Manufacturing Yogurt and Fermented Milks

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Blackwell Publishing Ltd
9600 Garsington Road, Oxford OX4 2DQ, UK
Tel.: +44 (0)1865 776868

Blackwell Publishing Asia
550 Swanston Street, Carlton, Victoria 3053, Australia
Tel.: +61 (0)3 8359 1011

First edition, 2006

Library of Congress Cataloging-in-Publication Data

Manufacturing yogurt and fermented milks /
editor, Ramesh C. Chandan ; associate editors,
Charles H. White, Arun Kilara, Y. H. Hui.—1st ed.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-0-8138-2304-1 (alk. paper)
ISBN-10: 0-8138-2304-8 (alk. paper)
1. Yogurt. 2. Fermented milk. 3. Dairy processing. 4. Food industry and trade.
I. Chandan, Ramesh C.

SF275.Y6M36 2006
637′.1476—dc22

2005017248

The last digit is the print number: 9 8 7 6 5 4 3 2 1

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Preface

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 a multi-billion-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 the 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, this 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 including yogurt, the book has multiple authors. The authors drawn from the industry and academia are acknowledged as experts in their respective fields. Many authors have utilized their lifelong 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 first of its kind in the literature. From 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 textbook to be used by upper undergraduate university students of dairy and food science to learn 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 the 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 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 textbook to the instructors and participants of the industry-oriented short courses on 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.

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Part I
Basic Background

1
History and Consumption Trends

Ramesh C. Chandan

OVERVIEW OF THE WORLD DAIRY INDUSTRY

The world production of cow's milk in the year 2003 was 398 million metric tons (see Table 1.1). The documented number of cows was 125,490 thousand heads. Individual cow milk yield varies widely in the world. Japan was the most efficient milk producer with a yield of 8.71 t/cow, followed by the United States with a yield of 8.50 t/cow.

MILK PRODUCTION IN THE UNITED STATES

During the last decades, the trend indicates decrease in dairy cow population (Table 1.2). Currently, nearly nine million cows produce 77.25 million metric tons (170,312 million pounds) of milk (USDA, 2004). As indicated in Table 1.2, there is a steady increase in milk production per cow. Approximately 20% of the world's milk is produced in the United States. The American dairy farmer has been able to achieve the current milk output by applying 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. In the year 2003, milk production per cow increased to 8,507 kg (18,749 lb). As a result of continuous efficiencies in milk production at the farm, milk production per cow has doubled in the last 30 years.

PRODUCTION OF DAIRY FOODS IN THE UNITED STATES

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 United States 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 shelf life of high-quality milk products, including yogurt and fermented milks. Currently, there are 800 dairy processing plants in the United States, where milk is transformed into more than 300 varieties and styles of cheese, 100 flavors of ice cream and frozen yogurt, and 75 flavors of several types of refrigerated yogurt. Dairy plants also produce an array of flavored and white milks ranging from fat-free to full fat, butter, sweetened condensed milk, evaporated milk, dry milk, lactose, and whey products, as well as cultured products such as sour cream and dips, buttermilk, yogurt, and yogurt drinks. More recently, the industry has introduced packaging and marketing innovations to compete

Table 1.1. Milk Production in the World in 2003

Country	Milk Cows (1000 head)	Milk Yield/Cow-(t)	Total Milk Produced (1000 t)
Canada	1,065	7.30	7,778
Mexico	6,800	1.00	9,784
United States	9,084	8.50	77,253
Argentina	2,000	3.98	7,950
Brazil	15,300	1.49	22,860
Peru	630	1.95	1,226
European Union	24,690	5.35	132,044
Romania	1,684	3.21	5,400
Russia	11,700	2.82	33,000
Ukraine	4,715	2.84	13,400
India	36,500	1.00	36,500
China	4,466	3.91	17,463
Japan	964	8.71	8,400
Australia	2,050	5.19	10,636
New Zealand	3,842	3.73	14,346
Total selected countries	125,490	–	398,040

Source: USDA, Service, FAS/CMP/DLP December, 2004.
http//www.fas usda.gov/dlp/circular2004/64-12Dairy/cowprod.pdf

aggressively for consumer food dollar share. Table 1.3 lists the products manufactured and their volumes during 1997–2002.

Dairy farmers and dairy processors alike abide by strict state and federal sanitary standards. Grade A Pasteurized Milk Ordinance (PMO) regulations are the recommendations of the Public Health Service of the Food and Drug Administration of United States Department of Health and Human Services (DHHS, 1999). The PMO is meant for voluntary adoption, but its importance in ensuring the quality and safety of milk supply in the country is recognized by the dairy industry as well as by the state regulatory and sanitation officials. The PMO is a constantly evolving set of regulations 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), and academic 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 at the farms

Table 1.2. Milk Production in the United States

Year	Milk Cows (1000 head)	Production/Cow (lb)	Total Milk Production (million pounds)
1994	9,494	16,179	153,602
1995	9,466	16,405	155,292
1996	9,372	16,433	154,006
1997	9,252	16,871	156,091
1998	9,154	17,189	157,348
1999	9,156	17,772	162,716
2000	9,206	18,201	167,559
2001	9,114	18,159	165,497
2002	9,139	18,608	170,063
2003	9,084	18,749	170,312

Source: http//usda.mannlib.cornell.edu/reorts/nassr/dairy/pmp-bb/2004/mkpr0204.txt.

