Yogurt continues to be one of the fastest growing food categories around the world. This book, now in a revised second edition, offers a comprehensive source of information on the manufacturing stages of yogurt and fermented milks from the receipt of raw materials to the packaging of the products. The health benefits of these products in the human diet are also addressed. Chapters are grouped into four sections: Basic Background, Manufacture of Yogurt, Manufacture of Fermented Milks, and Health Benefits. Coverage of manufacturing processes is supported by sound scientific, technological, and engineering principles.

This new edition of Manufacturing Yogurt and Fermented Milks addresses novel introductions in the marketplace, including unique textured Greek-style yogurt, yogurt cups with domes containing cereals, fruits and other additives, yogurts containing probiotics and prebiotics, yogurts with specific strains claiming digestive and immune-enhancing benefits, and yogurts fortified with vitamins A & D, calcium, fiber, and other health-enhancing ingredients.

Chapters have been updated throughout to highlight recent technological advances as well as changes in regulatory requirements in the United States for milk production, transportation, and processing. Other chapters have been revised to include developments and advancements in probiotics and prebiotics and their health attributes as well as possible health claims relative to their consumption. A new chapter on Greek and related yogurt products has been added.

It is hoped that this new edition will continue to be useful for food industry personnel involved in production, research and development, quality control/assurance, and purchasing managers. It will also be of interest to students of dairy food science and technology.

**THE EDITORS**

Dr Ramesh C. Chandan, President, Global Technologies, Inc., Coon Rapids, Minnesota, USA
Dr Arun Kilara, Principal, Nutri+Food Business Consulting, Chapel Hill, North Carolina, USA

**ALSO AVAILABLE FROM WILEY-BLACKWELL**

- Analytical Methods for Food and Dairy Powders
- Advances in Dairy Ingredients
- Membrane Processing – Dairy and Beverage Applications
Manufacturing Yogurt and Fermented Milks
Dedication

We dedicate this book to Professor Khem M. Shahani, who inspired, mentored and guided both of the editors of this book while they were graduate students at the University of Nebraska–Lincoln. In our opinion, Dr Shahani truly belonged to the distinguished world class of pioneers in conducting sound scientific studies on the beneficial health attributes of consuming live and active yogurt containing probiotics, as exemplified by *Lactobacillus acidophilus*, other lactobacilli and bifidobacteria. The groundbreaking work of his research laboratory at the University of Nebraska–Lincoln elucidated how yogurt culture containing active lactase enzyme helps in the digestion of lactose in lactose-malabsorbing individuals. Other research work showed a reduction of serum cholesterol as a result of consumption of *acidophilus* products. His research team demonstrated immune-system enhancement by the consumption of probiotic cultures. Furthermore, it provided evidence for the suppression of pathogenic bacteria (such as *Heliobacter pylori*, *E. coli*, *Salmonella* and *Staphylococcus aureus*) by *Lactobacillus acidophilus*. We were indeed fortunate to have worked on some of the areas mentioned above under Dr Shahani’s tutelage and direction.

Prior to Dr Shahani’s outstanding research findings, the scientific and medical community did not generally recognize or appreciate the health merits of live and active yogurt bacteria and probiotic cultures. With the help of Dr Shahani, compelling scientific data made a profound impact on the philosophy of health maintenance and improvement. The results of his probiotic research, as well as his numerous presentations to international audiences, brought credibility and convinced many clinicians around the world regarding the outstanding health benefits of consuming live and active probiotic cultures. In this regard, we believe that Dr Shahani initiated a movement to bring the science of probiotics and their use directly to consumers concerned with improving their health.

We dedicate this book to the memory of Dr Shahani for his outstanding pioneering work on yogurt and probiotic cultures.

Ramesh C. Chandan and Arun Kilara
Manufacturing Yogurt
and Fermented Milks

Second Edition

Edited by

Ramesh C. Chandan
Global Technologies, Inc.
Coon Rapids, Minnesota
USA

Arun Kilara
Nutri+Food Business Consulting
Chapel Hill, North Carolina
USA
## Contents

*List of contributors*  xi  
*Preface to the second edition*  xiii  
*Preface to the first edition*  xv  

### PART I BASIC BACKGROUND

1  **History and consumption trends**  3  
   Ramesh C. Chandan  
   1.1 Overview of the world dairy industry  3  
   1.2 Milk production in the USA  3  
   1.3 Production of dairy foods in the USA  4  
   1.4 Fermented/cultured dairy products  7  
   1.5 Occurrence and consumption of fermented milks in various regions  8  
   1.6 Major commercial fermented milks  11  
   1.7 Scandinavian fermented milks  15  
   1.8 Russian and Eastern European fermented milks  16  
   1.9 Middle Eastern fermented milks  16  
   1.10 South Asian fermented milks  17  
   References and further reading  19  

2  **Milk composition, physical and processing characteristics**  21  
   Guillaume Brisson and Harjinder Singh  
   2.1 Introduction  21  
   2.2 Milk composition  21  
   2.3 Milk components and processing characteristics  23  
   2.4 Physicochemical properties of milk  37  
   References and further reading  44  

3  **Regulatory requirements for milk production, transportation and processing**  49  
   Cary P. Frye  
   3.1 Introduction  49  
   3.2 From farm to factory  49  
   3.3 History of milk safety  50  
   3.4 United States Public Health Grade “A” Milk Safety Program  50  
   3.5 Inspection of milk safety  51  
   3.6 Farm requirements  52  
   3.7 Milk transportation  53
## Contents

3.8 Processing plant 54  
3.9 Hazard Analysis and Critical Control Point System 58  
3.10 Standards and regulations 60  
3.11 Milk pricing—US Federal Milk Marketing Orders 65  
  Glossary 68  
  References and further reading 68  

### 4 Regulations for product standards and labeling 71  
Cary P. Frye  
  4.1 US Code of Federal Regulations 71  
  4.2 US product standards of identity 71  
  4.3 Fermented milk and milk products 72  
  4.4 Stayed provisions 77  
  4.5 Frozen yogurt 79  
  4.6 Food additives and packaging 79  
  4.7 Labeling 80  
  4.8 Codex Standards and definitions for fermented-milk products 89  
  Glossary 91  
  References and further reading 92  

### 5 Principles of dairy processing 95  
Arun Kilara  
  5.1 Introduction 95  
  5.2 From farm to factory 95  
  5.3 Storage of raw milk 96  
  5.4 Overview of processing equipment in a dairy plant 99  
  5.5 Centrifugal operations 105  
  5.6 Thermal-processing systems 107  
  5.7 Homogenization 110  
  5.8 Membrane technology 111  
  5.9 Conclusion 113  
  Further reading 113  

