18 Dairy Products

1 Introduction

1.1 Definitions

The Code of Federal Regulations (CFR 21, part 131) describes milk as "*the lacteal secretions practically free of colostrum, obtained by complete milking one or more healthy cows* (U. S. Food and Drug Administration 2015). Milk may be obtained from hoofed other mammals in addition to cattle. Commercial milk animals include the bovine family [Bovidae] *water buffalo, sheep, goats, yaks*, the camel family [Camelidae], *llamas, alpacas, camels*; the deer family [Cervidae] wild *deer, reindeer, moose; and the horse family* [Equidae] – *horses, donkeys*. All commercial milk must be produced with the same hygienic standards expected for cow's milk (U.S. Department of Health and Human Services/ Public Health Service/Food and Drug Administration 2014).

The average herd size for US dairy farms increased from ~61 cows to 144 cows over the period 1992 to 2012 (see Table 18.1). Meanwhile, the number of dairy farms with >999 cows increased from 564 to 1807 farms whilst those farms with <100 cows declined in number from 134,931 to less than 50,000. Profitability increased with larger herd sizes (USDA Economics Statistics and Market Information System 2010; MacDonald and Newton 2016).

1.2 Milk Standards

Milk and milk products have traditionally been priced on the valued component, the fat. Standards have been established for this component and other components at both the federal and state levels. Standards for milk and milk products are described in CFR 21, part 131 (U. S. Food and Drug Administration 2015). Standards for raw milk intended for pasteurization should have 3.25% milk fat and 8.25% total solids- not fat. CFR standards also cover vitamin addition, optional ingredients, approved methods for analysis, allowed nomenclature and product labeling (Milk Facts 2016b) (Table 18.2).

Sanitary standards for "Grade A" milk are described in the "The Grade A Pasteurized Milk Ordinance" (U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration 2014). The Grade A pasteurized milk ordinance is discussed again in Sect. 3.2.

The composition of cow's milk varies depending on diet and species but whole milk is adjusted to contain approximately, 3.3% fat, 3.3% protein, 4.8% carbohydrate (mainly lactose), 0.7% ash (minerals), and almost 88% water (Table 18.3). Milk also contains vitamins and other nutrients in small amounts, making it a most complete of foods since young mammals survive on it exclusively.

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https://doi.org/10.1007/978-3-030-65433-7_18

The fat content of milk from Ayrshire and Brown Swiss, and especially from Guernsey and Jersey breeds, is slightly higher than that from Holstein cows, but the latter breed generally produces much more milk than the others do. Most milk is produced on farms that primarily raise dairy cattle.

2 Dairy Industry Oveview

2.1 Classification of the Dairy Industry

The dairy industry (NAICS 3115) comprises businesses that manufacture non-frozen milk products (NAICS 31151) or frozen dairy products (NAICS 31152). The former sector covers fluid milk, butter, cheeses and dehydrated products. The frozen dairy products are mainly ice cream and frozen yogurts (Table 18.4).

Table 18.1 Definition of a dairy farm

A dairy farm is any place or premises where one (1) or more lactating animals (cows, goats, sheep, water buffalo, or other hooved mammal) are kept for milking purposes, and from which a part or all of the milk or milk product(s) is provided, sold or offered for sale to a milk plant, receiving station or transfer station

Adapted from U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration (2014)

Table 18.2 Standards of identify for dairy products – Code of Federal Regulations

21CFR131	– Milk and cream
21CFR133	– Cheeses and related cheese products
21CFT135	– Frozen desserts

Reference: Adapted from Milk Facts (2016b)

2.2 United States Milk Production Statistics

The Holstein breed outnumbers all others used in the United States for the production of milk (Campbell and Marshall 2016). Jersey and Guernsey breeds tolerate hot weather better than Holsteins. Some Ayrshire, and Brown Swiss or Shorthorn breeds are used in colder areas. Current data (2014) shows the US accounts for 19% of the world total production for cow milk with 50% of American milk coming from just six States: California (20.5%), Wisconsin (13.7%), New York (6.69%), Idaho (6.67%) and Pennsylvania (5.25%). (Federal Milk Market Administrator 2015). The US produced 2.5 times more milk than any European Country, 4.5-fold more milk than New Zealand, and ~9-fold more milk compared to Australia (USDA Economic Research Services 2016; USDA Foreign Agricultural Services 2014) About 200 whey manufacturing establishments in the USA account for 25% of the global lactose production. Milk exports are predominantly as dried powder (40–50% US production) compared with 15% of fluid milk, 6% cheese, 3–8% butter, and 67–78% whey and lactose. (Progressive Dairy Man 2016; U.S. Dairy Export Council 2004).

2.3 Global Economic Significance of Milk

The global total amount of cow milk produced in 2016 was nearly 500 million metric tons (Table 18.5). The data confirms the US as the leading cow milk producing country. Considering all milk production from all livestock, shows the leading producer countries to be, India (18%),

Table 18.3 The composition of milk from a variety of sources

Source	Water	Protein	Casein	Whey P	Fat	Lactose	Ash
Buffalo	83.9	4.0	3.5	0.5	6.3	4.8	0.8
Cow	*86.9*	*3.5*	*2.8*	*0.7*	*3.5*	*4.8*	*0.7*
Goat	86.5	3.6	2.7	0.9	4.0	4.7	0.8
Sheep	82.0	4.6	3.9	0.7	7.2	4.8	0.85
Camel	86.5	3.6	2.7	0.9	4.0	5.0	0.5
Horse	88.8	2.5	1.3	1.2	1.9	6.2	0.5
Human	87.5	1.0	0.5	0.5	4.5	7.1	0.2

Table 18.4 Dairy product manufacturing industries (NAICS 3115)

	Dairy products manufacturing	Employees 2012	Number of businesses
31,151	Dairy product (except frozen)	115,728	1186
311,511	Fluid milk	54,833	420
311,512	Creamery butter	1849	38
311,513	Cheese	44,679	540
311,514	Dry, condensed, evaporated dairy product	14,367	188
31,152	Ice cream and frozen dessert	–	–
311,520	Ice cream and frozen dessert	20,933	401
Total		136,661	1587

Table 18.5 Global production and consumers of Cow's milk (1000 metric Ton)[a]

Area/region	Produced	%World	Cons	%Diff
EU	151,600	30.3	34,000	78
USA	96,343	19.3	26,521	72
India	68,000	13.6	62,750	8
China	38,000	7.6	15,570	59
Russia	30,085	6.0	9185	69
Brazil	27,100	5.4	10,095	63
New Zealand	21,150	4.2	497	98
Mexico	11,934	2.4	4183	65
Ukraine	10,100	2.0	5124	49
Argentina	10000.0	2.0	1800	82
Australia	9700	1.9	2700	72
Canada	8685	1.7	2945	66
Japan	7340	1.5	3900	47
Belarus	7175	1.4	1050	85
Korea South	2193	0.4	1529	30
Taiwan	380	0.1	381	0
Others	22	0.0	62	−182
World Total	499,807	100	182,292	64

[a]Data from 2016. Percentage difference (%Diff) between production & consumption (Cons) is potentially available for export. (Adapted from USDA Economic Research Services 2016; USDA Foreign Agricultural Services 2014)

USA (12%), Brazil (5%), China (5%), Germany (4%), France (3%), New Zealand (3%), turkey (2%), and Pakistan (2%).

About 10 species are currently farmed for milk production for human consumption. About 85% of the global milk supply is cow milk; the remainder is 11% buffalo milk, 2.5% goat milk, 1% sheep milk and 0.4% camel milk (FAO 2016). Exports of milk amounts to about 10% of global production. New Zealand is an exception where 95% of milk production is destined for export as ingredients and powders. Other major exporters for milk include the EU (28), US and Australia. India and some of the other large milk producer countries are not major importers and/ or exporters. China, the Russia Federation, Mexico, Indonesia and Algeria are some of the major importers (Table 18.6).

The per capita consumption of milk (2014) ranged from 100 liters per person per year (Finland, Ireland, Estonia, Australia) to 60–80 liters per person per year for some middle-consuming nations such as United States. Comparatively low per capita consumption of milk was observed for countries such as Iran, South Africa, Chile, Ukraine, Bulgaria, Egypt and China (Fig. 18.1).

2.4 Dairy Products

The US fluid milk sector (NAICS 311511), which comprises ~30% of the dairy industry by employment number, is divided into three sub-sectors. (i) bottled, vitaminized or flavored milk products. (ii) Manufactures of cream, sour cream and whipped toppings. (iii) Manufacturers of non-frozen yogurts (Table 18.4).

Manufacturers of creamery butter (NAICS 311512) are essentially dealing with various types of butter. Likewise, cheese manufacturing (NAICS 311513) includes real cheese, cheese spread, and a range of substitute cheese products. Whey by-product from cheese manufacturing is important economically. Globally, the main forms of dairy products from milk were fresh fluid milk (~45%), Cheese (25.4%), butter and ghee (23.2%), whole milk powder (3.7%) and skimmed dried milk (4.5%).

The total dairy products manufacture in the U.S (2014) exceeded 24 million metric tons derived from over 2500 manufacturing plants (Table 18.7). The largest percentage of products was ice cream and ice cream mixes (~50% total), followed by cheese and cottage cheese

Table 18.6 Global milk exports and imports (1000 metric tons)

Region/country	Export	%	Region/country	Import	%
New Zealand	18,375	27.1	China	13,345	20
EU	16,235	23.9	Russia Fed.	5158	8
USA	10,727	15.8	Mexico	2962	5
Australia	3277	4.8	Indonesia	2630	4
World	67,862		Algeria	2480	4
			World	65,133	

Reference: 2014 forecasts. (Adapted from Ragonnaud 2014)

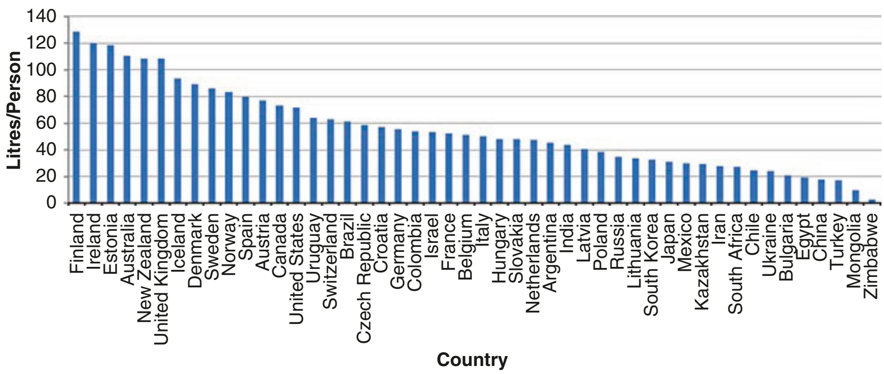


Fig. 18.1 Per capital consumption of milk in 52 countries. (Canadian Dairy Information Centre 2016b)

Table 18.7 Dairy products manufacture for the United States (2014)

Dairy product	No. plants[a]	Tonnes/1000	% total	Comment
Ice creams	581	9380.8	39.3	Regular, low fat, soft & hard
Cheese	536	5195.2	21.8	Excl. cottage cheese
Dry mix	484	2613.1	10.9	Regular, low fat, no fat ice cream
Yogurt	147	2158.1	9.0	Plain & flavored
Butter	81	842.3	3.5	
Condensed milk	62	828.8	3.5	Skim, whole, (un) sweetened,
NFDM	47	800.6	3.4	
Sour cream	107	591.9	2.5	
Cheese, cottage	56	477.8	2.0	Curd, creamed and low fat
Dry whey	29	388.4	1.6	For human use only
Frozen yogurt	139	251.4	1.1	Regular, low fat, no fat categories
Sherbet	161	171.9	0.7	
Dry mix (sh)	118	98.8	0.4	Sherbet dry mix
Buttermilk	25	50.4	0.2	Dry only
Whole dry milk	12	32.7	0.1	
Total	2585	23882.1	100.0	

Adapted from USDA Economics Statistics and Market Information System (2015)
[a]Manufacturing plants which produce more than one product may be counted twice-see Table (18.4)

(~24% total) and then yogurt (~9%). (USDA Economics Statistics and Market Information System 2015).

