18.1 Introduction

Microorganisms employed as starters for production of cultured dairy foods are divided into two types, based on the optimum temperature ranges at which they operate (Hutkins, 2006; Stanley, 2003; Vedamuthu, 2013a). The lactic acid bacteria incubated at temperatures above 35°C are referred to as thermophilic bacteria and those incubated at 20–30°C are called mesophilic starters.

Yogurt is derived by culturing with thermophilic cultures, which act in symbiosis with each other. In contrast, sour cream or cultured cream is obtained by fermentation with mesophilic lactococci and leuconostocs. Yogurt and sour cream do not involve whey formation and removal from curd. A notable exception is Greek yogurt, which has gained particular attention in recent years (Kilara & Chandan, 2013).

Cheese production involves removal of liquid whey, leading to partial dehydration and concentration of certain milk constituents. Most cheese varieties are produced with mesophilic cultures, but certain varieties use thermophilic bacteria. In addition, other microorganisms, like molds and yeasts, characterize certain cheese varieties. During cheese making, lowering of pH and addition of salt confer a preservative effect, resulting in extension of shelf life as well as safety for consumption. In cheese, the main milk components (proteins, fat, and minerals) are concentrated and protected from rapid deterioration by spoilage microorganisms. For consumers, cheese provides good nutrition, variety, convenience of use, portability, food safety, and novelty of flavors and textures. Modern packaging techniques confer even more extended shelf life, allowing the movement of cheese over long distances from the place of manufacture. There are some 400 varieties of cheese consumed throughout the world. The major varieties have distinctive flavor and texture ascribed primarily to the use of milk of various domesticated animals, discrete microbial cultures, enzymes, and ripening conditions. Their processing procedures influence final chemical composition resulting in distinct fermentation patterns, which in turn develop specific flavors and textures (Chandan & Kapoor, 2011a, 2011b).

At the turn of the last century, developments in melting processes, involving natural cheese of various ages, gave birth to a line of processed cheese products with controlled flavor and texture, and extended shelf life. In addition, various shapes, sizes, configurations, and sliced versions were created to provide varieties with novel applications. The consumer can use these products as ingredients in cooking of several dishes or as a ready-to-eat snack. These products are designed to be consumed as spreads or as slices in sandwiches, and function as a dip or topping on snacks.

Various fermented dairy foods may be consumed in original form or they may be mixed with fruits, grains, and nuts to yield delicious beverages, snacks, desserts, breakfast foods, or a light lunch. A variety of textures and flavors are generated by selection of lactic acid bacteria. A combination of lactic acid bacteria and their strains allows an interesting array of products to suit different occasions of consumption.

This chapter discusses general technical aspects of the manufacture of fermented dairy products with a focus on yogurt, sour cream, Cheddar, and process cheese. Other cultured milks and cheeses are not considered here in any depth. For more extensive treatment of various aspects of fermented dairy products including cheese, the reader is referred to several literature resources.
18.2 Consumption trends

Trends in the production and consumption of fermented dairy foods (e.g. yogurt, sour cream and dips, and natural cheese) in the US are presented in Table 18.1. Production and consumption of yogurt, sour cream, and cheese have registered significant gains in the time period of 1960–2011. Yogurt production in 2011 was 4272 million pounds with per capita consumption of 13.7 pounds. The growth of yogurt has been especially remarkable during this period. However, compared to Sweden, with per capita consumption of 62.8 pounds, US consumption is modest (Schultz, 2011). Sour cream production of 1264 million pounds with per capita consumption of 4.1 pounds has been fairly flat in recent years. Natural cheese production of 10,597 million pounds and per capita consumption of 33.5 pounds has shown modest growth.

Table 18.2 shows the trends in production and consumption of some cheese varieties in the period 2005–2011. Cheese production and consumption far exceed the production of yogurt and sour cream. The data in the table show that the per capita consumption of natural cheeses has gone up. Process cheese products are derived from natural cheeses and contain water and other food ingredients. Their consumption is relatively steady compared to natural cheeses. The most popular individual cheese variety in 2011 was Mozzarella, followed by Cheddar cheese. The per capita consumption of all Italian varieties grew.

During 2011, the supermarket sales of natural cheeses was 2271 million pounds (valued at $11,076 million). Cheddar cheese totaled 834 million pounds (valued at $3889 million), followed by Processed American cheese (760 million pounds valued at $2583 million) and Mozzarella cheese (475 million pounds valued at $2190 million) (IDFA, 2012).

18.3 Production of starters for fermented dairy foods

Fermented milk foods with desirable characteristics of flavor, texture, and probiotic profiles can be created by formulating the desired chemical composition of the milk substrate mix, judicious selection of lactic acid bacteria (starter), and fermentation conditions (Chandan, 1982; Chandan & Nauth, 2012; Chandan & Shahani, 1993, 1995). A starter is made up of one or more strains of food-grade microorganisms. Individual microorganisms utilized as a single culture (single or multiple strains), or in combination with other microorganisms, exhibit characteristics impacting the technology of manufacture of fermented milks.
Modern industrial processes utilize defined lactic acid bacteria as starters for fermented dairy products. For detailed descriptions of starter cultures, the reader is referred to Stanley (2003), Hutkins (2006), and Vedamuthu (2013a, 2013b). Table 18.3 summarizes some of the microorganisms used in the manufacture of yogurt and cultured cream.

The most common lactic acid bacteria employed for fermented dairy foods are: *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *Lactococcus lactis* subsp. *lactis*, and *Lactococcus lactis* subsp. *cremoris*. They are responsible for the acidic taste arising from lactic acid elaborated by their growth. *Leuconostoc* spp. are used for typical flavor in sour cream. In cheeses, *Lactococcus lactis* subsp. *lactis/cremoris*, *Lactobacillus helveticus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Streptococcus thermophilus* are employed for acid and distinct flavor development, while *Propionibacterium shermanii* secretes propionate, a natural shelf life extender. Furthermore, it is possible to deliver health-promoting microflora to the consumer of the food. In this regard, yogurt cultures, *Lactobacillus delbrueckii* subsp. *bulgaricus*(LB), *Streptococcus thermophilus*(ST), *Lactobacillus acidophilus*, *Lactobacillus casei*, and *Bifidobacterium* species are notable examples.

The cultures used in the manufacture of natural cheeses are shown in Table 18.4. The cultures are used to provide distinct flavor and textural attributes to a particular cheese variety. The metabolic products of culture growth leave a discrete profile on the sensory properties of cheese. In this regard, in addition to bacteria, edible molds extend color and flavor characteristics, typical of the variety of the cheese (blue, Roquefort, stilton, Camembert, Brie, Gorgonzola).

Adequate production of lactic acid is essential for lowering the pH to a level where critical flavor compounds (acetaldehyde, diacetyl and other compounds) are formed in sufficient quantity. Factors interfering with proper acid development will retard or prevent adequate flavor development. The culture may be incapable of producing adequate amounts of flavor due to a change in fermentation pattern induced by oxygen tension or due to a change in the balance of various bacterial cultures. In certain

### Table 18.3 Cultures used for production of yogurt and sour cream

<table>
<thead>
<tr>
<th>Yogurt</th>
<th>Cultured/sour cream</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Required by FDA regulations</strong></td>
<td></td>
</tr>
<tr>
<td><em>Streptococcus thermophilus</em></td>
<td><em>Lactococcus lactis</em> subsp. <em>lactis</em></td>
</tr>
<tr>
<td><em>Lactococcus lactis</em> subsp. <em>bulgaricus</em></td>
<td><em>Lactococcus lactis</em> subsp. <em>cremoris</em></td>
</tr>
<tr>
<td><em>Leuconostoc mesenteroides</em> subsp. <em>cremoris</em></td>
<td><em>Leuconostoc mesenteroides</em> subsp. <em>cremoris</em></td>
</tr>
<tr>
<td><strong>Optional</strong></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus acidophilus</em></td>
<td><em>Lactococcus lactis</em> subsp. <em>lactis</em> biovar. <em>diacetylactis</em></td>
</tr>
<tr>
<td><em>Lactobacillus casei</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactococcus lactis</em> subsp. <em>rhamnosus</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus reuteri</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus helveticus</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus gasseri ADH</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus plantarum</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactococcus lactis</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus johnsoni</em> LA1</td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus fermentum</em></td>
<td></td>
</tr>
<tr>
<td><em>Lactobacillus brevis</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium longum</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium breve</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium bifidum</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium adolescentis</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium animalis</em></td>
<td></td>
</tr>
<tr>
<td><em>Bifidobacterium infantis</em></td>
<td></td>
</tr>
</tbody>
</table>

Adapted from: IDFA (2012).
instances, acidity may be too high in relation to product standards. This problem may be encountered in yogurt production. High acidity is usually associated with high incubation temperature, long incubation period, or excessive inoculum (Chandan & O’Rell, 2013b).

Any change from the normal fermentation pattern is considered a defect. Insufficient acid development is one of the common defects in lactic cultures. When 1 mL culture inoculated into 10 mL of antibiotic-free, heat-treated milk produces less than 0.7% titratable acidity in 4 h at 35°C, it is considered a slow starter. Factors contributing to a slow starter may involve milk composition or extraneous inhibitors. Milk from mastitis-infected animals generally does not support the growth of lactic cultures. This effect is ascribed to the infection-induced changes in chemical composition of milk. For example, mastitis milk contains lower concentrations of lactose, higher chloride content and a higher pH than normal milk. Furthermore, a high leukocyte count in mastitis milk inhibits bacterial growth by phagocytic action. Heat treatment restores the culture growth in mastitis milk (Chandan, 1982).

Colostrum and late lactation milk contain non-specific agglutinins, which clump and precipitate sensitive strains of the starter. The agglutinins may possibly retard the rate of acid production by interfering with the transport

<table>
<thead>
<tr>
<th>Cheese varieties</th>
<th>Microorganism</th>
</tr>
</thead>
</table>
| Cheddar, Colby, Gouda, Edam, Monterey | *Lactococcus lactis* subsp. *lactis*  
*Lactococcus lactis* subsp. *cremoris* |
| Cream, Neufchatel, cottage | *Lactococcus lactis* subsp. *lactis*  
*Lactococcus lactis* subsp. *cremoris*  
*Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis*  
*Leuconostoc mesenteroides* subsp. *cremoris* |
| Swiss, Emmental, Gruyere, Samso, Fontina | *Leuconostoc lactis* subsp. *cremoris*  
*Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis*  
*Leuconostoc lactis* subsp. *cremoris*  
*Lactobacillus delbrueckii* subsp. *bulgaricus*  
*Lactobacillus delbrueckii* subsp. *lactis*  
*Lactobacillus casei* subsp. *casei*  
*Lactobacillus helveticus*  
*Streptococcus thermophilus*  
*Propionibacterium freudenreichii*  
*Propionibacterium shermanii* |
| Italian cheeses: Mozzarella, Provolone, Romano | *Lactococcus lactis* subsp. *lactis*  
*Streptococcus thermophilus*  
*Lactobacillus delbrueckii* subsp. *lactis*  
*Lactobacillus delbrueckii* subsp. *lactis* biovar. *diacetylactis*  
*Lactobacillus helveticus* |
| Brick, Limburger, Muenster, Trappist, Port Salut, St Paulin, Bel Paese, Tilsit | *Streptococcus thermophilus*  
*Lactobacillus delbrueckii* subsp. *lactis* |
| Blue-veined cheeses: Roquefort, Bleu, Stilton, Gorgonzola | *Lactococcus lactis* subsp. *lactis*  
*Lactococcus lactis* subsp. *cremoris*  
*Penicillium roqueforti* |
| Camembert, Brie | *Lactococcus lactis* subsp. *lactis*  
*Lactococcus lactis* subsp. *cremoris*  
*Streptococcus thermophilus*  
*Penicillium candidum*  
*Penicillium caseicolum*  
*Penicillium camemberti* |

of lactose and other nutrients. Seasonal variation of the solids-not-fat fraction of milk affects the growth and the balance of strains in culture.

Another cause of slow starters may be attributed to antibiotics in milk. Concentrations as low as 0.005–0.05 international units (IU) of antibiotics per mL of milk, used in mastitis therapy, are high enough to impact partial or full inhibition of the culture. Accordingly, it is imperative that residual antibiotic level in milk be monitored routinely to keep the milk supply suitable for cultured milk manufacture. In addition, prior degradation of milk constituents by microbial contaminants affects the growth of lactic organisms. Careful screening of milk for psychrotrophic organisms is necessary for quality flavor production by lactic cultures.

Many sanitizing chemicals, such as quaternary ammonium compounds, iodine and chlorine compounds, retard acid development by starter cultures. One to five parts per million of these sanitizing compounds are bactericidal to lactic cultures. Proper use of sanitizers includes verification of sanitizer concentration as well as removal of residual sanitizers from the pipes and vessels prior to the use of equipment for processing of fermented dairy products.

Avoiding the use of rancid milk is important not only from the standpoint of culture growth. The free fatty acids generated in rancid milk are inhibitory to culture growth (Chandan, 1982). More significantly, rancid milk would impart an objectionable flavor to the starter and the cultured dairy products derived therefrom.