### 6 Starter cultures for yogurt and fermented milks 115  
Ebenezer R. Vedamuthu  
  6.1 Introduction 115  
  6.2 Starter functions 118  
  6.3 Factors affecting starter performance 120  
  6.4 Microorganisms used in starters for cultured dairy products 127  
  6.5 Genus *Lactococcus* 130  
  6.6 Comments on Cit* Lactococcus lactis* ssp. *lactis* 136  
  6.7 Genus *Leuconostoc* 136  
  6.8 Genus *Streptococcus* 138  
  6.9 Genus *Lactobacillus* 140  
  6.10 Genus *Bifidobacterium* 142  
  6.11 Starter-culture production 142
6.12 Miscellaneous starters 146
6.13 Literature 146
References and further reading 147

7 Fermented dairy packaging materials 149
Aaron L. Brody
7.1 Introduction 149
7.2 Fundamentals of packaging 150
7.3 Packaging materials 151
7.4 Interactions between product and packaging 160
7.5 The package in product distribution 162
7.6 Graphic design and assessment 163
7.7 Economics of packaging 164
7.8 Regulation 165
7.9 Packaging and the environment 166
7.10 Packaging for yogurt and fermented dairy products 168
7.11 Future trends 174
References and further reading 174

8 Milk and milk-based ingredients 177
Isabelle Sodini and Phillip S. Tong
8.1 Introduction 177
8.2 Composition and specifications 177
8.3 Performances in yogurt formulation 178
8.4 Conclusion 189
References and further reading 189

PART II MANUFACTURE OF YOGURT 193

9 Yogurt: fruit preparations and flavoring materials 195
Kevin O’Rell and Ramesh C. Chandan
9.1 Introduction 195
9.2 Fruit as a raw material for yogurt preparations 196
9.3 Processing of fruit for use in yogurt fruit preparations 197
9.4 Formulation of fruit preparations 200
9.5 Processing yogurt fruit preparations 209
9.6 Packaging of fruit preparations 213
9.7 Acknowledgment 215
References and further reading 215

10 Ingredients for yogurt manufacture 217
Ramesh C. Chandan and Kevin O’Rell
10.1 Introduction 217
10.2 Dairy ingredients and their origin 217
10.3 Sweeteners 224
10.4 Stabilizers 233
References and further reading 236
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Principles of yogurt processing</td>
<td>239</td>
</tr>
<tr>
<td>Ramesh C. Chandan and Kevin O’Rell</td>
<td>11.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>11.2</td>
<td>Mix preparation</td>
<td>239</td>
</tr>
<tr>
<td>11.3</td>
<td>Heat treatment</td>
<td>239</td>
</tr>
<tr>
<td>11.4</td>
<td>Homogenization</td>
<td>241</td>
</tr>
<tr>
<td>11.5</td>
<td>Yogurt starter</td>
<td>242</td>
</tr>
<tr>
<td>11.6</td>
<td>Changes in milk constituents during yogurt production</td>
<td>256</td>
</tr>
<tr>
<td>References and further reading</td>
<td>260</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Manufacture of various types of yogurt</td>
<td>263</td>
</tr>
<tr>
<td>Kevin O’Rell and Ramesh C. Chandan</td>
<td>12.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>12.2</td>
<td>General manufacturing procedures applicable to all categories</td>
<td>263</td>
</tr>
<tr>
<td>12.3</td>
<td>Yogurt types, styles, subcategories and definitions</td>
<td>268</td>
</tr>
<tr>
<td>12.4</td>
<td>Market statistics on the yogurt trade</td>
<td>269</td>
</tr>
<tr>
<td>12.5</td>
<td>Manufacturing process for major yogurt categories</td>
<td>272</td>
</tr>
<tr>
<td>12.6</td>
<td>General manufacturing procedures for major types of yogurt</td>
<td>278</td>
</tr>
<tr>
<td>12.7</td>
<td>Post-culturing heat treatment</td>
<td>294</td>
</tr>
<tr>
<td>References and further reading</td>
<td>295</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Greek-style yogurt and related products</td>
<td>297</td>
</tr>
<tr>
<td>Arun Kilara and Ramesh C. Chandan</td>
<td>13.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>13.2</td>
<td>Greek-style yogurt</td>
<td>299</td>
</tr>
<tr>
<td>13.3</td>
<td>Chakka and shrikhand</td>
<td>305</td>
</tr>
<tr>
<td>13.4</td>
<td>Quarg and fromage frais</td>
<td>309</td>
</tr>
<tr>
<td>13.5</td>
<td>Mishti doi/dahi</td>
<td>315</td>
</tr>
<tr>
<td>References and further reading</td>
<td>317</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Plant cleaning and sanitization</td>
<td>319</td>
</tr>
<tr>
<td>Dennis Bogart</td>
<td>14.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>14.2</td>
<td>Cleaning</td>
<td>320</td>
</tr>
<tr>
<td>14.3</td>
<td>Sanitization</td>
<td>326</td>
</tr>
<tr>
<td>14.4</td>
<td>Phage control</td>
<td>328</td>
</tr>
<tr>
<td>14.5</td>
<td>A final thought</td>
<td>330</td>
</tr>
<tr>
<td>15</td>
<td>Yogurt plant: quality assurance</td>
<td>331</td>
</tr>
<tr>
<td>Kevin O’Rell and Ramesh C. Chandan</td>
<td>15.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>15.2</td>
<td>Regulatory obligations</td>
<td>331</td>
</tr>
<tr>
<td>15.3</td>
<td>Quality-control programs</td>
<td>341</td>
</tr>
<tr>
<td>15.4</td>
<td>National Yogurt Association criteria for live- and active-culture yogurts</td>
<td>346</td>
</tr>
<tr>
<td>15.5</td>
<td>Specification program</td>
<td>348</td>
</tr>
<tr>
<td>References and further reading</td>
<td>352</td>
<td></td>
</tr>
</tbody>
</table>
16 Sensory analysis of yogurt 353
Yonca Karagül-Yüceer and MaryAnne Drake
16.1 Introduction 353
16.2 Sensory-analysis techniques 353
16.3 Sensory analysis of yogurt 359
16.4 Conclusions 364
References and further reading 365

PART III  MANUFACTURE OF FERMENTED MILKS 369

17 Cultured buttermilk 371
Charles H. White
17.1 Introduction 371
17.2 Milk supply 373
17.3 Processing of milk 374
17.4 Buttermilk starter culture 374
17.5 Breaking, cooling, bottling and distribution 376
Acknowledgment 379
References and further reading 379

18 Cultured/sour cream 381
Bill Born
18.1 Early history 381
18.2 Present standards 383
18.3 Sour-cream products 388
References and further reading 390

19 Other fermented and culture-containing milks 393
Ebenezer R. Vedamuthu
19.1 Introduction 393
19.2 Dahi 395
19.3 Kefir 399
19.4 Koumiss 402
19.5 Acidophilus milk and sweet acidophilus milk 403
19.6 Probiotic milks 406
19.7 Bulgarian milk 407
19.8 Skyr 407
19.9 Viili 408
19.10 Kurut 409
References and further reading 409

PART IV  HEALTH BENEFITS 411

20 Functional foods and disease prevention 413
Ramesh C. Chandan and Nagendra P. Shah
20.1 Introduction 413
20.2 Functional foods 414
Contents

