaining 86–90% (Table 2.1). The cotyledon confers characteristic flavours and aromas of chocolate (Rohan & Stewart, 1967; Osman *et al*., 2004) and is composed of two types of parenchyma storage cells. Polyphenolic cells (14–20% dry bean weight) contain a single large vacuole filled with polyphenols and alkaloids including caffeine, theobromine and theophylline (Osman *et al*., 2004). The pigmented polyphenols, when undisturbed, confer deep purple colour to fresh Forastero cotyledons. Lipid–protein cells, on the other hand, have cytoplasm tightly packed with multiple small protein and lipid vacuoles and other components such as starch granules – all of which play roles in defining cocoa flavour and aroma characters (Kim & Keeney, 1984; Nazaruddin *et al*., 2001).

Reineccius *et al*. (1972) reported that fresh unfermented cocoa beans contained 15.8 mg/g sucrose and trace amounts of fructose, sorbose, mannitol and inositol. Berbert (1979) suggested that sucrose content at 24.8 mg/g unfermented beans formed about 90% of total sugars (27.1 mg/g). The reducing sugars, fructose and glucose form about 6% (0.9 and 0.7 mg/g, respectively) and others (including mannitol and inositol) at less than 0.50 mg/g. Differences have been attributed to method and time of harvesting, type and origin of cocoa beans (Reineccius *et al*., 1972). Tissue components remain compartmentalised, separating
Table 2.1  Bean composition of unfermented West African (Forastero) cocoa

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Dried beans (%)</th>
<th>Fat-free materials (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotyledons</td>
<td>89.60</td>
<td>—</td>
</tr>
<tr>
<td>Shell</td>
<td>9.63</td>
<td>—</td>
</tr>
<tr>
<td>Germ</td>
<td>0.77</td>
<td>—</td>
</tr>
<tr>
<td>Fat</td>
<td>53.05</td>
<td>—</td>
</tr>
<tr>
<td>Water</td>
<td>3.65</td>
<td>—</td>
</tr>
<tr>
<td>Ash (total)</td>
<td>2.63</td>
<td>6.07</td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>2.28</td>
<td>5.27</td>
</tr>
<tr>
<td>Protein nitrogen</td>
<td>1.50</td>
<td>3.46</td>
</tr>
<tr>
<td>Theobromine</td>
<td>1.71</td>
<td>3.95</td>
</tr>
<tr>
<td>Caffeine</td>
<td>0.085</td>
<td>0.196</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>0.30</td>
<td>0.69</td>
</tr>
<tr>
<td>Sucrose</td>
<td>1.58</td>
<td>3.86</td>
</tr>
<tr>
<td>Starch</td>
<td>6.10</td>
<td>14.09</td>
</tr>
<tr>
<td>Pectins</td>
<td>2.25</td>
<td>5.20</td>
</tr>
<tr>
<td>Fibre</td>
<td>2.09</td>
<td>4.83</td>
</tr>
<tr>
<td>Pentosans</td>
<td>1.27</td>
<td>2.93</td>
</tr>
<tr>
<td>Mucilage and gums</td>
<td>0.38</td>
<td>0.88</td>
</tr>
<tr>
<td>Polyphenols</td>
<td>7.54</td>
<td>17.43</td>
</tr>
<tr>
<td>Acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic (free)</td>
<td>0.014</td>
<td>0.032</td>
</tr>
<tr>
<td>Oxalic</td>
<td>0.29</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Sources: Rohan (1963) and Reineccius et al. (1972).

flavour constituents that may interact with cell membrane and wall breakdown during the subsequent fermentation.

### 2.3.2 Polyphenols and chocolate flavour quality

Cocoa is rich in polyphenols, specifically catechins (flavan-3-ols) and procyanidins, stored in cotyledon pigment cells and cocoa leaves (Osman et al., 2004). Depending on anthocyanin content, pigmentation in polyphenol-storage cells ranges from white to deep purple. Polyphenol and alkaloids, approximately 14–20% bean weight, are central to bean flavour character (Kim & Keeney, 1983). Three groups of polyphenols can be differentiated: catechins or flavan-3-ols (~37%), anthocyanins (~4%) and proanthocyanidins (~58%). The primary catechin is (−)-epicatechin, up to 35% of total polyphenols and from 34.65 to 43.27 mg/g of defatted freshly harvested Criollo and Forastero beans (Kim & Keeney, 1984). Less abundant is (+)-catechin with only traces of (+)-gallocatechin and (−)-epigallocatechin. Nazaruddin et al. (2001) reported total polyphenols ranged from 45 to 52 mg/g in cocoa liquor, 34 to 60 in beans and 20 to 62 in powder: (−)-epicatechin contents were 2.53, 4.61 and 3.81 mg/g, respectively.

The anthocyanin fraction is dominated by cyanidin-3-α-L-arabinoside and cyanidin-3-β-D-galactoside. Procyanidins are mostly flavan-3,4-diols and are four to eight or four to six bound to form dimers, trimers or oligomers with epicatechin as main extension subunit (Romanczyk et al., 1997). Fat-soluble polyphenols in dried fat-free fresh Forastero cocoa form 15–20%, which falls to approximately 5% after fermentation. Contents of 10% or
greater are considered a sign of poor fermentation. Higher concentrations of polyphenols lead to very astringent-tasting chocolate. *Criollo* cocoa beans have approximately two-thirds of this content of polyphenols, and anthocyanins have not been found (Lange & Fincke, 1970; Hansen *et al.*, 2000). Polyphenol reactions with sugar and amino acids contribute flavour and colour to cocoa beans and alkaloids to the bitterness (Lehrian & Patterson, 1983). During fermentation, protein breakdown occurs partly by hydrolysis to peptides and amino acids and partly by conversion to insoluble forms by the actions of polyphenols. Polyphenol oxidase promotes oxidative browning to give the characteristic chocolate brown colour of well-fermented Forastero beans.

### 2.3.3 Effects of proteins and sugars on flavour precursor formation

Cocoa cotyledons contain as storage proteins single albumin and globulin species (Biehl *et al.*, 1982a). The globulin, with two polypeptides of 47 and 31 kDa (Petitpher, 1990; Spencer & Hodge, 1992; Voigt *et al.*, 1993), is degraded in fermentation, the albumin (21 kDa) is not. Cocoa-specific aroma precursors can be generated in vitro from globulin in partially purified bean fractions by aspartic endoprotease and carboxypeptidase activities (Voigt *et al.*, 1994a). Cotyledon protein degradation into peptides and free amino acids appears central to flavour formation. The consensus is that the combined action of two proteases, namely aspartic endopeptidase and serine carboxy-(exo)peptidase, on vicilin (7S)-class globulin (VCG) storage polypeptide yields cocoa-specific precursors. The aspartic endopeptidase (EC 3.4.23) hydrolyses peptide bonds in VCG at hydrophobic amino acid residues, forming hydrophobic oligopeptides – substrates for the serine exopeptidase (EC 3.4.16.1) that remove carboxyl terminal hydrophobic amino acid residues (Biehl *et al.*, 1993; Voigt *et al.*, 1994b; Biehl *et al.*, 1996; Biehl & Voigt, 1999).