Table 1.3. Production of Dairy Products in the United States During 1997–2002

	Production Volume (millions of pounds)					
Product	1997	1998	1999	2000	2001	2002
Butter	1,151	1,168	1,277	1,251	1,236	1,237
Natural cheese	7,330	7,492	7,941	8,258	8,260	8,599
Processed cheese, foods and spreads	2,210	2,278	2,425	2,288	2,207	2,155
Frozen desserts[a]	1,569	1,624	1,623	1,068	1,571	1,576
Ice creams[a]						
Regular	914	935	972	980	981	989
Low fat	387	407	381	373	407	362
Nonfat	41	43	40	31	21	–
Cottage cheese						
Creamed	360	367	361	371	372	372
Low fat	347	361	359	364	371	370
Curd	458	466	465	461	454	–
Plain						
Whole milk	18,413	18,147	18,467	18,448	18,007	17,960
Reduced and low fat milk	23,709	23,449	23,571	23,649	23,630	23,610
Nonfat milk	9,139	9,203	8,985	8,435	8,225	8,030
Flavored milk and drinks	2,830	3,044	3,216	3,336	3,526	4,040
Half and half	883	895	960	1,008	1,146	1,140
Light cream	119	134	168	168	–	–
Heavy cream	504	515	555	743	797	720
Eggnog	102	102	109	93	105	127
Refrigerated yogurt	1,574	1,639	1,717	1,837	2,003	2,135
Frozen yogurt*	92	97	91	94	71	73
Sour cream and dips	794	817	841	914	990	1,031
Buttermilk	691	676	668	622	592	576

[a] Millions of gallons.
Source: IDFA, 2003.

and processing plants. These 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 until delivered to processing facilities. They also ensure that the processing of milk is in accordance with the state and federal food laws. In some instances, the state standards differ and may be even more stringent than the federal standards. The state and in some cases local communities have jurisdiction for standards for milk in their own market.

The PMO defines Grade A specifications and standards for milk and milk products to facilitate 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 would not require further inspections for acceptance by another state (see Chapter 3 for a detailed discussion on this topic).

The 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 45% reduction in the number of manufacturing facilities while the total milk output has increased by 4–5% annually. Continued investment will mean still lower processing costs and higher milk output.

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 humans domesticated animals. Evidence showing the use of fermented milks has been found in archeological research associated with the Sumerians and Babylonians of Mesopotamia, the Pharoes of northeast Africa, and Indo-Aryans of the Indian subcontinent (Chandan, 1982, 2002; Tamime and Robinson, 1999). Ancient Indian scriptures, the *Vedas*, dating back some 5,000 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 milk of various domesticated animals resulted in conservation of valuable nutrients, which otherwise would deteriorate rapidly under high ambient temperatures prevailing in South Asia and Middle East. Thus, the process permitted consumption of milk constituents for a period of time significantly longer than possible for milk itself. Concomitantly, conversion of milk to fermented milks resulted in the generation of 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 appropriate length of time. Depending on the type of lactic acid bacteria gaining entry from the environmental sources (air, utensils, milking equipment, milkers, cows, feed, etc.), the sour milk attains characteristic flavor and texture.

Approximately 400 diverse products derived from fermentation of milk are consumed around the world. Fermentation conserves the vital nutrients of the milk. Simultaneously, it modifies certain milk constituents enhancing their nutritional status and furnishes to the consumer live and active cultures in significant numbers, which provide distinct health benefits beyond conventional nutrition. Fermented milk products may be termed as "functional foods." They represent a significant and critical sector of the human diet. These products fit into the cultural and religious traditions and dietary pattern of many populations. In addition to the main ingredient, milk, other food ingredients are also used in the fermented milks to innovate a range of nutritional profiles, flavors, textures, and mouth feel, thereby offering an array of choices for the consumer. Fermented foods and their derivatives may constitute a staple meal, or may be consumed as an accompaniment to the meal. They may be also used as a snack, drink, dessert, condiment, or spread as well as an ingredient of cooked dishes.

Diversity of fermented milks may be ascribed to a number of factors: (a) Use of milk obtained from various domesticated animals, (b) application of diverse micro flora, (c) addition of sugar, condiments, grains, fruits, etc., to create a variety of flavors and textures, and (d) application of additional preservation methods, e.g., freezing, concentrating, and drying.

OCCURRENCE AND CONSUMPTION OF FERMENTED MILKS IN VARIOUS REGIONS

There is a diversity of fermented milks in the various regions of the world (see Table 1.4). As shown in Table 1.5, the 1998 annual per capita consumption of various fermented fluid milks in various countries has been reported to range from 0.2 to 45 kg.

This variety of fermented milks in the world may be ascribed to various factors.

Milk of various species

Milk of various domesticated animals differs in composition and produces fermented milk with a characteristic texture and flavor (Table 1.6). The milk of various mammals exhibits significant differences in total solid, 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, which have distinct functional properties. Caseins, in turn consist of α_{s1}-, β-, and κ-caseins. The ratio of casein fractions and the ratio of caseins to whey proteins differ widely in the milks of various milch animals. Furthermore, pretreatment of 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's milk is used for the production of fermented milks, including yogurt, in a majority of the countries

Table 1.4. Major Fermented Dairy Foods Consumed in the Different Regions of the World

