Influence of raw milk quality on processed dairy products: How do raw milk quality test results relate to product quality and yield?

Steven C. Murphy,[1] Nicole H. Martin, David M. Barbano, and Martin Wiedmann
Milk Quality Improvement Program, Department of Food Science, Cornell University, Ithaca, NY 14853

ABSTRACT

This article provides an overview of the influence of raw milk quality on the quality of processed dairy products and offers a perspective on the merits of investing in quality. Dairy farmers are frequently offered monetary premium incentives to provide high-quality milk to processors. These incentives are most often based on raw milk somatic cell and bacteria count levels well below the regulatory public health–based limits. Justification for these incentive payments can be based on improved processed product quality and manufacturing efficiencies that provide the processor with a return on their investment for high-quality raw milk. In some cases, this return on investment is difficult to measure. Raw milks with high levels of somatic cells and bacteria are associated with increased enzyme activity that can result in product defects. Use of raw milk with somatic cell counts >100,000 cells/mL has been shown to reduce cheese yields, and higher levels, generally >400,000 cells/mL, have been associated with textural and flavor defects in cheese and other products. Although most research indicates that fairly high total bacteria counts (>1,000,000 cfu/mL) in raw milk are needed to cause defects in most processed dairy products, receiving high-quality milk from the farm allows some flexibility for handling raw milk, which can increase efficiencies and reduce the risk of raw milk reaching bacterial levels of concern. Monitoring total bacterial numbers in regard to raw milk quality is imperative, but determining levels of specific types of bacteria present has gained increasing importance. For example, spores of certain spore-forming bacteria present in raw milk at very low levels (e.g., <1/mL) can survive pasteurization and grow in milk and cheese products to levels that result in defects. With the exception of meeting product specifications often required for milk powders, testing for specific spore-forming groups is currently not used in quality incentive programs in the United States but is used in other countries (e.g., the Netherlands).
Key words: somatic cell count, bacteria count, quality, premium incentive payment

INTRODUCTION

Changes in dairy product distribution patterns, product formulations, the export market, and consumer expectations have all resulted in a greater demand for dairy products that meet high quality standards both initially and over a longer shelf-life. To consistently manufacture high-quality dairy products, processors are demanding higher-quality raw milk, which can be defined as (1) compositionally complete (e.g., protein and fat levels within the norm); (2) free from off-flavors and odors; (3) free from detectable drug residues, added water, or other adulterants; (4) having low total bacteria counts; and (5) having low SCC. To ensure that they are using quality raw milk, processors routinely monitor supplies when they are received at the dairy processing plant and at the producer level.

Raw milk quality measurements most often considered in regard to potential effect on processed product quality are the SCC and total bacterial counts (e.g., standard plate count, SPC). At higher levels, somatic cells and bacteria are associated with increased activity of enzymes that damage milk components and potentially result in product defects. The ability of enzymes associated with increased SCC or bacteria counts to influence the quality of processed dairy products depends on several factors including enzyme level, specificity, heat stability, temperature of processing and storage, pH, moisture, and the presence of inhibitors and activators, thus the potential effect will vary with the enzyme, the product, and the conditions. Some enzymes, such as the native milk protease plasmin and select microbial enzymes, are heat stable and continue to act after pasteurization or more severe heat treatments (Fairbairn and Law, 1986; Mottar, 1989; Sørhaug and Stepaniak, 1997; Datta and Deeth, 2001; Considine et al., 2004; Ismail and Nielsen, 2010).