After continuous use, the starters may change their fermentation activity and consequently produce lower amounts of lactic acid (Chandan, 1982). Bacteriophages (virus-like organisms) may be an important cause of slow acid production by lactic cultures. When the phage has reached a maximum level, all sensitive bacterial cells are infected and lysed within 30–40 min. When lysis occurs, acid production by the affected culture stops unless some resistant bacteria are present to carry on fermentation. In case of phage attack in cultured milk plants, it is advisable to spray 200–300 ppm chlorine on processing equipment. Additionally, consider fogging the culture rooms with 500–1000 ppm of chlorine. Heat treatment of milk (75°C for 30 min or 80°C for 20 sec) is considered adequate to inactivate various phages that attack lactic acid bacteria. Such intensive heat treatment results in too soft curd and is therefore not suitable for production of most cheeses. Since cheese whey is a good source of phages, its reuse should be avoided.

Another step for phage control is to rotate cultures on different production days. Phages are strain specific. Culture rotation results in introducing different strains of the culture from day to day. Cultures containing multiple strains may also be helpful. Phage attack on a given strain would result in loss of acid production by the particular strain, while the other strains are still available to carry on fermentation. Phage activity requires calcium ions. By sequestering calcium with phosphates, it is possible to design and use a phage-resistant medium for propagating cultures in the plant. Accordingly, by using combinations of proper procedures, the probability of trouble with phage can be minimized (Chandan & Nauth, 2012).

Ropiness and gassiness in the bulk starter is another defect resulting from limited proteolytic activity of some starter strains, and is commonly observed with Cheddar cheese cultures. Also, it can be attributed to the presence of proteolytic bacteria in the starter culture. Some spore-formers that survive normal heat treatment of milk may also be involved.

Bitter taste (in the final product) is due to proteolytic activity of some starter strains, and is commonly observed with Cheddar cheese cultures (Chandan & Kapoor, 2013a, 2013b). Proteolysis leads to the formation of bitter peptides, which impart bitterness to cheese.

The factors influencing starter performance have been discussed by Vedamuthu (2013a). The cellular functions (chromosomal and extrachromosomal DNA) are encoded in the nuclear materials of the bacterial cell. The genetic materials could be altered by spontaneous or induced mutations, leading to changes in cellular metabolism, which in turn would alter acid generation and flavor production by the starter. The extrachromosomal material consists of plasmids, transposons, and introns. Work on the plasmids of mesophilic lactic acid bacteria has significantly elucidated basic principles relative to acid production, sugar utilization, proteolytic activity, citrate metabolism, bacteriophage resistance, and bacteriocin production (Vedamuthu, 2013a). The plasmids are known to code for several significant functions. Technology for transfer of plasmids has been developed by commercial culture manufacturers to introduce new strains with enhanced bacteriophage resistance, boosted health attributes, ability to accelerate cheese ripening, stability in flavor and texture production, and production of antimicrobial compounds and natural preservatives (Vedamuthu, 2013a).

The starter culture is a crucial component in the production of fermented dairy products of high quality and uniformity. An effective sanitation program, including filtered air and positive pressure in the fermentation area, should significantly control air-borne contamination and contribute to consistently high-quality products.
Commercial cultures may consist of single strains or mixed strains of the same species. Furthermore, they may be mixed strains of a combination of different genus and species of bacteria. They are designed for performance in the production of discrete cultured foods and intended to be used as per instructions issued by the culture manufacturer, which include temperature of incubation, inoculum level, and incubation time. Many plants use frozen direct-to-vat or freeze-dried direct-to-vat cultures for production of cultured dairy foods. However, for cost savings, some large manufacturers prefer to make bulk starters in their own plant from frozen or dry bulk cultures.

The medium for bulk starter production is antibiotic-free, non-fat dry milk reconstituted in water at 10–12% solids level. The medium is heated to 90–95°C and held for 30–60 min, then cooled to incubation temperature in the vat. For example, the incubation period for yogurt bulk starter ranges from 4 to 6 h and the temperature of 43°C is maintained by holding hot water in the jacket of the tank. The fermentation must be quiescent (lack of agitation and vibrations) to avoid phase separation in the starter following incubation. The progress of fermentation is monitored by titratable acidity or pH measurements at regular intervals. When the titratable acidity is 0.85–0.90%, (approximate pH 4.4), the fermentation is terminated by turning the agitators on and replacing warm water in the jacket with iced water. Circulating iced water drops the temperature of the starter to 4–5°C. The starter is now ready to use. Depending on the product to be manufactured, the inoculum size varies from 0.5% to 5%. If necessary, the starter may be stored at 4–5°C for 3–4 days.

18.4 Biochemical basis of lactic fermentation for flavor and texture generation

The major constituents of milk are altered by interaction with starter organisms. Lactose is first broken down to glucose and galactose, then to lactic acid via the glycolytic pathway by starter bacteria. Galactose is not readily broken down in some strains of lactic acid bacteria. Consequently, it accumulates in fermented products. In Mozzarella cheese, the galactose forms brown coloration on melting. The acid production results in lowering of pH and increase in viscosity until the liquid phase transforms to a solid gel phase in fermented milks. Another function of acid generation is its preservative effect, which extends shelf life of fermented milks. Furthermore, the starter enzymes are responsible for limited breakdown of proteins, amino acids, and fat, thereby generating key flavor compounds. In this regard, acetaldehyde is regarded as a typical flavor compound in yogurt whereas diacetyl is a distinctive flavor compound in buttermilk and sour cream (Vedamuthu, 2013a, 2013b).

In the production of cheeses, acid formation accelerates the activity of coagulating enzymes (chymosin), leading thereby to the formation of curd. The activity of the starter and other organisms during the aging of cheese leads to breakdown of casein and milk fat, giving particular cheeses their typical flavor and textural characteristics (Fox, 2003b; Singh & Cadwallader, 2008). The reader is referred to extensive literature on cheeses, including a series of articles on types, starter cultures, their chemistry and microbiology, manufacture of various types, and flavor generation (Bottazzi, 2003; Chandan, 2003; Farkye, 2003; Fox, 2003a, 2003b; Fox & McSweeney, 2003; McSweeney, 2003; Olsen, 2003; Stanley, 2003).

18.4.1 General principles of fermented dairy foods manufacture

Fermented milks are generally made from a mix standardized from whole, partially defatted milk, condensed skim milk, cream and/or non-fat dry milk. Yogurt is made from fat-standardized milk fortified with non-fat milk solids. Cultured sour cream is made from 18% fat cream supplemented with some non-fat milk solids for textural improvement. Many cheeses are made from pasteurized milk standardized for fat:solids-not-fat ratio. Standards of identity established by regulatory authorities in each country assure the consumer a defined product. Table 18.5 lists the standards for cultured fluid dairy foods in the US.

All dairy raw materials should be selected for high bacteriological and sensory quality. A general process for fermented dairy foods is illustrated in Figure 18.1.

The following sections summarize the essential parameters prescribed by the US Food and Drug Administration (FDA) regarding composition of yogurt, sour cream, Cheddar cheese, and process cheese.

18.5 Yogurt

Yogurt is a semi-solid fermented product made from a heat-treated standardized milk mix by the activity of
a characterizing symbiotic blend of *Streptococcus thermophilus* (ST) and *Lactobacillus delbrueckii* subsp. *bulgaricus* (LB) cultures. In addition to mandatory cultures, commercial yogurt contains adjunct cultures, primarily *Lactobacillus acidophilus*, *Lactobacillus casei*, and *Bifidobacterium* spp.

Yogurt is produced from the milk of various animals (cow, water-buffalo, goat, sheep, yak, etc.) in various parts of the world. Cow’s milk is the predominant starting material in industrial manufacturing operations in the US. In order to achieve a custard-like semi-solid consistency, the cow’s milk is fortified with dried or condensed milk.

Vitamin addition at a level of 2000 IU of vitamin A and 400 IU of vitamin D per quart (846 mL) is allowed. Permissible dairy ingredients are cream, milk, partially skimmed milk, skim milk, alone or in combination. Other optional ingredients include concentrated skim milk, non-fat dry milk, buttermilk, whey, lactose, lactalbumins, lactoglobulins, or whey modified by partial or complete removal of lactose and/or minerals. These ingredients are used to increase the non-fat solids content of yogurt, provided that the ratio of protein to total non-fat solids of the food and the protein efficiency ratio of all protein present shall not be decreased as a result of adding such ingredients. In addition, sweeteners such as sucrose, invert sugar, brown sugar, refiner’s syrup, molasses (other than blackstrap), high fructose corn syrup, fructose, fructose syrup, maltose, maltose syrup, dried maltose syrup, malt extract, dried malt extract, malt syrup, dried malt syrup, honey, maple sugar, except table syrup may be used. The regulations allow flavoring ingredients, color additives, and stabilizers.

### 18.5.1 Raw materials for yogurt

#### 18.5.1.1 Dairy ingredients

In the US, yogurt is a Grade A product (CFR, 2011). Grade A implies that the milk used must come from FDA-supervised Grade A dairy farms and Grade A manufacturing plants as per regulations enunciated in the *Pasteurized Milk Ordinance* (US Department of Health and Human Services, 2011a). To make yogurt mix, milk is supplemented with non-fat dry milk or condensed skim milk to increase the solids-not-fat (SNF). The FDA specification calls for a minimum of 8.25% non-fat milk solids (see Table 18.5). However, the industry uses up to 12% SNF in the yogurt mix to generate a thick, custard-like consistency. The milk fat levels are standardized to 3.25% for full-fat yogurt; low-fat yogurt is manufactured from mix containing 0.5–2% milk fat; non-fat yogurt mix has a milk fat level not exceeding 0.5% (CFR, 2011).

#### 18.5.1.2 Culture

Most of the yogurt is fermented with ST and LB. In addition, optional bacteria are incorporated along with the

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**Table 18.5 Essential FDA standards for composition of certain fermented milks in the US**

<table>
<thead>
<tr>
<th>Product</th>
<th>% Milk fat</th>
<th>% Milk solids-non-fat</th>
<th>% Titratable acidity expressed as lactic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yogurt CFR 131.200</td>
<td>Not less than 3.25</td>
<td>Not less than 8.25</td>
<td>Not less than 0.9</td>
</tr>
<tr>
<td>Low-fat yogurt CFR 131.203</td>
<td>Not less than 0.5 and not more than 2.0</td>
<td>Not less than 8.25</td>
<td>Not less than 0.9</td>
</tr>
<tr>
<td>Non-fat yogurt CFR 131.206</td>
<td>Not more than 0.5</td>
<td>Not less than 8.25</td>
<td>Not less than 0.9</td>
</tr>
<tr>
<td>Cultured milk CFR131.112</td>
<td>Not less than 3.25</td>
<td>Not less than 8.25</td>
<td>Not less than 0.5</td>
</tr>
<tr>
<td>Cultured low-fat milk∗  (buttermilk)</td>
<td>Not less than 0.5 and not more than 2.0</td>
<td>Not less than 8.25</td>
<td>Not less than 0.5</td>
</tr>
<tr>
<td>Cultured non-fat milk</td>
<td>Not more than 0.5</td>
<td>Not less than 8.25</td>
<td>Not less than 0.5</td>
</tr>
<tr>
<td>Cultured (sour) cream CFR 131.160</td>
<td>Not less than 18.0. After the addition of bulky flavors, etc.not less than 14.4</td>
<td>No standard</td>
<td>Not less than 0.5</td>
</tr>
</tbody>
</table>

∗ Commonly known as cultured buttermilk.

starter. *Lactobacillus acidophilus* is commonly used as an additional culture in commercial yogurt. Other cultures commonly added belong to various *Lactobacillus* and *Bifidobacterium* species because of their probiotic benefits. Probiotics are food-grade cultures which upon ingestion have been shown to impart several health benefits (for instance, immune enhancements, gastrointestinal improvements).

Commercial production of yogurt relies heavily on fermentation ability and characteristics imparted by the starter. The starter performance factors are rapid acid development; typical yogurt flavor, body, and texture;
exopolysaccharide-secreting strains to enhance viscosity of yogurt; scale-up possibilities in various production conditions, including compatibility with a variety and levels of ingredients used; fermentation times and temperatures; survival of culture viability during shelf life; exhibit probiotic properties and survival in the human gastrointestinal tract for certain health attributes; and minimum acid production during distribution and storage at 4–10°C until yogurt is consumed.

Fermentation constitutes the most important step in yogurt manufacture. To optimize parameters for yogurt production, an understanding of factors involved in the growth of yogurt bacteria is important to manage uniformity of product quality and cost-effectiveness of manufacturing operation.

Collaborative growth of ST and LB is a phenomenon unique to yogurt. Yogurt starter organisms display obligate symbiotic relationship during their growth in the milk medium. Although they can grow independently, they utilize each other’s metabolites to effect remarkable efficiency in acid production. In general, LB has significantly more cell-bound proteolytic enzyme activity, producing stimulatory peptides and amino acids for ST. The relatively high amino-peptidase and cell-free and cell-bound dipeptidase activity of ST is complementary to the strong proteinase and low peptidase activity of LB. Urease activity of ST produces CO₂, which stimulates LB growth. Concomitant with CO₂ production, urease liberates ammonia, which acts as a weak buffer, to prevent extreme pH conditions that are inhibitory to bacteria. Consequently, milk cultured by ST alone exhibits low titratable acidity (or high pH) of coagulated mass. Formic acid formed by ST, as well as by heat treatment of milk, accelerates LB growth. The rate of acid production by yogurt starter containing both ST and LB is considerably higher than by either of the two organisms grown separately.