Kirchhoff *et al.* (1989) observed a correlation between free amino acid accumulation and generation of specific aroma precursors, with pH-dependent proteolytic processes. Activities in both key enzymes are pH dependent, near to pH 3.8 – optimum for aspartic endopeptidase – more hydrophobic oligopeptides and less free amino acids are produced. Whereas close to 5.8 – the optimum for serine exopeptidase – there are increases in hydrophilic oligopeptides and hydrophobic amino acids. Related storage proteins or alternative peptidases both failed to produce appropriate flavour precursors. With a rapid fall to low pH (<4.5), reduction in flavour precursors is observed and slow diffusion of organic acids through cotyledons, timing of initial entry, duration of optimum pH and final pH are crucial for final flavour (Biehl & Voigt, 1999). Thus, bean composition interacts with fermentation in formation of cocoa flavour quality. Analysis of VCG proteins and proteolytic degradation products in five popular genotypes (Forastero, Criollo, Trinitario, SCA 12 and UIT1) concluded that character in chocolate may vary, but all genotypes had potential for abundant aroma content in raw cocoa (Amin *et al.*, 2002).

Electrophoretic (SDS-PAGE) analyses showed polypeptide species at 47, 31 and approximately 14.5 kDa, all derived from post-translational modification of a vicilin (7S) storage protein precursor observed in vivo as a 139-kDa trimer (Biehl *et al.*, 1982b; MacDonald *et al.*, 1994). Polypeptide and cDNA sequence data showed considerable homology to other 7S class storage proteins, and specifically α-globulin in cotton seeds (McHenry & Fritz, 1992; Spencer & Hodge, 1992). Specific cocoa aroma was obtained in vitro when this vicilin globulin was successively degraded by an aspartic endopeptidase and a carboxypeptidase and
products were roasted in the presence of reducing sugars (Voigt et al., 1994a, b). Acidification during fermentation is critical for final cocoa quality since the different pH optima of endo-protease and carboxypeptidase activities determine efficiency and products of proteolysis. The outcome is mixtures of hydrophobic and hydrophilic peptides, the latter more important for formation of typical aroma notes. In summary, it can be concluded that proteolysis of globulin is central to cocoa flavour formation.

Low-molecular-weight protein breakdown products and reducing sugars all contribute to Maillard reactions that produce cocoa flavour in roasting (Rohan & Stewart, 1967). Peptides and hydrophobic free amino acids, specifically leucine, alanine, phenylalanine and tyrosine, released during fermentation by aspartic proteinase and carboxypeptidase activities (Voigt et al., 1993, 1994a) contribute to flavour (Mohr et al., 1976) by reacting with fructose and glucose (Lopez et al., 1978). Cocoa fermentation protein breakdown has been characterised by Rohan and Stewart (1967), Lopez et al. (1978), Biehl and Passern (1982) and Biehl et al. (1985) and studied changes in sugars.

2.3.4 Microbial succession and enzymatic activities during flavour precursor generation in cocoa fermentation

During fermentation, microbial activity on the cocoa pulp generates heat and produces ethanol, acetic and lactic acids that kill the bean. Until the pods are split, the beans are microbiologically sterile. Once the pod is split, the beans and pulp are exposed to numerous sources of micro-organisms, including the farmer’s hands and implements, the pods exterior and largely insect activity on the farms. The immediate effect of this exposure is the initiation of the microbiological attack of the sugar-rich acidic pulp. At the initial stages of fermentation process, also known as the anaerobic hydrolytic phase, the pulp condition is anaerobic and anaerobic yeasts flourish.

The yeasts quickly generate an alcoholic fermentation, and the sugars in the pulp are converted to alcohol and carbon dioxide. The citric acid is used in the metabolism of the yeasts. This initiates a slow rise in the pH of the pulp material. The yeasts dominate the first 24–36 hours of the fermentation process, after which the rising pH creates a self-limiting factor on further proliferation. In addition, enzymes released by the yeasts attack the pectin constituents of the cell walls of the pulp mass. The subsequent release of the fluid cell contents runs off the fermenting pulp as what is referred to as ‘sweatings’. Examples of yeasts isolated during cocoa fermentation include *Saccharomyces cerevisiae*, *Kluyveromyces marxianus*, *Saccharomyces exiguus*, *Candida castelli*, *Candida saitoana*, *Candida guilliermondii*, *Schizosaccharomyces pombe*, *Pichia farinosa* and *Torulopsis* spp. (Schwan & Wheals, 2004).

The continuous breakdown of the pulp and its liquefaction result in the formation of voids between the cells in the pulp. The loss of fluids through the sweating process increases the rate of acid depletion as it is carried away in the run-off. These voids increase in size and allow air to percolate through the pulpy mass. The combination of this change from anaerobic to aerobic conditions in the substrate, the rise in pH as the citric acid is consumed and loss through sweating and increasing alcohol content being generated by the fermentation of the sugars leads to the eventual inhibition of yeast activity. This signals the end of the anaerobic phase of the process.

The second phase known as the oxidative condensation phase occurs under aerobic conditions and is initially dominated by lactic acid bacteria. Lactic acid bacteria increase
in numbers when part of the pulp and ‘sweatings’ had largely drained away, and the yeast population is declining. Yeast metabolism favours the growth of acidoduric lactic acid bacteria. Of the lactic acid bacteria isolated from cocoa fermentations *Acetobacter lovaniensis*, *Acetobacter rancens*, *Acetobacter xylinum*, *Gluconobacter oxydans*, *Lactobacillus fermentum*, *Lactobacillus plantarum*, *Leuconostoc mesenteroides* and *Lactococcus* (*Streptococcus*) *lactis* were the most abundant species in the first 24 hours of fermentation (Schwan & Wheals, 2004). As the microbial activity increases, the temperature of the bean mass also begins to increase until it reaches about 45°C (113°F). The conditions at this temperature are more favourable for the promotion of the growth of acetic acid-forming bacteria, replacing lactic acid formers as the dominant microflora.

After the decline in the populations of yeasts and lactic acid bacteria, the fermenting mass becomes more aerated. This creates conditions suitable for the development of acetic acid bacteria. These bacteria are responsible for the oxidation of ethanol to acetic acid and further oxidation of the latter to carbon dioxide and water. The acidulation of cocoa beans and the high temperature in the fermenting mass, which causes diffusion and hydrolysis of proteins in the cotyledons, have been attributed to the metabolism of these organisms. Thus, the acetic acid bacteria play a key role in the formation of the precursors of chocolate flavour. In general, the members of genus *Acetobacter* have been found to be more frequent than those of *Gluconobacter*. Species of *Acetobacter aceti* and *Acetobacter pasteurianus* have been isolated in most cocoa beans (Schwan & Wheals, 2004). The acetic acid formers go on to become about 80–90% of the microbial population, and their activities (heat and the acidity) eventually lead to the death of the seeds. This results in the breakdown of cellular components and a variety of reactions are initiated.

The increased aeration, increased pH value (3.5–5.0) of cocoa pulp and a rise in temperature to about 45°C in the cocoa mass in the later stages of fermentation are associated with the development of aerobic spore-forming bacteria of the genus *Bacillus*. Many *Bacillus* spp. are thermotolerant and others grow well at elevated temperatures. *Bacillus stearothermophilus*, *Bacillus coagulans* and *Bacillus circulans* were isolated from cocoa beans that had been subjected to drying and roasting (150°C) temperatures. Aerobic spore-forming bacteria produce a variety of chemical compounds under fermentative conditions. These contribute to the acidity and perhaps at times to the off-flavours of fermented cocoa beans. Indeed, it has been suggested that C3–C5 free fatty acids found during the aerobic phase of fermentation and considered to be responsible for off-flavours of chocolate are produced by *Bacillus subtilis*, *Bacillus cereus* and *Bacillus megaterium*. Other substances such as acetic and lactic acids, and 2,3-butanediol, all of which are deleterious to the flavour of chocolate, are also produced by *Bacillus* spp. (Schwan & Wheals, 2004). Pulp fermentation products penetrate slowly into beans causing swelling and stimulating enzymic reactions that yield flavour precursors, and on roasting characteristic flavour and aroma notes. Fresh beans with low contents of flavour precursors will have limited commercial usage and activities in fermentation will be unable to rectify this shortfall (Rohan & Stewart, 1967; Mohr et al., 1976; Voigt et al., 1994a). Appropriate amounts and ratio of precursors are essential for optimal flavour volatiles production in roasting.