Product Name	Major Country/Region
Acidophilus milk	United States, Russia
Ayran/eyran/jugurt	Turkey
Busa	Turkestan
Chal	Turkmenistan
Cieddu	Italy
Cultured buttermilk	United States
Dahi/dudhee/dahee	Indian subcontinent
Donskaya/varenetes/kurugna/ryzhenka/guslyanka	Russia
Dough/abdoogh/mast	Afghanistan, Iran
Ergo	Ethiopia
Filmjolk/fillbunke/fillbunk/surmelk/taettemjolk/tettemelk	Sweden, Norway, Scandinavia
Gioddu	Sardinia
Gruzovina	Yugoslavia
Iogurte	Brazil, Portugal
Jugurt/eyran/ayran	Turkey
Katyk	Transcaucasia
Kefir, Koumiss/Kumys	Russia, Central Asia
Kissel maleka/naja/yaourt/urgotnic	Balkans
Kurunga	Western Asia
Leben/laban/laban rayeb	Lebanon, Syria, Jordan
Mazun/matzoon/matsun/matsoni/madzoon	Armenia
Mezzoradu	Sicily
Pitkapiima	Finland
Roba/rob	Iraq
Shosim/sho/thara	Nepal
Shrikhand	India
Skyr	Iceland
Tarag	Mongolia
Tarho/taho	Hungary
Viili	Finland
Yakult	Japan
Yiaourti	Greece
Ymer	Denmark
Zabady/zabade	Egypt, Sudan

Adapted from Chandan, 2002; Tamime and Robinson, 1999.

around the world. In the Indian subcontinent, buffalo milk and blends of buffalo and cow milk are used widely for *dahi* preparation, using mixed mesophilic cultures (Aneja et al., 2002). In certain countries, buffalo milk is the base for making yogurt, using thermophilic cultures. Sheep, goat, or camel milk is the starting material of choice for fermented milks in several Middle Eastern countries.

Cultures for Production of Fermented Milks

Various microorganisms characterize the diversity of fermented milks around the world. In general, lactic fermentation by bacteria transforms milk into the majority of products. A combination of lactic starters and yeasts are used for some products and in a few cases lactic fermentation combined with molds make up the flora (Table 1.7).

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 the taste. Liquid yogurt is a prime example. Spoonable yogurt has significant commercial importance all over the world. It is available in cups and tubes. To enhance its health appeal, the

Table 1.5. Consumption of Fermented Milks in Certain Countries in 1998

Country	Per Capita (kg)
Netherlands	45.0
Finland	38.8
Sweden	30.0
Denmark	27.3
France	26.9
Iceland	25.3
Germany	25.0
Israel	24.8
Norway	19.3
Bulgaria	15.6
Austria	14.7
Spain	14.5
Czech Republic	10.0
Portugal	9.8[a]
Hungary	9.4
Poland	7.4
Slovakia	7.4
U.S.A.	7.4[b]
Australia	6.4
Argentina	6.0
Canada	3.6
Ukraine	3.4
South Africa	3.1
China	0.2

[a] In 1997.
[b] In 2003.
Source: IDF, 1999, with permission.

trend now is to deliver prebiotics as well as probiotic organisms through conventional yogurt. In many countries, probiotic yogurt and fermented milks are available. They are made with defined cultures that have been scientifically documented to display certain health benefits.

Yogurt/buttermilk may be concentrated through a process that removes whey by straining through cloth or by mechanical centrifugation to generate a cheese-like product. 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 *fromaige frais* in France. Similarly, cream cheese and *Neufchatel* cheese are obtained from sour cream and buttermilk.

To enhance the shelf life, fermented milks and yogurt may be sun-dried 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 the process of smoking and dipping in oil. *Labneh anbaris* and *shanklish* are partially dried yogurt products preserved in oil. Spices are added to *shanklish* and the balls made from this are kept in oil. In Iran, Iraq, Lebanon, Syria, and Turkey, concentrated yogurt is mixed with wheat products and sun-dried to get *kishk*. Frozen yogurt is available in the United States and Canada as well as in several other countries.

MAJOR COMMERCIAL FERMENTED MILKS

Yogurt represents a very significant dairy product around the world in recent times. It is a semisolid 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*. In certain countries, the nomenclature yogurt is restricted to the product made exclusively from the two cultures, whereas in other countries it is possible to label the product yogurt

Table 1.6. Proximate Composition of Milk of Mammals Used for Fermented Milks

	Total Solids (%)	Fat (%)	Total Protein (%)	Casein (%)	Whey Protein (%)	Lactose (%)	Ash (%)
Cow	12.2	3.4	3.4	2.8	0.6	4.7	0.7
Cow, zebu	13.8	4.6	3.3	2.6	0.7	4.4	0.7
Buffalo	16.3	6.7	4.5	3.6	0.9	4.5	0.8
Goat	13.2	4.5	2.9	2.5	0.4	4.1	0.8
Sheep	19.3	7.3	5.5	4.6	0.9	4.8	1.0
Camel	13.6	4.5	3.6	2.7	0.9	5.0	0.7
Mare	11.2	1.9	2.5	1.3	1.2	6.2	0.5
Donkey	8.5	0.6	1.4	0.7	0.7	6.1	0.4
Yak	17.3	6.5	5.8	–	–	4.6	0.9

Adapted from Chandan and Shahani, 1993; Chandan, 2002.