Yogurt organisms are micro-aerophilic in nature, which means foaming must be prevented in the production of yogurt. Heat treatment of milk drives out oxygen. It also wipes out competitive flora. Furthermore, heat produces sulphydryl compounds, which tend to generate reducing conditions in the medium. Lactic cultures prefer such micro-aerophilic conditions for their growth. Accordingly, rate of acid production is considerably higher in heat-treated milk than in raw or pasteurized milk. Although the heat treatment far exceeds time-temperature requirements for proper pasteurization, a legal pasteurization time-temperature regime is still mandated by the FDA in yogurt production.

18.5.1.3 Sweeteners
Yogurt mixes designed for manufacture of yogurt may contain appreciable quantities of sucrose. The sweeteners exert osmotic pressure in the system, leading to progressive inhibition and decline in the rate of acid production by the culture. Acid-producing ability of yogurt culture in mixes containing 8.0% sucrose is acceptable practice in the industry. Sucrose is the major sweetener used in yogurt production. High-intensity sweeteners (e.g. aspartame, sucralose, acesulfame K, steviosides, monk fruit, etc.) are used to produce “light” yogurt containing about 60% calories compared to normal sugar-sweetened yogurt. Low levels of crystalline fructose may be used in conjunction with aspartame and other high-intensity sweeteners to round up and improve overall flavor of “light” yogurt. Generally, commercial yogurts have an average of 4.06% lactose, 1.85% galactose, and 0.05% glucose.

18.5.1.4 Stabilizers
The primary purpose of using a stabilizer in yogurt is to produce smoothness in body and texture, impart gel structure, and reduce wheying off (or syneresis). The stabilizer increases shelf life and provides a reasonable degree of uniformity of the product. Stabilizers function through their ability to form gel structures in water, thereby leaving less free water for syneresis. A good yogurt stabilizer should not impart any flavor, should be effective at low pH values, and should be easily dispersed in the normal working temperatures in a food plant. The stabilizers generally used in yogurt are modified starch, gelatin, whey protein concentrates, and pectin. The stabilizer system used in yogurt mix preparations is generally a combination of starch and gelatin. Whey protein concentrates at 0.5–1% level are also widely used for their water-binding attributes.

18.5.1.5 Fruit preparations for flavoring yogurt
The fruit preparations for blending in yogurt are specially designed to meet the marketing requirements for different types of yogurt. They are generally present at levels of 10–15% by weight in the final product. A majority of the fruit preparations contain natural flavors to boost the fruit aroma and flavor. Flavors and certified colors are usually added to the fruit-for-yogurt preparations for improved eye appeal and better flavor profile. The fruit base should exhibit true color and flavor of the fruit when blended with yogurt, and be easily dispersible in yogurt without causing texture defects, phase separation, or syneresis. The pH of
the fruit base should be compatible with yogurt pH (approximately 4.4). The fruit should have zero yeast and mold population in order to prevent spoilage and to extend shelf life. For extensive discussion of fruit for yogurt, the reader is referred to O’Rell and Chandan (2013a).

18.5.2 Processing

Detailed discussion relative to yogurt manufacture is available in the literature (Chandan & O’Rell, 2013a-c; Tamime & Robinson, 2007). The general steps are summarized in the following pages.

18.5.2.1 Mix preparation

A yogurt plant requires a special design to minimize contamination of the products with phage and spoilage organisms. The plant is generally equipped with a receiving room to receive, meter or weigh, and store milk and other raw materials. In addition, facilities include a process and production control laboratory, a dry storage area, a refrigerated storage area, a mix processing room, a fermentation room, and a packaging room.

The mix processing room contains equipment for standardizing and separating milk, pasteurizing and heating, and homogenizing, along with the necessary pipelines, fittings, pumps, valves, and controls. To prevent entry of stray microorganisms, including bacteriophages, the fermentation room (housing fermentation tanks) is isolated from the rest of the plant. Filtered air under positive pressure is supplied to the room to generate clean room conditions. A control laboratory is generally set aside, where culture handling, process control, product composition, and shelf life tests are carried out to insure adherence to regulatory and company standards. Also, a quality control program is established by laboratory personnel. A utility room is required for maintenance and engineering services needed by the plant. The refrigerated storage area is used for holding fruit, finished products, and other heat-labile materials. A dry storage area at ambient temperature is primarily utilized for temperature-stable raw materials and packaging supplies.

Standardization of milk for fat and milk solids-not-fat content results in fat reduction and an increase of approximately 30–35% for other solid components (lactose, protein, mineral, and vitamin content). Nutrient density of yogurt mix is increased in relation to that of milk. Specific gravity changes from 1.03 to 1.04 g/mL at 20°C. Addition of stabilizers and sweeteners further impacts physical properties. All the additives are blended prior to heat treatment.

18.5.2.2 Heat treatment

Pasteurization equipment consists of a vat, plate heat exchanger or high-temperature, short-time (HTST) pasteurization system. The mix is subjected to much more severe heat treatment than conventional pasteurization temperature-time combinations. Heat treatment at 85°C for 30 min or 95–99°C for 7–10 min is an important step in manufacture. The heat treatment:
- produces a relatively sterile medium for the exclusive growth of the starter
- removes air from the medium to produce a more conducive medium for micro-aerophilic lactic cultures to grow
- causes thermal breakdown of milk constituents, especially proteins, releasing peptones and sulfhydryl groups, which provide nutrition and anaerobic conditions for yogurt culture
- produces physical changes in the proteins which have a profound effect on the viscosity of yogurt.

The heat treatment denatures and coagulates whey proteins (β-lactoglobulin in particular) which improves water-binding properties. Whey protein denaturation, of the order of 95%, enhances water absorption capacity, thereby creating a smooth custard-like consistency, high viscosity and stability from whey separation in yogurt. The intense heat treatment during yogurt processing destroys all the pathogenic flora and most vegetative cells of all microorganisms contained therein. In addition, milk enzymes inherently present are inactivated. From a microbiological standpoint, destruction of competitive organisms produces conditions conducive to the growth of desirable yogurt bacteria.

18.5.2.3 Homogenization

The homogenizer is a high-pressure pump that forces the mix through extremely small orifices. The process is usually conducted by applying pressure in two stages. The first stage pressure, of the order of approximately 14 MPa (2000 psi), reduces the average milk fat globule diameter size from approximately 4 μm (range 0.1–16 μm) to less than 1 μm. The second stage uses 3.5 MPa (500 psi) and is designed to break the clusters of fat globules apart with the objective of inhibiting creaming in milk. Homogenization aids in texture development (partially due to blending of stabilizers) and alleviates the surface creaming and wheying-off problems. Since homogenization treatment reduces the fat globules to an average of less than 1 μm in diameter, no distinct creamy layer (crust) is observed on the surface.
of yogurt produced from homogenized mix. The homogenizer and heat treatment systems are located in tandem. The homogenized and heat treated mix is brought to 43°C by pumping through an appropriate heat exchanger. It is then collected in fermentation tanks.

18.5.2.4 Fermentation.

Fermentation tanks for the production of cultured dairy products are generally designed with a cone bottom to facilitate draining of relatively viscous fluids after incubation. The starter is generally inoculated at 5% level. For temperature maintenance at approximately 43°C (110°F) during the incubation period, the fermentation vat is usually insulated and covered with an outer surface made of stainless steel. The vat is equipped with a heavy-duty, multispeed agitation system, a manhole containing a sight glass, and appropriate spray balls for clean-in-place (CIP) cleaning. In the CIP process, hot cleaning fluids are circulated through the equipment. The agitator is often of swept surface type for optimum agitation of relatively viscous cultured dairy products. For efficient cooling after culturing, plate or triple-tube heat exchangers are used.

18.5.2.5 Contribution of the culture to yogurt texture and flavor

Proper fermentation with yogurt culture leads to the formation of typical flavor compounds. Lactic acid, acetaldehyde, acetoin, diacetyl, and other carbonyl compounds constitute key flavor compounds of yogurt. The production of flavor by yogurt cultures is a function of time as well as the sugar content of yogurt mix. Acetaldehyde production in yogurt takes place predominantly in the first 1–2 h of incubation. Eventually, an acetaldehyde level of 2–41 ppm develops (Chandan & O’Rell, 2013b). The acetaldehyde level declines in later stages of incubation. Diacetyl varies from 0. to 0.9 ppm, and acetoin varies from 2.2 to 5.7 ppm (Routray & Mishra, 2011). Lactic acid content varies from 0.9% to 1.2%. Only a part of lactose is metabolized and approximately 70% remains intact in fermented yogurt mix. Acetic acid ranges from 50 to 200 ppm (Chandan & O’Rell, 2013b). These key flavor compounds are produced by yogurt bacteria. Among others, diacetyl and acetoin are also metabolic products of carbohydrate metabolism in ST.

The milk coagulum during yogurt production results from the drop in pH due to the activity of the yogurt culture. The ST is responsible for lowering the pH of a yogurt mix to 5.0–5.5 and the LB is primarily responsible for further lowering of the pH to 3.8–4.4 (and production of acetaldehyde).

Several mucopolysaccharide-producing strains of yogurt culture are utilized in the industry because they render yogurt more viscous. The texture of yogurt tends to be coarse or grainy if it is allowed to overferment prior to stirring or if it is disturbed at pH values higher than 4.6 (O’Rell & Chandan, 2013b). Incomplete blending of mix ingredients is an additional cause of a coarse smooth texture. Homogenization treatment and high fat content tend to favor smooth texture. Gassiness in yogurt may be attributed to contamination of the starters with spore-forming Bacillus species, coliform, or yeast, producing excessive CO2 and hydrogen. In comparison with plate heat exchangers, cooling with tube-type heat exchangers causes less damage to yogurt structure. Further, loss of viscosity may be minimized by well-designed booster pumps, metering units, and valves involved in yogurt packaging. The pH of yogurt during refrigerated storage continues to drop by approximately 0.2 pH units. Higher temperature of storage accelerates the drop in pH.

18.5.2.6 Changes in milk constituents

Among the carbohydrate constituents, the lactose content of yogurt mix is generally around 6%. During fermentation, lactose is the primary carbon source, resulting in approximately 30% reduction. However, a significant level of lactose (3.31–4.74%) is maintained in fresh yogurt (Chandan & Nauth, 2012). One mole of lactose (a disaccharide) gives rise to 1 mole of galactose and 1 mole of glucose. Through the glycolytic pathway, glucose is further converted to 2 moles of lactic acid and energy for bacterial growth. Lactic acid production results in coagulation of milk beginning at pH below 5.0 and completing at 4.6. Texture, body, and acid taste of yogurt owe their origin to lactic acid produced during fermentation. Although lactose is in large excess in the fermentation medium, lactic acid build-up beyond 1.5% acts progressively as an inhibitor for further growth of yogurt bacteria. Normally, fermentation is terminated by temperature drop to 4°C. To achieve this, the yogurt mass is typically pumped through a heat exchanger. To make the texture smooth, a texturizing cone is commonly inserted in the pipe leading to the heat exchanger. At 4°C, the culture is alive but its activity is drastically limited to allow fairly controlled flavor in marketing channels.

Hydrolysis of milk proteins is easily measured by liberation of -NH2 groups during fermentation. Free amino groups double in yogurt after 24 h. Proteolysis continues
during shelf life of yogurt, doubling free amino groups again in 21 days storage at 7°C. The major amino acids liberated are proline and glycine. The essential amino acids liberated increase 3.8–3.9-fold during storage of yogurt, indicating that various proteolytic enzymes and peptidases remain active throughout the shelf life of yogurt. The proteolytic activity of the two yogurt bacteria is moderate but quite significant in relation to symbiotic growth of the culture and production of flavor compounds (Chandan & Shahani, 1993, 1995).

Both ST and LB are documented in the literature to elaborate different oligosaccharides in yogurt mix medium. As much as 0.2% (by weight) of mucopolysaccharides have been observed after 10 days of storage. In stirred yogurt, drinking yogurt and reduced-fat yogurt, the potential contribution of exopolysaccharides to impart smooth texture, higher viscosity, lower syneresis, and better mechanical handling is noted. Excessive shear during pumping destroys much of the textural advantage because viscosity generated by the mucopolysaccharides is susceptible to shear. Most of the polysaccharides elaborated in yogurt contain glucose and galactose, along with minor quantities of fructose, mannose, arabinose, rhamnose, xylose, arabininose, or N-acetylglactosamine, individually or in combination. Molecular weight is of the order of 0.5–1 million daltons. An intrinsic viscosity range of 1.5–4.7 dL g⁻¹ has been reported for exopolysaccharides of ST and LB. The polysaccharides form a network of filaments, visible using a scanning electron microscope. The bacterial cells are covered by part of the polysaccharide and the filaments bind the cells and milk proteins. Upon shear treatment, the filaments rupture off from the cells, but maintain links with casein micelles. The so-called ropy strains of ST and LB are commercially available. They are especially appropriate for stirred yogurt production.