Subcellular changes in the cotyledons release key enzymes affecting reactions between substrates pre-existing in unfermented beans (Hansen et al., 1998). Enzymes exhibit different stabilities during fermentation and may be inactivated by heat, acids, polyphenols and proteases. Aminopeptidase, cotyledon invertase, pulp invertase and polyphenol oxidase are significantly inactivated, carboxypeptidase is partly inactivated, whereas endoprotease and glycosidases remain active during fermentation (Hansen et al., 1998). During the anaerobic
Cocoa cultivation, bean composition and chocolate flavour precursor formation

phase, the complex pigment components are attacked by glycosidases and are converted by hydrolysis to sugars and cyanidins. As well, sucrose is converted to glucose and fructose by invertase, the conversion of proteins to peptides and amino acids by proteinase and the conversion of polyphenols to quinines by polyphenols oxidase. During these processes, the colour of the cotyledons slowly changes, and in the case of Forastero varieties, the deep purple tissue is converted to a red-brown colour. As the anaerobic phase nears its termination, the products of the enzymatic actions remain to be further converted in subsequent reactions.

In the aerobic phase, cyanidin and protein–phenolic complexes undergo oxidative reactions, which are eventually expressed as the final spread of brown colour across the cotyledon surfaces as the repurple pigments react. Quinone, generated by the actions of the polyphenols oxidase, now reacts with hydrogen-bearing compounds. These in turn, form complexes with amines, amino acids and sulphur-bearing compounds, leading to the lessening of astringency and bitterness during subsequent roasting of the nibs. Clearly, the changes that occur within the bean during fermentation are very complicated and that the hydrolytic and subsequent oxidative reactions generate numerous biochemical complexes that serve as flavour precursors during the roasting process. The genetic make-up of the bean is also certainly crucial to this process. Hansen et al. (2000) noted that differences in enzyme activities can be partly explained by pod variation and genotype, but in general, activities present in unfermented beans seem not a limiting factor for optimal flavour precursor formation in fermentation. Significant fermentation effects may relate to factors such as storage protein sequence and accessibility, destruction of cell compartmentalisation, enzyme mobilisation and pulp and testa changes.

Proteases affect multiple cellular processes in plants, such as protein maturation and degradations associated with tissue restructuring and cell maintenance (Callis, 1995). Key aspartic proteinases (EC 3.4.23) have been characterised in a number of T. cacao gymnosperms (Mutlu & Gal, 1999), and activity in seeds of T. cacao has been extensively studied by Biehl et al. (1993). Partially purified aspartic proteinase had activity optima at 55°C and pH 3.5. Subsequently, Voigt et al. (1995) purified T. cacao seed aspartic proteinase into a heterodimer of 29 and 13 kDa polypeptides that efficiently hydrolysed T. cacao seed vicilin and (less effectively) trypsin inhibitor into peptides (Voigt et al., 1994a).

Two cDNA species, TcAP1 and TcAP2, respectively, encoding different polypeptides of the plant aspartic proteinase gene family, have been cloned and characterised (Laloi et al., 2002). Both genes are induced early in seed development and show significantly decreased expression as the seeds reach maturity. However, TcAP2 expression is induced to higher levels, suggesting the gene encodes the primary aspartic proteinase in the mature seed. It should also be noted that T. cacao seeds have unusually high levels of such aspartic proteinase activity (Voigt et al., 1994a). Guilloteau et al. (2005) noted that physical and biochemical properties of the active T. cacao seed TcAP2 aspartic proteinase complex are novel, suggesting the highly expressed gene product may represent a previously uncharacterised activity. Purified TcAP2 gene product efficiently degrades cocoa seed vicilin into low molecular products including di- and tripeptides, implying that this gene product may play an important role during fermentation.

A processing sequence is required to produce cocoa beans with good flavour. Pulp sugar fermentation should yield high levels of acids, particularly acetic acid (Voigt et al., 1994a). As seed pH decreases, cell structure is disrupted, which triggers mobilisation and/or activation of the primary aspartic proteinase activity with massive degradation of cellular protein (Biehl et al., 1982b, 1985). Fermentation proteinase and peptidase activities seem critical for good flavour quality (Voigt & Biehl, 1995; Laloi et al., 2002).
Significant differences in enzyme activities exist between cocoa genotypes, but simple and general relationships have not been established between genotype flavour potential and key enzyme activities in unfermented beans. Therefore, how enzymatic processes are regulated, and substrates and products that relate to desirable flavours, and limiting factors for the enzymatic contribution to fermentation processes remain unclear.

### 2.4 EFFECT OF GENOTYPE ON COCOA BEAN FLAVOURS

Genotype influences both flavour quality and intensity in chocolate (Luna et al., 2002; Taylor, 2002; Counet et al., 2004; Taylor & Roberts, 2004), likely determining quantities of precursors and activity of enzymes, and thus contributions to flavour formation. Reineccius (2006) concluded that varietal differences were primarily due to quantitative (as opposed to qualitative) differences in flavour precursor and polyphenol contents. Contents of sugars and enzymic breakdown of polysaccharides form an important source of precursors. However, post-harvest processes (fermentation and drying) and roasting have a strong influence on final flavours (Kattenberg & Kemming, 1993; Clapperton et al., 1994; Luna et al., 2002; Counet & Collin, 2003). Three primary cocoa types, Forastero (bulk grade), Criollo (fine grade) and hybrid, Trinatario (fine grade), show wide variations in final flavour (Beckett, 2000; Awua, 2002; Amoye, 2006). Nacional cocoa is viewed as a third fine variety, producing the well-known Arriba beans with distinctive floral and spicy flavour notes (Despreaux, 1998; Luna et al., 2002; Counet et al., 2004). These differences in flavour can be ascribed to bean composition variation from botanical origin, location of growth and farming conditions. Bulk varieties dominate blends, while fine grades, used in lesser quantities, are selected to make specific contributions to overall flavour profile.

Each bean variety has a unique potential flavour character. But growing conditions such as climate, amount and time of sunshine and rainfall, soil conditions, ripening, time of harvesting, and time between harvesting and bean fermentation – all contribute to variations in final flavour formation. Table 2.2 summarises how differences in genetic origin, cocoa variety and duration of fermentation influence flavour profile but different conditions may lead to significant differences in flavour from a single cocoa variety. A good example is