Table 1.7. Starter Cultures Used in the Manufacture of Commercial Fermented Milks

Product	Primary Microorganism(s)	Secondary/Optional Microorganism(s)	Incubation Temperature and Time	Major Function of Culture
Yogurt	*Lb. delbrueckii* subsp.b*ulgaricus, Strept. thermophilus*	*Lb. acidophilus, Bifidobacterium longum, Bifidobacterium bifidum, Bifidobacterium infantis, Lb.casei, Lb. lactis, Lb. rhamnosus, Lb. helveticus, Lb. reuteri*	43–45°C for 2.5 hours	Acidity, texture, aroma, flavor, probiotic
Cultured butter milk and sour cream	*Lc. lactis* subsp. *lactis*, *Lc. lactis* subsp. *cremoris, Lc. lactis* subsp. *lactis* var. *diacetylactis*	*Leuc. lactis, Leuc. mesenteroides* subsp. *cremoris*	22°C for 12–14 hours	Acidity, flavor, aroma
Probiotic Fermented milks	*S. thermophilus, Lb. acidophilus, Lb. reuteri, Lb. rhamnosus GG, Lb. johnsoni, Lb. casei, Bifidobacterium longum, Bifidobacterium bifidus*	*Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *cremoris*	22–37°C/37–40°C for 8–14 hours	Acidity, flavor, probiotic
Kefir	*Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *cremoris., Lb. delbrueckii* subsp. *bulgaricus, Lb. delbrueckii subsp lactis, Lb. casei, Lb. helveticus, Lb. brevis, Lb. kefir, Leuc. mesenteroides, Leuconostoc dextranicum*	**Yeasts**: *Kluyveromyces marxianus* subsp. *marxianus, Torulaspora delbruecckii, Saccharomyces cerevisiae, Candida kefir* **Acetic acid bacteria**: *Acetobacter aceti*	15–22°C for 24–36 hours	Acidity, aroma, flavor, gas (CO_2), alcohol, probiotic
Koumiss	*Lb. delbrueckii subsp. bulgaricus, Lb. kefir, Lb. lactis* **Yeasts**: *Saccharomyces lactis, Saccharomyces cartilaginosus, Mycoderma* spp.	**Acetic acid bacteria:** *Acetobacter aceti*	20–25°C for 12–24 hours	Acidity, alcohol, flavor, gas (CO_2)

Adapted from Chandan and Shahani, 1995; Hassan and Frank, 2001; Tamime and Robinson, 2002.

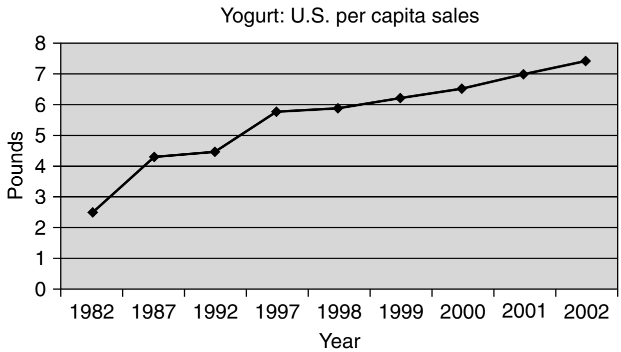

Figure 1.1. Trends in the per capita sales of yogurt in the United States.

made with yogurt cultures and adjunct probiotic cultures. The more common adjunct cultures are *Lactobacillus acidophilus*, Bifidobacterium spp., *Lactobacillus reuteri*, *Lactobacillus casei*, and *Lactobacillus rhamnosus GG, Lactobacillus gasseri*, and *Lactobacillus johnsonii LA1* (Chandan, 1999).

Yogurt is produced from the milk of cow, buffalo, goat, sheep, yak, and other mammals. In industrial production of yogurt, cow's milk is the predominant starting material. To get a custard-like consistency, cow's 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, and frozen. Details of yogurt technology are given in various texts (Chandan and Shahani, 1993; Chandan, 1997; Tamime and Robinson, 1999; Mistry, 2001; Robinson et al., 2002). This subject is detailed in chapters 9–16 in this book.

The popularity of yogurt has increased due to its perceived health benefits. Health-promoting attributes of consuming yogurt containing live and active cultures are well documented (Chandan, 1989; Chandan and Shahani, 1993; Fernandes et al., 1992). 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; Ouwehand et al., 1999; Hirahara, 2002; Salminen and Ouwehand, 2003). The beneficial effects documented in the numerous studies and reviews include prevention of cancer, reduction in diarrhea associated with travel, antibiotic 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.

Following world trends in increased consumption of fermented milks, the per capita sales of yogurt in the United States has also shown enormous growth. The past two decades has witnessed a dramatic rise in per capita yogurt consumption from nearly 2.5 to 7.4 lbs (Fig. 1.1). The increase in yogurt consumption may be attributed to yogurt's perceived natural and healthy image along with providing to the consumer convenience, taste, and wholesomeness attributes.

In the year 2003, yogurt sales in the United States exceeded \$2.7 billion. The total sales volume was 2,387 million pounds. From 1995 to 2002, as a snack and lunchtime meal, yogurt consumption grew by 60%. As a breakfast food, yogurt consumption increased by 75% during the same period.

It is interesting to note that the sale of cultured buttermilk is on the decline (Fig. 1.2), while the sales of yogurt and sour cream and dips are registering a significant growth. Buttermilk sales declined from 1,039 million pounds in 1987 to 592 million pounds in 2002. Yogurt drinks, on the other hand, are exhibiting significant growth. Sour cream and dips sales have grown from 694 million pounds in 1987 to 1,031 million pounds in 2002. The recent popularity of Mexican cuisine has, in part, enhanced the consumption of sour cream.