Other interesting metabolites are produced by yogurt culture. Among them are bacteriocins and several antimicrobial compounds. Benzoic acid (15–30 ppm) in yogurt has been detected and associated with metabolic activity of the culture (Chandan et al., 1977). These metabolites tend to exert a preservative effect by controlling the growth of contaminating spoilage and pathogenic organisms gaining entry post fermentation. As a result, the product attains extension of shelf life and a reasonable degree of safety from food-borne illness. As a consequence of fermentation, yogurt organisms multiply to a count of 10⁸ to 10¹⁰ colony-forming units (CFU) g⁻¹. Yogurt bacteria occupy some 1% of the volume or mass of yogurt (Chandan, 1982). These cells contain cell walls, enzymes, nucleic acids, cellular proteins, lipids, and carbohydrates. Lactase or β-galactosidase has been shown to contribute a major health-related property to yogurt. Clinical studies have concluded that yogurt containing live and active cultures can be consumed by millions of lactose-deficient individuals without developing gastrointestinal distress or diarrhea (Chandan, 2002, 2011, 2013; Chandan & Kilara, 2008).

Yogurt is an excellent dietary source of calcium, phosphorus, magnesium, and zinc for human nutrition. Research has shown that bioavailability of the minerals from yogurt is essentially equal to that from milk (Chandan & Nauth, 2012; Chandan & O’Rell, 2013b). Since yogurt is a low pH product compared to milk, most of the calcium and magnesium occurs in ionic form, which may have positive implications for the bioavailability of the minerals.

During and after fermentation, yogurt bacteria affect the vitamin B content of yogurt. The processing parameters and subsequent storage conditions influence the vitamin content at the time of consumption. Incubation temperature and fermentation time exert a significant balance between vitamin synthesis and utilization of the culture. In general, there is a decrease of vitamin B₁₂, biotin, and pantothenic acid and an increase of folic acid during yogurt production. Nevertheless, yogurt is still an excellent source of vitamins inherent to milk.

### 18.5.3 Manufacturing procedures for different yogurt varieties

#### 18.5.3.1 Plain yogurt

Plain yogurt is the basic style, and forms an integral component of fruit-flavored yogurt. The steps involved in the manufacturing of various types of yogurt are shown in Table 18.6.

Plain yogurt normally contains no added sugar or flavors, in order to offer the consumer natural yogurt flavor for consumption as such or as an option of flavoring with other food materials of the consumer’s choice. In addition, it may be used for cooking or for salad preparation with fresh fruits or grated vegetables. In most recipes, plain yogurt is a good substitute for sour cream, providing lower calories and fat alternative. The fat content of yogurt may be standardized to the levels preferred by the market. Labeled as “yogurt,” full-fat yogurt is mandated to have a minimum of 3.25% fat. Also, the size of package may be geared to market demand. Polystyrene and polypropylene cups and lids are the chief packaging materials used in the industry.
18.5.3.2 Fruit on-the-bottom (sundae) style yogurt

In this type, two-stage fillers are used. Typically, 59 mL (2 oz) of fruit preserves or special fruit preparations are layered at the bottom, followed by 177 mL (6 oz) of inoculated (cultured) yogurt mix on the top. The top layer may consist of yogurt mix containing stabilizers, sweeteners, and the flavor and color indicative of the fruit on the bottom. After placing lids on the cups, incubation and setting of the yogurt take place in the cups (typically at 43°C). When a desirable pH of 4.4–4.5 is attained, the cups are placed in refrigerated rooms with high-velocity forced air for rapid cooling. At the time of consumption, the fruit and yogurt layers are mixed by the consumer.

18.5.3.3 Blended/Swiss style/stirred style or blended yogurt

Swiss-style yogurt is produced by blending the fruit preparation thoroughly in fully fermented yogurt base obtained after bulk culturing in fermentation tanks.

<table>
<thead>
<tr>
<th>Table 18.6 Main steps for manufacturing plain, Greek and fruit-flavored refrigerated yogurt</th>
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<tbody>
<tr>
<td>Plain yogurt</td>
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<tr>
<td>1. Standardize mix for fat (0.3–3.25%) and non-fat solids (10–12%) using skim milk, cream, non-fat dry milk and condensed skim milk.</td>
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<tr>
<td>2. Heat-treat the mix at 97°C for 10 min.</td>
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<tr>
<td>3. Homogenize at 1500 psi, 60°C. Cool to 45°C.</td>
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<tr>
<td>5. Incubate at 43°C until pH reaches 4.5.</td>
</tr>
<tr>
<td>6. Break curd. Centrifuge/strain enough whey to concentrate solids (~2 times). Cool to 4°C.</td>
</tr>
<tr>
<td>7. For plain Greek yogurt, if required, blend cream to standardize fat content.</td>
</tr>
<tr>
<td>8. For fruit-on-the-bottom Greek yogurt, dispense fruit preparation into cups. Blend cream in plain Greek yogurt to standardize fat and layer Greek yogurt on the top of the fruit.</td>
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<tr>
<td>11. Blast-cool to 4°C. Store and distribute under refrigerated conditions.</td>
</tr>
</tbody>
</table>
Stabilizers, especially gelatin, are commonly used in this form of yogurt, unless milk solids-not-fat levels are relatively high (12–14%). In this style, cups are filled with an in-line blended mixture of fermented yogurt base and fruit. Pumping of yogurt-fruit blend can result in considerable loss of viscosity. Upon refrigerated storage for 48 h, the clot is reformed and viscosity is recovered, leading to a fine body and texture. Fruit incorporation at 10–15% is carried out by the use of a fruit feeder. Prior to packaging, the texture of fermented yogurt base can be made smoother by pumping it through a valve or a cone made of stainless steel mesh. The incubation times and temperatures are co-ordinated with the plant schedules. Incubation temperatures lower than 40°C in general tend to impart a slimy or sticky appearance to yogurt. Overstabilized yogurt possesses a solid-like consistency and lacks a refreshing character. Spoon-able yogurt should not have the consistency of a drink; it should melt in the mouth without chewing.

18.5.3.4 Greek style yogurt

This product is characterized by high viscosity and heavy body. The distinct body is obtained by straining/centrifuging some of the whey from plain yogurt (see Table 18.6) to obtain 20–25% solids. In some cases, it is formulated to achieve high solids (using milk protein concentrate, non-fat milk solids, whey protein concentrate, etc.), followed by culturing (Kilara & Chandan, 2013). It is generally a non-fat product, but the fat content can be standardized by blending pasteurized milk or cream to the strained yogurt mass to obtain low-fat or full-fat variations. Another variation consists of adding fruit to market fruit-on-the bottom or blended style Greek yogurt. Commercial Greek yogurt generally contains twice as much protein as regular yogurt.

18.5.3.5 Light yogurt

Light yogurt is generally of the blended/stirred type, which is made without any added sugar. High-intensity sweeteners (commonly aspartame or sucralose) replace the sugar in the formulation. The synthetic sweetener may be added through the fruit preparation. More commonly, a pasteurized solution of the high-intensity sweetener is blended, directly in-line into the fermented base. Light yogurt is generally a blended type yogurt which uses a special fruit preparation containing 30–60% fruit. The fruit preparation (10–12ºBrix) is designed for use at 10–18% level (O’Rell & Chandan, 2013a). The major consumer driver for light yogurt consists of significantly lower sugar content and calories.

18.5.3.6 Yogurt beverages

Also called drinking yogurt, yogurt smoothie and yogurt drink, this product is made in a similar procedure as used for stirred style or blended yogurt. It is a low-viscosity yogurt made from low solids mixes. However, fruit preparations generally consist of juices and purees. The stabilizers used are non-thickening types, such as high methoxy pectin, modified starch, gelatin, and certain gums used to impart smooth body and to control whey separation during the product shelf life. A recent trend is to include fructo-oligosaccharide prebiotics, like inulin, and to fortify with a significant daily requirement of most vitamins and minerals. In general, various probiotic strains are included in the product. All the beverages contain live and active cultures to qualify them as a functional food (Schoenfuss & Chandan, 2011).

A variation of drinking yogurt consists of blending yogurt with water and fruit juice, and subjecting the blend to extra shear (homogenization) to reduce viscosity. Kefir is another fermented milk beverage. Kefir culture containing lactobacilli, leuconostocs, acetic acid bacteria, Streptococcus thermophilus and yeasts is used as the starter for this drink, giving it a distinctive flavor. Most kefir products are sweetened with sugar and flavored with fruit juices. In the US, kefir contains no yeast and consequently no alcohol or gas.

18.5.3.7 Aerated yogurt (mousse/whips)

This category of yogurt resembles mousse, in that the product acquires a novel foam-like texture. The aeration process is similar to the ice cream process, but the degree of overrun (extent of air content) is kept low, around 20–50%. Foam formation is facilitated by use of appropriate emulsifiers and the stability of foam is achieved by using gelatin in the formulation. After bulk fermentation and cooling, aerated yogurt is produced with appropriate equipment (Oakes, Tanis, or Mondo), injecting a controlled volume of an inert gas (nitrogen) to create foam in the product. Nitrogen assists in controlling oxidative deterioration. The amount of overrun is related to texture and mouthfeel attributes of the product. It is desirable to insure constant overrun from day to day in order to market a consistent product. The volume of yogurt in the cup is also related to the degree of overrun. Accordingly,
overrun control ensures the correct weight of the product in the cup (Schoenfuss & Chandan, 2011).

18.5.3.8 Frozen yogurt
Both soft-serve and hard-frozen yogurts have gained popularity in recent years. The popularity of frozen yogurt has been propelled by its low-fat and non-fat options. Frozen yogurt is a low-acid product, resembling low-fat ice cream in flavor and texture, with only 0.3% titratable acidity. There are no federal legal requirements for frozen yogurt but a few states do have legal definitions. A common procedure involves blending skim milk fermented with yogurt culture with low-fat ice cream mix to yield frozen yogurt mix. Another procedure uses controlled fermentation of low-fat ice cream to pH ~5.9–6.0. In some instances, the blend is pasteurized to insure destruction of pathogens as well as yogurt bacteria in the resulting low-acid food. To provide live and active yogurt culture in the finished product, frozen culture concentrate must be blended with the pasteurized product. The blend is flavored and frozen in an ice cream freezer or soft ice cream machine similar to frozen dessert manufacture.

18.5.4 Packaging and storage
Most plants attempt to synchronize the packaging lines with the termination of the incubation period. Generally, textural defects in yogurt products are caused by excessive shear during pumping or agitation. Therefore, special pumps are preferred over centrifugal pumps for moving the product after culturing or ripening.

For incorporation of fruit, it is advantageous to use a fruit feeder system. Various packaging machines of suitable speeds (up to 400 cups per minute) are available to package various kinds and sizes of yogurt products.

Yogurt is generally packaged in plastic containers varying in size from 4 oz to 32 oz (113–904 g). The machines use volumetric piston filling. The product is sold by weight and the machines delivering volumetric measure are standardized accordingly. The pumping step of fermented and flavored yogurt base exerts some shear on the body of yogurt.

Cups of various shapes characterize certain brands. Some plants use preformed cups. The cup may be formed in the yogurt plant by injection molding, a process in which beads of plastic are injected into a mold at high temperature and pressure. In this type of packaging, a die-cut foil lid is heat sealed on to the cups. Foil lids are cut into circles and procured by the plants from a supplier along with preformed cups. A plastic overcap may be used. In some cases, partially formed cups are procured and assembled at the plant. Some other plants use roll stock, which is used in form-fill-seal systems of packaging. In this case, cups are fabricated in the plant by a process called thermoforming which involves ramming a plug into a sheet of heated plastic. Multipacks of yogurt are produced by this process.

Following the formation of cups, they are filled with the appropriate volume of yogurt and heat sealed with foil lids. They are then placed in cases and transferred to a refrigerated room for cooling and distribution. In breakfast yogurt, a mixture of granola, nuts, chocolate bits, dry fruit, and cereal is packaged in a small cup and sealed with a foil. Subsequently, the cereal cup is inverted and sealed on the top of the yogurt cup. This package is designed to keep the ingredients isolated from the yogurt until the time of consumption. This system helps to maintain crispness in cereals and nuts, which otherwise would become soggy or interact adversely if mixed with yogurt at the plant level.

Some interesting innovations in yogurt packaging include spoon-in-the-lid and squeezable tubes (Panell & Schoenfuss, 2007). The former adds convenience in eating yogurt, while the squeezable tubes add versatility of use for children. They may be included in lunch boxes for consumption in school. In addition, yogurt-in-tubes is freeze-thaw stable, which adds another dimension of convenience and versatility. The tubes/cups are packaged in cases and stored at 4°C.

18.5.4.1 Quality control
Quality control programs include controlling product composition, viscosity, color, flavor, body and texture, as well as fermentation process. Daily tests for chemical composition of the product, pH, and sensory quality constitute the core of quality assurance. Product standards of fats, solids, viscosity, pH (or titratable acidity), and organoleptic characteristics should be strictly adhered to (O’Rell & Chandan, 2013c).