20.3 Bioactive dairy ingredients 415
20.4 Milk fat 421
20.5 Probiotics 422
20.6 Fortification 429
20.7 Physiologically active ingredients 429
   References and further reading 429

21 Health benefits of yogurt and fermented milks 433
Nagendra P. Shah
21.1 Introduction 433
21.2 Yogurt and other fermented milks 435
21.3 Health benefits of fermented milks 438
   References and further reading 448

22 Probiotics and fermented milks 451
Nagendra P. Shah
22.1 Introduction 451
22.2 Taxonomy of lactic-acid bacteria 451
22.3 Probiotic bacteria 452
22.4 Selection criteria for probiotics 453
22.5 Health benefits of Lactobacillus acidophilus and bifidobacteria 459
22.6 Conclusion 465
   References and further reading 466

Index 469
List of contributors

Dennis Bogart  
Randolph Associates, Inc.  
Birmingham, Alabama,  
USA  

Bill Born  
Dairy Consultant (retired from Dean Foods Co.)  
Rockford, Illinois,  
USA  

Guillaume Brisson, PhD  
Riddet Institute  
Massey University  
New Zealand  

Aaron L. Brody, PhD  
President & CEO  
Packaging/Brody, Inc.  
Duluth, Georgia,  
USA  

Ramesh C. Chandan, PhD  
Consultant  
Global Technologies, Inc.  
Coon Rapids, Minnesota,  
USA  

MaryAnne Drake, PhD  
Department of Food Science  
North Carolina State University  
Raleigh, North Carolina,  
USA  

Cary P. Frye  
Vice-President, Regulatory Affairs  
International Dairy Foods Association  
Washington, DC,  
USA  

Yonca Karagül-Yüceer, PhD  
Assistant Professor  
Canakkale Onsekiz Mart University  
Department of Food Engineering  
Terzioglu Campus  
Turkey  

Arun Kilara, PhD  
Principal, Nutri+Food Business Consulting  
Chapel Hill, North Carolina,  
USA  

Kevin O’Rel  
Senior Vice President, Operations/R&D  
The YoCrunch Company, LLC  
Rosemont, Illinois,  
USA  

Nagendra P. Shah, PhD, FAIFST  
Professor of Food Science  
The University of Hong Kong  
Pokfulam Road, Hong Kong  

Harjinder Singh, PhD, FRSNZ  
FIAFoST Director  
Riddet Institute  
Massey University  
New Zealand  

Isabelle Sodini, PhD  
Portocork America  
Napa, California,  
USA  

Phillip S. Tong, PhD  
Director, Dairy Products Technology Center  
California Polytechnic State University  
San Luis Obispo, California,  
USA
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ebenezer R. Vedamuthu, PhD</td>
<td>Consultant</td>
<td>Corvallis, Oregon, USA</td>
</tr>
<tr>
<td>Charles H. White, PhD</td>
<td>Randolph Associates, Inc.</td>
<td>Birmingham, Alabama, USA</td>
</tr>
</tbody>
</table>
Preface to the second edition

The first edition of *Manufacturing Yogurt and Fermented Milks* was published in 2006. The book was well received and it is gratifying to note that the publisher wants to bring out the second edition. A number of developments have taken place since the first edition was published. Yogurt continues to be one of the fastest-growing food categories in the USA as well as in the rest of the world. New introductions in the marketplace include health-oriented smoothies/drinks, yogurts containing probiotics and prebiotics, yogurts with specific strains claiming digestive and immune-enhancing benefits, uniquely textured Greek-style yogurt and yogurt fortified with vitamins A and D, calcium, fiber and other health-enhancing ingredients. Greek-style yogurt, with its new texture and attractive consumer-positive attribute (twice as much protein), now commands nearly one-quarter of the total yogurt market in the USA. Similarly, frozen yogurt has taken hold, and new offerings include probiotics and health-oriented ingredients.

The second-edition chapters have been updated to highlight the changes since the first edition. More importantly, the advances in regulatory requirements for milk production, transportation and processing in the USA have been discussed. Accordingly, regulatory standards for milk, yogurt and fermented milks which have been developed and adopted by the US Food and Drug Administration (FDA) and the Codex Alimentarius Commission have been included. The new edition also deals with the extensive changes that have occurred in the regulations for product standards and labeling.

The chapter on the principles of dairy processing (Chapter 5) has been updated with respect to membrane processing technology. New developments in starter technology with respect to new cultures (mild, gel-forming) and probiotic strains have been discussed. The dairy-packaging chapter (Chapter 7) has also been updated.

Recent developments relative to fruit preparations and flavoring materials for yogurt manufacture have been added. The current practices of using milk and milk-based ingredients have been incorporated. In particular, newer ingredients (milk-protein concentrate and other nondairy ingredients) have been included. The chapters on the principles of yogurt processing have been updated to include developments in Greek-style yogurt, stevia-based high-intensity sweeteners, smoothies/yogurt drinks and probiotic yogurts. A new chapter on Greek-style and other concentrated yogurt products (Chapter 13) has been added in recognition of the fact that currently, almost 30% of the yogurt market in the USA consists of Greek-style yogurt. The chapters on plant cleaning (Chapter 14) and quality assurance (Chapter 15) have been brought up to date.

Other chapters have been revised to include developments and advancements in the areas of probiotics and prebiotics and their health attributes, as well as possible health claims relative to their consumption.

The book is intended to focus primarily on the yogurt and fermented-milks industry in North America in general and the USA in particular. The material on scientific principles and the basis of yogurt technology has universal applications throughout the world. It is
hoped that the updated second edition will continue to be useful for university students in dairy food science and technology and food-industry personnel involved in production, research and development, quality control/assurance and purchasing.

Ramesh C. Chandan, Minneapolis, Minnesota
Arun Kilara, Chapel Hill, North Carolina
Preface to the first edition

Fermented dairy products other than cheeses have been consumed around the world for thousands of years. Nevertheless, their industrial production is relatively a new innovation. Yogurt has emerged as an outstanding new product of recent times. It has occupied a very significant position of consumer acceptance and growth in North America and throughout the world. In the United States, yogurt, buttermilk, sour cream, and probiotic drinks have become multibillion dollar industry. The yogurt market continues to grow on an annual basis.

The literature on yogurt and fermented milks is vast and diverse. It encompasses the basic and fundamental aspects as well as applied and practical facets of the industry. This book is intended to disseminate the applied and practical aspects. Some basic science is included only to facilitate understanding of the practice of manufacturing yogurt and fermented milks. Overall, our objective is not to provide fundamental information. Instead, attempts have been made to deal with the application of the science of yogurt and fermented milks to their manufacture and emphasize the practices in vogue in the industry.

As mentioned above, the book is dedicated to the manufacture of yogurt and fermented milks. In view of the multidisciplinary nature and continued fast developments in the technology and packaging of fermented milks, the book has multiple authors. The authors drawn from the industry and academia are experts in their respective fields. Many authors have utilized their life-long experience in the product development, quality assurance, and manufacture of yogurt and fermented milks in their contributed chapters. Their contribution to the writing of the book makes this book unique and the first of its kind in the literature. From a comprehension and readability standpoint, an effort has been made to make the book reader-friendly.