3 Fluid Milk

3.1 Milking

Milking on a commercial scale is mostly carried out using machines. (Food and Agriculture Organization of the United Nations 1998). At first, a small amount of milk is drawn and examined for impurities, after which the cups of the milking machine are applied to the clean, sanitary teats of the cow. After milking, the cups are immersed in a nonirritating bactericidal agent before they are applied to the teats of another cow. Milk from the cow passes through the milking machine from which it flows through a glass or stainless steel pipe to a bulk cooling refrigerated at 40 °F (4.4 °C). (American Cheese Society 2015).

3.2 Transportation of Fluid Milk

Milk is transported from the farm to the receiving station or fluid milk processing plant in a milk tank truck or pickup tanker. Pickup tankers are insulated, stainless steel tanks, usually having a holding capacity of more than 5000 gallons (18,925 liters) on a trailer handled by a motorized vehicle. There is no significant rise in the temperature of the milk during the period required for transportation and delivery to the processing plant. Grade "A" raw milk is expected not to exceed 10 °C and be cooled for <7 °C for on-farm storage (U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration 2014).

Upon receiving the milk, the product undergoes a series of tests for odor and flavor, overall volume, butter fat content and for the presence of antibiotics (Sect. 3.3). The milk is then pumped from the bulk tank into the tanker truck through a sanitized plastic hose after which the hose is capped. The final step is to prepare a weight ticket for the farmer and tabulate the weight, temperature, and other data of the product on a record sheet.

In accordance with the milk ordinance, pickup tankers, including auxiliary equipment such as hoses, must be cleaned and sanitized, as are dairy farm milking and milk-holding equipment, after delivery of the product to the processing plant (U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration 2014).

3.3 Milk Quality Testing, Quality Assurance

3.3.1 Testing Farm Milk

When receiving the milk, the operator of the tanker tests the product, which has been stored in a bulk tank, for odor and flavor and, if not suitable, the milk is rejected. If acceptable, the volume of the product in the bulk tank is measured with a rod. It is then agitated, after which a sample is taken in a glass or plastic bottle from which the butterfat content will be determined, because farmers are paid on the basis of butterfat content.

A commingled sample is also taken to be tested for the presence of antibiotics using the *Bacillus stearothermophilus* disc assay or equivalent as required by the Pasteurized Milk Ordinance of the U.S. Quick tests approved by the FDA such as the Charm II Beta-lactam Tests (Charm Sciences Inc. of Malden, Massachusetts) also enable farmers, processors, and quality laboratories to examine milk for antibiotics quickly and accurately. Another tests-kit (SNAP Beta-lactam Test Kit, IDEXX Laboratories, Maine USA) was approved in 2003 for detection of penicillin G, amoxicillin, ampicillin, ceftiofur and cephapirin residue in co-mingled milk (U. S. Food and Drug Administration 2003). If there is no problem with the collected milk, then samples from the individual farmers need not be tested. If there is a problem, however, each individual farm sample must be tested, and the farmer responsible for the contaminated milk may be liable for ensuing losses. Because of such severe financial consequences, farmers are very careful not to

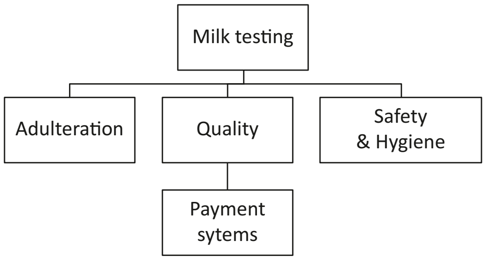


Fig. 18.2 Rational for milk quality testing

Table 18.8 Milk quality testing methods

Tests	Comment
Quantity	Volume or weight of milk produced
Organoleptic testing	Appearance, Taste, odor, flavor
Composition	Water, protein, fat, lactose, minerals etc.
Physical / chemical	Density, Water addition, pH, Alcohol test
Hygiene	Total bacterial count
Hygiene	Somatic cell count for mastitis
Adulteration	Water, skim milk, fat removal
Drug residues	Antibiotics

Reference: Summarized from Draaiyer et al. (2009) and FAO (2016)

attempt to sell milk from cows that have been recently treated with antibiotics (Vieira 2013).

3.3.2 Laboratory Milk Tests

Milk testing is performed for a number of common reasons to do with assuring quality and determining payments to milk producers. Other quality issues include the potential to increase yield, detection of milk adulteration, as well as the evaluation of standard attributes. The following is a brief account of milk quality testing based on a FAO handbook intended for small milk producers (Draaiyer et al. 2009) (Fig. 18.2).

Sampling milk from the producer is one of the first steps before testing. Milk may be sampled periodically, randomly or samples may be collected and combined to provide a comingled batch for testing. Accurate and representative sampling is important. First, a specialized instrument is used for milk agitation, and a dipper is applied for sample removal and transfer to pre-sterilized containers. In some cases, preservatives (potassium dichromate, bronopol, formaldehyde or hydrogen peroxide) may be added to the milk before transportation to the laboratory.

A range of techniques are frequently applied in the milk testing laboratories and briefly outlined below (Table 18.8).

1. The quantity of milk can be measured by weighing or by volume measurements. For larger quantities, it is easier to weigh than to measure volume.
2. Organoleptic testing. The purpose of organoleptic testing is to determine appearance, taste, and odor, and flavor characteristics of milk; the appearance of milk should be whitish yellow. The taste should be light and slightly sweet. A sour taste is indicative of acidic milk, which suggests some degree of fermentation implying unacceptable contamination or age. The flavor of milk should not be rancid or bitter and nor should there by other taints (feed, malty, salty etc.).
3. The chemical or proximate composition of milk is clearly an important aspect of quality. Determination of fat content is one of the most important tests, frequently using the Gerber test or Babcock test. In both cases, milk is mixed with sulfuric acid and the volume of fat remaining undissolved is recovered by centrifugation and measured. Protein content of milk can be readily determined using formaldehyde titration.
4. The total solids (TS) content of milk is normally measured from density measurements using a hygrometer also called a lactometer in dairy chemistry. The hydrometer is very useful and versatile and able to be applied for lactose, TS and also solids not fat (SNF) content;

$$\mathrm{TS}(\%) = 0.25(\mathrm{L}) + 1.22\,\mathrm{fat}\% + 0.72$$

$$\mathrm{SNF} = \mathrm{TS}(\%) - \mathrm{Fat}\%$$

In the preceding equations, L is last two integers from the lactometer (hygrometer) reading, and fat% is fat content determined from chemical analysis.

Additional physical and chemical characteristics may be determined for milk such as, water, pH, and coagulation degree with heating or alcohol. The water content can be used to detect illegal addition by producers. Adulteration by water addition changes in the specific gravity of milk, which can be readily detected by the ubiquitous hygrometer. The readings are used in conjunction with fat% values to estimate water addition. Incidentally a range of adulterations go beyond water, and include re-addition of skimmed milk, addition of whey proteins or non-whey proteins, and or additions of milk from species other than cow.

Measurement of pH or titrable acidity is to check for milk fermentation. A couple of indirect measurements of acidity are also available which depend on a measurement of milk protein coagulation degree after the addition of alcohol or after a short degree of boiling. The following texts provide additional materials on milk testing (Al-Saqer et al. 1999; Rombaut et al. 2002; Tamime 2009).

4 Milk Hygiene and Safety

4.1 The Grade "A" Milk Ordinance

The US standard for milk hygiene or "the Grade A Pasteurized Milk Ordinance" (PMO) provides detailed recommendations for milk production, handling, processing and retail (U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration 2014). Different States may adopt all or some parts of the PMO but the ordinance applies for all milk traded across State lines (Meyer 2015).[1] The Codex standards for milk and milk products considers "milk safety" as the responsibility of all stakeholders within the Agri-food system: producers, processors, distributers and retailers (Codex Alimentarius Commission 2004). Hygiene Issues surrounding the premises and fixtures (premises, utensils, personnel training etc.) for milk production are covered by the general requirements for Good Manufacturing Practices (GMP) (Table 18.9).

[1]At the time of writing the 2013 edition of the Grade A PMO (430 pages) is available online.

Table 18.9 Primary production factors and milk hygiene

Environmental hygiene Clean water, no cross contamination of milk
Hygienic production of milk Cf. GMP Prescriptions Regarding Premises, Good Animal Health, General Hygienic Practice Feeding, veterinary drugs, Hygienic milking
Handling, storage and transport of milk Milking equipment Storage equipment Premises for, and storage of, milk and milking-related equipment Collection, transport and delivery procedures and equipment

Adapted from Food and Agriculture Organization of the United Nations (1998)

The milk hygiene principles for smallholders (less than 10 milking cow per farmer or herd) involve broadly similar requirements as the GMP for commercial-scale units. However, it may be that small-scale milk producers experience other challenges, owing to the lower degree of mechanization, greater likelihood for hand milking, and use of small-scale milk collection units. Milk hygiene is attracting attention in the developing world, where the smallholder dairy farms are more common (Kurwijila 2006; Shija 2013).

4.2 Microorganisms in Milk

Though raw milk from healthy livestock is sterile, bulk tank milk is not free from microorganisms (Angulo et al. 2009; Vissers & Driehuis 2009; Verraes et al. 2014). Most of the microorganisms associated with raw milk arise by cross contamination from the farm environment, i.e. from animal feed, feces, bedding, or soil. Some bacteria derive also from the udder and teats particularly where these become infected, and swollen in the condition called mastitis (Table 18.10).

The raw milk microorganisms belong to one of the following classes, (i) normal, harmless or potentially beneficial, (ii) pathogens found also in other foods items (Chap. 8, Sect. 2), or (iii) zoonosis microorganisms that transmit animal

Table 18.10 Major bacteria from raw milk

Gram negative, psychrotroph
Pseudomonas species
Enterobacteria
Other
Gram positive spore forming
Bacillus species
Bacillus licheniformis
Bacillus cereus
Clostridium species
Lactic acid bacteria
Pathogenic bacteria
Campylobacter
E. coli
Listeria monocytogenes
Yersinia
Staphylococcus aureus

Adapted from Touch & Deeth (2009), Vissers & Driehuis (2009)

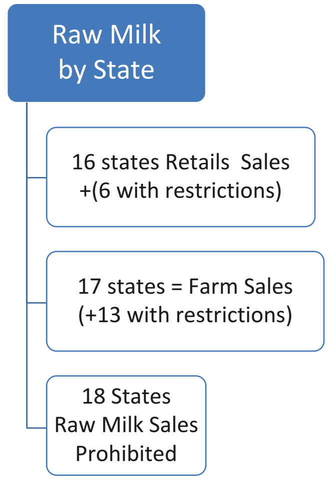


Fig. 18.3 Legislation surrounding the sales for raw milk. (Adapted from Marler Clark Associates (Clark 2016))

diseases to humans via raw milk. In addition to those listed in Table (18.10), the milk-associated pathogens can include, Salmonella spp, streptococcus species, *Clostridium botulinum*, *Mycobacterium bovis*, and *Toxoplasma gondii* (Vissers & Driehuis 2009, Quigley et al., 2013; Verraes et al., 2014; Verraes et al., 2015).

In the United States, certified milk is produced from herds that have been inspected, tested, and found to be free from disease. There are bacterial standards for certified milk that limit the number and types of bacteria that are allowed (The American Association Of Medical Milk Commissions Inc. 1999).

4.3 Raw Milk Controversy

It is claimed that raw milk contain higher levels of nutrients, which could be lost by heating (Anon 2015; Food Safety News 2016). Other reasons suggested for raw milk consumption include, a superior taste and flavor, and curative properties (Lejeune and Rajala-Schultz 2009, Lucey 2015, 6442; Oliver et al. 2009).