The flavor defects can be described as too acid, too weak fruit flavor, unnatural, etc. The sweetness level may be excessive or weak, or may exhibit corn syrup flavor. The ingredients used may impart undesirable flavors such as stale, metallic, old ingredients, oxidized, rancid, or unclean. Lack of control in processing procedures may cause overcooked, caramelized, or excessively sour flavor notes in the product. Proper control of processing parameters and ingredient quality ensure optimum flavor.
The shelf life and safety aspects of yogurt. Efficiency of equipment and environmental sanitation can be verified by enumeration techniques involving exposure of poured plates to atmosphere in the plant or making a smear of the contact surfaces of the equipment, followed by plating. Filters on the air circulation system should be changed frequently. Walls and floors should be cleaned and sanitized frequently and regularly.

The packaging materials should be stored in dust-free and humidity-free conditions. The filling room should be fogged with chlorine or iodine regularly. Quality control checks on fruit preparations and flavorings should be performed (spot checking) to ascertain sterility and to eliminate yeast and mold entry via fruit preparation. Refrigerated storage of the fruit flavorings is recommended.

In hard-pack frozen yogurt, a coarse and icy texture may be caused by formation of ice crystals due to fluctuations in storage temperatures. Sandiness may be due to lactose crystals resulting from too high levels of milk solids. A soggy or gummy defect is caused by too high a milk solids-not-fat level or too high a sugar content. A weak body results from too high overrun and insufficient total solids. It is evident that good microbiological quality of all ingredients is necessary for fine organoleptic quality and shelf life of the product.

**18.5.5 Live and active status of yogurt culture**

Yogurt products enjoy an image of being health-promoting foods. The type of cultures and their viability, as well as active status, are important attributes from a consumer standpoint (Chandan, 2002). Quality control tests are necessary to insure “live and active” status of the culture. As per National Yogurt Association standards (National Yogurt Association, 2008), yogurt must pass an activity test. The cultures must be active at the end of the shelf life stated on the package. Samples of yogurt stored at a temperature between 1°C and 10°C for the duration of the stated shelf life are subjected to the activity test. This test is carried out by pasteurizing 12% (w/v) solids non-fat dry milk at 92°C for 7 min, cooling to 43.3°C, adding 3% inoculum of the material under test, and fermenting at 43.3°C for 4 h. The total yogurt organisms are enumerated in the test material both before and after fermentation by a standard procedure (IDF, 2003). The activity test is met if there is an increase of 1 log or more of yogurt culture cells during fermentation.
Generally, at the time of manufacture, live and active refrigerated yogurt should contain not less than 100 million \( (10^8) \) CFU/g. Assuming that storage temperature of yogurt through distribution channels and the grocery store is 4–7°C, a loss of 1 log cycle in culture viability is expected during the period between manufacture and consumption. Therefore, at the time of consumption, yogurt should deliver at least 10 million \( (10^7) \) CFU/g of live yogurt organisms per gram of product. In case yogurt undergoes temperature abuse, it is desirable to manufacture yogurt with even higher counts of viable culture to assure that at consumption stage, the product contains at least 10 million \( (10^7) \) CFU/g.

Yogurt products with live and active cultures are associated with several health attributes. The literature describes several strain-specific benefits corroborated by credible clinical studies (Sanders & Marco, 2010). The benefits include stimulation of the immune system, improvement of digestive regularity, reduction of lactose intolerance symptoms, enhancement of calcium absorption, reduction of serum cholesterol and risk of cardiovascular disease, enhancement of resistance to colonization by pathogenic organisms, and restoring the normal balance of gastrointestinal microflora (Chandan, 2011).

### 18.5.6 Nutrient profile of yogurt

The typical composition and nutrient profile of yogurt is shown in Table 18.7. In general, yogurt contains more protein, calcium, and other nutrients than milk, reflecting the extra solids-not-fat content. Therefore, its nutritional profile is similar to that of milk fortified with non-fat solids. A distinctive dimension of nutrition and health is furnished by the culturing process used for making yogurt. Therefore, active bacterial mass and products of

<table>
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<tr>
<th>Table 18.7 Typical nutrient profile of yogurt</th>
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<td>Nutrient/100 g</td>
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<td>Moisture</td>
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<td>Calories, kcal</td>
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<td>Protein, g</td>
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<td>Total fat, g</td>
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<td>Saturated fatty acids, g</td>
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<td>Monounsaturated fatty acids, g</td>
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<tr>
<td>Polyunsaturated fatty acids, g</td>
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<tr>
<td>Cholesterol, mg</td>
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<td>Carbohydrates, g</td>
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<tr>
<td>Total dietary fiber, g</td>
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<tr>
<td>Ash, g</td>
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<tr>
<td>Phosphorus, mg</td>
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<td>Niacin, mg</td>
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<td>Ascorbic acid, mg</td>
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1 NDB No. 01118; 2 NDB No. 01117; 3 NDB No. 43261; 4 NDB No. 01120; 5 NDB No. 01203.
the lactic fermentation further distinguish yogurt from milk. As stated earlier, live and active cultures in yogurt products contribute interesting health benefits to the consumers of yogurt that are not reflected in the nutrition label.

### 18.6 Cultured (or sour) cream

Cultured cream (or sour cream) is manufactured by ripening pasteurized cream of 18% fat content with lactic and aroma-producing bacteria. The FDA has defined sour cream in section 131.160 (CFR, 2011): “Sour cream results from the souring, by lactic acid producing bacteria, of pasteurized cream.” It contains not less than 18% milk fat. The fat content may be lower in sour cream products containing bulky ingredients, but it cannot dip below 14.4%. Sour cream must have a titratable acidity of at least 0.5%, expressed as lactic acid. Optional ingredients include stabilizers to improve texture and to avoid wheying-off. The stabilizers help to maintain body and enhance shelf life. In addition, sodium citrate up to 0.1% may be added as a flavor precursor. Salt, rennet, and flavoring ingredients including nutritive sweeteners and fruit products are permitted. Acidified sour cream (CFR Section 131.162) is obtained by direct addition of food-grade acids to pasteurized cream containing 18% milk fat. The process involves no fermentation. All other FDA requirements are identical to those for cultured sour cream.

The fermenting bacteria generate lactic acid to create an acid gel and butter-like (diacetyl) aromatic flavor. The starter for cultured cream is composed of acid producer (Lactococcus lactis subsp. lactis) and/or Lactococcus lactis subsp. cremoris. The aroma component is provided by Leuconostoc mesenteroides subsp. cremoris and/or Lactococcus lactis subsp. lactic biovar diacetylcis. The lactococci use lactose to produce up to 0.8% lactic acid by a homofermentative pathway, while the aroma producers are heterofermentative. They generate d-lactic acid, ethanol, acetic acid, and CO₂ from lactose. The typical flavor of sour cream is ascribed to diacetyl, which is produced from citrate. Leuconostocs break down acetaldehyde to ethanol. Acetaldehyde gives yogurt its typical flavor (green apple flavor), whereas this flavor is undesirable in sour cream. Some strains of lactococci produce viscosity-generating exopolysaccharides. It is common to utilize starters containing 60% acid producers, 25% acid and viscosity generators, and 15% flavor producer organisms (Goddik, 2012).

Cultured cream is used as an adjunct in baked potatoes and other hot dishes. The texture of sour cream must be maintained (lack of syneresis, no viscosity loss) on hot dishes. It forms a topping on vegetables, salads, fish, meats, and fruits. It can be utilized as a filling in cakes or in soups in place of buttermilk or sweet cream. It is an integral part of many Mexican dishes. It can be dehydrated by spray drying and used as an ingredient wherever its flavor is needed.

### 18.6.1 Processing

#### 18.6.1.1 Raw materials

The basic raw material of cultured sour cream is cream of high organoleptic and microbiological standards. Cream used in the manufacture of cultured cream should be fresh, with a relatively low bacterial count. During cream separation from milk, the bacteria tend to concentrate in the lighter phase, cream, thereby enhancing its vulnerability to spoilage. Raw cream should not be subjected to turbulent mixing, which leads to activation of lipase, disruption of milk fat globule membrane, and subsequent rancid flavor. Non-fat milk solids are needed to standardize sour cream mix. Condensed skim milk or non-fat dry milk is generally used to increase the solids-not-fat in sour cream mix to 9.0–9.5%. In addition, most sour cream processors use stabilizers to increase viscosity and stability and to prevent whey separation. Stabilizers for sour cream containing 18% milk fat consist of a combination of gelatin, modified starch, Grade A whey products, guar gum, locust bean gum, carrageenan, sodium phosphate, and calcium sulfate at a level of 1.5–1.8%. This stabilizer combination is increased to 1.75–2.0% in low-fat sour cream. The non-fat version uses a blend of modified starch, propylene glycol monoster and additional water-binding agents like microcrystalline cellulose, cellulose gum, and gum acacia. This blend is used at a level of 6.2–6.6% (Goddik, 2012). Sodium citrate is added to act as a precursor of flavoring compound generation during fermentation, thereby enhancing the flavor of sour cream. It aids in the production of minor levels of CO₂ (Born, 2013). This gas needs to be controlled by judicious selection of starter to avoid lid popping or swelling of packages. The coagulating enzyme chymosin (single-strength rennet) at the rate of 5 mL/100 gallons of mix is carefully added for texture improvement. The starter procured from culture suppliers is especially designed for sour cream production.
18.6.1.2 Mix preparation
Cream is blended with non-fat dry milk (or condensed skim milk) to standardize composition to 18.5% milk fat and 27.5% total solids at 4°C. Next, the stabilizer is incorporated and care is taken to insure hydration of the gums without incorporation of air and excessive foam formation.

18.6.1.3 Homogenization
The mix is preheated to 71°C for homogenization treatment. The mix is typically homogenized by two single-stage passes at 2500 psi (17.2 MPa) pressure. This step helps to produce firm-bodied sour cream.

18.6.1.4 Heat treatment
Next, the mix is heat treated at 73.9–79.4°C for 30 min (vat pasteurization) or at 82.2–85°C for 3–4 min (HTST process) (Born, 2013). The intense heat treatment denatures whey proteins, leading to enhanced water absorption as well as higher viscosity and a smooth thick body after culturing. The pasteurized-homogenized mix is cooled to 21.1–23.9°C and transferred to a cone-bottom processing vat.

18.6.1.5 Ripening
The pasteurized mix is inoculated with direct set or bulk sour cream starter, similar to yogurt processing. Rennet is also incorporated at 5 mL/100 gallons mix. To avoid grainy texture, rennet is diluted with water (1:40) and gently stirred into the vat. During culturing, the vat contents are not disturbed to avoid consistency problems. The incubation is continued until pH drops to 4.5 prior to breaking. For institutional sale, some manufacturers process cultured cream in individual-size packs. The packages are filled with inoculated mix and incubated to develop desirable acidity and subsequently cooled. In some cases, the packages are filled soon after ripening, followed by cooling. A heavy-bodied product is formed on cooling in the package.

18.6.1.6 Breaking
The set bulk sour cream is broken with slow-sweep agitation (Born, 2013). With the agitator off, the cream is pumped using a positive drive pump through a screen, back pressure valve or similar smoothening device, to a packaging machine. Occasional agitation may be needed to insure that whey pockets are blended back into the main body of the sour cream.

18.6.1.7 Packaging and cooling
Sour cream containing live organisms is packaged into appropriate containers at incubation temperature (21–24°C). The packages are then transferred to coolers at 4°C for cooling overnight. This process allows the clot to reform and maximum body firmness is achieved. Factors affecting viscosity of cultured cream are: acidity, mechanical agitation, heat treatment, solids-not-fat content, rennet addition, and homogenization. The lactic cultures *Lactococcus lactis* subsp. *diacetylactis* and *Leuconostoc cremoris* not only provide flavor, but also enhance the smoothness, and to some extent the viscosity, of cultured cream.

18.6.1.8 Hot pack process
In this case, ripened sour cream is blended with a commercial stabilizer to confer heat stability under acidic conditions. The blend is subjected to pasteurization at 74°C for 30 min or at 85°C for 1 min to destroy the culture, enzymes, and contaminants in the finished product, followed by packaging while still hot (Chandan, 1982). Accordingly, hot pack processing ensures long shelf life. Packaging in a plastic or metal container with a hermetically sealed lid further ensures prevention of recontamination by microorganisms as well as protection from oxidative deterioration of milk fat in the finished product. The flavor of the hot pack process is not identical to fresh sour cream. It may be postulated that some of the volatile flavor compounds are lost as a result of heat treatment.

18.6.1.9 Sour cream with lower fat content.
Consumer demand for low-fat dairy foods has resulted in several lower fat sour cream products in the marketplace. The standard of identity of sour cream was changed to accommodate products such as sour half and half with 10.5% fat, reduced-fat sour cream (13.5% fat), and non-fat or fat-free sour cream (<0.5 fat/serving of 1 tbsp). These products use extra levels of non-fat solids, whey proteins and stabilizer blends to achieve body and texture comparable to regular sour cream. With extra solids-not-fat in the mix, care should be taken to select a culture with low CO₂ production. Otherwise, the packages would bulge with gas pressure.
18.6.1.10 Filled sour cream
This product may be defined as cultured cream in which part or all of the milk fat has been replaced by vegetable oils or fats. It appears to have advantages over conventional cultured cream in terms of price, caloric value or saturated fatty acid content. Non-fat milk suspension or skim milk is mixed with an appropriate emulsifier and appropriate vegetable oil. Homogenization of the mix and subsequent fermentation result in an acceptable product used mainly in chip dip production. In this regard, a suitable product may be manufactured using a process identical to that for cultured cream with the exception of the starting material.