Regulatory limits designed to protect public health under the US Pasteurized Milk Ordinance (**PMO**; FDA 2013) for grade A producer milk are 750,000/mL bulk tank SCC (**BTSCC**) and 100,000 cfu/mL SPC. Most producers strive to meet more stringent values often linked to quality incentives or "premium" payments offered by cooperatives or other buyers of raw milk. These incentives are typically tier based, with higher-quality raw milk receiving a higher premium payment. Combinations of tier goals generally range from 100,000 to 350,000 cells/mL for SCC and from 5,000 to 20,000 cfu/mL for bacteria counts (Table 1). For example, a higher payment would be given to a producer with raw milk that has a monthly average SCC of <100,000 cells/mL and bacteria count of <5,000 cfu/mL compared with a producer with an SCC of 250,000 cells/mL and bacteria count of 15,000 cfu/mL. In most cases, meeting premium incentive requirements is based on meeting additional test criteria (e.g., free from antibiotics; acceptable freezing points; and in some cases meeting limits of alternative bacterial methods such as the laboratory pasteurization count or preliminary incubation count). Manufacturing grade milk (e.g., grade B milk) that can be used for cheese and other non-grade-A dairy products has less stringent bacterial standards (i.e., 500,000 cfu/mL) but the same SCC standards under the USDA Dairy Programs (USDA, 2011). Grade B milk represents a small percentage (~1%) of the US milk supply (USDA, 2015) and typically is not included in premium incentive programs.

Although the reasoning for offering monetary incentives for higher-quality raw milk may be simply to encourage and reward dairy farmers for their efforts, the likely rational for processors is to pay for high-quality raw milk that allows for more efficient processing and the manufacture of higher-quality products as a return on their investment. Milk-quality premiums are sometimes used as a competitive milk procurement tool to attract high-quality milk to a plant. The influence of raw milk quality based on SCC and bacterial numbers has been studied for many products, but most published work is based on the use of relatively high count raw milks. Additional work considering lower levels of these parameters and products with longer shelf-life expectations is needed. In addition, a growing need exists for more specific microbiological testing, such as for endospore (spore)-forming bacterial groups that might survive processing and cause further defects in some products (e.g., pasteurized milk). This article will provide an overview of raw milk–quality testing parameters and the current knowledge on the influence of the quality of bovine raw milk on processed dairy products, with an emphasis on levels of SCC, total bacteria counts, and spore-formers in raw milk. We will also provide a perspective on the current status of producer milk quality and the role of quality incentive programs. Where applicable, we will attempt to identify areas where further work is needed.

RAW MILK SCC AND DAIRY PRODUCT QUALITY

Somatic cells found in bovine milk are primarily lymphocytes, macrophages, and polymorphonuclear leucocytes, but they may also include a low percentage of epithelial cells (Schukken, 2007). Increases in SCC levels in raw milk are associated with mastitis, an inflammatory reaction of the mammary gland most often due to bacterial infection. Although an SCC of approximately 70,000 cells/mL is considered average for milk from an uninfected, healthy udder quarter, counts of 200,000 to 250,000 cells/mL are often used as benchmark values of infection because mean values vary with age, days in milk, and production levels (Schukken, 2007). The SCC can exceed several million cells per milliliter in milk from an infected quarter, and as the percentage of infected quarters increases, so does the BTSCC. Although BTSCC have been used to estimate the percentage of the herd infected, these values vary based on the infecting agent, stage of infection, and other factors (Auldist and Hubble, 1998; Le Maréchal et al., 2011).

Somatic cell count levels in US grade A raw milk are determined by electronic or direct microscopic methods outlined in *Standard Methods for the Examination of*

Table 1. Examples of SCC and SPC limits[1] used to qualify for tiered[2] milk quality incentive payment programs[3]

Quality test	Tier 1	Tier 2	Tier 3
SPC range	5,000–10,000	10,000–15,000	10,000–20,000
SCC range	100,000–200,000	150,000–250,000	200,000–350,000

[1]Ranges based on information provided from 3 cooperatives that have farms in New York State and the surrounding area.

[2]Tier 1 provides the highest incentive price per hundredweight, and tier 3 the lowest.

[3]To receive incentives, all 3 cooperatives required negative ("not found") drug residue tests. Other criteria required by 1 or more included laboratory pasteurization count limits, preliminary incubation count limits, freezing point limits, sediment value limits, and dairy farm inspection scores.