Currently, raw milk can be purchased within 29 States. Some 18 States prohibit the sale of raw milk for human consumption (Fig. 18.3). Cow-share schemes or direct sale methods are some of the ways for sourcing raw milk (Oliver et al. 2009). One popular cow-share scheme involve consumers buying shares in dairy farms, and then receiving "dividends" as co-owners, in the form of raw milk. Cow-share schemes and the range of intra-state legislations surrounding raw milk have been extensively discussed (Lejeune and Rajala-Schultz 2009; Lucey 2015; Oliver et al. 2009); the following documents reflect well the history and legal aspects of raw milk provision in the United States (Angulo et al. 2009; Meyer 2015).

The risks of food poisoning following the consumption of non-pasteurized milk was estimated to be 150-fold greater than the risks from pasteurized milk. Moreover, the severity of infections and the likelihood of hospitalizations were higher for consumers of non-pasteurized milk compared with pasteurized milk. Most certified milk is pasteurized. Between1993–2006 some 60% of food-borne disease outbreaks associated with dairy foods were linked with raw unpasteurized milk resulting in two deaths and more than 2000 hospitalizations (Langer et al. 2012). A further survey covering 2007–2013 (Table 18.11) found 81 outbreaks due to non-pasteurized milk, 979 cases of illness and 73 hospitalizations (Mungai et al. 2015).

Worldwide, the consumption of raw milk and milk products (cheeses and butter) seems rather common. Many people within the Mediterranean, East Asia, Sub-Sahara Africa, and the Middle East consume raw milk from goat, sheep, camel,

Table 18.11 Raw milk hazards – statistics, sources and myths

Outbreaks 2007–2012
Number of outbreaks 81
Number of cases 900+
Hospitalizations = 73, deaths = 0
Non-pasteurized milk products
Unpasteurized milk or cream
Soft cheeses (Brie and Camembert)
Mexican-style soft cheeses made from unpasteurized milk
Yogurt made from unpasteurized milk
Pudding made from unpasteurized milk
Ice cream or frozen yogurt made from unpasteurized milk
Raw milk (RM) myths
Pasteurized milk is less nutritious than RM
RM products (soft cheese, ice cream, and yogurt) are safe.
Raw milk labeled "organic." is safe
RM from non-symptomatic animals is safe
RM has curative properties

References: compiled from multiple sources. (Mungai et al. 2015)

Table 18.12 Measures for reducing bacteria in milk

Cleaning and Sanitation (teat, udder area, utensils, storage tanks)
Cold storage of milk (2 °C)
Carbon dioxide addition
Sterilization H202 /SCN (lacto-peroxidase
Lactoferrin addition
Lactic acid bacteria
Heat treatment, (Pasteurization, HSTS)

Reference: Adapted from Touch and Deeth (2009)

water buffalo or donkey. Interestingly, researchers also found infected herds were common in some of the areas mentioned (Colavita et al. 2016; Verraes et al. 2014). Diseases likely to be transmitted to humans by bacteria in raw milk, include, Q fever (*Clostridium burnetii*), bovine tuberculosis (*Mycobacterium bovis*), caprine or goat tuberculosis (*Mycobacterium caprae*), brucellosis (Brucella species) and tick-borne encephalitis virus (Leedom et al. 2006; Verraes et al. 2014; Asante et al. 2019; Conte and Panebianco 2019).

Pasteurization was adopted in North America in the last century partly to deal with the high risks of bovine tuberculosis, typhoid or scarlet fever from drinking cow's milk. Initial activism for pasteurization came from doctors and pediatricians concerned with securing clean milk for feeding infants (Lederle 1907; Rickards 1909; Rotch 1907). By 1948 pasteurization was mandatory in many states. Sales of raw milk across State-lines were prohibited from 1987 (Centers for Disease Control and Prevention 2015; U. S. Food and Drug Administration 2016).

In summary, pasteurization of milk (and other liquid foods and beverages) improves safety as well as shelf life. In general, pasteurized milk is not sterile and must be refrigerated. However, the temperature /time controls are designed to reduce the number of microbial pathogens present by thousands to million-fold. Starting with good quality milks from a healthy herd (see below), and then pasteurizing this product hygienically helped to improve infant mortality and general public health (Ranking et al. 2017; Currier and Widness 2018). It is noteworthy that human donor milk is now being pasteurized to protect infants from transmissible diseases (Goya and Calvo 2018; Meeks et al. 2019).

4.4 Controlling Bacterial Contamination of Milk

Unless the udder is infected, it may not be an important source of contamination. Other sources of microbial contamination of milk are the body of the cow; milking machines and other equipment and utensils (Harding 1995; Vissers & Driehuis 2009). Some measures to limit the number of bacteria present in raw milk are summarized in Table 18.12 (Touch and Deeth 2009).

Large dairy farms often have a special wash pen for cows to be milked. Utensils, including the milking machine, should be cleaned and disinfected either with live steam or with a solution of chlorine (about 200 ppm of available chlorine). Bulk milk tanks may be cleaned with detergent and water then sanitized with chlorine solution. Outlet valves and the outside of the tank must be cleaned and sanitized manually. Cleaning in place (CIP) may be used to clean, sanitize, and rinse the milk pipeline, the teat cup assembly, and the bulk milk tank if a vacuum or pressure system is available. As noted above, milk producers and processors must comply with GMP requirements closely (Chaps. 7, 8 and 9).

5 Processing of Fluid Milk

Fluid milk and dairy products undergo a range of unit operations or processing e.g. heating, centrifugation, homogenization, dehydration concentration, membrane separation (ultrafiltration), fermentation and packaging. Processing transforms milk from a comparatively low cost and perishable commodity into higher value products. Elements of diary technology have been discussed in several important texts (Goff 2016; Robinson 1993a, b; Spreer 1998; Varnam and Sutherland 2012; Walstra et al. 2005). The following is a brief outline of the processing methods for fluid milk.

5.1 Whole Milk

Processing whole milk starts with clarification, which involves passing the fluid through a low speed centrifuge similar to a cream separator (Fig 18.4). The purpose of the clarifier is to separate out dirt and sediment that might be present. The milk is then pumped into a storage tank equipped with an agitator and standardized for butterfat content by adding enough cream or skim milk (milk from which cream has been removed) to provide the fat content required by State regulations. Some milk is fortified with vitamin D so that one serving of milk (8 oz. or 236 ml) will then contain 25% of the Daily Value (DV). Low fat and skim milk will usually be fortified with vitamin A also to give 10% of the DV per serving.

The next step in fluid milk processing is to pasteurize it. In the old "vat method," milk must be heated to 145 °F (62.8 °C) and held at this temperature for 30 min (Lewis 2012). Other temperature-time combinations (Table 18.13) are available for milk pasteurization in order to achieve similar effects (U.S. Department of Health and Human Services/Public Health Service/Food and Drug Administration 2014).

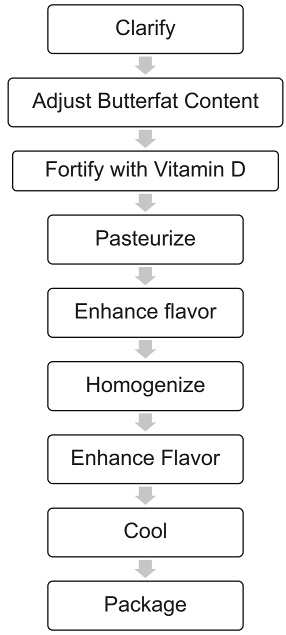


Fig. 18.4 A process chart for pasteurized whole milk

Table 18.13 Temperatures for food pasteurization

Temperature		Time
145 °F[a]	62.8 °C	30 min
161 °F[a, b]	71.7 °C	15 s
191 °F	88.3 °C	1 s
204 °F	95.6 °C	0.05 s
212 °F	100.0 °C	0.01 s
280 °F	137.8 °C	>2 s

Notes:[a]For products with >10% fat the process temperature is increased by 5 °F (~3 °C), [b]High Temperature Short time (HTST) pasteurization. (Adapted from U. S. Food and Drug Administration 2015)

Pasteurization temperatures ensure the destruction of the most heat-resistant pathogen in milk, *Coxiella burnetti*, the bacterium that causes Q fever (Cerf and Condron 2006). Milk may be pasteurized using an insulated vat, the plate heat exchanger (Fig. 18.5) or a tubular heat exchanger. Most commercial operations adopt one of several equivalent pasteurization temperatures (Table 18.13). Pasteurization is described further in Chap. 12 (Sect. 8.5).

In a process called deodorization, milk may be given a flavor treatment to provide a product that is uniform in odor and taste. Milk is instantly heated to about 195 °F (90.6 °C) with live steam

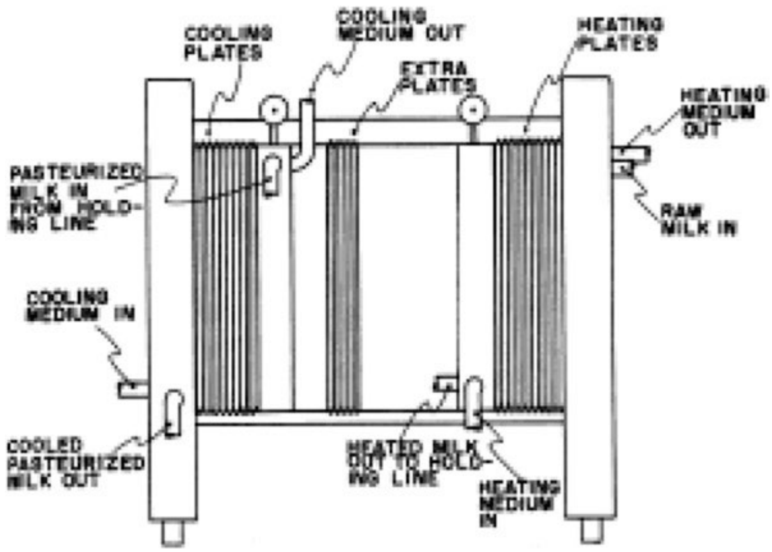


Fig. 18.5 A plate pasteurizer

(injected directly into the product) and then subjected to a vacuum of about 10 in. (25.4 cm) in one chamber and to a vacuum of about 22 in. (55.9 cm) in another chamber. The high-vacuum treatment serves to regulate flavor, to cool the milk to about 150 °F (65.6 °C), and to evaporate water that may have been added through the injection of steam. After the flavor treatment, and while the milk is still hot, it is usually homogenized by passing it through a small orifice that breaks up the fat globules to a small size, preventing the separation of cream from the milk. The milk is then cooled rapidly to about 35 °F (1.7 °C).

During HTST pasteurization, deodorization treatment and homogenization, milk is passed through heating and cooling cycles at such a rapid rate that at no time is it held for long periods at high temperatures (Kurtz et al. 1971).

Following the processing and cooling stages, milk is filled mechanically into containers made of waxed or plastic-coated cartons of volumes between 2 quarts (1.9 liters) and 1gallon (3.8 liters), and the containers are sealed. In this state, milk should be held as close to 32 °F (0 °C) as possible until consumed.

Sometimes, milk may be stored for hours or even days before processing. In these cases, large dairy plants employ a thermization step where milk is heated 145.4–149 °F (63–65 °C) for about 15 s and then chilled to 40 °F (4.4 °C) or below rapidly. The spore-forming spoilage organisms are not eliminated in this process but may revert to their vegetative state where, they are more vulnerable towards pasteurization eventually. Some countries prohibit double pasteurization so a phosphatase (enzyme) test must be done on the milk to ensure that it had not been entirely pasteurized before it goes through the second heat treatment and final pasteurization step.

Ultra-High-Temperature (UHT) milk is produced by heating at temperatures of 275–284 °F (135–140 °C) for a few seconds. The milk is then homogenized, cooled, and filled aseptically into sterile containers. The UHT plants can use two major types of heating to reach these high temperatures, indirect heating or direct steam heating (see Figs. 18.6 and 18.7). These systems are further described by the following references (Gillis et al. 1985; Hill 1988; Horner et al. 1980). The shelf life of UHT milk is between 40 and 45 days at 40 °F (4.4 °C) in situations where the shelf life using conventional HTST and packaging in non-sterile containers is often less than 20.