#### Table 2.2 Origin, cocoa variety and fermentation duration effects on flavour character

<table>
<thead>
<tr>
<th>Origin</th>
<th>Cocoa type</th>
<th>Duration (days)</th>
<th>Special flavour character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecuador</td>
<td>Nacional (Arriba)</td>
<td>Short 2</td>
<td>Aromatic, floral, spicy, green</td>
</tr>
<tr>
<td>Ecuador</td>
<td>Criollo (CCN51)</td>
<td>2</td>
<td>Acidic, harsh, low cocoa</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>Trinitario</td>
<td>1.5</td>
<td>Floral, fruity, acidic</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Trinitario</td>
<td>2</td>
<td>Low cocoa, acidic</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Criollo</td>
<td>2</td>
<td>Fruity, nutty</td>
</tr>
<tr>
<td>Zanzibar</td>
<td>Criollo</td>
<td>Medium 6</td>
<td>Floral, fruity</td>
</tr>
<tr>
<td>Venezuela</td>
<td>Forastero</td>
<td>5</td>
<td>Fruity, raisin, caramel</td>
</tr>
<tr>
<td>Ghana</td>
<td>Forastero</td>
<td>5</td>
<td>Strong basic cocoa, fruity notes</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Forastero/Trinitario</td>
<td>6</td>
<td>Acidic, phenolic</td>
</tr>
<tr>
<td>Trinidad</td>
<td>Trinitario</td>
<td>Long 7–8</td>
<td>Winy, raisin, molasses</td>
</tr>
<tr>
<td>Grenada</td>
<td>Trinitario</td>
<td>8–10</td>
<td>Acidic, fruity, molasses</td>
</tr>
<tr>
<td>Congo</td>
<td>Criollo/Forastero</td>
<td>7–10</td>
<td>Acidic, strong cocoa</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>Trinitario</td>
<td>7–8</td>
<td>Fruity, acidic</td>
</tr>
</tbody>
</table>

Source: Afoakwa et al. (2008a).
the difference in flavour profile between a single Forastero variety produced originally in Ghana and now grown in Malaysia (Clapperton, 1994), arising possibly through geographic, climatic conditions and duration and/or method of fermentation.

Bulk cocoas typically show strong flavour characters, and fine cocoas are perceived as aromatic or smoother (Kattenberg & Kemming, 1993; Jinap et al., 1995; Luna et al., 2002). Clapperton et al. (1994) noted consistent differences in flavour attribute, specifically overall cocoa flavour intensity, acidity, sourness, bitterness and astringency. Bean origins include the West African Amelonado variety (AML), four Upper Amazon clones – Iquitos Mixed Calabacillo 67 (IMC67), Nanay 33 (NA33), Parinari 7 (PA7) and Scavina 12 (SCA12) – and Unidentified Trinatario (UIT1) grown in Sabah, Malaysia. Flavour characters in UIT1 differed from West African Amelonado, characterised by intense bitterness and astringency associated with caffeine and polyphenol contents. Fermented beans from Southeast Asia and the South Pacific are characterised by a higher acidity (more lactic and acetic acids) than West African beans (Clapperton et al., 1994) due to varietal differences, box fermentation and rapid artificial drying.

Cocoa liquors differ in sensory character. The West African groups (Ghana, Ivory Coast and Nigeria) are generally considered sources of standard (benchmark) cocoa flavour with a balanced but pronounced cocoa character, with subtle to moderate nutty undertones. Cameroon liquors are renowned for bitterness and those from Ecuador for floral-spicy notes. American and West Indian varieties range from aromatic and winy notes from Trinidad cocoa to the floral or raisin-fruity notes of Ecuadorian stocks, making unique contributions to blends. Asian and Oceanian beans exhibit a range of flavour profiles ranging from subtle cocoa and nutty/sweet notes in Java beans to the intense acid and phenolic notes of Malaysian (De La Cruz et al., 1995). Counet et al. (2004) reported that fine varieties with short fermentation processes had high contents of procyanidins, while Trinatario from New Guinea and Forastero beans were specifically higher in total aroma. Aroma compounds formed during roasting were found to vary quantitatively directly with fermentation time and inversely with procyanidin content of cocoa liquors.

High concentrations of phenol, guaiacol, 2-phenylbutenal and γ-butyrolactone characterise Bahia beans known for typical smoked notes. Also reported are higher contents of 2-methylpropanal and 3-methylbutanal in Caracas (Venezuela) and dried, fermented Trinidad beans (Dimick & Hoskin, 1999). Of Maillard products, Reineccius (2006) reported that roasting yields higher levels of pyrazines in well-fermented beans (Ghana, Bahia) than in less-fermented (Arriba) or unfermented from Sanchez (Dominican Republic) or Tabasco (Mexico). Lower in astringency and bitterness imparted by polyphenols, Criollo beans, in which anthocyanins are absent, is often less fermented than Forastero (Carr et al., 1979; Clapperton, 1994; Clapperton et al., 1994; Luna et al., 2002).

2.5 FLAVOUR DEVELOPMENT DURING POST-HARVEST TREATMENTS OF COCOA

2.5.1 Fermentation processes

Fermentation is essential for development of appropriate flavours from precursors. After pod harvest, beans and adhering pulp are transferred to heaps, boxes or baskets for fermentations lasting from 5 to 6 days for Forastero beans, but for Criollo only 1–3 days. Typical heap fermentation of beans covered with plantain leaves in a West Africa cocoa farm is as shown
in Figures 2.11 and 2.12. On the first day, the adhering pulp liquefies and drains off, with steady rises in temperature. Under anaerobic conditions, micro-organisms produce acetic acid and ethanol that inhibit germination and contribute to structural changes such as removal of the compartmentalisation of enzymes and substrates, with movements of cytoplasmic components through the cocoa cotyledon generally between 24 and 48 hours of bean fermentation. By the third day, the bean mass will have heated typically around 45°C, remaining at 45–50°C until fermentation is complete (Lehrian & Patterson, 1983; Schwan et al., 1995; Fowler, 1999; Kealey et al., 2001).

Mucilaginous pulp of beans undergoes ethanoic, acetic and lactic fermentations with consequent acid and heat stopping germination, with notable swelling and key changes in cell membranes facilitating enzyme and substrate movements. Differences in pH, titratable
acidity, acetic and lactic acid concentrations, fermentation index and cut test scores for cocoa beans from different origins are reported (Jinap & Dimick, 1990; Luna et al., 2002; Misnawi et al., 2003). Chemistry of cocoa beans fermentation has been reviewed (Ziegleder, 1990; Lopez & Dimick, 1991; Buyukpamukcu et al., 2001; Luna et al., 2002; Misnawi et al., 2003; Schwan & Wheals, 2004; Kyi et al., 2005).

During fermentation, the rate of diffusion of organic acids into the cotyledons, timing of initial entry, duration of the optimum pH and final pH are crucial for optimum flavour formation (Biehl & Voigt, 1999). Beans of higher pH (5.5–5.8) are considered unfermented – with low fermentation index and cut test score – and those of lower pH (4.75–5.19), well fermented. Fermentation techniques can reduce acid notes and maximise chocolate flavours (Lopez, 1979; Holm et al., 1993; Beckett, 1999; Whitefield, 2005). Ziegleder (1991) compared natural acid (pH 5.5–6.5) and alkaline (pH 8.0) cocoa extracts obtained by direct extraction – the former possessed a more intense and chocolate aroma than the latter, attributed to high contents of aromatic acids and sugar degradation products with persistent sweet aromatic and caramel notes. Cocoa beans of lower (4.75–5.19) and higher pH (5.50–5.80) were scored lower for chocolate flavour and higher for off-flavour notes, respectively, and chocolate from intermediate pH (5.20–5.49) beans was scored more highly for chocolate flavour (Jinap et al., 1995).

Sucrose and proteinaceous constituents are partially hydrolysed, phenolic compounds are oxidised and glucose is converted into alcohols, oxidised to acetic and lactic acids during fermentation. Beans subsequently undergo an anaerobic hydrolytic phase, followed by aerobic condensation. Timing, sequence of events and degree of hydrolysis and oxidation vary between fermentations. Concentration of flavour precursors is dependent on enzymatic mechanisms. Colour changes also occur with hydrolysis of phenolic components by glycosidases accompanied by bleaching, influencing final flavour character (Lopez & Quesnel, 1973; Biehl et al., 1990; Lopez & Dimick, 1991, 1995).