Dairy Products (**SMEDP**, 17th ed.; Nierman, 2004). Methods used to qualify grade A milk supplies are approved through the National Conference on Interstate Milk Shipments (**NCIMS**) process. Automated flow cytometry systems such as the Bentley Somacount (Bentley Instruments, Chaska, MN), Fossomatic 5000/FC (Eden Prairie, MN), and Delta SomaScope (Advanced Instruments, Norwood, MA) are used most often in producer testing programs. The direct microscopic SCC is also an approved method and serves as the reference method for calibration of electronic systems. These same methods are used for testing in some USDA Federal Milk Markets in which milk SCC is part of a regulated multiple component pricing system, in which differences in producer payment is based on a graduated scale in 1,000 cells/mL increments, with added payment below 350,000 cells/mL and lower payment above 350,000 cells/mL. Under the USDA Federal Milk Market Orders (**FMMO**) payment system the needs for SCC calibration accuracy and analytical performance are different than for the NCIMS program. In the NCIMS program, the method only needs to correctly determine if producer milk is higher or lower than 750,000 cells/mL as per the grade A standard without consideration of SCC over a lower and wider range. Manufacturing grade milk that might be used for non-grade-A dairy products is also tested by the same methods as used for grade A milk (USDA, 2011).

Aside from determining if producer milk complies with the regulatory limit, BTSCC are routinely used as indicators of milk quality, herd health, and management practices. Mastitis infection has a direct influence on the composition and yield of the milk of an infected cow, whereas total herd health and BTSCC are associated with farm productivity and potential effect on dairy product quality. Extensive reviews on the association of mastitis and SCC on milk and dairy product quality have been published by Auldist and Hubble (1998) and Le Maréchal et al. (2011). From an economic perspective, increased BTSCC is associated with decreased herd milk yield and farmer profit. From a product-quality perspective, increased BTSCC are associated with altered milk composition, increased enzyme activity, and an increased risk for product defects. The native milk protease plasmin is significant in this regard; a comprehensive review of its properties and roles in dairy products has been provided by Ismail and Nielsen (2010). Plasmin is present in milk as the active enzyme and as the inactive precursor plasminogen. Increased plasmin activity associated with increased SCC is thought to occur primarily because of the action of plasminogen activators (e.g., urokinase) associated with somatic cells. Plasmin is most active at pH 7.5 to 8.0, and the optimum temperature for enzyme activity is 37°C; hence, much of the damage done to milk proteins by plasmin likely occurs in the udder before milking. Once milk SCC has been elevated in a cow, the increased proteolytic activity may remain elevated even after milk SCC has decreased (Saeman et al., 1988).

Plasmin actively hydrolyzes β-casein and the α-caseins, but its ability to hydrolyze κ-casein has not been clearly established (Auldist and Hubble, 1998; Ismail and Nielsen, 2010; Le Maréchal et al., 2011). Whey proteins appear to be mostly resistant to plasmin hydrolysis (Ismail and Nielsen, 2010). Plasmin's role in the breakdown of caseins is significant because they are the major milk proteins captured in the coagulation process (e.g., cheese making). Plasmin hydrolysis of β-casein results in γ-caseins and proteose-peptones, which are lost in the whey during cheese manufacture (Auldist and Hubble, 1998).

Both plasmin and plasminogen are heat resistant, withstanding pasteurization and to some extent UHT treatments. Plasmin and plasminogen are essentially unaffected by minimum HTST conditions (72°C/15 s), whereas after typical UHT processing (138°C/2 s), 20 to 40% of activity has been reported to remain; however, temperatures above 147°C have resulted in complete inactivation (Datta and Deeth, 2001; Ismail and Nielsen, 2010). In general, plasmin activity and what remains after heat treatment depend on a complex interaction of plasminogen, plasminogen activators, and plasminogen activator inhibitors and their associated heat stabilities.