The book is organized into twenty-two chapters and divided into four parts. Part I covers the basic background with eight chapters. The objective is to prepare the reader for the manufacturing of yogurt and fermented milks by providing relevant information on product trends, regulatory aspects, dairy processing technologies, packaging techniques, starter cultures use, and laboratory analysis.

Part II is devoted to the manufacture of yogurt. This part also consists of eight chapters. It includes raw materials, namely dairy and dairy-based ingredients, fruits and flavors, stabilizers, sweeteners (nutritive and high intensity), principles of yogurt processing, types of yogurt products on the market and their manufacturing techniques, quality control procedures, sensory evaluation of yogurt, and plant cleaning and sanitizing programs. The formulation, regulatory aspects, labeling, processing equipment, and packaging operations of various products have been included.

Part III contains three chapters detailing the manufacturing technology of cultured buttermilk, sour cream, and miscellaneous fermented milks popular throughout the major regions of the world. It also includes culture-containing milks that are not cultured and retain the sensory characteristics of milk but concomitantly provide beneficial probiotic cultures to the consumer.
Part IV deals with the overall health benefits of yogurt and fermented milks. This topic has assumed much interest in view of consumer perception of health promotion attributed to functional foods like yogurt and fermented milks. This part brings to the reader a brief review of our understanding of both perceived and real benefits. A concise account of the scientific and clinical evidence associated with the benefits of consuming yogurt and milks containing probiotic cultures, prebiotics and synbiotics has been reviewed. This is a timely subject because new products with health claims are increasingly appearing in the market. We feel that this is the direction for future growth of the industry engaged in yogurt and fermented milks manufacture.

This book is the culmination of efforts to provide a systematic and relatively simplified version of the information available on significant aspects of manufacturing yogurt and fermented milks. It is intended as a text book to be used by upper undergraduate university students of dairy and food science to learn the theory and practice of technology associated with the manufacture of yogurt and fermented milks. Graduate students should find the book useful as a reference book to obtain information on applied science and technology of yogurt and fermented milks. The industrial bias of the book should appeal to practitioners of food science and technology in the food industry. In this case, it would provide a ready reference material for plant operators, personnel performing functions in quality control/assurance, and research and development. The book should also be helpful for the food industry personnel engaged in taking purchasing decisions. Since the book conveys collated practical information on yogurt and fermented milks in entirety, it should be useful as a text book to the instructors and participants of the industry-oriented short courses in cultured dairy products.

We acknowledge the worldwide contribution of all the scientists, technologists and engineers who have established modern principles for the manufacture of yogurt and fermented milks to provide the consumer with a truly functional family of foods that furnish vital dairy nutrients as well as unique, wholesome and healthy products.

Ramesh C. Chandan, Minneapolis, Minnesota
Charles H. White, Mississippi State, Mississippi
Arun Kilara, Chapel Hill, North Carolina
Y.H. Hui, Sacramento, California
Part I
Basic background
1 History and consumption trends

Ramesh C. Chandan

Global Technologies, Inc., Coon Rapids, Minnesota, USA

1.1 Overview of the world dairy industry

According to the UN Food and Agriculture Organization (FAO, 2011), the world production of milk in 2009 was 701.4 million metric tons (MT). This was estimated to increase to 713.6 million MT in 2010 and to 727.6 million MT in 2011. India is the largest producer of milk (including milk of cows and water buffaloes) in the world, with an estimated 121.7 million MT in the year 2011.

The 2009 world production of cow milk in the selected countries shown in Table 1.1 was 432.7 million MT. The documented number of cows was 129,296 thousand heads. Individual cow-milk yield varies widely around the world. In 2009, the USA and Japan were the most efficient milk producers, with 9.33 MT/cow, followed by Canada, with a yield of 8.46 MT per cow. Milk yield was lowest in India (1.13 MT/head), followed by Brazil (1.67 MT/head) and Mexico (1.70 MT/head).

1.2 Milk production in the USA

The trend in the last decade indicates a noticeable decrease in dairy-cow population, from 9.151 million heads in the year 1998 to 9.117 million heads in 2010 (Table 1.2). In the year 2010, 9.117 million cows produced 87.46 million MT (192,819 million pounds) of milk (IDFA, 2011). Table 1.2 also shows that during the period 1998–2010 there is a steady increase in milk production per cow, from 7.79 MT (17,185 pounds) to 9.59 MT (21,149 pounds). Concomitantly, milk production in the USA registered an increase from 76.33 million MT (157,262 million pounds) to 87.46 million MT (192,819 million pounds). Approximately 20% of the world’s milk is produced in the USA. The American dairy farm has been able to achieve its current milk output through the application of scientific and management advancements in milk production. On the dairy farm, selection of dairy cows, their breeding, and judicious use of balanced feed rations have been instrumental in increasing milk output per cow. As a result of continuous efficiencies in milk production at the farm,
milk production per cow has doubled in the last 30 years. California continues to be the leading milk-producer state, followed by Wisconsin, New York, Idaho and Pennsylvania.

### 1.3 Production of dairy foods in the USA

At dairy farms, modern milking and milk-handling equipment, including automated milking systems, have improved the speed of cleaning, sanitizing, cooling and delivering good-quality raw milk to processing plants. The USA has the distinction of being the largest processor of milk and dairy products in the world. Advanced processing and packaging technologies ensure efficient delivery and a long shelf-life of high-quality milk products, including yogurt and fermented milks. Currently, the US dairy industry is valued at 110 billion US dollars (USD). Approximately 30% of the US milk produced on the farm is

---

**Table 1.1** World milk production in 2009. Adapted from USDA (2011a) and DairyCo (2011).

<table>
<thead>
<tr>
<th>Country</th>
<th>Milk cows (1000 head)</th>
<th>Milk yield/cow (MT/ head)</th>
<th>Total milk production (1000MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>979</td>
<td>8.46</td>
<td>8280</td>
</tr>
<tr>
<td>Mexico</td>
<td>6400</td>
<td>1.70</td>
<td>10866</td>
</tr>
<tr>
<td>USA</td>
<td>9203</td>
<td>9.33</td>
<td>85881</td>
</tr>
<tr>
<td>Argentina</td>
<td>2100</td>
<td>4.93</td>
<td>10350</td>
</tr>
<tr>
<td>Brazil</td>
<td>17200</td>
<td>1.67</td>
<td>28795</td>
</tr>
<tr>
<td>EU-27</td>
<td>24192</td>
<td>5.53</td>
<td>133700</td>
</tr>
<tr>
<td>Russia</td>
<td>9530</td>
<td>3.42</td>
<td>32600</td>
</tr>
<tr>
<td>Ukraine</td>
<td>2856</td>
<td>3.98</td>
<td>11370</td>
</tr>
<tr>
<td>India</td>
<td>42600</td>
<td>1.13</td>
<td>48160</td>
</tr>
<tr>
<td>China</td>
<td>7115</td>
<td>4.00</td>
<td>28445</td>
</tr>
<tr>
<td>Japan</td>
<td>848</td>
<td>9.33</td>
<td>7910</td>
</tr>
<tr>
<td>Australia</td>
<td>1676</td>
<td>5.56</td>
<td>9326</td>
</tr>
<tr>
<td>New Zealand</td>
<td>4597</td>
<td>3.69</td>
<td>16983</td>
</tr>
<tr>
<td>Total</td>
<td>129296</td>
<td>–</td>
<td>432666</td>
</tr>
</tbody>
</table>