The rise in yogurt consumption is also related to the choices available in the marketplace. Besides the varieties of flavors, diversification in yogurt market includes variety of textures, packaging innovations to fulfill consumer expectations of health food trends, convenience, portability plus a magnitude of eating

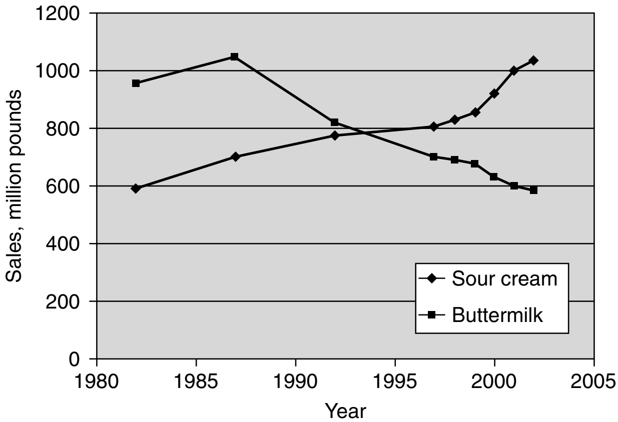

Figure 1.2. Trends in the total sales of buttermilk and sour cream and dips in the United States.

occasions. Figure 1.3 illustrates segmentation and various forms of yogurt available in the U.S. market.

Cultured buttermilk is an important fermented milk of the United States. It is obtained from pasteurized skim or part skim milk cultured with lactococci and aroma-producing bacteria leuconostoc. Generally, milk is standardized to 9–10% milk solids-not-fat and <0.5% fat and heat-treated at 85°C for 30 minutes or at 88–91°C for 2.5–5 minutes. After homogenization at 137 kPa (2,000 psi), it is inoculated with lactic starter and ripened for 14–16 hours at 22°C. When the pH reaches 4.5,

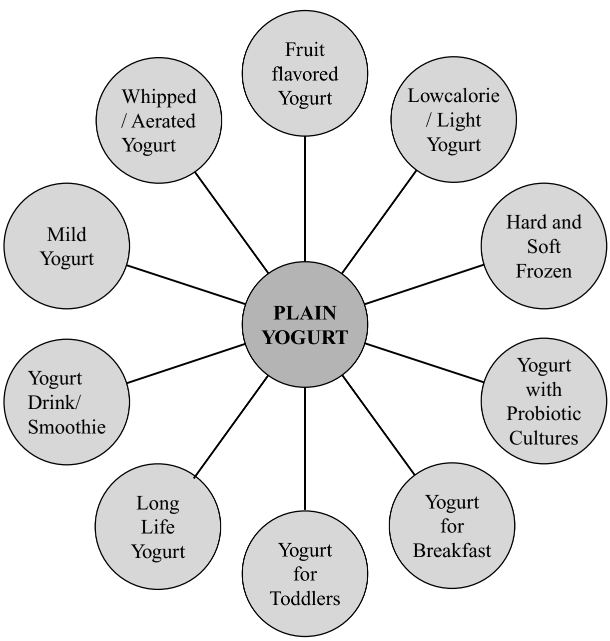

Figure 1.3. Segmentation of yogurt market.

the coagulum is broken and blended with 0.18% salt and butter flakes while cooling to 4°C. The product is bottled in paper/plastic containers.

Buttermilk is primarily consumed as a beverage. In addition, it is used in cooking, especially bakery items (see Chapter 17 for a detailed discussion on cultured buttermilk).

Sour/cultured cream is a significant fermented milk product in North America. It is manufactured by culturing pasteurized cream with lactococci and aroma-producing bacteria, leuconostoc (Table 1.7). It has a butter-like aroma and flavor. Cream is standardized to 18% fat, 9% milk solids-not-fat, and 0.3% stabilizer to get stable acid gel. The blend is heat-treated at 72°C for 20 minutes and homogenized at 172 kPa (2,500 psi) at 72°C, single stage, two times. It is cooled to 22°C, inoculated with 2–5% of the starter, and cultured for 16–18 hours at 22°C or until pH drops to 4.7. It is packaged in cartons and cooled to 4°C so that it develops thick consistency. Individual serving cups and packages are also available. In this case, fermentation is carried out by filling seeded base, followed by packaging and cooling.

Crème fraiche is popular in France and other European countries. This product resembles sour cream, except that it contains up to 50% fat as compared to 18% fat in sour cream and has a higher pH of 6.2–6.3.

Cultured cream is used as a topping on vegetables, salads, fish, meats, and fruits and as an accompaniment to Mexican meals. It is also used as a dip, as a filling in cakes, in soups, and in cookery items. Chapter 18 contains a detailed discussion on sour/cultured cream.

Culture-containing milks are seeded but are unfermented milks delivering significant doses of probiotic microorganisms. In this case, the growth of the culture is intentionally avoided to preserve the fresh taste of milk. Accordingly, the product is stored at refrigeration temperatures at all times. In the past, acidophilus milk was marketed by fermenting sterilized milk with *Lb. acidophilus.* The inoculated base was incubated at 37°C for 24 hours. The plain product developed titratable acidity of 1–2%. Consequently, it had a very harsh acidic flavor. Its popularity declined rapidly as sweetened yogurt with fruit flavors began to dominate the market. However, *Lb. acidophilus* does have a strong consumer appeal. Most of the yogurts now sold in the United States contain *Lb. acidophilus*, which is either added after culturing with yogurt culture or is cocultured with yogurt culture.