While plasmin has been implicated as a major cause of milk protein degradation, other proteases in milk have been identified as having activity against the caseins, including the leucocyte proteases elastase and cathepsin B, D, and G (Considine et al., 2004; Le Maréchal et al., 2011). Increased activities of these enzymes have been associated with increased SCC, but their role in dairy product quality has not been fully investigated. Elastase possibly influences coagulation properties of milk, and cathepsin B and D may play a role in cheese ripening. Partial activity has been demonstrated after commercial pasteurization (Considine et al., 2004). Besides proteolysis, increased lipolysis in milk, presumably due to lipoprotein lipase activity, has also been associated with mastitis or high SCC raw milk (Murphy et al., 1989; Ma et al., 2000). Increased free fatty acids (**FFA**) as a result of lipolytic activity can have a direct influence on milk and dairy product flavor (i.e., rancidity and related defects). When defects characteristic of enzymatic activity develop over time in pasteurized or other heat-treated (e.g., UHT) dairy products that are free from defects initially and free from microbial contamination and growth after heat treatment, heat-stable enzymes are likely to blame.

Cheese

A summary of research on the use of raw cow's milk with increasing SCC levels in cheese manufacture is presented in Table 2. Most research findings are based on the effect of using low (e.g., <250,000 cells/mL) compared with high (e.g., >500,000 cells/mL) SCC milk on the manufacture of Cheddar cheese (Grandison and Ford, 1986; Mitchell et al., 1986; Politis and Ng-Kwai-Hang, 1988a,b,c; Barbano et al., 1991; Rogers and Mitchell, 1994; Auldist et al., 1996a), although other cheeses have been evaluated (Cooney et al., 2000; Mazal et al., 2007; Andreatta et al., 2007; Vianna et al., 2008). Increased SCC have been associated with decreased casein in cheese milk, increased rennet coagulation time, increased cheese moisture, decreased moisture-adjusted cheese yield or cheese yield efficiency, and reduced cheese quality. For example, Rogers and Mitchell (1994) compared cheese made from milks collected from cows grouped based on SCC status with SCC levels at <200,000, 300,000 to 400,000, and >800,000 cells/mL and found that the highest SCC milk resulted in higher moisture (+2%), increased rennet coagulation time (+25%), and decreased moisture adjusted yield (−9%) as well as inferior texture and flavor compared with the cheese made from milk with lower SCC levels. Negative effects of using milk with SCC >500,000 cells/mL were reported in most of the work cited in Table 2, although some studies only evaluated the use of raw milk with SCC well above 500,000 cells/mL, with several approaching or exceeding 1,000,000 cells/mL. As producer BTSCC have improved, studies evaluating the effect of lower SCC levels on product quality and yield are more relevant. Politis and Ng-Kwai-Hang (1988b) evaluated milks from individual cows with a range of SCC from 100,000 to 1,000,000 cells/mL and found that using milk with SCC at >500,000 cells/mL had a significant negative effect on moisture-adjusted yield and efficiency of yield. Most of this loss in yield occurred in milks with SCC between 100,000 and 500,000 cells/mL, whereas the rate of loss was not as dramatic as SCC became higher. Based on their findings, they suggested that 300,000 cells/mL could be a critical level. Barbano et al. (1991) made cheese from milk collected from cows grouped in 3 SCC levels (<106,000, 127,000 to 544,000, and 556,000 to 1,300,000 cells/mL) after the milk was stored 1 and 5 d at 4°C. They found that cheese milk from the 2 higher SCC groups had lower levels of casein as a percentage of true protein (**CN%TP**) and higher relative protease activity, which would have a direct effect on cheese yield. They also observed that cheese made from the high SCC milks had higher moisture and that cheese yield efficiency was lower. Lower yield was associated with higher loss of fat and protein in the whey when using high SCC milk. Although the authors concluded that using milk with a SCC above 127,000 cells/mL has a negative effect on CN%TP and cheese yield efficiency compared with milk with SCC <106,000 cells/mL, little change was observed as SCC increased from 127,000 to 1,300,000 cells/mL, suggesting that proteolysis was not linearly related to SCC in the cows studied, which was similar to the findings of Politis and Ng-Kwai-Hang (1988b). Barbano et al. (1991) also cautioned that similar effects might not be seen in milks commingled from cows with different SCC levels because most of the influence on cheese yield was likely the result of casein breakdown before milk is effectively cooled (e.g., in the udder) and weighted averages must be considered.