**Table 1.2** Milk production in the USA. Adapted from IDFA (2011).

<table>
<thead>
<tr>
<th>Year</th>
<th>Milk cows (1000 head)</th>
<th>Milk yield/cow</th>
<th>Total milk production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pounds</td>
<td>MT</td>
</tr>
<tr>
<td>1998</td>
<td>9151</td>
<td>17185</td>
<td>7.79</td>
</tr>
<tr>
<td>1999</td>
<td>9153</td>
<td>17763</td>
<td>8.06</td>
</tr>
<tr>
<td>2000</td>
<td>9199</td>
<td>18197</td>
<td>8.25</td>
</tr>
<tr>
<td>2001</td>
<td>9103</td>
<td>18162</td>
<td>8.24</td>
</tr>
<tr>
<td>2002</td>
<td>9139</td>
<td>18608</td>
<td>8.44</td>
</tr>
<tr>
<td>2003</td>
<td>9081</td>
<td>18759</td>
<td>8.51</td>
</tr>
<tr>
<td>2004</td>
<td>9010</td>
<td>18960</td>
<td>8.60</td>
</tr>
<tr>
<td>2005</td>
<td>9050</td>
<td>19550</td>
<td>8.87</td>
</tr>
<tr>
<td>2006</td>
<td>9137</td>
<td>19895</td>
<td>9.02</td>
</tr>
<tr>
<td>2007</td>
<td>9189</td>
<td>20204</td>
<td>9.16</td>
</tr>
<tr>
<td>2008</td>
<td>9315</td>
<td>20395</td>
<td>9.25</td>
</tr>
<tr>
<td>2009</td>
<td>9203</td>
<td>20573</td>
<td>9.33</td>
</tr>
<tr>
<td>2010</td>
<td>9117</td>
<td>21149</td>
<td>9.59</td>
</tr>
</tbody>
</table>
processed into fluid milk and cream products (Schultz, 2011b). Fluid milk products include whole milk (3.25% fat), reduced-fat milk (2% fat), low-fat milk (1% fat), nonfat milk (<0.5% fat), half and half (10.5 to <18% fat), light cream (18 to <30% fat), light whipping cream (30 to <36% fat), heavy cream (not less than 36% fat), cultured milk (3.25% fat), cultured reduced-fat milk (2% fat), cultured low-fat milk (1% fat), cultured nonfat milk (<0.5% fat) (cultured buttermilk), yogurt (3.25% fat), reduced-fat yogurt (2% fat), low-fat yogurt (1% fat), nonfat yogurt (<0.5% fat) and cottage cheese (4, 2, 1 or <0.5% fat).

The remaining 70% of farm milk is used in dairy manufacturing plants, where it is transformed into more than 300 varieties and styles of cheese, 100 flavors of ice cream, frozen desserts and frozen yogurt. In addition, dairy plants produce an array of flavored milk, ranging from fat-free to full-fat, butter, sweetened condensed milk, evaporated milk, dry milk, lactose, whey products and cultured products such as sour cream and dips, buttermilk and yogurt drinks/smoothies. According to Schultz (2011a), Wisconsin has the most dairy plants (210), followed by New York state (108) and California (106). The dairy-processing industry has demonstrated several packaging and marketing innovations in competing aggressively for consumer food dollar share.

The products manufactured in the years 2006–2010 and their volumes are shown in Table 1.3. Butter production increased from 0.66 million MT (1448 million pounds) to 0.71 million MT (1564 million pounds), whereas natural cheese registered an increase from 4.32 million MT (9525 million pounds) to 4.73 million MT (10436 million pounds). Process cheese declined from 1.06 million MT (2349 million pounds) to 0.96 million MT (2124 million pounds). Frozen desserts, including ice cream, whole milk, reduced-fat and low-fat milk, fluid cream and egg nog showed a decline. Nonfat milk and flavored milks showed some increase in volume. In the fermented-dairy-products category, refrigerated yogurt displayed explosive growth, from 1.50 million MT (3301 million pounds) in 2006 to 1.90 million MT (4181 million pounds) in 2010. However, sour cream and dips showed a relatively steady production volume (0.57 million MT (1256 million pounds) to 0.59 million MT (1292 million pounds)), whereas buttermilk production declined from 0.23 million MT (504 million pounds) to 0.21 million MT (473 million pounds).

During 2001–2006, per capita consumption of skim milk, 2% milk and whole milk declined slightly. In 2008, whole-milk consumption per capita was 22.9 kg (50.7 pounds), followed by 28.5 kg (62.9 pounds) for 2% milk, 10.2 kg (22.4 pounds) for 1% milk and 12.3 kg (27.1 pounds) for nonfat milk (Schultz, 2011b). Compared to the previous year, the 2010 total sales of conventional fluid milks declined by 1.8%. Whole-milk sales fell by 5.4%, nonfat white milk by 1.4% and flavored whole milk by 4.1%. However, sales of low-fat white milk and flavored reduced-fat milk increased by 2.3 and 1.1%, respectively.

The frozen dessert category comprised 385 plants in 2010. These plants manufactured 3452 million l (912 million gallons) of regular ice cream, 1438 million l (380 million gallons) of low-fat ice cream, 188 million l (49.7 million gallons) of frozen yogurt and 187 million l (49.3 million gallons) of sherbet (Schultz, 2011a). The most popular flavor of ice cream continued to be vanilla (29%), followed by chocolate (14%) and strawberry (3.3%). The per capita consumption of regular ice cream in 2008 was 6.3 kg (13.9 pounds); that of low-fat ice cream was 3.1 kg (6.8 pounds). The per capita consumption of ice cream (10% fat or less) has declined in recent years. However, the premium ice-cream (16–18% fat) market has prospered. Also, frozen-yogurt consumption was 1.9 kg (4.3 pounds) per person (Schultz, 2011a).