Nitrogenous flavour precursors formed during anaerobic phases are dominated by the amino acids and peptides available for non-oxidative carbonyl–amino condensation reactions promoted in elevated temperature phases such as fermentation, drying, roasting and grinding. Although degraded to flavour precursors, residual protein is also diminished by phenol–protein interactions. During aerobic phases, oxygen-mediated reactions occur, such as oxidation of protein–polyphenol complexes formed anaerobically. Such processes reduce astringency and bitterness: oxidised polyphenols influence subsequent degradation reactions (Rohan, 1964; Dimick & Hoskin, 1999; Counet et al., 2004; Kyi et al., 2005).

Fermentation method determines the final quality of products produced, especially flavour. Previous studies on post-harvest pod storage and bean spreading had shown marked improvement in chocolate flavour and reductions in sourness, bitterness and astringency (Meyer et al., 1989; Biehl et al., 1990). In commercial production, similar effects were obtained through combinations of pod storage, pressing and air blasting (Said et al., 1990). Variations in such factors as pod storage and duration affect the pH, titratable acidity and temperature achieved during fermentation, influencing enzyme activities and flavour development (Biehl et al., 1990).

Important flavour-active components produced during fermentation include ethyl-2-methylbutanoate, tetramethylpyrazine and certain pyrazines. Bitter notes are evoked by theobromine and caffeine, together with diketopiperazines formed from roasting through thermal decompositions of proteins. Other flavour precursor compounds derived from amino acids released during fermentations include 3-methylbutanal, phenylacetaldehyde, 2-methyl-3-(methylidithio)furan, 2-ethyl-3,5-dimethyl- and 2,3-diethyl-5-methylpyrazine (Taylor, 2002).
Immature and unfermented beans develop little *chocolate* flavour when roasted, and excessive fermentation yields unwanted *hammy* and *putrid* flavours (Fowler, 1999; Beckett, 2000; Zaibunnisa *et al.*, 2000; Reineccius, 2006).

### 2.5.2 Drying

Flavour development from cocoa beans precursors continues during drying with development of characteristic brown colour. After fermentation, the beans are removed from the heaps or boxes and dried in the sun on raised platforms covered with mats (Figs 2.13 and 2.14) or on the ground (Fig. 2.15) until fully dried within 7–8 sunny days. During the process, major polyphenol oxidising reactions are catalysed by polyphenol oxidases, giving rise to new flavour components, and loss of membrane integrity, inducing brown colour formation. Use of artificial drying can increase cotyledon temperatures, causing case hardening. Dimick and

![Fig. 2.13](image1.png) **Fig. 2.13** Farmers drying cocoa on raised platforms.

![Fig. 2.14](image2.png) **Fig. 2.14** Drying of cocoa beans on raised platforms.
Hoskin (1999) reported that case hardening restricts loss of volatile acids, with detrimental effects on final chocolate flavour.

After fermentation and drying, the target for cocoa beans is approximately 6–8% moisture contents. For storage and transport, moisture contents should be less than 8% or mould growth is possible (Carr et al., 1979; Fowler et al., 1998; Kealey et al., 2001; Awua, 2002). Indicators of well-dried, quality beans are good brown colour and low astringency and bitterness and an absence of off-flavours such as smoky notes and excessive acidity. Sensory assessment of cocoa beans dried using different strategies, i.e. sun drying, air blowing, shade drying and oven drying, suggested sun-dried beans (Figs 2.16 and 2.17) were rated higher in chocolate development with fewer off-notes (Dias & Avila, 1993; Buyukpamukcu et al., 2001; Amoye, 2006; Granvogl et al., 2006). Table 2.3 summarises key odourants in cocoa mass following fermentation and drying stages.
Fig. 2.17  Dried cocoa beans.

Table 2.3  Dominant odour-active volatiles in cocoa mass

<table>
<thead>
<tr>
<th>Compound</th>
<th>Odour quality</th>
<th>Flavour dilution factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2- and 3-methylbutanoic acid&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Sweaty</td>
<td>2048</td>
</tr>
<tr>
<td>3-Methylbutan&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Malty</td>
<td>1024</td>
</tr>
<tr>
<td>Ethyl 2-methylbutanoate&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Fruity</td>
<td>1024</td>
</tr>
<tr>
<td>Hexanal&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Green</td>
<td>512</td>
</tr>
<tr>
<td>Unknown&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Fruity, waxy</td>
<td>512</td>
</tr>
<tr>
<td>2-Methoxy-3-isopropylpyrazine&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Peasy, earthy</td>
<td>512</td>
</tr>
<tr>
<td>(E)-2-octanal&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Fatty, waxy</td>
<td>512</td>
</tr>
<tr>
<td>Unknown&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Tallowy</td>
<td>512</td>
</tr>
<tr>
<td>2-Methyl-3-(methylthio)furan&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Cooked meat-like</td>
<td>512</td>
</tr>
<tr>
<td>2-Ethyl-3,5-dimethylpyrazine&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Earthy, roasty</td>
<td>256</td>
</tr>
<tr>
<td>2,3-Diethyl-5-methylpyrazine&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Earthy, roasty</td>
<td>256</td>
</tr>
<tr>
<td>(E)-2-nonenale&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Tallowy, green</td>
<td>256</td>
</tr>
<tr>
<td>Unknown&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Pungent, grassy</td>
<td>128</td>
</tr>
<tr>
<td>Unknown&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Sweet, waxy</td>
<td>128</td>
</tr>
<tr>
<td>Phenylacetaldehyde&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Honey-like</td>
<td>64</td>
</tr>
<tr>
<td>(Z)-4-heptanal&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Biscuit-like</td>
<td>64</td>
</tr>
<tr>
<td>δ-Octenolactone&lt;sup&gt;a&lt;/sup&gt;&lt;sup&gt;,b&lt;/sup&gt;</td>
<td>Sweet, coconut-like</td>
<td>64</td>
</tr>
<tr>
<td>γ-Decalactone&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Sweet, peach-like</td>
<td>64</td>
</tr>
</tbody>
</table>

Sources: <sup>a</sup>Belitz and Grosch (1999); <sup>b</sup>Schnermann and Schieberle (1997).
Cocoa cultivation, bean composition and chocolate flavour precursor formation

<table>
<thead>
<tr>
<th>Influential factors</th>
<th>Theobroma cacao</th>
<th>Determining factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean constituents</td>
<td></td>
<td>Polyphenols</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Storage proteins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrophobic amino acids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sugars</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enzyme activity</td>
</tr>
<tr>
<td>Post-harvest treatment</td>
<td></td>
<td>Ripening level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maturity level</td>
</tr>
<tr>
<td>Harvesting, pre-conditioning and fermentation</td>
<td></td>
<td>Aerobic condensation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anaerobic hydrolysis (proteolysis)</td>
</tr>
<tr>
<td>Drying</td>
<td></td>
<td>Total acids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moisture level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polyphenol level</td>
</tr>
</tbody>
</table>

**Fig. 2.18** Mechanism of cocoa flavour precursor formation and character from bean composition and post-harvest treatment.

Frauendorfer and Schieberle (2006) identified similar flavour compounds in cocoa powder using molecular sensory correlations. Off-notes from incomplete drying or rain soaking may result in high levels of water activity and mould contamination, producing high concentrations of strongly flavoured carbonyls, leading to alterations in bean flavour, producing hammy off-flavours, which is also correlated with overfermentation (Dimick & Hoskin, 1999; Misnawi et al., 2003).