Although SCC appears to have a clear effect on cheese manufacture, especially when numbers are high, specifying precise levels that would affect cheese yield and quality would be difficult. Controlled research to obtain specific target SCC levels is challenging. As shown in Table 2, significant variability was present in study design and parameters and some studies were based on limited trials. Methods of obtaining milk with SCC at different levels included collecting milk from farm bulk tanks (**BT**) with different SCC levels, collecting and blending milk from cows with different SCC levels, increasing SCC in milk through induced infection, and blending mastitic milk with good milk. Aside from inherent differences in individual cows and herds, other variables to consider in reviewing and interpreting these studies include milk composition, milk storage times, cheese-making procedures, and the analytical methods used. Only 2 studies reported the bacteria counts of the raw milk used (Barbano et al., 1991; Rogers and Mitchell, 1994). Regardless, the research shows that using raw milk with increasing SCC heightens the risk of reduced cheese yield and quality. To provide more guidance to the industry, Geary et al. (2013) used meta-analysis techniques to evaluate the available literature on the relationship of SCC to both raw milk (32 references) and Cheddar cheese (13 references) composition. This analysis supported the overall conclusions that using raw milk with increased SCC has a significant effect on increasing cheese moisture and significantly reduces cheese protein recovery and levels and fat recovery, which can influence yields. When the authors used their model to determine milk value (Geary et al., 2014), they estimated a 2.05% reduction in yield when milk SCC increased from <100,000 cells/mL to >400,000 cells/mL, supporting the conclusions of Politis and Ng-Kwai-Hang (1988b) and Barbano et al. (1991) that increases of SCC in this lower range are important. When their analysis was further incorporated into a model based on processing costs and com-

Table 2. Influence of elevated SCC levels in raw milk on cheese characteristics and yields[1]

Reference	Cheese type	SCC level studied (cells/mL)	Study design overview	Influence of higher SCC level
Mitchell et al. (1986)	Cheddar	Compared <500,000 with >500,000	Bulk tank milk from 30 farms selected based on BTSCC[2] over 1 yr. Standardized casein to fat ratio. Milks included 17 low, 13 high SCC trials.	Yield: decreased moisture adjusted yield Moisture: higher (+2%) Coagulation: increased RCT[3] (+18%) Quality: no significant difference in flavor grade; higher SCC cheese had softer texture
Grandison and Ford (1986)	Cheddar	Range of SCC from <50,000 to >2,000,000	Prepared milks with 0, 10, 20, 30% of high SCC from infused (*Escherichia coli*) cow's milk in low SCC milk. Trials with morning milk (n = 4) and morning and evening milk combined (n = 4).	Yield: no effect Moisture: higher (up to +6%) Coagulation: no effect on RCT; decreased strength Quality: inferior flavor and texture; softer, wetter, stickier cheese curds; defects (reduction of firmness and springiness; increased stickiness) were progressive with increased SCC
Politis and Ng-Kwai-Hang (1988a,b,c)	Cheddar	Range of SCC from 100,000 to 1,000,000 Compared 100,000 with >500,000/1,000,000	Cheese made from milk of individual cows (42) made monthly for 1 yr (370 cheeses total).	Yield: decreased adjusted yield (−5%/−8.7%) and decreased efficiency of yield (−11%/−13%) Moisture: higher (NA/+4.4%) Coagulation: increased RCT 2.2%/20.7% Quality: inferior Notes: attributed lower yields to losses in whey
Barbano et al. (1991)	Cheddar	Compared <106,000 with 127,000–544,000 to 556,000–1,300,000	Pooled milk from 10 to 12 individual cows with similar SCC. Made cheese after 1 and 5 d at 4°C with 3 levels of SCC (n = 7, n = 8, n = 7).	Yield: yield efficiency decreased above 106,000 Moisture: higher (+3.4%) Coagulation: not determined Quality: not reported Notes: attributed lower yields to losses in whey
Rogers and Mitchell (1994)	Cheddar	Compared <250,000 with >500,000 (mean = 830,000)	Collected milk from 2 farms; pooled milk based on mastitis status.	Yield: decreased (−9%) Moisture: higher (+2%) Coagulation: increased RCT (25%) Quality: inferior flavor and texture Notes: attributed lower yields to losses in whey
Auldist et al. (1996a)	Cheddar	Compared 252,000 with 1,400,000	Collected milk from herds with late lactation cows and based on previous BTSCC (3 trials in 8 d).	Yield: decreased moisture adjusted yield (−9.2%) Moisture: higher (+8.1%) Coagulation: not reported Quality: textural defects related to high moisture; flavor defects of lipolytic or oxidized
Cooney et al. (2000)	Swiss	Compared 113,000 with 228,000 to 528,000	Blended milk from high SCC cows at the end of lactation with low SCC bulk tank milk and made cheese with 3 levels of SCC (n = 3, n = 6, n = 5).	Yield: not reported; observed increased protein loss in whey Moisture: no difference Coagulation: not reported Quality: increased water soluble N in cheese initially and over aging period
Mazal et al. (2007) Vianna et al. (2008)	Prato	Compared <200,000 with >700,000	Collected from 2 groups of 5 cows with low and high SCC (3–4 reps).	Yield: no difference Moisture: higher (+3%) Coagulation: increased RCT (+30%) Quality: inferior flavor and texture initially
Andreatta et al. (2007)	Mozzarella	Compared <200,000 with >800,000	Pooled milk from individual cows in single herd based on SCC level; cow numbers not given	Yield: no difference Moisture: no difference Coagulation: not reported Quality: increased free fatty acids and decreased protein on storage; no difference in textural parameters