18.6.1.11 Imitation sour cream
This product is made with vegetable oil and sodium caseinate replacing all the milk fat in its formulation. An imitation sour cream may be prepared by emulsifying a suitable fat in suspensions of casein compounds or soybean protein products. A suitable emulsifier, stabilizer, flavor, and color may be incorporated in the starting mix. It may be fermented or directly acidified.

18.6.1.12 Sour cream dip
Party dips are based on sour cream or filled sour cream or imitation sour cream. The dips are made by blending appropriate seasoning bases. By packaging under refrigerated conditions, the product has a shelf life of 2–3 weeks under refrigerated storage. However, for a shelf life of 3–4 months, a hot pack process is used (Chandan, 1982). To build extra body and stability, 1–2% non-fat dry milk and 0.8–1.0% stabilizer are incorporated at 80 °C in formulating sour cream. The mixture is pasteurized by holding for 10 min, and homogenized at 17.2 kPa to resuspend and produce a smooth product. The seasonings are blended at this stage while the mix is still at 80 °C, followed by hot packing in sealed containers. Upon cooling and storage at 5 °C, a partial vacuum inside the container assists in the prevention of oxidative deterioration to yield an extended shelf life of 3–4 months.

18.6.1.13 Quality control
In general, quality control considerations applicable to refrigerated yogurt are relevant to cultured cream. Table 18.8 summarises typical quality problems and steps needed to rectify them.

18.7 Cheeses

18.7.1 Types of cheeses
There are more than 400 varieties of cheese recognized as distinctive varieties in the world. Different cheese varieties use different techniques, specific starters and varying acidity development regimes, brine or dry salting and distinct ripening conditions to develop their textures and flavors (Bottazzi, 2003; Chandan & Kapoor, 2011a, 2011b; Hill, 2009). Some cheeses are made without cultures and coagulating enzymes. In such cheese manufacture, curd formation is carried out by adding edible acid directly to hot milk (Chandan, 2003, 2007).

Natural cheese is made directly from milk. Some cheeses, like ricotta, are made from whey or milk-whey blends. Most cheeses are obtained after curding or coagulation of milk, cream, partly skimmed milk, buttermilk or a mixture of these raw materials. The coagulum obtained is stirred and heated, followed by draining of the whey and collecting and pressing the curd. Cheese may be ripened or sold as fresh product. Ripening is also referred to as curing or maturing. It is carried out by storing cheese in cold rooms at 10–18 °C for at least 2–3 months, during which time the development of acid continues and other chemical and bacteriological changes take place to bring about the desired flavor, aroma, body, and texture in the cheese. Based on its body or texture, cheese may be classified as very hard (Romano, Parmesan), hard (Cheddar, Swiss, etc.), medium (Brick and Limburger), or soft (Camembert) (Fox, 2003a; Olson, 2003). Fresh cheeses do not undergo ripening. Hard cheeses are prepared by different traditional methods using lactic acid cultures to develop characteristic flavors. Rennet/chymosin is typically used in the process as the coagulating enzyme. The hard cheeses normally contain salt.

Figure 18.2 shows the classification based on whether the cheese is ripened or not. Figure 18.3 contains classification of cheeses based on moisture content, firmness, and ripening microorganisms.

Dairy ingredients in cheese manufacture are milk, non-fat milk, or cream, used alone or in combination. Milk (CFR 131.110) is defined by the Code of Federal Regulations (CFR, 2011) as the lacteal secretion, practically free from colostrum, obtained by the complete milking of one or more healthy cows, which may be clarified. Fat content may be adjusted by separating part of the fat. Concentrated milk (CFR 131.115), reconstituted milk, and dry whole milk (CFR 131.147) may also be used. Non-fat milk means skim milk, concentrated skim milk, reconstituted
### Table 18.8 Typical flavor, body, and texture quality problems in sour cream

<table>
<thead>
<tr>
<th>Defect</th>
<th>Probable cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flavor defects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insufficient flavor</td>
<td>Low citrate level in milk</td>
<td>Add 0.02–0.05% (up to 0.1%) sodium citrate prior to the mix. Insure flavor producing bacteria in the starter</td>
</tr>
<tr>
<td></td>
<td>Poor acid development</td>
<td>Use correct incubation temperature. Insure pH at breaking is 4.5</td>
</tr>
<tr>
<td></td>
<td>Flavor masked by too much stabilizer</td>
<td>Use correct level and type of stabilizer system</td>
</tr>
<tr>
<td></td>
<td>Acetaldehyde accumulation</td>
<td>Use proper culture for sour cream</td>
</tr>
<tr>
<td></td>
<td>High incubation temperature and/or excessive incubation time</td>
<td>Follow standard procedure for incubation temperature and time</td>
</tr>
<tr>
<td>Green/yogurt flavor</td>
<td>Copper and iron contamination</td>
<td>Avoid exposure to copper utensils</td>
</tr>
<tr>
<td></td>
<td>Exposure to fluorescent light or sunlight</td>
<td>Protect product from direct sunlight/UV light exposure</td>
</tr>
<tr>
<td>Oxidized (cardboard) flavor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yeast-like/cheesy flavor</td>
<td>Contaminating yeast growth</td>
<td>Sanitation check. Avoid return milk</td>
</tr>
<tr>
<td>Rancid flavor</td>
<td>Cream/raw milk contains heat-stable lipases</td>
<td>Do not mix pasteurized and raw dairy ingredients prior to homogenization</td>
</tr>
<tr>
<td></td>
<td>Poor handling of raw milk/cream during pumping</td>
<td>Use fresh cream and follow standard processing procedures</td>
</tr>
<tr>
<td>Bitter flavor</td>
<td>High psychrotrophic bacterial counts in milk/cream</td>
<td>Use cream of high microbiological quality</td>
</tr>
<tr>
<td></td>
<td>Excessive proteolytic activity of starter culture</td>
<td>Use right starter designed for sour cream</td>
</tr>
<tr>
<td>Unnatural/chemical flavor</td>
<td>Absorbed flavors from environment</td>
<td>Avoid storage/exposure of sour cream to solvents, cleaning supplies, fruit, and vegetables</td>
</tr>
<tr>
<td></td>
<td>Contamination with residual cleaning compounds/sanitizers</td>
<td>Insure absence of residue of cleaning compounds and sanitizers in the pipes and tanks</td>
</tr>
<tr>
<td><strong>Body and texture defects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak body</td>
<td>Heat treatment of the mix is insufficient or excessive</td>
<td>Heat treatment should be set at 85°C/3–4 min or 74°C/30 min</td>
</tr>
<tr>
<td></td>
<td>Milk solids-not-fat too low</td>
<td>Fortify with 2–3% non-fat dry milk</td>
</tr>
<tr>
<td></td>
<td>Stabilizer level low</td>
<td>Use appropriate stabilizers-thickeners Insure full hydration</td>
</tr>
<tr>
<td></td>
<td>Agitation too severe during and/or after fermentation</td>
<td>Use rennet in sour cream mix Check homogenizer efficiency</td>
</tr>
<tr>
<td>Grainy texture</td>
<td>Acidity too high</td>
<td>Insure quiescent fermentation and control shear after fermentation</td>
</tr>
<tr>
<td></td>
<td>Non-fat dry milk or excessive rennet not dispersed properly</td>
<td>Exercise rigid acidity control</td>
</tr>
<tr>
<td></td>
<td>Excessive heat treatment of mix</td>
<td>Dispersion equipment check</td>
</tr>
<tr>
<td></td>
<td>Screen/back pressure valve left out of line between tank and filler</td>
<td>Dilute rennet prior to dispersing Discount high heat treatment</td>
</tr>
<tr>
<td></td>
<td>Stabilizer (pectin, alginate, carrageenan) reaction with protein</td>
<td>Use standard heat treatment Use in-line screen to smoothen the texture</td>
</tr>
<tr>
<td>Chalky/powdery texture</td>
<td>Too much non-fat dry milk</td>
<td>Insure proper ratio of stabilizer ingredients for sour cream production</td>
</tr>
<tr>
<td>Free whey pockets</td>
<td>Temperature/physical shock for packages</td>
<td>Avoid excessive agitation of mix during setting</td>
</tr>
<tr>
<td></td>
<td>Low solids mix, improper heat treatment of mix, wrong stabilizer or improper blending</td>
<td>Check on the quality and quantity of dry milk</td>
</tr>
<tr>
<td>Gummy body</td>
<td>Breaking above pH 4.5</td>
<td>Check formulation sheet for stabilizer level</td>
</tr>
<tr>
<td></td>
<td>Too much stabilizer</td>
<td>Change starter.</td>
</tr>
<tr>
<td></td>
<td>The starter produces excessive polysaccharides</td>
<td></td>
</tr>
</tbody>
</table>

skim milk, and non-fat dry milk. Cream means cream, reconstituted cream, dry cream, and plastic cream. Water, in a sufficient quantity to reconstitute concentrated and dry forms, may be added. Cheese can be made from cream, whole milk, reduced-fat, low-fat or non-fat milk or from mixtures thereof. Some cheeses are made from whey, whey cream, or whey-milk mixtures. Furthermore, milk of sheep, goats, water-buffaloes, and other milk producing animals yields distinct color, flavor, and texture profiles (Aneja et al., 2002).

Most cheeses are made from pasteurized milk. FDA regulations require that every particle of milk shall have been heated in properly designed and operated equipment to 63°C or 72°C and held continuously at or above that temperature for 30 min or 15 sec, respectively (CFR 133.3d). Pasteurized dairy ingredients must conform to the phosphatase test for legal pasteurization.

Hydrogen peroxide treatment may be used in lieu of heat treatment (cold pasteurization), followed by a sufficient quantity of catalase preparation to eliminate the hydrogen peroxide. The weight of the hydrogen peroxide shall not exceed 0.05% of the weight of the dairy ingredients and the weight of the catalase shall not exceed 20 parts per million of the weight of dairy ingredients treated (CFR 133.113). If the dairy ingredients are not pasteurized, the cheese is cured at a temperature of not less than 1.7°C (35°F) for at least 60 days.

As with all cultured products discussed in this chapter, starters for cheese making are composed of harmless
cultures. They are used for acid and flavor production during cheese making and curing. Coagulants or clotting enzymes include calf rennet/chymosin and/or other clotting enzymes of animal, plant, or microbial origin.

Calcium chloride, in an amount not more than 0.02% (calculated as anhydrous calcium chloride) of the weight of the dairy ingredients, can be used as a coagulation aid. Ripening aids of enzymes of animal, plant, or microbial origin aid in curing or flavor development. The level of such enzymes cannot exceed 0.1% of weight of the milk used (CFR 133.102). Cheese colors may be used to give characteristic color to certain cheeses and to give light cream color to cheeses made from winter milk, which

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**Figure 18.3** A classification of cheeses based on moisture content, firmness, and ripening microorganisms. Source: Chandan and Kapoor (2011a).
normally lacks creamy color. Certain lipases and protease preparations are added to cow’s milk to accelerate ripening and to simulate the traditional flavor of feta, Romano, and Parmesan cheese.

Slices or cuts of most cheeses in consumer-sized packages may contain an optional mold-inhibiting ingredient consisting of sorbic acid, potassium sorbate, sodium sorbate, or any combination of two or more of these, in an amount not to exceed 0.3% by weight, calculated as sorbic acid (CFR 133.173).

18.7.2 Cheddar cheese

Cheddar cheese, named after a town of the same name in England, is a variety of firm and hard cheese made from standardized milk, which is then cured for as long as 6 months. If no color is used, Cheddar has a cream-like appearance; goat’s milk Cheddar is white. The US Code of Federal Regulations requires Cheddar cheese to contain a minimum milk fat content of 50% by weight of the solids, and the maximum moisture content is specified at 39% by weight (CFR, 2011). The production of Cheddar cheese is described in brief below. The reader is referred to Clark and Agarwal (2007) for a comprehensive review of Cheddar cheese and related cheeses. Low-sodium Cheddar cheese is Cheddar cheese that contains not more than 96 mg sodium/pound of finished product. Reduced-fat Cheddar cheese contains 19.2–22.9% fat and 49% moisture.

18.7.2.1 Essentials of Cheddar cheese production

18.7.2.1.1 Standardization of milk

Milk is standardized to a fat:casein ratio of 1.47. Various automated milk standardization instruments are used. For instance, milk analyzers based on infrared technology improve production efficiency as well as the quality and consistency of cheese. Fat content of raw milk can be reduced to a desirable level by the use of a separator. Another way is to add skim milk.

18.7.2.1.2 Heat treatment of milk

Certain cheeses are made from raw milk. Public health concerns dictate that such cheeses must be held at 1.67°C or higher for at least 60 days before they can be consumed (CFR 133.113). For fresh (unripened) cheeses, the FDA regulations require heat treatment of 71.1°C for 15 sec or 63°C for 30 min for proper pasteurization of milk for cheese making (CFR 133.3). Some plants use “thermization” treatment of 63–65°C for a few seconds to prevent the spoilage of milk stored over weekends, but the milk requires full pasteurization prior to cheese making. The pasteurized milk is tempered to 31°C and transferred to a cheese vat.