Dairy farmers and dairy processors alike abide by strict state and federal sanitary standards. Grade A Pasteurized Milk Ordinance (PMO) regulations are basically the
recommendations of the Public Health Service of the Food and Drug Administration (FDA) of the United States Department of Health and Human Services (USDHHS, 2009). The PMO is meant for voluntary adoption, but its importance in ensuring the quality and safety of the milk supply in the country is recognized by the dairy industry as well as by state regulatory and sanitation officials. The PMO is a constantly evolving set of regulations designed to accommodate advancements and developments in science and technology related to milk production, processing, packaging and distribution. From time to time, modifications in the regulations are adopted following an agreement among the representatives of government, industry (milk producers, processors, equipment manufacturers and suppliers), academia and research institutions. To conform to the PMO, dairy farms and dairy plants are visited regularly by representatives of government regulatory agencies, who conduct quality-assurance and safety inspections. The inspectors confirm herd health, oversee veterinary practices, monitor sanitation of the facilities and milking equipment, and verify that the milk is being rapidly cooled and properly stored before delivery to processing facilities. They also ensure that the processing of milk is in accordance with the state and federal food laws. In some instances, state standards differ and may be even more stringent than the federal standards. The state, and in some cases local communities, has jurisdiction over standards for milk in its own market. The reader is referred to Chapter 3 for information on the regulatory requirements for milk production, transportation and processing. Chapter 4 details product standards and labeling.

Table 1.3 Production of dairy products in the USA during 2006–2010. Adapted from IDFA (2011) and USDA (2011b).

<table>
<thead>
<tr>
<th>Product</th>
<th>Million pounds for year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>Butter</td>
<td>1448</td>
</tr>
<tr>
<td>Natural cheese</td>
<td>9525</td>
</tr>
<tr>
<td>Processed cheese(^a)</td>
<td>2349</td>
</tr>
<tr>
<td>Frozen desserts(^d)</td>
<td>1576</td>
</tr>
<tr>
<td>Ice creams(^d)</td>
<td></td>
</tr>
<tr>
<td>Regular</td>
<td>982</td>
</tr>
<tr>
<td>Low-fat and nonfat</td>
<td>393</td>
</tr>
<tr>
<td>Cottage cheese(^b)</td>
<td>778</td>
</tr>
<tr>
<td>Milk (plain)</td>
<td></td>
</tr>
<tr>
<td>Whole</td>
<td>16443</td>
</tr>
<tr>
<td>Reduced- and low-fat</td>
<td>24271</td>
</tr>
<tr>
<td>Nonfat</td>
<td>8123</td>
</tr>
<tr>
<td>Other fluid milk products</td>
<td>894</td>
</tr>
<tr>
<td>Flavored milk and drink</td>
<td>4452</td>
</tr>
<tr>
<td>Fluid cream(^c)</td>
<td>2459</td>
</tr>
<tr>
<td>Egg nog</td>
<td>132</td>
</tr>
<tr>
<td>Refrigerated yogurt</td>
<td>3301</td>
</tr>
<tr>
<td>Frozen yogurt(^d)</td>
<td>66</td>
</tr>
<tr>
<td>Sour cream and dips</td>
<td>1256</td>
</tr>
<tr>
<td>Buttermilk</td>
<td>504</td>
</tr>
</tbody>
</table>

\(^a\)Includes process cheese, foods, spreads and cold pack.

\(^b\)Includes creamed, low-fat and nonfat cottage cheese.

\(^c\)Includes half and half, light cream and heavy cream.

\(^d\)Millions of gallons.
The PMO defines Grade A specifications and standards for milk and milk products in order to facilitate the movement of milk across state lines. Market milk, cream, yogurt, cultured buttermilk and sour cream are governed by the Grade A standards. Reciprocity rights maintain that milk conforming to the PMO sanitary standards in one state will not require further inspection for acceptance by another state.

The dairy-food industry has consolidated and continued to make large investments in new, state-of-the-art dairy manufacturing facilities. During the past decade, such developments have enabled a drastic reduction in the number of manufacturing facilities, while total output has increased by 4–5% annually. Continued investment will mean still lower processing costs and higher milk output.

### 1.4 Fermented/cultured dairy products

Fermented dairy foods have constituted a vital part of human diet in many regions of the world since times immemorial. They have been consumed ever since the domestication of animals. Evidence for the use of fermented milks comes from archeological findings associated with the Sumerians and Babylonians of Mesopotamia, the Pharoes of northeast Africa and the Indo-Aryans of the Indian subcontinent (Chandan, 1982, 2002; Vedamuthu, 1991; Ahmed and Wangsai, 2007; Tamime and Robinson, 2007; Chandan and Nauth, 2012.). Ancient Indian scriptures, the Vedas, dating back some 5000 years, mention *dadhi* (modern *dahi*) and buttermilk. Also, the ancient Ayurvedic system of medicine cites fermented milk (*dadhi*) for its health-giving and disease-fighting properties (Aneja et al., 2002).

Historically, products derived from fermentation of the milk of various domesticated animals resulted in conservation of valuable nutrients which would otherwise deteriorate rapidly under the high ambient temperatures prevailing in South Asia and the Middle East. Thus the process permitted consumption of milk constituents over a period significantly longer than was possible for milk itself. Concomitantly, conversion of milk to fermented milks resulted in the generation of a distinctive viscous consistency, smooth texture and unmistakable flavor. Furthermore, fermentation provided food safety, portability and novelty for the consumer. Accordingly, fermented dairy foods evolved into the cultural and dietary ethos of the people residing in the regions of the world where they owe their origin.

Milk is a normal habitat of a number of lactic-acid bacteria, which cause spontaneous souring of milk held at bacterial-growth temperatures for an appropriate length of time. Depending on the types of lactic-acid bacteria gaining entry from environmental sources (air, utensils, milking equipment, milking personnel, cows, feed), the sour milk attains a characteristic flavor and texture.

Approximately 400 diverse products derived from the fermentation of milk are consumed around the world. As mentioned before, fermentation conserves vital nutrients of milk. Simultaneously, it modifies certain milk constituents to enhance their nutritional status, and furnishes to the consumer live and active cultures in significant numbers, providing distinct health benefits beyond conventional nutrition. The fermented-milk products may be termed “functional foods.” They represent a significant and critical sector of human diet. The products fit into the cultural and religious traditions and dietary patterns of the people who consume them. In addition to the main ingredient, milk, other food ingredients are incorporated, innovating a range of nutritional profiles, flavors, textures and mouth feels, thereby offering an array of choices for the consumer.
The fermented foods and their derivatives constitute a staple meal, or may be consumed as an accompaniment to a meal. They may be also used as a snack, drink, dessert, condiment or spread, or as an ingredient of cooked dishes.

The diversity of fermented milks may be ascribed to:

- Use of milk obtained from a variety of domesticated animals.
- Application of diverse microflora as starters.
- Addition of sugar, condiments, grains, fruits and nuts to create a variety of flavors and textures.
- Application of additional preservation methods; for instance, freezing, concentrating and drying.

1.5 Occurrence and consumption of fermented milks in various regions

The diversity of fermented milks in various regions of the world is illustrated in Table 1.4. The variety of fermented milks in the world may be ascribed to various factors.

1.5.1 Milk of various species

Milk of various domesticated animals differs in composition and produces fermented milk with a characteristic texture and flavor (Table 1.5).