Alternative methods for pasteurizing milk and other liquid foods do not involve direct heating. Pulsed electrical fields (PEF), oscillating magnetic fields, high hydrostatic pressure, intense light pulses, and irradiation are being considered as methods for milk pasteurization. Whilst using short-duration, high-intensity PEF the temperature of milk does not exceed 131 °F (55 °C). Treatment of the liquid food takes place between two electrodes and lasts for less than 1 s (Fig. 18.8). Raw skim milk processed by PEF

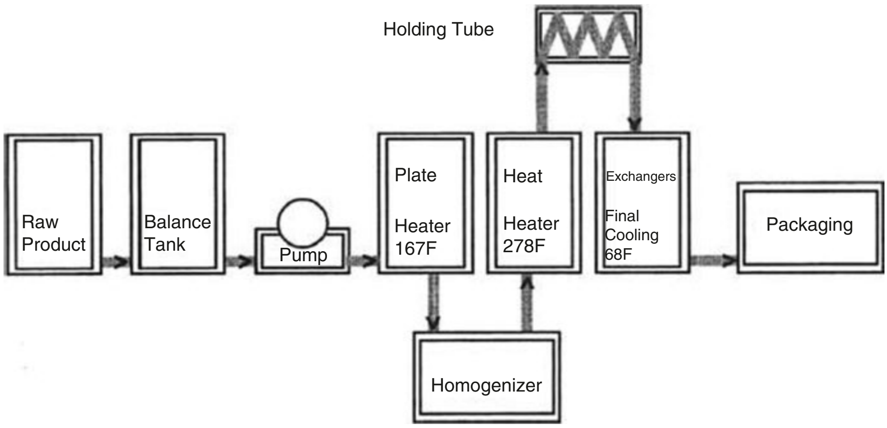


Fig. 18.6 UHT processing with indirect steam injection

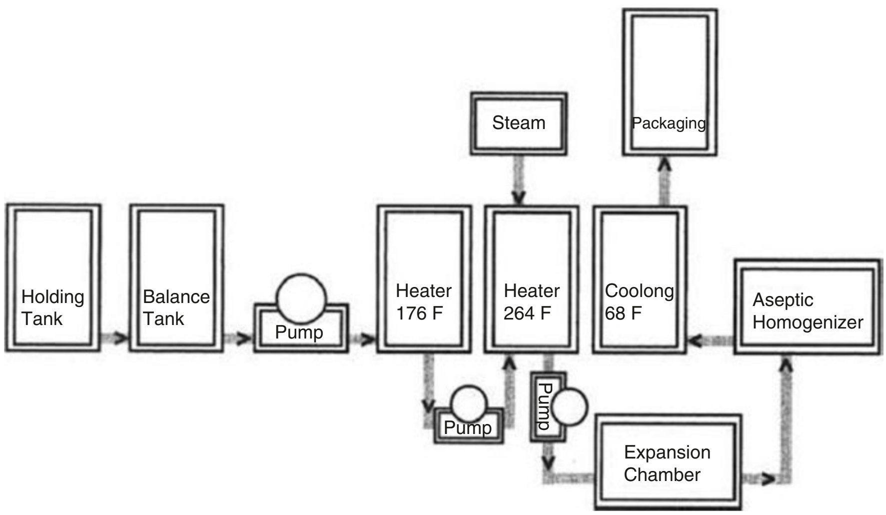


Fig. 18.7 UHT processing with direct steam heat

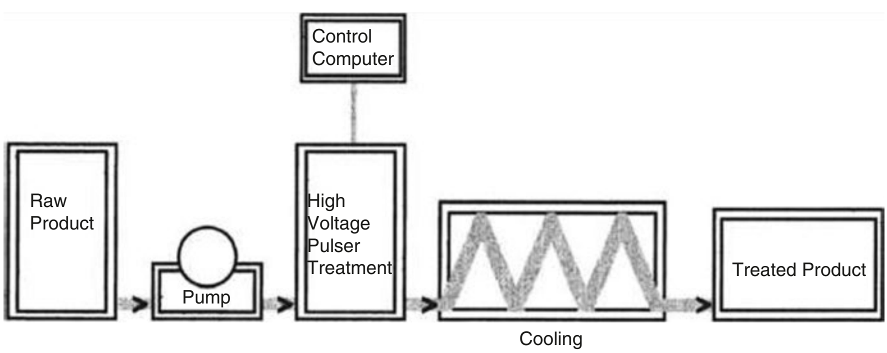


Fig. 18.8 Continuous PEF process for liquid foods

technology showed few or no changes in the physical and chemical properties and a sensory panel found no difference between heat-pasteurized milk and PEF milk (Morales-De la Pena and Martin-Belloso 2009; Mosqueda-Melgar et al. 2008; Otunola et al. 2008; Sepulveda et al. 2009). The storage life of milk processed by PEF treatment was 2 weeks at 40 °F (4.4 °C) and sometimes longer (Buckow et al. 2014).

5.2 Skim Milk

Skim milk (0.5% fat) and reduced-fat milk (0.2–.5% fat) are derived from whole milk which is passed through a centrifuge at high speeds, after the milk has been heated to 90–110 °F (32.2–43.3 °C), to remove the butterfat as cream. These products are usually fortified with vitamins A and D prior to pasteurization and cooling. In some cases, sodium caseinate (a derivative of casein, the main protein in milk) is also added.

The cream from the centrifuge may be separated as approximately 40% butterfat (heavy cream), 30% butterfat (all-purpose cream), or 20% butterfat (light cream). The creams higher in butterfat may be diluted with skim milk to provide the various fat densities or to produce a product known as half-and-half (about 10.5% butterfat). Cream tends to spoil more quickly than milk, and so it is usually given a more drastic heat treatment during pasteurization. For batch pasteurization cream is heated to 150–155 °F (65.6–68.3 °C) for 30 min prior to cooling. When the HTST method is used, cream is heated to 166–175 °F (74.4–79.4 °C) for 15 s prior to cooling. A product called table cream (light cream or half-and-half) is homogenized after pasteurization. After pasteurization, cream is cooled to 35 °F (1.7 °C) and containerized. Cream is held at 35–40 °F (1.7–4.4 °C) until consumed or subjected to additional processing.

5.3 Non-fat Dried Milk

Large quantities of skim and low-fat milk are dried by, a variety of methods, most commonly spray drying or drum drying (Chap. 14). Dried milk (usually the spray-dried type that contains about 5% moisture) may be re-humidified to slightly higher moisture content after drying. This treatment agglomerates the fine milk particles to form clumps of milk powder, which results in a product that dissolves or disperses in water much more readily than the finely powdered dried milk (Chap. 15, Sect. 3.2).

6 Other Dairy Products

6.1 Ice Cream

6.1.1 Economic Significance

The characteristics of good ice cream and allied products have been well documented (Goff and Hartel 2013). The estimated value for the global ice cream trade was US$74billion with the largest markets being, US >Italy > China, followed by Australia, Brazil, Russia and UK. The per capita consumption of ice cream was highest in New Zealand, Australia, USA and Finland. Some of the lowest consumers of ice cream occur in China, Brazil and Mexico (Clarke 2012; Goff and Hartel 2013).

6.1.2 Standards for Ice Cream

Standards for American ice cream and frozen desserts are described in 21CFR135.110 (Milk Facts 2016b; U. S. Food and Drug Administration 1978; US Government Publishing Office 1978). Ice cream is defined as, a product manufactured by freezing and aerating a pre-pasteurized mix of dairy ingredients. The major frozen desserts include, non-dairy ice cream made using milk protein and vegetable oil, gelato – Italian ice cream containing custard and eggnog, milk ice, sorbet – aerated dessert containing fruit juice and syrup, sherbet – like sorbet with some cream and or milk added (Clarke 2012) (Table 18.14).

Table 18.14 Ice cream and other frozen desserts (21 CFR135)

135.110 Ice cream and frozen custard.
135.115 Goat's milk ice cream.
135.130 Mellorine.
135.140 Sherbet.
135.160 Water ices

Reference: From (Milk Facts 2016b; U. S. Food and Drug Administration 1978; US Government Publishing Office 1978)

Table 18.15 Composition of ice cream (21 CFR135.110)

Composition	Quantity	Comments
Total solids	>1.6lbs/ gallon	>160 g/l equivalent or 16% (w/v)
Milk fat	10–16%	Cream
Milk Not fat, solids	9–12%	Casein, whey proteins and lactose
Sweeteners	12–16%	Mainly high-fructose corn syrup
Stabilizers & emulsifiers	0.2–0.5%	Polysaccharide thickening agents
Water	55–64%	From added Grade A milk
Density	>4.51lbs/ gallon	450 g/l liquid & 550 cc of Air (cf. over-ran, foaming)

Standards for diary ice cream vary in different countries and regional blocks (Clarke 2012; Goff and Hartel 2013). American dairy ice cream (Table 18.15) shows a minimum of 10% (average 14%) milk fat, and a range of optional ingredients including cream; milk or skimmed milk; sugars (sucrose, dextrose, corn syrup or high-fructose corn syrup); stabilizers which may be gelatin, vegetable gums, or modified food starches; pasteurized eggs or egg whites; flavorings such as vanilla; fruit juices or extracts; cocoa; chocolate; candy; cookies; nuts; or just about anything the imagination and food science will allow. When nut is added this is not counted as part of the solids content, but rather as flavor.

The compositions of ice cream from New Zealand, Australia and Canada were similar to ice cream from the US, as regards milk fat content (10–16%), total solids content (16–20%) and density (450 g/l). In the UK ice cream tends to have a minimum of 5% milk fat, and 2.5% protein (Clarke 2012; Goff and Hartel 2013). French-style ice cream or custard ice creams have egg yolk added to improve texture. These must be pasteurized and use of homemade recipes that call for raw eggs is not recommended since salmonella might be present. The acceptable protein content of ice cream is not specified in many jurisdictions; indeed milk protein may be optional. Vegan ice cream does not containing animal (dairy) derived ingredients (Mullan 2016).

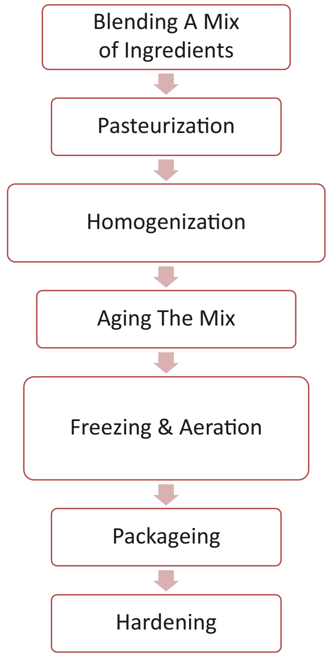


Fig. 18.9 A process diagram for ice cream manufacture

6.1.3 Ice Cream Manufacturing

The manufacturing of dairy ice cream involves mixing liquid dairy ingredients and liquid sweeteners separately (Fig. 18.9). These are then combined, blended together, and then the mixture is allowed to "soak" for a period of time (20 min) before it is pasteurized, homogenized, cooled with agitation to 36°F (2.2°C) and held in storage tanks.

Ice cream pre-mix is combined with flavors and then added to the ice cream freezer, which is a tube with walls refrigerated to 5–15 °F (−15 to −9.4 °C). The freezer is fitted with blades that rotate and scrape the mix from inner walls as it whips air into the mixture. The amount of air whipped into the ice cream mix is under government regulation because ice cream cannot contain less than 1.6 lb. of total solids per gallon and the total weight must be at least 4.5 lb. Air incorporated into the mix (Percentage overrun) can be calculated by the following formula:

$$Overran = 100 \times \left(\frac{Volume\ of\ ice\, cream - Volume\ of\ mix}{Volume\ of\ ice\, cream} \right)$$

6.1.4 Low-Fat Ice Cream

The nutritional profile for ice cream shows a high level of nutrients of concern: saturated fat, cholesterol and sugar (Appendix 1). However, the principles of food literacy (Chap. 6) imply that ice cream can be eaten *in moderation* as part of a balanced diet (Berkheiser 2019). Many recipes for ice cream are available that have reduced levels of fat. In addition to regular ice cream, the consumer can choose from low-fat ice cream or no-added sugar varieties. Compared to regular ice cream, low fat ice cream and no-added sugar varieties may have 2–3 fold lower Calories, total fat, cholesterol / or sugar. (Berkheiser 2019). Premium ice cream varieties have the highest total Calories, which implies that these expensive brands should be eaten with still greater moderation. The nutrient profile for some typical ice cream varieties can be found in Appendix 1.