18.7.2.1.3 Additives

Certain additives are permitted. Calcium chloride, at 0.02% level in milk, accelerates coagulation and improves cheese yield. Cheese color (at the rate of 70 mL/1000 kg of milk) ensures uniformity of cheese color throughout the year. For white Cheddar, no color is added. In this regard, norbixin (anatto seed extract) and carotenoids are used. In certain cheeses, titanium dioxide and chlorophyll-based colorants are permitted in cow’s milk to simulate the white appearance of milk of goat, sheep, and water-buffalo.

18.7.2.1.4 Starters

In Cheddar cheese, a starter is used to introduce desirable Lactococcus cultures for acidification and to accelerate coagulation of milk. The starter may be prepared in the plant or purchased for direct inoculation of milk. As mentioned earlier, bulk starter containing Lactococcus lactis subsp. lactis/cremoris is added at the rate of 0.5–2%.

18.7.2.1.5 Coagulation

Coagulation is a key step in cheese making. When the culture growth is indicated by a pH drop of 0.05 pH unit (increase of 0.01% titratable acidity (TA)), rennet/chymosin is added to the vat at the rate of 190 mL/1000 kg of milk after diluting with 10–40 volumes of water.

18.7.2.1.6 Cutting

When the curd is firm enough (usually in 25 min), it is cut using two sets of knives, horizontal and vertical, made of arranged wires separated by 9.5 cm (3/8”). The horizontal and vertical knives are used in succession for three-dimensional cutting of the curd, resulting in cubes of curd suspended in whey liquid. After 5 min, the curd is agitated very gently for 10 min.

18.7.2.1.7 Cooking

The vat contents are cooked at the rate of 1°C/5 min to reach 39°C in 30 min. If the whey has higher pH at cutting, cooking is extended to 60 min. Cooking is continued
until the pH of whey drops to 6.2–6.3; it may take 75 min to achieve this acidity. The curd should shrink to about the half of the original size observed before cooking. It should be firm with no soft or mushy center. The curd should not stick together when pressed manually.

18.7.2.1.8 **Whey drainage**

At this point, the Cheddaring process starts by removing 50–70% of the whey. The curd is continuously stirred and the remaining whey continues to drain to dry out the curd.

18.7.2.1.9 **Cheddaring**

The curd is piled 4–5” (10.2–12.7 cm) deep along the sides of the vat for matting/congealing. Whey drains slowly through a trench, which is cut in the middle. The front edges of matted curd are cut and layered on the adjacent slabs, which are then cut further into 2–3” thick strips and piled again. The temperature of the curd is maintained at 30–35°C. The slabs are turned repeatedly at 5–15-min intervals during a 2-h period.

18.7.2.1.10 **Milling**

When the pH of whey drops to 5.3–5.4, the slabs are milled and whey is continuously removed. At this stage, the curd slab should peel, reminiscent of chicken breast. Milling involves running the slabs through a milling machine and cutting them into small finger-size curds. After milling, the curds are stirred vigorously to avoid matting. At this stage, the curds should have round and smooth edges. The curd temperature should be maintained at 27–32°C during milling.

18.7.2.1.11 **Salting**

After 15–30 min, the curd is sprinkled with salt. To impart the true taste of sodium chloride, the salt used in cheese making should not be iodized. The amount of salt varies from 2 to 3 kg/1000 kg of initial milk. More moist curd needs more salt to drop the moisture within the proper range for Cheddar cheese. Salting results in more whey drainage. The target salt content of cheese is 1.7% (w/w). The salted whey drippings are removed.

18.7.2.1.12 **Hooping**

Next, a disposable plastic or cheese cloth liner is inserted into a 20 lb hoop and 22 lb of curd is weighed into the cheese hoops, which are usually made of stainless steel. The lid is placed on the top prior to pressing.

18.7.2.1.13 **Pressing**

The hoops are lined up in the press and pressed for 12–18 h at 10–20 psi (75 kPa). Pressing time is much shorter in automated systems. After pressing, the blocks are removed from the hoops, vacuum packed in films and shrunk skin-tight by dipping in hot water, and transferred to the ripening room.

18.7.2.1.14 **Ripening**

The purpose of ripening is to generate cheese flavor attributed largely to lipid and protein breakdown caused by bacterial enzymes. Ripening temperature varies from 5–8°C for slow ripening or 10–16°C for fast ripening. Slow ripening leads to better flavor control. The ripening period may vary from 3 to 9 months or even longer to achieve a sharper flavor. Cheddar cheese standards are a minimum of 50% fat in dry matter and a maximum of 39% moisture (CFR 133.113). However, for long-hold Cheddar, the moisture should not exceed 36%. For short-hold Cheddar, the moisture content ranges from 37% to 39%. Cheddar cheese yield is generally around 9.5–10.0 kg/100 kg of milk.

18.7.3 Pasteurized process cheese

At the turn of the 20th century, developments in melting processes, involving natural cheese of various ages, gave birth to a line of process cheese products with controlled flavor, texture, and functionality, and extended shelf life. Pasteurized process cheese is the food prepared by comminuting and mixing, with the aid of heat, one or more cheeses of the same or two or more varieties (except cream cheese, Neufchatel cheese, cottage cheese, creamed cottage cheese, cook cheese, hard grating cheese, semi-soft part-skim cheese, part-skim spice cheese, and skim milk cheese) with an emulsifying agent into a plastic homogeneous mass (CFR 133.169). Heating is at not less than 65.5°C and for not less than 30 sec. Moisture content shall not exceed 1% more than constituent natural cheese, but not exceed 43% (i.e. Colby: less than 40%, Swiss: less than 42%, Limburger: less than 51%). Fat in dry matter is similar to natural cheese, not less than 47% in general (e.g. Swiss: not less than 43%; Gruyere: not less than 45%). Pasteurized process cheese is prepared by melting Cheddar and other types of cheeses, usually the hard-pressed varieties, and emulsifying them with salts, especially citrates and phosphates, and often water. The mixture
is heated to kill bacteria present and has, after packing in foil, a long keeping quality.

*Pasteurized process cheese food* is similar to pasteurized process cheese, except it must contain moisture not exceeding 44% and fat content not less than 23% (CFR 173.173). It may also contain optional dairy ingredients: cream, milk, skim milk, buttermilk, cheese whey solids, anhydrous milk fat, and skim milk cheese for manufacturing. The pH is adjusted to not below 5.0 with vinegar, lactic acid, citric acid, phosphoric acid, or acetic acid. It cannot contain more than 3% emulsifying agents and 0.2% sorbic acid.

*Pasteurized process cheese spread* is similar to pasteurized process cheese food, but is spreadable at 21 °C. It has moisture content of 44–60% and fat content not less than 20% (CFR 133.179). It may contain optional dairy ingredients, emulsifying agents, and gums (less than 0.5%). Acids may be added to achieve a pH not below 4.0. Sweetening agents may be used (sugar, dextrose, corn sugars). Sorbic acid (less than 0.2%) may be used as a preservative.

*Cold pack cheese (club cheese)* involves blending without heating various cheeses. Only cheese from pasteurized milk shall be used. Its moisture content is the same as that of individual cheeses and the fat content in dry matter is not less than 47% in most cheeses except Swiss (not less than 43%) and Gruyere (not less than 45%) (CFR 133.123). Cold pack cheese may contain acids to standardize pH to not below 4.5. Sorbic acid (less than 0.3%) can be used as a preservative.

*Cold pack cheese food* is prepared by comminuting and mixing (without heating) cheeses and other ingredients like cream, milk, skim, buttermilk, whey solids, and anhydrous milk fat. Acids may be added to standardize pH to not less than 4.5 (CFR 124). Sweetening agents (sugar, corn solids) may also be used. Sorbic acid (0.3%) may be used as a preservative. Guar gum or xanthan gum may be used (0.5%). Moisture content cannot exceed 44% and fat content is not less than 23%.

### 18.7.4 Mechanization in the cheese industry

Automation and mechanization in cheese production have resulted in economies of scale and establishment of mega plants handling several million kilograms of milk per day. The standardization of cheese milk for fat:casein ratio is done by automated systems. Cheese making is done in automated vats in which computer-controlled filling, culture addition, renneting, cutting, stirring, cooking, and emptying operations form an integral part. These vats are enclosed double-jacketed vats with mechanical cutting and stirring devices. The cutting and stirring blades rotate on a shaft vertically or horizontally by a variable speed drive. Computer-controlled sequences in cheese process and in-line pH control further help in saving labor. Many vats are equipped with an automated gel-strength analyzer to standardize the end point of the cutting phase. Curd and whey separation is done on a draining conveyer. In a cheddaring tower, vacuum and air pressure are used for compaction of the curd. The curd is milled and salted in a salting/mellowing conveyer. The salted curd is pressed and formed into 40 lb (or 640 lb) blocks in a block former, followed by mechanized packaging and conveying to the ripening room. Barrel cheese is of the order of 500 lbs per barrel.

### 18.7.5 Quality control

The US FDA has established compositional standards for natural cheeses (Table 18.9). It is imperative to ascertain that the products produced in a cheese plant adhere to the standards. In this regard, the processing parameters should be standardized for each cheese and standard procedures need to be followed by plant personnel.

The appearance, color, body, and texture as well as flavor are critical consumer attributes of high-quality cheese. Common defects in appearance and color of Cheddar cheese are shown in Table 18.10. Commonly observed defects and remedial measures are also included. The appearance of mold is avoided by use of a mold inhibitor or netamycin dip and effective packaging techniques. In this regard, vacuum packaging in transparent plastic cheese films is very helpful to protect cheese from contact with air.

For judging true flavor, body, and textural characteristics of cheese, it is necessary to temper the cheese sample to 10–15.6 °C. A cheese trier is a double-edged curved knife commonly employed for sampling large blocks of cheese. The trier is penetrated into the cheese block, rotated one-half turn, and pulled out to obtain a long cylindrical piece of cheese known as a plug. This piece is examined for aroma, body, texture, and flavor of the cheese sample. Cheddar cheese should ideally give a waxy and smooth-sided plug which should bend fairly well without snapping but should break slowly upon bending. Flavor, body, and texture are a function of the fermentation pattern. The breakdown of protein and fat leads to chemically simpler and more volatile compounds. Control of bacteriological and biochemical transformations is therefore necessary to insure consistent good quality.

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**Table 18.10: Common defects in appearance and color of Cheddar cheese**

- **Defect**: Astringent
  - **Description**: The cheese has a bitter taste or a sour, metallic flavor.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Brittle
  - **Description**: The cheese is too hard or breaks easily.
  - **Remedial Measures**: Adjust the pH and moisture content, use proper refrigeration, and ensure proper aging.

- **Defect**: Dodgey
  - **Description**: The cheese has a dry, white coating on the surface.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Dull
  - **Description**: The cheese has a dull, matte appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Fatty
  - **Description**: The cheese has a greasy or oily appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Greasy
  - **Description**: The cheese has a greasy or oily appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Hard
  - **Description**: The cheese is too hard or breaks easily.
  - **Remedial Measures**: Adjust the pH and moisture content, use proper refrigeration, and ensure proper aging.

- **Defect**: Honeycomb
  - **Description**: The cheese has a honeycomb or sponge-like appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Inflated
  - **Description**: The cheese has a puffed or inflated appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Nutritional
  - **Description**: The cheese has a dry, white coating on the surface.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Soft
  - **Description**: The cheese is too soft or lacks body.
  - **Remedial Measures**: Adjust the pH and moisture content, use proper refrigeration, and ensure proper aging.

- **Defect**: Spongy
  - **Description**: The cheese has a sponge-like appearance.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.

- **Defect**: Stale
  - **Description**: The cheese has a stale or off-flavor.
  - **Remedial Measures**: Use a mold inhibitor or netamycin dip, ensure proper pH control, and use effective packaging techniques.
of cheese. The reader is referred to Partridge (2009) for sensory evaluation of Cheddar cheese as a parameter of quality.

Table 18.11 shows common defects in the body and texture of cheese and suggested steps to avoid them. Table 18.12 enumerates flavor defects in Cheddar cheese and suggestions for avoiding them.

In addition, quality factors include functionality and behavior when used in cooking. The melting character and stability to heat (no fat separation) are also desirable attributes, particularly for process cheese varieties.

### 18.8 Sustainability efforts in whey processing

The dairy industry is making many efforts to mitigate negative environmental impacts of fermented dairy food processing, but deep discussion is beyond the scope of this chapter. However, to that end, whey utilization must not be overlooked.

Whey is the liquid substance obtained by separating the coagulum from milk, cream or skim milk in cheese making (Huffman & Ferreira, 2011). Whey also originates from casein manufacture. Sour cream and yogurt manufacture do not yield whey, except in the case of Greek yogurt where large volumes of whey are generated as a result of the straining/centrifuging step. Whey contains about half of the solids of whole milk. Its composition depends largely on the variety of cheese being made. For every kilogram of cheese produced, approximately 9 kg of whey is generated. The whey solids are valuable additions to the functional properties of various foods, as well as a source of valuable nutrients. Functional and nutritional products have been developed from whey.