Sweet acidophilus milk is an acceptable substitute for acidophilus milk of the past era. The product is made from pasteurized and chilled low-fat milk to which a concentrate of *Lb. acidophilus* culture has been incorporated to deliver a minimum of one million organisms per milliliter. It is sold in refrigerated form and has a shelf life of 2–3 weeks. For more details see Chapter 19. More recently, additional probiotic organisms have been included to enhance healthy connotation of the product. Among the additional cultures are Bifidobacteria, *Lb. delbrueckii* subsp. *bulgaricus, S. thermophilus*, and *Lb. casei.* Additional details are given in chapters 20, 21 and 22.

FERMENTED MILKS OF SCANDINAVIA

As shown in Table 1.6, the Scandinavians have a high per capita consumption of fermented milks. The fermented milks of Scandinavia are distinctive in flavor and texture. They are generally characterized by a ropy and viscous body, and include *viili*, *ymer*, *skyr*, *langfil*, *keldermilk*, and several local products.

viili, a fermented milk of Finland, is sold plain as well as fruit-flavored. Its fat content ranges from 2% to 12%. Milk standardized to required fat level is heat-treated at 82–83°C and held at this temperature for 20–25 minutes. Homogenization is avoided. It is then cooled to 20°C and inoculated with 4% starter consisting of diacetyl producing *Lactococcus lactis* subsp. *lactis, Leuconostoc mesenteroides* subsp. *cremoris*, and a fungus *Geotrichum candidum.* Following packaging in individual cups, the product is incubated at 20°C for 24 hours, which results in acid development (0.9% titratable acidity) and cream layer on the top. The cream layer traps the fungus giving a typical musty odor to the product (Mistry, 2001). The fermentation process also elaborates mucopolysaccharides imparting ropiness and viscosity to the product.

Ymer is a Danish product with characteristic high protein (5–6%) and pleasant acidic flavor with buttery aroma. Protein enrichment is achieved by ultrafiltration technology prior to fermentation. Alternatively, the traditional process involves removal of whey by draining curd after fermentation or by inducing separation of whey by first heating the curd followed by removing the whey. The standardized milk base is heated to 90–95°C for 3 minutes and cooled to 20°C. It is then inoculated with mesophilic culture consisting of a blend of *Lc. lactis* subsp. *lactis* biovar. *diacetylactis* and *Leuc. mesenteroides* subsp. *cremoris.*

After incubation at 20°C for 18–24 hours, the product is cooled and packaged.

Skyr is another Scandinavian product. In Iceland, this product is obtained by fermenting skim milk with yogurt culture and a lactose-fermenting yeast. A small amount of rennet may be used to develop heavier body. The milk base is cultured at 40°C until a pH of 4.6 is achieved in 4–6 hours. It is then allowed to cool to 18–20°C and held for additional 18 hours for further acidification to pH 4.0. Following pasteurization, the mass is centrifuged using a clarifier-type separator at 35–40°C to concentrate the solids and achieve a protein level of around 13%. *Skyr* has typical flavor compounds consisting of lactic acid, acetic acid, diacetyl, acetaldehyde, and ethanol.

FERMENTED MILKS OF RUSSIA AND EAST EUROPE

Kefir is relatively the most popular of fermented milks in Russia, Eastern Europe, and certain Asian countries. In addition to lactic fermentation, this product employs yeast fermentation as well. Thus, a perceptible yeast aroma and alcohol content characterize these products. Also, a fizz is noticed due to the production of carbon dioxide as a result of yeast growth. *Kefir* preparation involves natural fermentation of cow's milk with *kefir* grains. *Kefir* grains are a curd-like material, which are filtered-off after each use and reused for inoculation of the next batch. *Kefir* grains contain polysaccharides and milk residue embedded with bacteria *Lb. kefir*, *Lb. kefirogranum*, and species of leuconostocs, lactococci, and lactobacilli. Along with bacteria, the grains contain yeasts including *Saccharomyces kefir, Candida kefir*, and *Torula* species. Milk is heated to 85°C for 30 minutes, cooled to 22°C, and incubated with *kefir* grains for 12–16 hours to obtain traditional *kefir*. Typical flavor compounds in *kefir* are lactic acid, acetaldehyde, diacetyl, ethanol, and acetone.

In the United States, *kefir* is appearing in some markets. It varies from traditional *kefir* in that it is fermented with a blend of species of lactococci and lactobaclli. Some yeast is used to give only traces of alcohol. The commercial product is blended with sugar and fruit juices/flavors.

Koumiss is obtained from mare's milk or cow's milk, using a more defined culture containing *Lb. delbrueckii* subsp. *bulgaricus*, *Lb. acidophilus*, and torula yeasts. This therapeutic product has perceived health benefits and is recommended for all consumers, especially those with gastrointestinal problems, allergy, and hypertension and ischemic heart diseases (Mistry, 2001). Since mare's milk has only 2% protein, no curdling is seen in the product. It contains 1–1.8% lactic acid, 1–2.5% ethanol, and enough carbon dioxide to give a frothy appearance to the product (more detailed discussion on this topic is given in Chapter 19).

FERMENTED MILKS OF MIDDLE EAST

Fermented milks and their products have been historically associated with the Middle East.

Laban rayeb is prepared at home by pouring raw whole milk in clay pots and allowing the fat to rise at room temperature. The top cream layer is removed and partially skimmed milk is allowed to undergo spontaneous fermentation. Some variations of the product exist. One of these is *laban khad*, which is fermented in a goat pelt. The other is *laban zeer*, which is distinctly fermented in earthenware pots. The organisms responsible for fermentation are thermophilic lactobacilli in summer season and mesophilic lactococci in winter season (Mistry, 2001).