The milk of various mammals exhibits significant differences in total solids, fat, mineral and protein content. The viscosity and texture characteristics of yogurt are primarily related to its moisture content and protein level. Apart from quantitative levels, protein fractions and their ratios play a significant role in gel formation and strength. Milk proteins further consist of caseins and whey proteins with distinct functional properties. In turn, caseins consist of $\alpha_{s1}$-, $\beta$- and $\kappa$-caseins. The ratios of casein fractions and the ratios of casein to whey protein differ widely in milks of various mammals. Furthermore, pretreatment of the milk of different species prior to fermentation produces varying magnitudes of protein denaturation. These factors have a profound effect on the rheological characteristics of fermented milks, leading to bodies and textures ranging from drinkable fluid to firm curd. Fermentation of the milk of buffalo, sheep and yak produces a well-defined custard-like body and firm curd, while the milk of other animals tends to generate a soft gel consistency.

Cow milk is used for the production of fermented milks, including yogurt, in a majority of the countries around the world. In the Indian subcontinent, buffalo milk and blends of buffalo and cow milk are used widely for dahi (a type of fermented milk) making, using mixed mesophilic cultures (Aneja et al., 2002). Buffalo milk is the base for making yogurt using thermophilic cultures in several Asian countries, whereas sheep, goat and camel milk are the starting materials of choice for fermented milks in several Middle Eastern countries.

1.5.2 Cultures for production of fermented milks

Various microorganisms characterize the diversity of fermented milks around the world. Lactic fermentation by bacteria transforms milk into the majority of products (Salampessy and Kailasapathy, 2011). A combination of lactic starters and yeasts is used for some
products, and in a few cases lactic fermentation combined with molds makes up the flora. For a summary of starter cultures around the world, see Table 1.6.

### 1.5.3 Forms of fermented milks

Fermented milks may be mixed with water to make a refreshing beverage. Salt, sugar, spices or fruits may be added to enhance taste. Liquid yogurt is the prime example. Spoonable yogurt has significant commercial importance all over the world. It is sold in cups and tubes. In the USA, the 2010 yogurt production in 116 processing plants was 1.9 billion kg
Table 1.5  Approximate composition of the milk of mammals used for fermented milks. Adapted from Chandan and Shahani (1993) and Chandan (2002).

<table>
<thead>
<tr>
<th>Mammal</th>
<th>% total solids</th>
<th>% fat</th>
<th>% total protein</th>
<th>% casein</th>
<th>% whey protein</th>
<th>% lactose</th>
<th>% ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow</td>
<td>12.2</td>
<td>3.4</td>
<td>3.4</td>
<td>2.8</td>
<td>0.6</td>
<td>4.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Cow, zebu</td>
<td>13.8</td>
<td>4.6</td>
<td>3.3</td>
<td>2.6</td>
<td>0.7</td>
<td>4.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Buffalo</td>
<td>16.3</td>
<td>6.7</td>
<td>4.5</td>
<td>3.6</td>
<td>0.9</td>
<td>4.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Goat</td>
<td>13.2</td>
<td>4.5</td>
<td>2.9</td>
<td>2.5</td>
<td>0.4</td>
<td>4.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Sheep</td>
<td>19.3</td>
<td>7.3</td>
<td>5.5</td>
<td>4.6</td>
<td>0.9</td>
<td>4.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Camel</td>
<td>13.6</td>
<td>4.5</td>
<td>3.6</td>
<td>2.7</td>
<td>0.9</td>
<td>5.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Mare</td>
<td>11.2</td>
<td>1.9</td>
<td>2.5</td>
<td>1.3</td>
<td>1.2</td>
<td>6.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Donkey</td>
<td>8.5</td>
<td>0.6</td>
<td>1.4</td>
<td>0.7</td>
<td>0.7</td>
<td>6.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Yak</td>
<td>17.3</td>
<td>6.5</td>
<td>5.8</td>
<td>–</td>
<td>–</td>
<td>4.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 1.6  Starter cultures used in the manufacture of commercial fermented milks. Adapted from Chandan and Shahani (1995), Josephsen and Jespersen (2004), Tamime and Robinson (2007) and Chandan and Nauth (2012).

<table>
<thead>
<tr>
<th>Product</th>
<th>Primary microorganism(s)</th>
<th>Secondary/optimal-microorganism(s)</th>
<th>Incubation temperature and time</th>
<th>Major function of culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yogurt</td>
<td><em>Lb. delbrueckii</em> subsp.<em>bulgaricus</em></td>
<td><em>Lb. acidophilus</em></td>
<td>43–45°C/2.5 hours</td>
<td>Acidity, texture, aroma,</td>
</tr>
<tr>
<td></td>
<td><em>Strept. thermophilus</em></td>
<td><em>Bifidobacterium longum/</em></td>
<td></td>
<td>flavo, probiotic</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>bifidum/infantis</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Lb. casei/lactis/rhamnosus/</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>helveticus/reuteri</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultured buttermilk and</td>
<td></td>
<td></td>
<td>22°C/12–14 hours</td>
<td>Acidity, flavor, aroma</td>
</tr>
<tr>
<td>sour cream</td>
<td><em>Lc. lactis subsp. lactis</em></td>
<td><em>Leuconostoc lactis</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Lc. lactis subsp. cremoris</em></td>
<td><em>Leuconostoc mesenteroides</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>subsp. cremoris</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probiotic fermented</td>
<td><em>Strept. thermophilus</em></td>
<td><em>Lc. lactis subsp.</em></td>
<td>22–37°C/37–40°C/8–14 hours</td>
<td>Acidity, flavor, probiotics</td>
</tr>
<tr>
<td>milks</td>
<td></td>
<td><em>lactis/cremoris</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kefir</td>
<td><em>Lc. lactis subsp. lactis/cremoris</em></td>
<td><em>Yeasts:</em></td>
<td>15–22°C/24–36 hours</td>
<td>Acidity, aroma, flavor,</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Kluyveromyces marxianus</em> subsp.*</td>
<td></td>
<td>gas (CO₂), alcohol,</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>marxianus</em></td>
<td></td>
<td>probiotics</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Torulaspora delbrueckii</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Saccharomyces cerevisiae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Candida kefir</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Acetic-acid bacteria:</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Acetobacter aceti</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koumiss</td>
<td><em>Lb. delbrueckii subsp. bulgaricus</em></td>
<td><em>Acetic-acid bacteria:</em></td>
<td>20–25°C/12–24 hours</td>
<td>Acidity, alcohol, flavor,</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Lb. kefir/lactis</em></td>
<td></td>
<td>gas (CO₂)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Yeasts:</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Saccharomyces lactis</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Saccharomyces gracilus</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Mycoderma spp.</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(4.2 billion pounds) (Schultz, 2011a). The current yogurt retail market is estimated to be over 4 billion USD. Greek-yogurt consumption is rising rapidly, and in 2012 it commanded >30% of the total yogurt market. The per capita consumption of all types of yogurt in the USA in 2010 was 6.14 kg (13.53 pounds) (IDFA, 2011), which is only 21% of the per capita consumption in Sweden, reported to be 28.48 kg (62.8 pounds). To enhance its health appeal, the trend now is to deliver prebiotics as well as probiotic organisms through conventional yogurt (Sanders and Marco, 2010). In many countries, yogurt and fermented milks with probiotic cultures are available. These are made with defined cultures that have been scientifically documented to display certain health benefits (Sanders, 2007; Chandan and Kilara, 2008; Chandan, 2011). It has been estimated that about 80% of the yogurt sold in the USA contains probiotic Lactobacillus acidophilus (Schultz, 2011a). Yogurt is regarded as a functional food. It is being used as an ingredient in breakfast cereals, ice cream, food for cats and dogs, tooth paste, mouthwash, facial masks and suntan products (Schultz, 2011a). Sour-cream production in the USA totaled 0.544 billion kg (1.2 billion pounds) in 2010. The number of plants manufacturing sour cream was 116.