Dairy soft-serves and ice milks use low amounts of butterfat and fat-free ingredients, skim milk, water, and thickeners such as modified food starches and other gums, e.g. locust bean, and carrageenan. These retain large amounts of water and entrap air when whipped into the product during the freezing process, thus giving the product a fatlike mouth feel with reduced calories and cholesterol. Ice cream substitutes are discussed further in Sect. 6.8.

6.1.5 Quality of Ice Cream

The quality of ice cream is discussed extensively in several dedicated texts and monographs on the subject (Arbuckle 2013; Clarke 2012; Goff & Hartel 2013; Marshall 2003; Stogo 1998). In the dairy quality control laboratory, many of the tests done on other dairy products are also done on ice cream. Tests for ice cream quality include the analysis of butterfat, protein, total solids, antibiotics, and a variety of microbial tests including standard plate counts and coliforms.

6.2 Yogurt

6.2.1 Cultured Milk Products

Yogurt belongs in a group of products made from cultured milk (e.g. cheese, buttermilk, sour cream, and yogurt). Cultured milk products are products formed from the controlled fermentations of milk. The reactions for milk fermentations transform lactose into lactic acid through the actions of lactobacilli.

Because of lactose fermentation, the acidity of milk drops to pH 4.6 where casein has no net electrical charge and therefore coagulates to form a curd. The sharp "prickly" taste of cheeses and yogurt is from lactic acid produced by bacterial fermentation. Codex defines fermented milks products as "*...products obtained by fermentation of milk, by the action of suitable microorganisms and resulting in reduction of pH with or without coagulation*,,..[where] *the starter microorganisms shall be viable, active and abundant in the product to the date of minimum durability*". (Codex Alimentarius Commission 2003).

Currently, the best-known fermented milk products in North America include products such as acidophilus milk, cultured buttermilk, sour cream, kefir, koumiss, filmjoik, viili and crème fraiche (MilkIngredients.Ca 2011a). An international listing of some fermented milk products is shown in Table (18.16) but this is a small fraction of the variety of products documented in the "Encyclopedia of fermented fresh milk products" (Kurmann et al. 1992).

The science behind fermented milk products (in particular yogurt) is well documented and the reader should refer to the following texts for more in-depth information (Tamime and Robinson 1999a, b; Chandan et al. 2008; Tamime 2008).

6.2.2 Economic Significance of Yogurt

Yogurt is growing in popularity in the United States but the largest producers and consumers are found in Europe. For 2015, the world production total for yogurt was just over 40 million metric tons representing a 34% increase compared to 2010 (Fig. 18.10). For the period 2010–2015, the value for yogurt trade increased from US$31 billion to US$71 billion per year. The yogurt producing regions include Asia, Middle East + Africa, Western Europe and Eastern Europe. The countries having the highest yogurt manufacturing volumes were, China >Iran >Turkey, Russia >, USA > Germany. Some commercial producers of yogurt are listed in Table 18.17 (Preben Mikkelsen (PM) Food and Dairy Consulting 2013).

6.2.3 Standards for Yogurt

The US Code of Federal Regulations (CFR21 CFR.131.200) describes yogurt as, "*the food produced by culturing one or more of optional dairy ingredients .... with a characterizing bacterial culture that contains the lactic acid-producing bacteria culture that contains Lactobacillus bulgaricus and Streptococcus thermophilus*". The ingredients for yogurt are listed as "*Cream, milk, partially skimmed milk, or skim milk, used alone or in combination*". The overall standards for yogurt composition are flexible and allow for a wide range of optional ingredients and additives (Table 18.18).

Sometimes there are requirements for specific numbers of viable microorganisms within yogurt. For instance, Canadian yogurt should contain ten million viable microorganisms per gram (Milk Ingredients.Ca, 2016). The requirement for live organisms is not applicable where yogurt has been purposely heat treated after fermentation in order to prolong the storage life.

Yogurt is used in developed countries as a dessert, between-meal snack, complete lunch, and diet food. People eat yogurt as part of a balanced

Table 18.16 Selected fermented milk products from around the world

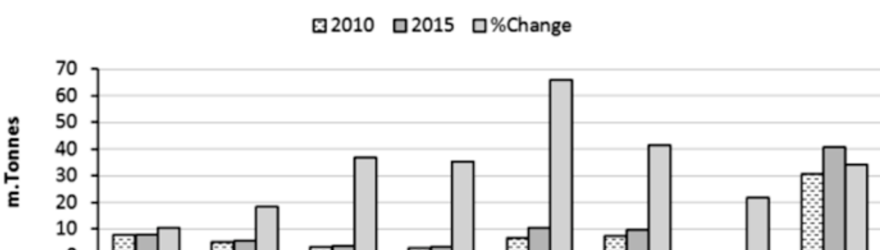
Product	Origins
Airag	Mongolia
Amasi	Southern Africa
Cheese	Worldwide
Chhu	India, Nepal, China
Chhurpi	India, Nepal, China
Dahi	India, Nepal, China
Dadih, Dadiha	Indonesia, Sumatra
Kefir	Russia
Koumiss (Kumys)	Russia, Mongolia
Laban rayeb	Egypt
Leben	Africa
Misti	India
Nunu (nono)	West Africa
Philu	India
Shrikhand	India
Somar	India
Viili	Finland
Yogurt	Worldwide

Adapted from Tamang et al. (2016)

Table 18.17 Global yogurt production companies (1000 metric tons)

Company	Production
Danone	6000
GM/Yoplait	1200
Nestle	900
Yakult	850
Lactalis/Parmalat	840
Friesland Campina	700
WBD-Pepsico	680
Muller	580
Wahaha	550
Fronterra	460

From (Preben Mikkelsen (PM) Food and Dairy Consulting 2013)



	W. Europe	E. Europe	N. America	S. America	Asia	Mid.East/ Afr	Oceanie	World
2010	7.17	4.53	2.74	2.5	6.22	6.91	0.23	30.3
2015	7.92	5.36	3.75	3.38	10.31	9.77	0.28	40.7
%Change	10.5	18.3	36.9	35.2	65.8	41.4	21.7	34.3

Fig. 18.10 World yogurt production by region (million metric tons). (Drawn using data from Preben Mikkelsen (PM) Food and Dairy Consulting 2013)

Table 18.18 Composition of yogurt (21 CFR131.200)

Composition	Quantity	Comments
Optional ingredients	Single or combinations	Cream, milk, partially skimmed milk, or skim milk
Milk fat	>3.2%	Roese-Gottlieb Method
Not fat, solids (NFS)	>8.25%	Proteins (caseins and whey proteins) and lactose
Titrable acidity	>0.9%	Lactic acid
Nutritive carbohydrate sweeteners	Unspecified	Sugar, brown sugar; molasses (not blackstrap); high fructose corn syrup; fructose; fructose syrup; maltose; maltose syrup, dried maltose syrup; malt extract, malt syrup, dried malt honey; maple sugar; or other sweeteners except table syrup
Flavoring ingredients	Unspecified	Nature unspecified
Stabilizers & emulsifiers	0.2–0.5%	Mainly polysaccharide thickening agents
Vitamins (optional)	Vit. A & D	4000 Units Vitamin A, 2000 Units Vitamin D per quart

Reference: Milk Facts (2016b)

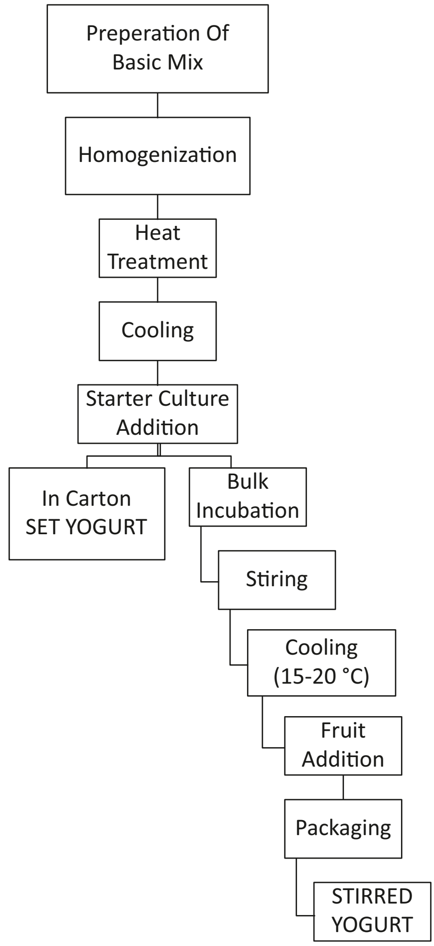


Fig. 18.11 Process flow chart for yogurt manufacturing. (Adapted from Robinson and Tamine 1993)

diet because they like it and feel that it favorably affects their health. Flavored yogurts made from low-fat or skim milk are very popular and unflavored yogurts are eaten plain or are used as substitutes for some of the more fatty dairy products such as sour cream or some cheeses.

Yogurt may have a consistency of a smooth viscous liquid, a soft curd, or a solid frozen dessert. The soft curd, one of the most popular products, is easily spooned out of its container without free whey. Acceptable colors and stabilizers may be added to improve appearance and texture but unlike in cultured buttermilk, no salt is added. Sugar may also be added to neutralize the sour taste of acid and many yogurts have fruit added. The amount of fat in yogurt varies depending on the milk used in the process. Most yogurts in the United States are made with skim or low-fat milk and have a fat content of up to about 1.7%. Some yogurt is still made with whole milk and will contain about 3.25% fat.

6.2.4 Yogurt Manufacturing

Modern cultured yogurt manufacturing is associated with high degrees of mechanization, but its center point is a unique bacterial fermentation. The basic steps for yogurt manufacture involve; preparation of milk mix, homogenization, heat treatment, addition of starter culture or fermentation microorganisms and then packaging (Fig. 18.11).

Preparation of Basic Mix

The only dairy product needed for yogurt production is milk but skim milk, condensed milk, nonfat dry milk solids, modified starches, alginates, and gums may be added to produce low-fat or nonfat products (Aziznia et al. 2009; Peker and Arslan 2013). These mixes must be blended, homogenized, and pasteurized. The initial stage for yogurt manufacture involves a range of separate unit operations.

Milk for yogurt manufacture undergoes standardization for protein and fat content. With inline milk standardization there is continuous sampling, and testing for protein, fat, and lactose to enable efficient process control. Upon completion, of this stage the milk has undergone a process of standardization in relation to fats, protein and carbohydrate content. The mixture is then homogenized to achieve efficient mixing and to reduce milk fat globule size.

Heat Treatment

The aims of heat treatment are several fold; (i) destruction of microorganisms present in their vegetative state, (ii) denaturation of whey proteins to promote their interactions with casein and (iii) changes and redistribution of minerals in milk. The pasteurization temperatures are higher than those employed for the destruction of thermophiles. Vat pasteurization can be achieved at 190.4 °F (88 °C) for 30 min or HTST at 203 °F (95 °C) for 5–10 min. The mixture is then cooled to an optimum incubation temperature of 113 °F (45 °C) needed for the growth of thermophilic microorganisms (Rasic and Kurmann 1978; Robinson and Tamine 1993).

Starter Culture, Yoghurt Fermentation

Yogurts are produced using mixed cultures of two microorganisms, *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* (Matalon and Sandine 1986; Tamine and Robinson 1976, 2007a). The microorganisms may be present naturally in milk but quality starter cultures produced from commercial stocks are added to milk previously heat-treated to inactivate any indigenous microbes.