### 2.6 CONCLUSION

Chocolate flavour resides not only in a volatile aromatic fraction of flavour-active components but also in non-volatile compounds influencing taste perception. Its complex composition depends on the cocoa bean genotype, specifically on contents of bean storage proteins, polysaccharides and polyphenols. The inheritance and regulation of such flavour origins remain an area for advanced research. Enzymic and microbial fermentations after harvest induce physical and chemical changes in beans over 5–7 days with key browning reactions of polyphenol with proteins (∼12–15% total) and peptides, giving colours characteristic of cocoa. Drying limits mould growth during transportation and storage, reducing bean...
moisture content from 60 to 8%. Sun drying is favoured for flavour development and can be carried out above or on hard surfaces, with differences in airflow and final moisture content. Beans are transported under controlled storage conditions to chocolate manufacturing sites, or processed in the origin country to add value with requirements for traceability in quality assurance. Following critical review of the entire process, a summary of the parameters important for chocolate flavour generation has been developed (Fig. 2.18). An appropriate starting composition can be converted through controlled post-harvest treatments and subsequent processing technologies to a high-quality flavour character. Cocoa bean fermentation is crucial to not only the formation of key volatile fractions (alcohols, esters and fatty acids) but also provision of flavour precursors (amino acids and reducing sugars) for important notes contributing to chocolate characters. Drying reduces levels of acidity and astringency in cocoa nibs by decreasing the volatile acids and total polyphenols.
3 Industrial chocolate manufacture – processes and factors influencing quality

3.1 INTRODUCTION

Chocolates are semisolid suspensions of fine solid particles from sugar and cocoa (and milk, depending on type), making about 70% in total, in a continuous fat phase. Cocoa solids are derived from beans obtained from the fruit of *Theobroma cacao*, with world production dominated by Forastero types, made up of small, flattish and purple beans. Another type, Criollo, is presently rare in production; Trinitario, a disease-resistant hybrid of Criollo and Forastero, regarded as a flavour bean (Awua, 2002), is about 5% of world production. Growth of Forastero, in the trade name basic or bulk cocoa, occurs mainly in West Africa and Brazil. Criollo (flavour cocoa) is largely grown in Central and South America. West Africa now produces approximately 70% of world cocoa (ICCO, 2008). New demand for Fairtrade and premium products has stimulated improvements in quality assurance that make possible single variety and origin chocolates.

Primary chocolate categories are dark, milk and white that differ in content of cocoa solid, milk fat and cocoa butter. The outcome is varying proportions of carbohydrate, fat and protein (Table 3.1). Chocolate manufacturing processes (Beckett, 2000; Awua, 2002; Whitefield, 2005) differ due to variation in national consumer preferences and company practices.

Central to chocolate character is continuous phase lipid composition, which influences mouthfeel and melting properties. Chocolate triglycerides are dominated by saturated stearic (34%) and palmitic (27%) fatty acids and monounsaturated oleic acid (34%). Chocolates are solid at ambient (20–25°C) and melt at oral temperature (37°C) during consumption, giving a smooth suspension of particulate solids in cocoa butter and milk fat (Beckett, 1999; Whitefield, 2005). This constrains lipid composition. The oral epithelia are also sensitive to gradations of smoothness, which selects for desirable lipid crystal forms.

Despite high lipid and sugar contents, chocolate consumption makes a positive contribution to human nutrition through provision of antioxidants, principally polyphenols including flavonoids such as epicatechin, catechin and notably the procyanidins. White chocolates differ from milk and dark through the absence of cocoa nibs containing antioxidants, reducing the product’s shelf-life (Beckett, 2000; Whitefield, 2005). Chocolates also contain minerals, specifically potassium, magnesium, copper and iron (Holland et al., 1991). Differences in the sensory characters of chocolate can be attributed to use of different cocoa types, variations in ingredient proportions, use of milk crumb instead of milk powder, blending techniques and processing methods. Specifications depend on type of chocolate and its intended use (Jackson, 1999).

As chocolates melt in the mouth, the continuous fat phase inverts into the oral continuous aqueous phase mixing with saliva that dissolves the sugar particles. Lipids and cocoa solids coat oral epithelial surfaces. Oral particle dissolution influences perception of coarseness...
and solvation at rates corresponding to size and work input such as mastication, tongue compression and swallowing (Lee & Pangborn, 1986). Particle size distribution and ingredient composition therefore influence perception of primary taste (gustation) and oral volatiles release with retronasal flavour characters in magnitude and temporal profile.

Rheological properties of chocolate are important in manufacturing process for obtaining high-quality products with well-defined texture (Servais et al., 2004). Chocolates with high viscosity have a pasty mouthfeel, persisting in the mouth (Beckett, 2000). Viscosity relates to composition, processing strategy and particle size distribution. Apparent viscosity in aqueous solutions influences flavour ‘by mouth’ and taste intensity during consumption (Denker et al., 2006), thus rheological measurements often give information related to sensory character of chocolate.

This chapter assesses current information relating to cocoa processing technology and techniques, bean roasting strategies and their effects on chocolate quality and chocolate manufacturing operations. Factors influencing finished product quality such as particle size distribution and ingredient composition have also been discussed in relation to their effects on the rheological, textural and sensory qualities in chocolates.

### 3.2 COCOA PROCESSING AND TECHNOLOGY

#### 3.2.1 Bean selection and quality criteria

Chocolate manufacturers must follow a set of guidelines and quality criteria if they are to produce products that maintain the consumers’ loyalty to their products. Before processing, the quality of beans is evaluated using two different methods. With the first technique, the beans are assessed for the following indicators:

1. Degree of fermentation
2. Moisture content (maximum 6%)
3. Number of defects
4. Number of broken beans
5. Bean count (number per 100 g)
6. Degree of mouldiness
7. Flavour profile
8. Colour
9. Fat content (minimum 52%)
10. Fat quality relating to percentage of free fatty acids (as oleic acid)
11. Shell content (10–12%)
12. Uniformity of bean size
13. Insect and rodent infestation

---

**Table 3.1** Dark, milk and white chocolate: major constituents

<table>
<thead>
<tr>
<th>Product</th>
<th>Carbohydrate (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark chocolate</td>
<td>63.5</td>
<td>28.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Milk chocolate</td>
<td>56.9</td>
<td>30.7</td>
<td>7.7</td>
</tr>
<tr>
<td>White chocolate</td>
<td>58.3</td>
<td>30.9</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Source: Afoakwa et al. (2007a).
The second technique is evaluated based on the size of the beans using either bean count (number of beans per 100 g) or the weight in grams of 100 beans. On the international cocoa market, different bean sizes attract different prices. Beans with smaller sizes usually contain proportionately lower amount of nibs, higher shell content, lower fat content and attract lesser prices. Typically, beans from Asian origin have higher shell content than beans from West Africa.

The bean cut test is used to assess defects and the degree of fermentation. In this process, a sample of 300 beans are randomly selected and split open longitudinally. The cut surfaces are then examined and assessed based on the following criteria:

1. Flat and shrunken beans
2. Mouldy beans
3. Slaty beans
4. Germinated beans
5. Degree of insect and rodent infestation

All these factors affect the flavour and taste of the finished products, for which the beans would be used. Good cocoa beans should be well fermented, dry and free from insect and rodent infestation, abnormal odours and contaminations/adulterations.