Yogurt/buttermilk may be concentrated by removing whey via straining through cloth or by mechanical centrifugation to generate high-protein product. This forms the basis of Greek yogurt in Europe and North America. The concentrate may be mixed with herbs, fruit, sugar or flavorings to yield shrikhand in India, quarg/tvorog/topfen/taho/kwarg in Central Europe and fromage frais in France. Similarly, cream cheese and Neufchâtel cheese are obtained by culturing their respective bases standardized for fat and nonfat solids.

To extend shelf-life, fermented milks and yogurts may be sun-dried to concentrate them or spray-dried to get a powder form. Leben zeer of Egypt and than/tan of Armenia are examples of concentrated yogurt without whey removal. In Lebanon, the concentrated yogurt is salted, compressed into balls, sun-dried and preserved in oil. Another way to preserve yogurt is to smoke it and dip it in oil. Labneh anbaris and shanklish are partially dried yogurt products preserved in oil. Spices are added to shanklish and the balls produced are kept in oil. In Iran, Iraq, Lebanon, Syria and Turkey, the concentrated yogurt is mixed with wheat products and sun-dried to get kishk. More information on this topic is available in Chapter 19.

Frozen yogurt is available in North America and countries around the world.

### 1.6 Major commercial fermented milks

#### 1.6.1 Yogurt

Yogurt represents a very significant dairy product worldwide in modern times. It is a semi-solid fermented product made from a heat-treated standardized milk mix by the activity of a symbiotic blend of Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus (Clark and Plotka, 2004; Ozer, 2010). In certain countries, the nomenclature “yogurt” is restricted to the product made exclusively from the two lactic cultures, whereas in other countries it is possible to label a product as “yogurt” if it is made with yogurt cultures and adjunct probiotic cultures. The more common adjunct cultures are Lactobacillus acidophilus, Bifidobacterium spp., Lactobacillus reuteri, Lactobacillus casei, Lactobacillus rhamnosus GG, Lactobacillus gasseri and Lactobacillus johnsonii LA1 (Chandan, 1999; Pannell and Schoenfuss, 2007; Maity and Misra, 2009; Chandan and Nauth 2012). For a detailed account of the health attributes of probiotics, the reader is referred to clinical studies summarized in USProbiotics (2012).
Yogurt can be produced from the milk of cow, buffalo, goat, sheep, yak and other mammals. However, in industrial production of yogurt, cow milk is the predominant starting material. To get a custard-like consistency, cow milk is generally fortified with nonfat dry milk, milk-protein concentrate or condensed skim milk. Varieties of yogurt available include plain, fruit-flavored, whipped, drinking-type, smoked, dried, strained/Greek and frozen. Details of yogurt technology are given in various chapters and texts (Chandan and Shahani, 1993; Chandan, 1997; Mistry, 2001; Robinson et al., 2002; Tamime and Robinson, 2007; Gurakan et al., 2010; Chandan and Nauth, 2012). In order to meet the regulatory obligations regarding food safety, product standards and labeling, it is imperative to conduct standard analytical tests, as discussed by Deibel and Deibel (2008).

The popularity of yogurt has been propelled by its perceived health benefits. The health-promoting attributes of consuming yogurt containing live and active cultures are well documented (Chandan, 1989; Fernandes et al., 1992; Chandan and Shahani, 1993; Patel and Walker, 2004; Yildiz, 2010; USProbiotics, 2012). The current trend of using prebiotics and probiotic cultures in the manufacture of fermented milks and yogurt products is supported by clinical trials (Chandan, 1999, 2007, 2011; Khurana and Kanawjia, 2007; Sanders, 2007). The beneficial effects documented in numerous studies and reviews include prevention of cancer, reduction in diarrhea associated with travel, antibi-otic therapy and rotavirus, improvement of gastrointestinal health, enhancement of immunity of the host, amelioration of lactose-intolerance symptoms, protection from infections caused by food-borne microorganisms, control of vaginitis and vaccine-adjuvant effects (Chandan and Kilara, 2008). More information is given in Chapter 20, 21 and 22 of this book.

Following the world trends relating to the enhanced consumption of fermented milks, the per capita sales of yogurt in the USA have also shown enormous growth. The past 3 decades have witnessed a dramatic rise in per capita yogurt consumption, from nearly 1.13 kg (2.5 pounds) in 1980 to 6.12 kg (13.5 pounds) in 2010 (IDFA, 2011). Figure 1.1 illustrates the trends in per capita consumption of yogurt, sour cream and dips and buttermilk in the last decade. The increase in yogurt consumption may be attributed to yogurt’s perceived natural and healthy image, providing to the consumer convenience, taste and wholesomeness attributes. Sour-cream consumption per person increased slightly in 2010 to 1.90 kg (4.2 pounds), but this was below 1.99 kg (4.4 pounds), the record level observed in the years 2005 and 2007. Buttermilk consumption per person continues to decline from 0.99 kg (2.2 pounds) in 2000 to 0.68 kg (1.5 pounds) in 2010.

In the year 2010, yogurt sales in the USA topped 1896 million kg (4181 million pounds). Yogurt is widely used as a breakfast food, snack or lunchtime meal.

It is interesting to note that cultured-buttermilk consumption is on the decline (Figure 1.1) as yogurt registers its significant growth. Of late, Greek yogurt has exhibited a significant growth within the yogurt category, capturing approximately 30% of the total yogurt market. The rise in yogurt consumption is also related to the choices available in the marketplace. Besides the varieties of flavors, diversification in the yogurt market includes different textures and packaging innovations—fulfilling consumer expectations of health-food trends, convenience and portability—plus a magnitude of eating occasions.

Buttermilk sales declined from 471 million kg (1039 million pounds) in 1987 to 214 million kg (472 million pounds) in 2010. Sour-cream-and-dips sales have grown from 315 million kg (694 million pounds) in 1987 to 586 million kg (1292 million pounds) in 2010. The recent popularity of Mexican cuisine has in part enhanced the consumption of sour cream.

Figure 1.2 illustrates the segmentation of various forms of yogurt in the US market.