Therefore, for economic viability, sustainability and

<table>
<thead>
<tr>
<th>Table 18.9 US FDA compositional standards for natural cheeses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Asiago, fresh</td>
</tr>
<tr>
<td>Asiago, medium</td>
</tr>
<tr>
<td>Asiago, old</td>
</tr>
<tr>
<td>Blue</td>
</tr>
<tr>
<td>Brick</td>
</tr>
<tr>
<td>Caciocavalle</td>
</tr>
<tr>
<td>Siciliano</td>
</tr>
<tr>
<td>Camembert, soft ripened</td>
</tr>
<tr>
<td>Cheddar</td>
</tr>
<tr>
<td>Colby</td>
</tr>
<tr>
<td>Cottage, dry curd</td>
</tr>
<tr>
<td>Cottage, low fat</td>
</tr>
<tr>
<td>Cottage, creamed</td>
</tr>
<tr>
<td>Cream</td>
</tr>
<tr>
<td>Edam</td>
</tr>
<tr>
<td>Gammelost</td>
</tr>
<tr>
<td>Gorgonzola</td>
</tr>
<tr>
<td>Gouda</td>
</tr>
<tr>
<td>Granular, stirred curd</td>
</tr>
<tr>
<td>Gruyere</td>
</tr>
<tr>
<td>Hard, grating</td>
</tr>
</tbody>
</table>

* % fat in cheese per se.
### Table 18.10 Problems related to color and appearance of Cheddar cheese

<table>
<thead>
<tr>
<th>Defect</th>
<th>Probable cause</th>
<th>Remedial measure</th>
</tr>
</thead>
</table>
| Acid-cut, bleached/faded, dull looking portions or entire surface of cheese | Excessive acid development in the whey or at packing stage  
Non-uniform moisture distribution in the cheese | Watch acid development carefully  
Take precautions to insure consistent and uniform moisture retention in curd |
| Mottled appearance, irregularly shaped light and dark areas on cheese surface | Combining curds of different colors, batches or moisture contents  
Uneven acid development in curd  
Growth of yeast and bacteria accompanied by typical fruity flavor and pasty body. H₂O₂ production by microorganisms | Avoid mixing starter after color addition  
Strain the starter before adding to vat  
Try to cut curd into uniform size particles  
Handle curd carefully to avoid drying during matting and cheddaring steps |
| Seamy, showing light colored lines around curd pieces. In extreme form cracked cheese | Exudation of fat in curd pieces due to excessive forking  
Warmer temperature  
Lack of dissolution of salt | Press curd at 85–90 °F  
Allow all the salt to dissolve completely  
Avoid too much forking of curd  
Wash greasy curd at 90 °F and drip dry the curd immediately |
| White specks or granules or smeared with white powder material | Generally tyrosine if present in aged cheese. Derived from crystallization of calcium lactate if present in young cheese | Ripen at consistent temperature; prevent temperature fluctuations  
Vacuum package  
Avoid oxygen in the package by vacuum/flushing with CO₂/N₂ gas |
| Moldy appearance                           | Mold growth on the surface                                                                           | Insure tight seals on cheese packages  
Avoid oxygen in the package by vacuum/flushing with CO₂/N₂ gas |


### Table 18.11 Body and texture defects in Cheddar cheese

<table>
<thead>
<tr>
<th>Defect</th>
<th>Probable cause</th>
<th>Remedial measure</th>
</tr>
</thead>
</table>
| Corky, dry and hard     | Lack of acid development  
Low fat in cheese  
Overcooked cheese curd  
Low moisture retention in cheese curd  
Excessive salt levels | Follow standard production procedures  
Avoid ripening at high temperatures  
Control acid development and moisture level in cheese  
Optimize ripening time and temperature  
Control acid development in relation to time and temperature parameters |
| Crumbly, mealy and short body | Excessive acid production and low moisture retention in cheese | Avoid ripening at high temperatures  
Control acid development and moisture level in cheese  
Optimize ripening time and temperature  
Control acid development in relation to time and temperature parameters |
| Rubberly or curdy       | Lack of curing conditions  
Excessive acid development  
Excessive moisture content | Optimize ripening time and temperature  
Control acid development in relation to time and temperature parameters  
Standardize fat in cheese milk  
Cook curd to desirable firmness (higher temperature, longer period)  
Avoid piling curd slabs too high or too soon while cheddaring curd |
| Pasty, sticky or wet    | Too high fat content  
Moisture content too high | Optimize ripening time and temperature  
Control acid development in relation to time and temperature parameters  
Standardize fat in cheese milk  
Cook curd to desirable firmness (higher temperature, longer period)  
Avoid piling curd slabs too high or too soon while cheddaring curd |

environmental reasons, whey processing is an integral part of cheese operations. In 2006, the US cheese industry produced 90.5 billion pounds of liquid whey (Ling, 2008) as a by-product.

In the past, whey was not efficiently utilized for human and animal nutrition products but dumped into rivers or sprayed over fields, resulting in wastage of the food resource and causing gross environmental pollution. Now, new technologies have enabled whey conversion into food ingredients of notable commercial significance. Dry sweet whey is produced by drying of defatted fresh whey obtained from Cheddar and Swiss cheese manufacture. It contains all the constituents except water in the same relative proportion as in liquid whey. Dry acid whey is similar to dry sweet whey but is produced by drying of fresh whey obtained from cottage and ricotta cheese manufacture.

The techniques of concentration or reverse osmosis, followed by evaporation and drying, recover all the solids, while the other systems (ultrafiltration, microfiltration, etc.) are fractionating techniques. Concentration reduces the amount of water, thereby lowering shipping costs through reduced bulk and improved keeping quality and providing a product more suitable for direct use in

Table 18.12 Flavor problems in Cheddar cheese

<table>
<thead>
<tr>
<th>Flavor defect observed</th>
<th>Probable cause</th>
<th>Remedial measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitter taste</td>
<td>Excessive moisture, Low salt level, Proteolytic strains of starters and/or contaminating microflora, Excessive acidity, Poor milk quality and/or sanitary conditions, Excessive rennet/chymosin, Hydrophobic peptides</td>
<td>Use less starter, Ripen for shorter time and/or lower temperature, Check salt level and salting technique, Check starter for purity/suitability, Improve cleaning and sanitizing practices, Control acid and rate of acid production</td>
</tr>
<tr>
<td>High acid/sour</td>
<td>Excessive acidity, Excessive moisture, Too much starter level, High acid milk used, Improper expulsion of whey from curd, Low salt level</td>
<td>Use less starter, Shorten ripening period, Follow standard procedure for cutting, cooking and salting steps</td>
</tr>
<tr>
<td>Fruity/fermented/ yeasty</td>
<td>Low acidity, Excessive moisture, Dirty equipment, Poor-quality milk, Microbial lipases from contaminated microflora, Late lactation milk or accidental homogenization of milk</td>
<td>Improve sanitation, Check and improve water quality, Follow standard procedure for cheese making and equipment cleaning, Check salting procedure, Check cheese milk for rancid flavor, Avoid excessive agitation, foaming and temperature fluctuations of raw milk, Avoid microbial contamination of milk and cheese by improving sanitation</td>
</tr>
<tr>
<td>Rancid/soapy</td>
<td>Milk lipases activated by improper milk production and handling practices, Microbial lipases from contaminating microflora, Late lactation milk or accidental homogenization of milk</td>
<td>Check starter activity, Increase starter level, Check curing temperature, Extend curing period, Follow standard procedure for fat standardization in milk and cheese making, Avoid excessive agitation, foaming and temperature fluctuations of raw milk, Avoid microbial contamination of milk and cheese by improving sanitation</td>
</tr>
<tr>
<td>Flat/weak/ low flavor</td>
<td>Lack of acid production, Low-fat milk used for cheese making, Excessively high cooking temperature, Too low ripening temperature/too short ripening period</td>
<td>Check starter activity, Increase starter level, Check curing temperature, Extend curing period, Follow standard procedure for fat standardization in milk and cheese making, Avoid excessive agitation, foaming and temperature fluctuations of raw milk, Avoid microbial contamination of milk and cheese by improving sanitation</td>
</tr>
<tr>
<td>Musty/moldy</td>
<td>Extensive mold growth on cheese surface, Usually associated with milk production (feed and physiological condition of cows), Seal cheese blocks/barrels to eliminate oxygen entry, Avoid milk with these flavors</td>
<td>Seal cheese blocks/barrels to eliminate oxygen entry, Avoid milk with these flavors</td>
</tr>
<tr>
<td>Miscellaneous off-flavors: barny, feed, malty, onion, weed</td>
<td>Seal cheese blocks/barrels to eliminate oxygen entry, Avoid milk with these flavors</td>
<td>Seal cheese blocks/barrels to eliminate oxygen entry, Avoid milk with these flavors</td>
</tr>
</tbody>
</table>

foods. The cost of removing a pound of water in an efficient evaporator may be about one-tenth the cost of removing it in a spray dryer. This consideration has encouraged the development of more uses of whey and whey fractions in concentrated form.

Drying gives maximum concentration, extends storage stability and provides a product amenable to food incorporation. Using an appropriate dryer, dairy processors convert sweet whey into a stable, non-hygrosopic and non-caking product. In this process, high solids whey concentrate is spray dried to a free moisture content of 12–14%, causing lactose to take on a molecule of water and become crystallized. This causes whey solids to convert from a sticky, syrup-like material into a damp powder with good flow characteristics. For drying acid cottage cheese whey, a commercial dryer combines spray drying with through-flow continuous bed drying. The concentrate is spray dried in the hot air chamber to 12–15% moisture. The particles fall to a continuous, porous, stainless steel belt where lactose undergoes rapid crystallization. Crystallization of lactose before final drying is mandatory for drying acid whey. A belt conveys the product to another chamber where the whey is further dried by dehumidified air that moves through the porous bed.

Fractionated whey products are produced by membrane technology (including ultrafiltration, reverse osmosis (RO), electrodialysis, etc.) and ion exchange techniques. The pressure-activated processes separate components on the basis of molecular size and shape. RO is the process in which virtually all species except water are rejected by the membrane. The osmotic pressure of the feed stream in such a system often will be quite high. Consequently, to achieve adequate water flux rates through the membrane, such systems often use hydrostatic operating pressures of 5883.6 kg/cm² (600 psi) or greater. Ultrafiltration (UF) is the process in which the membrane is permeable to relatively low molecular weight solutes and solvent (permeate), but is impermeable to higher molecular weight materials (Huffman & Ferreira, 2011). The permeability and selectivity characteristics of these membranes can be controlled during the fabrication process so that they will retain only molecules above a certain molecular weight. Thus, UF is essentially a fractionating process, while RO is effectively a concentrating process. One advantage of UF over other processes is that by varying the amounts of permeate removed, a wide variety of protein concentrates, ranging up to 60% protein, can be obtained. Higher levels can be obtained by simultaneously adding fresh water and concentrating by UF, a process called diafiltration. Permeate (the material that passes through the filter) is used for manufacture of milk sugar, lactose, by condensing and crystallization. Lactose crystals are harvested and dried in a tumble dryer.

In the ion exchange process, whey is passed through two containers filled with special synthetic resins, which have the ability to exchange ions. In the first container, the special synthetic resins exchange hydrogen ions for cations in the whey. Here, the positive ions of the salt are captured and acid is formed by the release of hydrogen ions. The whey is then passed over the anion exchanger where hydroxyl ions are exchanged for negative ions of the salt, and water is formed. When the mobile ions of the resins are completely replaced by other ions, the resin must be regenerated for further use. This is done by passing an acid (hydrochloric) solution through the cationic exchanger, and a basic solution (NaOH) through the anionic exchanger.

Electrodialysis, a combination of electrolysis and dialysis, is the separation of electrolytes, under the influence of an electric potential through semi-permeable membranes. The driving force is an electric field between the anode (positively charged) and the cathode (negatively charged). Between the anode and the cathode, a number of ion-selective membranes are placed which are permeable only to anions or cations. Every other membrane has a positive charge repelling positive ions and allowing negative ions to pass, and in between there is a negatively charged membrane doing just the opposite. In principle, whey is pumped through every second space between two membranes, and a solution of NaCl (cleaning solution) is pumped through the compartments between the whey streams. The ions move from the whey stream into the cleaning solution where they are retained, because they cannot move any further. The cleaning solution contains minerals, acid, some lactose and small nitrogenous molecules. The membranes are cleaned chemically. Protein molecules remain in the fluid while the minerals are removed. The process results in a protein concentrate.

Lactose is crystallized from condensed whey or from permeate (50–60%, solids) obtained by ultrafiltration fractionation of milk or whey. The supersaturated solution is cooled under specific conditions to crystallize lactose. Lactose crystals are harvested and washed to remove the mother liquor and dried. Crude lactose obtained this way contains about 98% lactose. Food-grade and more refined USP (United States Pharmacopeia) grades are produced from crude lactose by protein precipitation, decolorization with activated carbon and subsequent demineralization. Lactose is further refined by recrystallization or by spray drying.

Whey protein concentrates are products derived from whey by removal of minerals and lactose. The process of
protein concentration utilizes ultrafiltration, electrodialysis, and ion exchange technologies. On a dry basis, the protein concentrate contains a minimum of 34% or 50% protein. Whey protein isolate contains at least 92% protein. The manufacture and uses of whey products are discussed in detail by Huffman and Ferreira (2011) and later in this book.

References