Another key criterion is the flavour quality. In this regard, considerations must be given to the desired quality of the finished chocolate and/or products upon which or in which the chocolate would be used. For instance, harsh cocoa and bitter notes are required to contrast a very sweet or heavily flavoured centre, using delicately flavoured beans such as Java beans (Urbanski, 1992). It is important to note that just because a bean comes from a flavour grade stock does not mean it will automatically improve a product’s profile. The overall impact a particular stock has on its inclusion upon the blend has to be carefully assessed. Also noteworthy is the fact that while beans are characteristically typed, flavour quality may vary from year to year, crop to crop, etc., and therefore requires a continuous assessment of availability of the beans before using them in recipe formulations (Urbanski, 1992; Fowler, 1999).

The following are five examples of the varied selection of bean blends in assorted products types and explanations of the reasoning involved in their selections. For the industrial production of:

1. **Milk chocolate**: The use of predominantly medium roast West African beans with Ecuadorian beans is advised. This blend would deliver a good clean cocoa note with nutty and slightly fruity undertones. It is important to note that the addition of the highly acidic Brazilian and Malaysian beans would negatively contrast with the milky notes desired.
2. **Light milk chocolate**: This product could be made from lightly roasted Java beans that are known for their light colour and very mild overall flavour with distinctive nutty overtones. This would help attain a good standard of identity for milk chocolate, as the coating would be several shades lighter than a 100% West African bean. It could be best used to complement very delicately flavoured centres.
3. **High-quality semisweet chocolate**: The use of predominantly West African stock is advised for its cocoa character and slightly nutty undertones (light to medium roast) to heighten desirable notes and limit burnt/bitter notes. This blend when complemented by Caracas and Trinidad beans would contribute floral and slightly spicy notes to create a balanced yet unique profile.
4. *Harsh bittersweet chocolate:* This product is mainly designed for use on very sweet and highly flavoured cream centres as it produces very harsh and bitter coatings. If eaten alone, this coating may be harsh enough to be objectionable to many consumers. However, in a finished piece as described, it complements and balances the product’s flavour. Delicate flavour grades would be wasted in such a product as they would be overridden fully by the bitterness, astringency and acidity of the blend.

5. *Semisweet cookie drop:* The use the dominant West African beans is advised in this product to provide a good cocoa impact. The strong profiles of the Brazilian and Sanchez components complement and contrast the West African component. In this application, a robust flavour is desirable for contrast in the baked cookies (Minifie, 1989; Urbanski, 1992).

### 3.2.2 Cleaning, breaking and winnowing

Before processing, cocoa beans are passed through the processes of cleaning, breaking and winnowing to obtain nibs of consistent quality. These processes also ensure that the nibs are cleaned (free from dirt and infestation), well broken and properly deshelled. The kernels (nibs) obtained after the process must be of uniform size to achieve constant quality. The process involves, first, sieving the beans and removing all extraneous materials such as stones, strings, coins, wood pieces, soil particles and nails. The cleaned beans are then broken to loosen the shells from the nibs using multiple steps to avoid an excess of fine particles. The products obtained are then sieved into smaller number of fractions to obtain optimal separation during subsequent winnowing. The fractions are then transported to the winnowing cabinet where the lighter broken shells are removed by a stream of air. The breaking and winnowing steps are vital in separating the essential components of the bean, the nibs from the shells, and the shells are then discarded and sold for use as agricultural mulch or as fertilisers. Strong magnets are then used to remove magnetic foreign materials from the nibs, which are then stored, awaiting further processing.

### 3.2.3 Sterilisation

Sterilisation is the technique of exposing the cocoa beans or nibs to sufficiently higher temperatures for a sufficiently long times to destroy all micro-organisms in the beans. Depending on the factory and equipment used, this process can either be done before or after the roasting process. The treatment can be done in a batch or continuous process by wetting or heating with steam, all micro-organisms that might have contaminated the nibs during the post-harvest processes of fermentation, drying, bagging and transportation. The process ensures that the Total Plate Count (TPC) is reduced to less than 500 per gram, and all pathogenic bacteria are destroyed. After sterilisation, the nibs can then be roasted directly (natural process) or can be alkalised first by the Dutch process before roasting. In situations where sterilisation is done after roasting, the heat treatment is used to ensure total destruction of heat-resistant bacteria and spores that might have survived the high temperatures of the roasting process. The procedure is to inject, over a period of about 20 seconds, a fine water spray of steam into the roasting drum at the end of the roasting period (Awua, 2002). This guarantees a considerable reduction in microbial count in the roasted nibs.
3.2.4 Alkalisation

The technique of alkalisation was first introduced by a Dutchman known as van Houten in 1928 and therefore named it as the Dutch process. All cocoa, beans, nibs or liquor that is so treated is described as ‘alkalised’ or ‘Dutched’ (ADM Cocoa, 2006). This consists of treating the cocoa nibs with an alkali solution such as potassium or sodium carbonate. The alkali is used to raise the pH of the beans or nibs from 5.2 to 5.6 to near neutrality at 6.8–7.5, depending on the alkali used, and the purposes are primarily to modify the colour and flavour of cocoa powder or cocoa liquor, and also improve dispersibility or suspension of the cocoa solids in water. During the process, the alkali solution is sprayed into the drum after it has been charged with the nibs, which is then slowly dried at a temperature below 100°C (212°F) (Awua, 2002). The chemistry on effects of alkalisation on colour and flavour formation of cocoa and chocolates have been described in Chapter 4.

3.2.5 Roasting

Cocoa beans are roasted to develop further the original cocoa flavour that exists in the form of precursors generated during the processes of fermentation and drying of the beans. During roasting of the dried fermented beans, several physical and chemical changes take place, which include the following:

1. Loosening of the shells.
2. Moisture loss from the beans to about 2% final content.
3. The nibs (cotyledons) become more friable and generally darken in colour.
4. Additional reduction in the number of micro-organisms present in the beans. This helps attain food-grade products, such as cocoa butter, cocoa powder and cocoa liquor, which have stringent microbiological specifications.
5. Degradation of amino acids takes place and proteins are partly denatured. The natural reducing sugars are almost destroyed during degradation of amino acids.
6. Losses of volatile acids and other substances that contribute to acidity and bitterness. A large number of compounds have been detected in the volatile compounds including aldehydes, ketones, pyrazines, alcohols and esters. The substances that undergo only minimal changes are the fats, polyphenols and alkaloids (Minifie, 1989).

Awua (2002) explained that the degree of changes is related to the time and temperature of roasting and the rate of moisture loss during the process. The roasting temperature varies between 90 and 170°C depending on the type of roasting adopted, being dry or moist roasting.

Three main methods of roasting are employed within the cocoa processing industry and these include the following:

1. Whole bean roasting
2. Nib roasting
3. Liquor roasting

Whole bean roasting is usually the traditional way of producing cocoa liquor. By this process, the beans are roasted first before winnowing to facilitate removal of the shells which are broken by high-speed impact against metal plates. During the process, the heat causes some of the fat to migrate into the shells, thus resulting in a loss of some cocoa butter. This is
particularly important in the case of broken or crushed beans. Nib roasting is done by first removing the shells before roasting, and by this many of the limitations of whole bean roasting are overcome. This also makes it possible to treat the nibs with alkaline or sugar solution during roasting to help improve flavour development in certain types of cocoa. In liquor roasting, thermal pre-treatment is often used before winnowing for liquor roasting. The nib is then ground to liquor before roasting. The major disadvantage of both nib and liquor roasting is that the shell must be removed before it has been loosened from the nib by heating, and this may result in poor separation, especially with some type of cocoa. As a result, a variety of machines have been developed to thermally pre-treat the beans. These develop a high surface temperature and evaporate the internal moisture, which in turn builds up a pressure within the bean, causing the shell to come away from the nib.