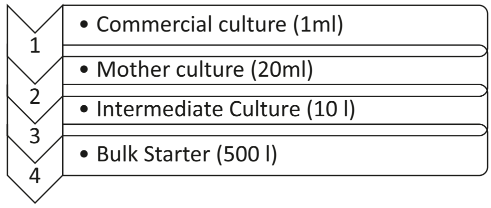


Fig. 18.12 Maintenance and propagation of yogurt starter culture

The job of maintaining and propagating starter cultures, in sufficient quantities for large scale manufacture is the responsibility of the food microbiologists (Matalon and Sandine 1986; Tamine and Robinson 1976, 2007a). Starting with a 1 ml batch of commercial culture, these will be grown up to 500 ml in order to produce sufficient quantity to transform a 25,000 liter vat of yoghurt, at an addition rate of 2% (see below). For long term storage and or transportation, starter cultures are lyophilized to powdered form and transported dry (Chap. 15, Sect. 4.3) (Fig. 18.12).

The two bacteria are kept as a mixed culture usually. The starter culture is added as a suspension comprising 2–5% of the total mix. In the case of non-stirred yogurt (Fig. 18.11) the inoculated milk is filled into containers that may contain fruit and is incubated until a pH of 4.4 (0.9–1.2% titrable acid as lactic) is attained (Table 18.19).

As noted earlier, the aim of yogurt fermentation is to lower the pH sufficiently to promote casein coagulation but a great many other changes occur which affect product quality (Matalon and Sandine 1986). The rate of acidification is important and a slow rate of acidification produces better texture. Alongside of the pH decrease, starter cultures produce changes in lipids, protein and carbohydrates thereby changing flavor, texture and other attributes.

The main flavor compounds in yoghurt are believed to be acetaldehyde, diacetyl, acetic acids (Fig. 18.12) produced from glucose metabolism (Hefa 2010; Routray and Mishra 2011).

Microorganisms forming a starter culture work cooperatively (Crow and Curry 2002). The faster growing *S. thermophilus* produces lactic acid which lowers the medium pH and encourages *L.*

Table 18.19 Some bacteria used as starter culture for milk fermentation

Species	Temp ° C	Lactic acid %	Prot[a]	Used in
Streptococcus thermophilus	40–45	0.7–0.8	Yes	Acidified milk,
Lactococcus lactis[a]	25–30	0.5–0.7	Yes	Acidified milk
Lactococcus cremoris	25–30	0.5–0.7	Yes	Acidified milk
Lactococcus diacetylactis	25–30	0.3–0.6	Yes	Acidified milk,
Leuc cremoris	25–30	0.2–0.4	Yes	Acidified milk
Lactobacillus acidophilus	37	0.6–0.9	–	Acidified milk
Lactobacillus helveticus	40–45	2.0–2.7	Yes	Acidified milk
Lactobacillus bulgaricus	40–45	1.5–2.0	Yes	Acidified milk
Bifidobacterium	37	0.4–0.9	–	Acidified milk

[a]Protease producing strains, During the 1980's the taxonomy of lactic acid bacterial underwent revision and streptococcus strains important for food fermentations were reclassified as Lactococcus (Stiles and Holzapfel 1997)

bulgaricus growth. *L. bulgaricus* is more proteolytic and helps liberates amino acids and peptides that stimulate the growth of *S. thermophilus.* As the acidity decreases to about pH 5.0 due to the action of *S. thermophilus*, the production of acetaldehyde by *L. bulgaricus* is inhibited and eventually the medium pH falls to pH 4.0–pH 4.4. Milk used for yogurt must be penicillin-free, for *S. thermophilus* is sensitive to it.

Typically, yogurt is cooled and held at about 39.2 °F (4 °C). Sundae style just described above requires mixing by the consumer. Yogurt may also be made in a "Swiss" style where fruit puree, sugar, and stabilizer are blended with fresh fermented yogurt at 60.8 °F (16 °C), packaged and cooled.

Some varieties of yogurt available are listed in Table 18.20. The basic yogurt can be modified. For example, fruit preserves can be added at about a 15% level but have been added up to 27%. Stabilizers are not usually required for plain whole-milk yogurt but flavored, low fat, or nonfat varieties may require the addition of gelatin, agar, modified food starches, or gums at levels of about 0.4–0.5%. The stabilizers can be added prior to pasteurization but care must be taken that excess amounts are not used or a sticky, gummy, hard mouth feel and free whey may result.

Table 18.20 Listing of some different types of yogurts*

Basic types	Lifestyle/demographic products
Greek style yogurt	Yogurt for toddlers
Kefir	Yogurt for kids
Frozen yogurt	Yogurt for men
Drinkable yogurt	100 calorie yogurt
Savory yogurt	Yogurt for men
Breakfast cereal yogurt	Functional yogurt
Set yogurt	High protein yogurt
Fruit yogurt	Probiotic yogurt
Low fat, not fat, regular	Tube yogurt
Swiss type	Organic yogurt
Yogurt cheese	Lactose free yogurt
	Enriched yogurt

*From various internet sources

Frozen flavored yogurts are made from a mix that is prepared and pasteurized much like ice cream mixes. Frozen yogurt is then frozen in much the same manner as ice cream with various levels of overrun. Liquid yogurts are made from whole and skim milk, and low-lactose yogurts that have been produced with milk treated with a lactase enzyme prior to fermentation, are examples of other yogurt-based products.

6.2.5 Yogurt Quality

Virtually all stages of yogurt manufacture may affect product quality, including the nature of ingredients-milk, cream and proteins added manufacturing / processing factors, packaging and storage. As noted earlier food quality encompasses a great number of dimensions (Chap. 6) but this discussion will be limited to nutritional and sensory quality.

Quality problems that arise with yogurt include separation of whey or syneresis, which can be overcome by higher temperature treatment prior to inoculation, in order to facilitate whey protein-casein interactions, (Kroger 1976). The texture of yoghurt is also improved by increasing the degree of homogenization.

Obviously, the inoculation and fermentation stage can also affect product quality. For instance, too much acid production, caused by too rapid a growth of *L. bulgaricus*, is undesirable. Normal yogurt has 0.9–1.5% acid but rapid growth of starter culture can lead to 2–3% acidity. Careful maintenance of fermentation temperatures and the use of pure cultures help to solve this problem. Premature curdling of milk may occur with yogurt that has had fruit added, especially Swiss style yogurt. When the fruit rests on the bottom, this rarely occurs. Another problem occurs owing to the presence of thermophilic bacteria or yeast in the milk. Off-flavors, such as bitterness caused by the bacteria, and alcohol and gas produced by the yeast will result from low quality or improperly handled milk. Use of high-quality milk and proper quality control will solve these problems (Byland et al. 2003).

6.2.6 Nutritional Quality of Yogurt

Nutritionally, yogurt is an excellent food, giving all of the protein benefits from milk but especially in the case of low-and nonfat yogurts, with less fat and cholesterol. Yogurt is frequently discussed also in terms of probiotic qualities derived from the presence of live microorganisms. Flavored low-fat yogurts may have more calories than expected because of added fruits and sugar (Table 18.21).

Lactobacillus acidophilus and *Bifidobacterium* strains may be added to yogurt because of the believe that they survive transit through the GI tract and function as probiotic organism (Guarner et al. 2005; Morelli 2014; Sarkar 2008). For instance, health claims indicating yogurt could help deal with lactose digestion were approved in Europe (EFSA Panel on Dietetic Products 2010). However, claims that yogurt could reduce the risks of acute diarrhea for patients taking antibiotics were not approved (Table 18.22).

There are also speculations currently about other health-benefits of yogurt e.g. related to cardiovascular disease, type 2 diabetes, weight-loss, cardiovascular disease, gastroenteritis, and hypertension (Astrup 2014; Chen et al. 2014; Marette and Picard-Deland 2014). Yet many yogurt health claims have yet to be evaluated and (dis)approved by food legislators before these can be used for labeling purposes. Meanwhile unsubstantiated claims risks court action.[2] Therefore, more research into the health effects of yogurt and other dairy products is needed (World Health Organization 2009).

Table 18.21 Nutritional information for one cup (227 gm) of various yogurts

	Calories	Fat (g)	Sat. Fat (g)	Calories from fat
Nonfat plain yogurt	126	<1	0.3	3
Low-fat plain yogurt	143	4	2.3	36
Whole milk plain yogurt	139	7	4.8	63
Nonfat flavored yogurt (fruit added)	204	<1	0.3	3
Low-fat flavored yogurt (fruit added)	232	2	1.6	18
Nonfat flavored yogurt sweetened with Aspartame (fruit added)	100	<1	<1	0

Note: These values vary with different brands. Read the labels for accurate amounts

6.3 Cheese

Cheese as a fermented milk product. The basic idea behind cheese manufacturing is to concentrate milk solids (lipid, protein, and minerals) by coagulation to form a semi-solid material (Fox and McSweeney 2004). Cheese has 50% less moisture and roughly six to 7-fold increased level of protein and lipids compared to fluid milk (Table 18.23). The recovery of milk solids is quite efficient during cheese production. Using 100 g of milk will produce 10.4 g of cheese (~5.4 g dry matter).

[2]An example court action associated with the advertising claims for a popular brand of probiotic yogurt is described in Wikipedia https://en.wikipedia.org/wiki/Activia#Class_action_in_2008.E2.80.932009 (Accessed Aug, 2016)

Table 18.22 Nutrition and health claims related to some yogurt components

Reference	Authorized
2010;8(10):1763	"Live yoghurt cultures in yoghurt improve digestion of lactose in yoghurt in individuals with lactose mal-digestion (EFSA Panel on Dietetic Products 2010)
	Non-Authorized
ACTIMEL® Lactobacillus casei DN-114 001 plus yoghurt	Fermented milk with probiotic Lactobacillus casei DN-114 001 and yoghurt decreases Clostridium difficile toxins in the gut (of susceptible ageing people). Presence of Clostridium difficile toxins is associated with the incidence of acute diarrhea
2011;9(4):2029 Lactobacillus rhamnosus LB21 NCIMB 40564	Helps to strengthen and maintain balance in the gut flora
2009;7(9):1247 Yoghurt with probiotic bacteria Bifidobacterium animalis ssp. lactis & Lactobacillus acidophilus	Contains millions of bacteria, maintain the balance of natural flora in your body, can aid digestion and general well-being. Helps to maintain harmony in your digestive system
Dairy products (milk, cheese and yoghurt)	Three portions of dairy food every day, as part of a balanced diet, may help promote a healthy body weight during childhood and adolescence

Reference: Adapted from (Europa 2016) with wording edited lightly to retain original form

Table 18.23 Comparing cheese and milk composition (%Fresh weight basis)

	Water	Protein	Fat	Lactose	Ash
Cow milk	87.5	3.5	3.9	4.8	5.4
Cheese	41.0	25	31	2.0	4.5
% Change	−53	614	695	−58	−17

6.3.1 Nutritional characteristics of cheese

Cheese is considered a good source of, calcium, protein, and vitamin D (Walther et al. 2008). For instance, one study found that cheese was the #2,

Table 18.24 Effect of cheese on the nutrient intake of US children (1–18 years)*

Nutrient	% Intake	Rank	#Food Groups
Total Fat	9.3	1	18
Saturated Fat	16.3	1	18
Calcium	19.4	2	11
Sodium	8.1	3	15
Protein	9.7	4	15
Cholesterol	9.6	5	11
Energy	4.7	7	21
Vit. D	2.3	8	8
Potassium	2.0	14	15

*Summarized from, Keast et al. (2013)

#4 and #8 source of calcium, dietary protein and vitamin D for US children between the ages of 2–18 years old as shown in Table 18.24 (Keast et al. 2013). Milk was the #1 source of calcium, protein and Vitamin D. The contribution of cheese to dietary protein intake was just below poultry and meat ranked #2 and #3, respectively. Eggs and fish ranked far below cheese as a source of dietary protein at #14 and #15, respectively (Keast et al. 2013). Cheese contributed negligible dietary carbohydrates, total sugar or added sugar. The dietary fiber contribution from cheese was negligible also (Keast et al. 2013). Nutritional surveys of the type described above (Keast et al. 2013) are important because they reflect (i) food composition and (ii) habitual intake. For instance, it may be inferred that cheese is eaten in appreciable amounts by children in the US and that this product provides them with high amounts of specific nutrients some of which are desirable (Keast et al. 2013).