Kishk is obtained from *laban zeer*. Wheat grains are soaked, boiled, sun-dried, and ground to powder form. The blend of wheat and *laban zeer* is allowed to ferment further for another 24 hours and portioned into small lumps and sun-dried. The dried *kishk* has 8% moisture and 1.85% lactic acid. After proper packaging, its shelf life is of the order of several years. *Kishk* may contain spices.

Labneh is prepared by concentrating fermented milk, after fermentation process is completed. Milk is fermented with yogurt culture and then concentrated using Quarg separator. This product contains 7–10% fat.

Zabady is an Egyptian product obtained by fermenting milk that has been concentrated by boiling and then fermented with yogurt culture. Further concentration of milk solids is achieved by heating it and separating the whey.

FERMENTED MILKS OF SOUTH ASIA

The fermented milks discussed below and the products derived from these are of commercial importance in India, Pakistan, and Bangladesh (Aneja et al., 2002; Mathur, 2002).

Dahi, also called curd, is a semisolid product obtained from pasteurized or boiled buffalo or a mixture of cow and buffalo milk by souring natural, or otherwise, by a harmless lactic acid or other bacterial culture. *Dahi* may contain cane sugar. It should have at minimum the same percentage of fat and solids-not-fat as the milk from which it is prepared (Aneja et al., 2002).

To prepare good quality of *dahi*, right type of culture is essential. A mixed culture containing *Lc. lactis* subsp. *lactis, Lc. lactis* subsp. *diacetilactis*, or *Leuc.* species, *Lc. lactis* subsp. *cremoris* in the ratio of 1:1:1 may be used. In addition, *S. thermophilus* may be a component of *dahi* culture or a culture composed of *Lc. lactis* subsp. *lactis* and *Lc. lactis* subsp. *diacetilactis* may be employed.

Mild *dahi* is made from mesophilic lactococci. Leuconostocs may be adjunct organisms for added buttery aroma and flavor. Sour *dahi* contains additional cultures belonging to thermophilic group, which are generally employed in the manufacture of yogurt.These thermophilic organisms grow rapidly at 37–45°C, producing *dahi* in less than 4 hours.

Mishti doi is a fermented milk product, having cream to light brown color, firm consistency, smooth texture, and pleasant aroma. It contains 2–9% fat, 10–14% solids-not-fat, and 17–19% sugar. The most common sweetener used is cane sugar. In some special varieties of *mishti doi* fresh palm jaggery is used as a sweetener. Typically, a mix comprising 71.26% milk (3% fat, 9% solids-not-fat), 5.32% cream (35% fat), 5.42% nonfat dry milk, and 18% crystalline sugar is blended. Caramel (0.1%) may be added as a flavor. This mix is heat-treated at 85–90°C for 15 min and homogenized. The heating process develops light brown color in the mix. The mixture is cooled to 42°C. The starter is added at 1% level. Following dispersion of the starter, *mishti doi* mix is dispensed into sanitized cups and lids are heat-sealed to make the packaging airtight as well as to prevent leakage of the mix. The sealed cups are then incubated at 42 ± 1°C for about 6–8 hours until the acidity develops to 0.7–0.8%. The product is moved to a cold room (4°C) with minimum disturbance because at this stage the product has a weak body and unstable top layer. Excessive shaking may result in undesirable cracks on the top layer or in the curd mass. *Mishti doi* is used as a dessert and snack in India and Bangladesh.

Shrikhand is a *dahi*-based product. The cultured milk or *dahi* is separated from whey to get *chakka*, which is blended with sugar, color, flavor, and spices to reach a desired level of composition and consistency. The final product contains 8.5% fat, 10% protein, 42% sugar, and 60% total solids. The acidity of the product is usually between 1.10% and 1.20%, expressed as lactic acid. Skim milk (9% solids-not-fat, 0.05% fat) is heated to 90°C for 10 seconds in a High-Temperature Short-Time pasteurizer, cooled to 30°C, and inoculated with 0.25–0.50% *dahi* culture. After 8 hours of incubation period or titratable acidity of 0.8%, the curd is ready for further processing. *Chakka* is prepared by separating the whey from *dahi* employing a basket centrifuge or a desludging centrifuge. *Shrikhand* is prepared by adding sugar at the rate of 80% of the amount of *chakka* and mixed in a planetary mixer. Predetermined amount of plastic cream (80% fat) is added along with sugar and flavorings/spices to *chakka* to obtain at least 8.5% fat in the finished product. *Shrikhand* is used primarily as a snack and dessert.

Lassi is a refreshing beverage derived from *dahi*. It is a popular drink of India, especially North India. Significant advancements have been made toward the industrial production of *lassi* through application of ultra high temperature (UHT) technology (Aneja et al., 2002). Standardized milk (9–10% solids-not-fat and 0.5–1.0% milk fat) is heated to 85°C for 30 minutes or at 91°C for 2.5–5 minutes, cooled to 25°C, and cultured with *dahi* starter. It is then fermented at 25°C to lower the pH to 4.5. The set curd is broken with the help of a stirrer and at the same time 30% sugar solution is added to get 8–12% sugar concentration in the blend. In some variations, fruit flavor may be incorporated. *Lassi* is then homogenized at 13.7 kPa (2000 psi) and UHT processed at 135–145°C for 1–5 seconds and packaged aseptically employing standard equipment. See Chapter 13 for details on Lassi.