### 3.2.6 Nib grinding and liquor treatment

Nib grinding involves milling of cocoa nibs to form cocoa liquor. The purpose is to produce as low a viscosity as possible to obtain smooth cocoa powder and chocolate taste during subsequent use of the liquor. The nib has a cellular structure containing about 55% cocoa butter in solid form locked within the cells. Grinding of nib cells releases the cocoa butter into liquor with particle size up to 30 µm, and for production of cocoa powder, fine grinding is particularly important. The viscosity of the liquor is related to the degree of roasting preceding the grinding and to moisture content of the nib.

Many machines are used for reducing the nibs into liquor, and these include stone mills, disc mills, pin or hammer mills and bead or ball mills. The grinding is done in a multistage process, and the heat treatment generated during the grinding process causes the cocoa butter in the nib to melt, forming the cocoa liquor. The refined cocoa liquor is heated in storage tanks at a temperature of about 90–100°C for aging and microbial destruction, after which the liquor is packaged for sale (Awua, 2002). Typically approximately 78–90% of cocoa butter is collected by pressing; residual lipids may be removed by supercritical fluid extraction (Beckett, 2000).

### 3.2.7 Liquor pressing

Cocoa butter constitutes about half the weight of the cocoa nib. This fat is partially removed from the cocoa liquor by means of hydraulic presses applying pressures as high as 520 kg/cm², and the larger presses take a charge of up to 113.4 kg per pressing cycle. Depending on the pressing time and the settings of the press, the resulting cake may have a fat content of between 10 and 24%. Two kinds of cocoa cake can be obtained by the process:

1. High-fat cake containing between 22 and 24% residual fat in the pressed cake
2. Low-fat cake containing between 10 and 12% residual fat in the pressed cake

The cocoa butter extracted is discharged into receptacles from which it is pumped into an intermediate tank for further processing.

### 3.2.8 Cake grinding (kibbling)

After pressing, the cakes released are quite big to handle and are therefore passed through kibbling machines to be broken down into smaller pieces, known as kibbled cake. The kibbled
cake obtained is stored by fat content and degree of alkalisation, and may be blended before pulverisation to obtain the desired type of cocoa powder.

### 3.2.9 Cocoa powder production

The powder grinding lines usually comprise hammer-and-disc or pin mills, which pulverise cocoa cake particles into the defined level of fineness of cocoa powder. The powder is then cooled after pulverisation so that the fat of the cocoa powder crystallises into its stable form. This prevents any discolouration (fat bloom) and the formation of lumps in the bags after packing, a phenomenon that is caused by insufficient crystallisation of the fat at the moment of filling (ADM Cocoa, 2006). The free flowing powder is then passed through sieves and over magnets prior to packing in bulk containers or four-ply multiwall paper bags lined with polyethylene.

### 3.3 CHOCOLATE MANUFACTURING PROCESSES

Chocolate manufacturing processes generally share common features (Fig. 3.1) such as:

1. **Mixing**
2. **Refining**
3. **Conching of chocolate paste**
4. **Tempering and depositing**
5. **Moulding and demoulding**

The outcome sought is smooth textures of products considered desirable in modern confectionery and elimination of oral perceptions of grittiness.

#### 3.3.1 Mixing

Mixing of ingredients during chocolate manufacture is a fundamental operation employed using time–temperature combinations in a continuous or batch mixers to obtain constant formulation consistency. In batch mixing, chocolate containing cocoa liquor, sugar, cocoa butter, milk fat and milk powder (depending on product category) is thoroughly mixed normally for 12–15 minutes at 40–50°C. Continuous mixing is usually used by large chocolate manufacturers such as Nestlé and Cadbury using well-known automated kneaders, producing somewhat tough texture and plastic consistency (Minifie, 1989; Beckett, 2000; Awua, 2002).

#### 3.3.2 Refining

Refining of chocolate is important to the production of smooth texture that is desirable in modern chocolate confectionery. Mixtures of sugar and cocoa liquor (and milk solids depending on the type of chocolate) at an overall fat content of 8–24% are refined to particle size of less than 30 µm normally using a combination of two- and five-roll refiners (Beckett, 1999, 2000). Final particle size critically influences the rheological and sensory properties. A five-roll refiner (Fig. 3.2) consists of a vertical array of four hollow cylinders,
Mixing

Refining

Conching

1st Stage: Dry conching
2nd Stage: Pasty phase
3rd Stage: Liquid conching

Tempering

Enrobing

Moulding

Panning (b)

Packaging

Sugar
Cocoa liquor
Cocoa butter
Skimmed milk powder (SMP)\(^{(a)}\)

Agglomeration of ingredients in thick paste, continuously or with batch mixers

Size reduction of mix via two-three- or five-roll refiner

Final flavour development, final viscosity of the sample with conche rotations for 4–24 hours

Most stable form of cocoa butter crystals – Form V via heating/cooling systems (maintained at 35°C)

Note: (a) Skimmed milk powder is only used in milk chocolate manufacture;
(b) Panning means that the chocolate is used as coating for hard centres such as nuts.

Fig. 3.1 Processing steps for chocolate manufacture (Afoakwa et al., 2007a).

temperature controlled by internal water flow, held together by hydraulic pressure. A thin film of chocolate is attracted to increasingly faster rollers, travelling up the refiner until removed by a knife blade. Roller shearing fragments solid particles, coating new surfaces with lipid so that these become active, absorbing volatile flavour compounds from cocoa components.

Texture in milk chocolate appears improved by a bimodal distribution of particles with a small proportion having sizes up to 65 µm. Optimum particle size for dark chocolate is lower at less than 35 µm although values are influenced by the product and composition (Awua, 2002). Refiners, in summary, not only affect particle size reduction and agglomerate breakdown, but distribute particles through the continuous phase coating each with lipid.
3.3.3 Conching

Conching is regarded as the endpoint or final operation in the manufacture of bulk chocolate, whether milk or dark. It is an essential process that contributes to development of viscosity, final texture and flavour. Conching is normally carried out by agitating chocolate at more than 50°C for few hours (Beckett, 2000). In the early stages, moisture is reduced with removal of certain undesirable flavour-active volatiles such as acetic acid, and subsequently interactions between disperse and continuous phase are promoted.

In addition to moisture and volatile acid removal, the conching processing promotes flavour development due to the prolonged mixing at elevated temperatures, giving a partly caramelised flavour in non-milk crumb chocolate. The process also aids reduction in viscosity of refiner pastes throughout the process, and reduction in particle size and removal of particle edges (Minifie, 1989; Beckett, 2000; Awua, 2002).

The name of the equipment, the conche, is derived from the Latin word ‘shell’, as the traditional conche used in chocolate manufacture resembled the shape of a shell. Figure 3.3 is an illustration of a Frisse conche. The Frisse conche is a typical example of an overhead conche used in modern chocolate industry. It consists of a large tank with three powerful intermeshing mixer blades, providing shearing and mixing action. The internal mechanics of Frisse conche is as shown in Figure 3.3. Conching times and temperatures vary (Awua, 2002) typically: for milk crumb 10–16 hours at 49–52°C, with milk powder products 16–24 hours at up to 60°C, and with dark chocolates at 70°C and continue up to 82°C. Replacing full-fat milk powder with skimmed milk powder and butter fat, temperatures up to 70°C may be used (Awua, 2002). To give chocolate a suitable viscosity, additional cocoa butter and lecithin can be added towards the end of conching to thin or liquefy the chocolate prior to tempering (Beckett, 2000; Whitefield, 2005).