Cheese has been found to influence the diet of adults from the Republic of Ireland, leading to significant changes in 10 or more nutrients, e.g. total energy, protein, fat, calcium, vitamins, sodium, total fat, saturated fat, monounsaturated fat etc. People consuming high levels of cheese tended to be males and younger compared to non-consumers (average age 39.5 vs 51 years). The body mass index or BMI for consumers and non-consumers were not different (Feeney et al. 2016). More generally, cheese is considered a potential source of functional food components

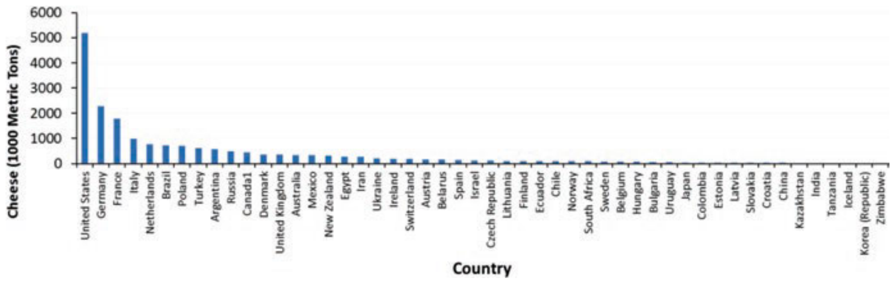


Fig. 18.13 Cheese production in selected countries ('000 metric tons). (Data from for 2016 (Canadian Dairy Information Centre 2016c))

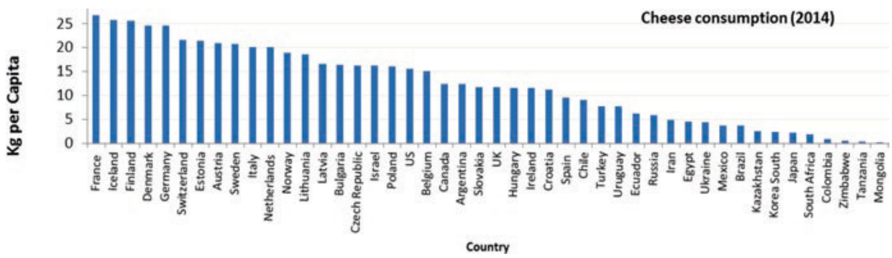


Fig. 18.14 Per capita cheese consumption (Kg/person). (Data from 2016 (Canadian Dairy Information Centre 2016a))

including, medium chain fatty acids and bioactive peptides (Haelein 2004; Walther et al. 2008; Feeney et al. 2021).

A number of so-called nutrients of concern are associated with cheese (Table 18.24). The US children's survey (Keast et al. 2013) showed cheese was ranked #1 as source of total fat and #1 for saturated fat. Dietary sodium from cheese (rank #3) fell behind of table salt (rank #1) and yeast bread/rolls (rank #2). Cholesterol intake from cheese, ranked 5th out of 11 food groups examined. Although saturated fat is a risk factor for coronary heart disease, dairy fat sources were not associated with heart disease risk. One possible explanation maybe that dairy fat may contain saturated fat alongside of counterbalancing (health promoting) dairy components (Huth and Park 2012; O'Sullivan et al. 2013).

6.3.2 Economic Significance of Cheese

Cheese is consumed the world over but the vast majority of the global production of cheese takes place in the US (22%) and the European Union (66%). The value of the global cheese market is estimated at US$79billion per annum (2012) projected to reach US$105 billion by the year 2019 with an annual growth rate of 4.5% (Transparency Market Research 2014). The cheese industry is described as mature, sophisticated and demanding (Law and Tamime 2011). The US is ranked #1 for individual countries, with an annual cheese production of 5.7 million metric tons or about 11.4 billion lbs. (Canadian Dairy Information Centre 2016c) (Fig. 18.13).[3]

Over the period 2008–2012, the 27% of global cheese production, which was exported, was valued at US$27billion (Vlahović et al. 2014). About 80% of the international trade in cheese involved European nations with EU(27) accounting for 76% of world exports (Table 18.25). Most of the US cheese production was consumed domestically. France, Iceland, Finland and Denmark are the biggest consumers for cheese per capita (Fig. 18.14).

[3]The US cheese production matches the net output from the next four top-ranked nations (France, Germany, Italy and Netherlands) combined.

Table 18.25 Top global exporters & importers for cheese (2008–2012)

Export country	% World	Import	% World
Germany	18.6	Germany	12.1
France	11.8	Italy	9.1
The Netherlands	11.6	Gt. Britain	8.2
New Zealand	5.2	Russia	5.7
Italy	5.0	The Netherlands	4.2

Reference: Adapted from Vlahović et al. (2014)

Table 18.26 Some well known cheeses globally

Type	Origins
Brie, Camembert	France
Edam, Gouda, *Limburger*	Netherlands
Cheddar, Cheshire	England
Emmentaler, Gruyere	Switzerland
Parmesan	Italy
Brick, Coldy	US

6.3.3 Standards for Cheese

There are between 400–1200 different types of cheeses globally (Beattie 2008; Helweg 2010). About 1750 cheeses were categorized according to the type of milk (by species), the texture, color, country and whether they are vegetarian (Cheese.com 2016). More generally, cheeses are classified based on, (i) the use of raw or pasteurized milk, (ii) level of moisture, fat content and overall texture – e.g. soft, semi-hard or hard cheese, (iii) type of coagulation – acid, rennet or acid and heat, (iv) extent of ripening – fresh versus ripened, (v) international standards or style of manufacture (American Cheese Society 2015) (Table 18.26).

The identity of some European cheeses are protected by their geographic origins in accordance with the protected designation of origin (PDO), protected geographical indication (PGI), or traditional specialties guaranteed (TSG) schemes. Within the European market, only cheeses produced in specific regions can be named using those designations (Vlahović et al. 2014).

The most popular types of cheese in the US are the Italian-style cheeses (42% production) such as mozzarella cheese used as pizza toping. The American type cheeses (Cheddar, Colby, Monterey, and Jack) are also popular and together make up 40% of the total production (Table 18.27). It is feasible also, that some-minor volume cheeses could have passionate followers and be suited for highly specific culinary applications. The largest quantities of cheeses are produced in the states of Wisconsin, California, Idaho, New Mexico and New York (Table 18.27).

Table 18.27 Different types of cheeses common in the United States

Cheeses	2016 Annual (000 metric tons)	%
American types	2314	40
Cheddar[a]	1707	29
Other Am. types[b]	608	10
Blue and Gorgonzola	47	1
Brick and Muenster	84	1
Cream and Neufchatel	406	7
Feta	58	1
Gouda	15	0
Hispanic	124	2
Italian types	2506	43
Mozzarella	1967	34
Parmesan	176	3
Provolone	188	3
Ricotta	106	2
Romano	32	1
Other Italian types	37	1
Swiss	152	3
All other types	83	1
Total cheese	5790	100

[a]American type cheese = Cheddar, Colby, Monterey, and Jack

Extracted from (USDA Economics Statistics and Market Information System 2016). [a]Annual forecast

6.3.4 Cheese Manufacturing

The critical steps in cheese making involve, coagulation of milk protein using bacterial fermentation and rennet, draining of the curd, pressing, combination of cheeses (process cheese), aging with further fermentation by bacteria or molds, packaging and storage (American Cheese Society 2015; Hill 2016a). Some cheeses may be manufactured using raw milk, or milk that has been heat-treated at temperatures below those for pasteurization (Fig. 18.15).

Starter cultures are used for most cheeses in a manner similar to yogurt (Sect. 6.2). The cultures may be one strain or a mixed culture of bacteria

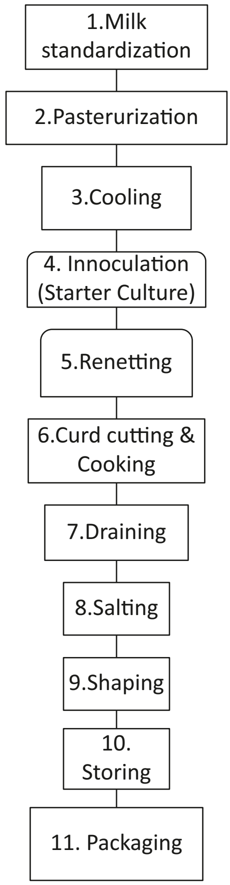


Fig. 18.15 A process chart for cheese manufacturing. (Adapted from Milk Facts 2016a)

that work in a symbiotic manner. Cheese starter cultures may be lyophilized (freeze-dried) with milk components, or frozen with liquid nitrogen at −320.8 °F (−196 °C) and held in this state. Both methods yield viable cultures but the dry method requires no special containers or storage facilities other than a freezer or refrigerator. Most cultures are lactobacillus (L) or streptococcus (S) strains (Table 18.28).

Some cheesemakers have successfully held lactic starters for several years but most usually start a new one from a dry, lyophilized culture every 3 or 4 weeks. A continual sub-culturing of microbial starters is necessary to ensure consistency of quality. This rotation must be adhered to or problems could develop.

Setting the milk means preparing warm milk with a starter culture or rennet extract to form a smooth curd block. The curd may be either an acid casein curd set with a starter or a sweeter, calcium para-casein curd set with rennet and starter. The acid curd takes from 5 to 16 h whereas the sweeter curd can be completed in 15–30 min. With acid curds casein micelles coagulate when the acidity of milk reaches about pH 4.6 which the pH where they have not net charge. With renneting curd, kappa-casein undergoes enzymatic hydrolysis, leading to a loss of negative charge so that the remaining casein particles coagulate.

Table 18.28 Some bacterial starter cultures used for cheese and other cultured products (§)

Culture	Temp. °C	Functions	Product use
Propionibacterium freudenreichii subsp. shermanii	15–40	Flavor, CO_2 eye formation	Swiss cheese, Emmental cheese
Lactobacillus delbrueckii subsp. bulgaricus	40–45	Acid and flavor	Buttermilk
Lactobacillus delbrueckii subsp. lactis	40–45	Acid, proteolytic	Parmesan, Emmental
Lactobacillus helveticus	40–50	Acid, flavor, Probiotic	Swiss cheese, Emmental, Cheddar, Parmesan
Streptococcus thermophilus	40–45	Acid	Emmental, Cheddar, Italian cheese,
Streptococcus diacetilactis, now Lactococcus lactis	20–35	Acid and flavor	Sour cream, ripened cheese, butter, buttermilk, starter cultures, cheese All types of cheese

(§) (From, Matalon & Sandine 1986; Tamine & Robinson, 1976; Tamime & Robinson, 2007a; Tamine 2008).

Cutting the curd must be done carefully and will increase the curd surface area many times. This leads to effective whey expulsion and permits the equal-sized smaller curds to be cooked throughout. Larger cubes give a higher-moisture cheese. Cooking causes the curds to contract and also drives off the free whey. Cooking also influences curd texture, gains time for lactic acid development, and arrests it. It also suppresses the growth of spoilage organisms and influences the final moisture content.

Draining simply separates the whey from the curd by passing it through a straining device. In industry, this is accomplished by lining the exit gate of the vat with a sieve or having a sieve lay the entire length of the vat. Dipping is usually done in smaller operations by scooping curds into perforated molds or colanders or by inserting a coarse cloth into the kettle and bagging all the curds. Regardless of the method, his step accomplishes separation of whey and concentration and coalescing of curds, and pro vides additional time for lactic acid development.

A process of knitting and transformation of curds includes the process of “cheddaring” in cheddar cheese where slabs of the curd are piled one on top of another and acid is allowed to develop to about 0.5% and more moisture is expelled. Other knitting processes include preliminary packing and pressing of brick and blue cheese curd, and the pulling and processing of acid-ripened provolone and mozzarella cheeses. These processes result in the characteristic texture of the various cheeses.