Chapter 19 in this book contains a detailed discussion on various fermented milks available in the world.

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2
Milk Composition, Physical and Processing Characteristics*

Ramesh C. Chandan

INTRODUCTION

From a physiological standpoint, milk is a unique biological secretion of the mammary gland endowed by nature to fulfill the entire nutritional needs of the neonate. Following parturition, milk is the secretion of normally functioning mammary gland of the females of all mammals. The yield and composition of milk vary among various species to entirely meet postnatal growth requirements of the offspring. Milk, therefore, contains all the chemicals in the form of six major nutrients, viz., water, fat, proteins, carbohydrates, minerals, and vitamins that are ideal for nourishment. Milk and milk products are used as components of many food products around the world.

Milk is an integral part of fermented milks, including yogurt, and considered by many as an ideal vehicle to deliver beneficial cultures as well as probiotics and ingredients known to stimulate activity of the benefical cultures and the microflora of the human gastrointestinal tract. The conversion of milk into fermented milks augments the nutritional value of inherent milk constituents. Additionally, the fermentation process generates metabolic and cellular compounds that have positive physiological benefits for the consumer.

This chapter provides basic information relative to milk composition that is relevant to the processing of yogurt and fermented milks. For detailed discussions, the reader is referred to Wong et al., 1988; Jensen, 1995; Swaisgood, 1996; Fox and McSweeney, 1998; and Walstra et al., 1999.

DEFINITION OF MILK

Chemically speaking, milk is a complex fluid in which more than 100,000 separate molecules and

*The information in this chapter has been derived from *Handbook of Fermented Foods*, published by Science Technology Systems, West Sacramento, CA, ©2004. Used with permission.

chemical entities have been found, the levels of which vary with the species. In terms of physical chemistry, milk is an opaque, white heterogeneous fluid in which various constituents are held in multidispersed phases of emulsion, colloidal suspension, or solution.

Worldwide, milk from cows, water buffaloes, goats, sheep, camel, mare, and other mammals is used for human consumption. However, cow's milk entails by far the most important commercial significance.

According to the Food and Drug Administration (FDA) of the United States, milk refers to cow's milk. Milk from other species must be labeled to indicate the species. For instance, milk from goats must be called goat's milk. Milk is the whole, clean lacteal secretion of one or more healthy cows properly fed and kept, excluding that obtained within 15 days before calving and 3–5 days after. This would exclude colostrum, the milk secreted immediately after giving birth. The definition of Grade A milk as per FDA standards of identity is "the lacteal secretion practically free of colostrum, obtained by complete milking of one or more healthy cows, which contains not less than 8.25% milk solids not fat and not less than 3.25% milk fat."

MILK COMPOSITION

The chemical makeup of milk and its physicochemical behavior provide scientific basis for the basic processing of milk and the manufacture of products. The composition of milk is generally described in terms of its commercially important constituents, milk fat and nonfat solids or milk solids not fat (MSNF). The MSNF consists of protein, lactose, and minerals. These solids are also referred to as "serum solids." The term "total solids" refers to the serum solids plus the milk fat. The major constituents of milk are given in Table 2.1.

The ash content is not quite equivalent to the salt level in milk. In the determination of mineral content, some salts like chlorides and organic salts are volatilized or destroyed as a result of high temperature exposure during routine mineral analysis by the ash method. The data given in Table 2.1 refer to all major breeds of cows in North America. Milk from Jersey and Guernsey breeds would be closer to a higher fat and protein range.

FACTORS AFFECTING COMPOSITION OF MILK

Apart from the differences due to the breed, certain additional factors also influence the gross composition of milk: (a) individuality of animal, (b) stages of milking, (c) intervals of milking, (d) completeness of milking, (e) frequency of milking, (f) irregularity of milking, (g) portion of milking, (h) different quarters of udder, (i) lactation period, (j) yield of milk, (k) season, (l) feed, (m) nutritional level, (n) environmental temperature, (o) health status, (p) age, (q) weather, (r) oestrum or heat, (s) gestation period, (t) exercise, (u) excitement, and (v) administration of drugs and hormones. In general, these variables tend to average out in commercial pooled milk used by dairy processors, but they do display an interesting seasonal pattern. The seasonal variations in protein and mineral content have an important impact on viscosity and gel structure of yogurt and fermented products. During late spring and early summer months, milk in some areas of the United States registers low protein and calcium content resulting in poor viscosity in finished yogurt. During these months of low-protein milk, it is necessary to compensate by raising the solids-not-fat (SNF) content of yogurt mix by 0.25–0.50%. However, because of the current widespread use of stabilizers (modified starch and gelatin) in yogurt mix, the seasonal variations in protein content do not impact viscosity and texture to the extent it does in natural yogurt in which no stabilizers are used.

PHYSICAL STRUCTURE

Various interactive forces between the chemical constituents of milk determine the technological behavior of milk. Milk has well-defined physical equilibria between various constituents that exist mainly in three forms, viz., emulsion, colloidal solution, and true solution. Milk lipids are present as an "oil-in-water" type of emulsion in the form of microscopic

Table 2.1. Composition of Bovine Milk

	Water	Fat	Protein	Lactose	Ash
Average, %	86.6	4.1	3.6	5.0	0.7
Range, average %	84.5–87.7	3.4–5.1	3.3–3.9	4.9–5.0	0.68–0.74

Source: Adapted from Swaisgood, 1996.