Salting can be done by spreading salt over the curds or by dipping the pressed cheese into brine solutions. Salting improves flavor, texture, and appearance while slowing or stopping the lactic acid fermentation when it has reached its optimum level. Salting also depresses the growth of spoilage organisms and reduces moisture, thus controlling it in the final product.

Pressing removes moisture and gives the cheese its shape. Care must be taken not to press with too much force in some cheeses such as Roquefort or blue cheese. If they are pressed too compactly, no air will be able to seep into the cheese and carbon dioxide will not be able to escape easily. Both of these are necessary for the successful growth of the molds needed to develop the characteristic flavors, aromas, and textures in the finished cheese.

The special applications cover a wide range of processes, from creaming cottage cheese to the addition of special microorganisms to ripen cheeses such as brick or Lim burger.

Process cheeses are very popular in the United States and are manufactured by combining different types of cheeses as ingredients. Generally, not fully aged (green) cheese is ground together with some aged cheese and water, emulsifiers (i.e., disodium phosphate), salt, and powdered skim milk are added. The ingredients are heated, mixed, and extruded into molds.

Cheese making is an art as well as an application of advanced sciences. The success in this industry depends on a logical sequence of fixed steps where the emphasis is varied and the incorporation of special applications gives cheeses their various similarities and differences (Davies and Law 1984; Fox et al. 2004; Fox and McSweeney 2004; Hill 2016a).

6.3.5 Cheese Quality

Many bacteria including *S. lactis, L. bulgaricus, and S. diacetilactis* can perform the milk fermentation reaction. In some cheeses such as Swiss and Gruyere, the propionic acid fermentation leads to the typical flavor and eyes. A distinct flavor may arise when a fine balance between diacetyl, propionic acid, acetic acid, and other related compounds exists. In some fermentations, large amounts of $C0_2$ and hydrogen gas are produced and the cheese body is distorted. Cheeses affected include Swiss and Gruyere and large blowholes occur several months after the cheese is placed in curing rooms.

Another fermentation that causes spoilage and deterioration of the food is caused by the coliform group of bacteria. *Escherichia coli* and *Aerobacter aerogenes* are included in this coliform group and they are usually present in milk

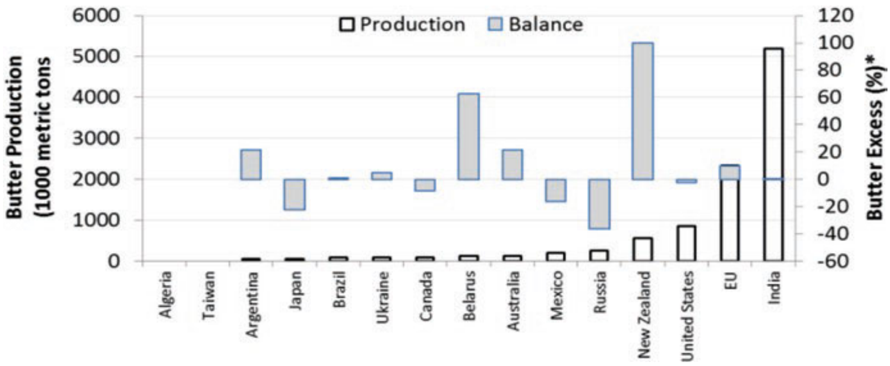


Fig. 18.16 Butter production in selected countries and excess (%) compared to consumption (2016)

of poor quality. Their fermentation produces large amounts of carbon dioxide, resulting in slits in the cheese curd and obnoxious and unclean flavors in the cheese. Rapid production of lactic acid by starter culture bacteria will prevent their growth.

6.4 Whey

The fluid byproduct of cheese making is whey that comprises 5% lactose, 2% other milk components, and 93% water. Some whey is used for the production of ricotta cheese. Currently, cheese whey is mined as a source of ingredients, mainly lactose and whey protein. Whey protein is used as protein supplements in drinks, baked goods, ice cream, sherbet, candy, fudge, and other confections (Diaz et al. 2009).

6.5 Butter

Butter is made from cream having a butterfat content of 25–40%, into which the bacterium *Streptococcus diacetyllactis* has been added. Bacterial fermentation produces diacetyl, the major flavor component in butter. Butter contains 20% water in the form water-in-oil emulsion. Some bacteria may grow in this water and produce lipase, which will de-esterify some fatty acids and cause rancidity, giving off-flavors and odors. Salt of about 1–2.5% by weight is added to butter to add flavor and inhibits the growth of the rancidity-causing bacteria. Sweet butter, which contains no salt, is more perishable than salted butter (Fig. 18.16).

The global production of butter (2016) amounts to approximately ten million metric tons. The leading butter producers are, India > EU > USA > New Zealand > Russia. As most butter is destined for domestic consumption, the nominal “buffer excess” or difference between production and consumption is 0% for most countries. There can be shortfalls in butter supply for some countries which is met through imports, notably Russia > Japan > Mexico > Canada. Countries that produce butter in excess of domestic consumption include, New Zealand > Belarus > Argentina > Australia (USDA Foreign Agricultural Services 2016a).

6.6 Buttermilk

Buttermilk is the liquid produced when 40% cream is churned leading to the separation of milk lipids as butter. Buttermilk contains whey protein, casein, milk-fat globule membrane (MFGM) fraction and phospholipids (Sodini et al. 2006; MilkIngredients.Ca, 2011b). Two other buttermilk variants are available from churning, i.e. whey milkfat (milk fat recovered from whey) or cultured cream used for European-style butter (Sodini et al. 2006). The higher fat content for buttermilk compared to whole milk increases the tendency towards oxidative rancidity and the need for preservation by spray drying to form buttermilk powder. The average composition of buttermilk powder was reported as, moisture (3%), protein (34%), fat (6–20%) and ash (8%) (MilkIngredients.Ca, 2011b); the phospholipid content was 1.2–1.8 (g/100g) dry weight basis for buttermilk powder (Sodini et al. 2006). Buttermilk is a functional ingredient for baked products, ice cream, dry mixes, breading, batter, puddings and beverages (MilkIngredients.Ca, 2011b).

Cultured buttermilk is distinct from sweet buttermilk obtained by churning butter directly. Some commercial production of cultured buttermilk starts with skim milk, which is then subjected to pasteurization, fermentation, cooling, flavoring and packaging (Gettys and Davidson 1985). Cultured buttermilk is also produced from cream. Various starter cultures were reported for buttermilk fermentation including, e.g. *Streptococcus lactis*, *Streptococcus cremoris* – renamed *Lactococcus lactis*, *Lactococcus cremoris* respectively. The flavor of buttermilk is due to a combination of lactic acid, amino acids, diacetyl, acetaldehyde formed by fermentation. Section 6.2.1 and Chap. 7, Sect. 5.3 contain additional information on cultured milk products.

6.7 Sour Cream

Sour cream as the product formed by fermenting pasteurized cream. The production of sour cream is similar to buttermilk. It is prepared from light cream (16–20% butterfat) to which 8–9% nonfat milk solids and sometimes stabilizers (e.g., gelatin, gums, or modified starches) are added. After pasteurizing and homogenizing, the same bacteria used for buttermilk are added for the conversion of sugars to acid. (Lactococcus lactis, Table 18.28). The product is packaged and cooled and should be held at 35–40 °F (1.7–4.4 °C) until consumed. USDA standards require that full-fat sour cream has not less than 18% milk fat, whilst "reduced-fat" and "lite" sour cream have 25% and 50% less milk fat compared to the full-fat product (United States Department of Agriculture 2000). Consumer preference for sour cream was linked with products having high viscosity, dull appearance and cooked/ milky flavor (Shepard et al. 2013).

6.8 Dairy Product Substitutes

Dairy product substitutes have been developed for economic, religious, and health considerations (Table 18.29). Dairy-free options may be chosen by consumers affected with health issues such as lactose intolerance, lactose sensitivity or milk allergy. Vegetarian and vegans may also choose dairy free products, in order to void cow's milk. A Jewish dietary law (kashrut) which requires the separation of meat from milk may also lead to the adoption of non-dairy drinks after meat-based meal (Feder 2016; Schaeffer 2016).

Historically, one of the earliest non-dairy analogues and certainly one of the most controversial was margarine, which led to legislations to protect butter producers in the US as well as France (Brown 2011). These times, dairy product substitutes are received with less hostility. Non-dairy creamers or coffee whiteners are widely known. Tofu-based frozen desserts, and fluid milk-like products and cheese substitutes (milk fat is replaced with vegetable fat and vegetable protein) continue to be developed for direct

Table 18.29 Selected dairy product substitutes or analogues

Analogue	Comments	Examples
Plant Milk	Plant based W/O emulsions, suspensions	Soy Milk, Almond Milk, Rice Milk, Oat Milk, Almond Milk, Corn Milk, Potato Milk, Hazelnut Milk,
Cream	DehydratedW/O emulsions	Coffee Whitener, Non-dairy Creamer, toppings
Cheese	Soy protein systems	Tofu based cheese analogues
Sour cream	Soy based	fermented crème analogue
Ice cream	Plant based	Rice dream
Butter	W/O emulsion	Margarine

Reference: Adapted from Feder (2016) and Schaeffer (2016) consumption, and as primary ingredients for catering applications.

The plant-based beverages (soymilk, almond milk, rice milk) were worth US$8 billion in 2014 and projected to reach US$19.5 billion in 2020 (MarketsandMarkets 2016). Soymilk, almond milk and rice milk were the most important product types with sales of soymilk expected to reach US$13.6 billion in 2020. The largest regional market share for plant-based beverages was Asia-Pacific (45%) followed by North America, and Europe. As noted above a high incidence of lactose intolerance in certain consumers groups (e.g. from Asia-Pacific, African, and the Mediterranean) is one possible reason for switching from milk to non-milk based substitutes (Simons 2016).

6.9 Further Reading

Dairy product manufacturing has been covered by highly regarded textbooks and monographs (Robinson 1993b; Tamime and Robinson 1999, b; Varnam and Sutherland 2012; Walstra et al. 2005). An interesting source book titled, the Tetra Pak "Dairy Process Handbook" is worth viewing in particularly because many dairy machinery and process equipment discussed in this chapter are illustrated there (Byland et al. 2003). The American Cheese Society's "Best practices guide for cheese makers" contains a great deal of advice on milking and handling for the small-scale producer (American Cheese Society 2015).

Appendix 1: The nutritional characteristics of vanilla ice cream varieties (§)

Nutrient composition (per 100 g sample)	(1) Vanilla	(2) Fat free	(3) Rich/premium	(4) Light	(5) Light (no sugar)	(6) Light, soft serve
Water (g)	61.0	64.4	57.2	59.8	65.5	69.6
Energy (kcal)	207.0	138.0	249.0	180.0	169.0	126.0
Protein (g)	3.5	4.5	3.6	4.8	4.0	4.9
Total lipids (g)	11.0	0.0	16.2	4.8	7.5	2.6
Saturated fatty acids (g)	6.8	0.0	10.3	2.9	4.1	1.6
Cholesterol (mg)	44	24	92	27	27	12
Ash (g)	0.9	1.1	0.8	1.1	1.2	1.1
Carbohydrate	23.6	30.1	22.3	29.5	21.4	21.8
Sugars (g)	21.2	6.3	20.6	22.1	6.5	18.7
Fiber (g)	0.7	1.0	0.0	0.3	0.0	0.0
Calcium (mg)	128	149	117	161	136	157
Phosphorous (mg)	105	150	105	103	75	121
Potassium (mg)	199	302	157	208	196	221
Sodium (mg)	80	97	61	74	96	70

(§)Notes: Table design based on Berkheiser (2019). Data is for 6 out of 21 legacy files for vanilla ice cream extracted from FoodData Central (USDA Agricultural Research Service 2021)

Sample database numbers and descriptions: (1) NDB 19095 Ice creams, vanilla; (2) NDB 19867 Ice creams, vanilla, fat free; (3) NDB 19089 Ice creams, vanilla, rich; (4) NDB 19088 Ice creams, vanilla, light; (5) NDB 19260 Ice creams, vanilla, light, no sugar added, and (6) NDB 19096 Ice creams, vanilla, light, soft-serve

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