[1]Adapted from Auldist and Hubble (1998) and Le Maréchal et al. (2011).

[2]BTSCC = bulk tank SCC.

[3]RCT = rennet coagulation time.

ponent values (Geary et al., 2014), they concluded that this level of increase in SCC could result in a reduction in net annual revenue to the processor of 3.2%.

Pasteurized Fluid Milks

Most fluid milk consumed in the United States is HTST pasteurized (i.e., 72°C for 15 s) with an anticipated shelf-life of 14 to 21 d. A few operations still use batch pasteurization (i.e., 63°C for 30 min). The influence of increased SCC on the quality and shelf-life of pasteurized fluid milk has only been evaluated in a few studies. Early work (Janzen, 1972; Rogers and Mitchell, 1989) found that increased SCC was associated with lower flavor quality in pasteurized milk, but these evaluations were based on limited trials and sensory analysis alone and provided no bacteriological data on the raw or pasteurized milk. For example, Rogers and Mitchell (1989) evaluated HTST (75°C for 15 s) or batch (63°C for 30 min) pasteurized milks made from raw milk from grouped cows with SCC of <250,000, 250,000 to 500,000, 500,000 to 1,000,000, and >1,000,000 cells/mL collected from 2 farms (87 milks total). Milks were scored by 2 "official graders" after 1, 7, and 14 d storage at 4°C. They found significantly lower flavor scores at 14 d with pasteurized milks made from raw milks from one farm when SCC was >500,000 cells/mL compared with <250,000 cells/mL. Pasteurized milk made from the highest SCC raw milk from the other farm had significantly lower flavor scores on d 1, but differences were not significant after 7 and 14 d. Based on conflicting results from the 2 different farms, the authors suggested that any correlation of raw milk SCC and pasteurized milk quality over shelf-life was inconclusive and that other factors were likely involved.

A more analytical approach was used by Ma et al. (2000), who evaluated HTST pasteurized 2% fat milks made from milk collected from the same cows (4 trials over 2 wk) before and after an induced somatic cell response (i.e., an infused mastitis infection). Bacteria counts of all raw milks used were low. Milks were HTST pasteurized (74°C for 34 s) and stored at 5°C for 21 d and monitored over shelf-life for lipolysis, proteolysis, and sensory attributes. Mean SCC (n = 4) was 45,000 cells/mL before infection, representing an exceptional BTSCC, and 850,000 cells/mL after infection. During storage, the rates of lipolysis, as determined by increasing FFA levels, and proteolysis, as determined by decreasing CN%TP, were 3 and 2 times higher, respectively, in pasteurized milks made from raw milk with high (850,000 cells/mL) compared with low (45,000 cells/mL) SCC. At 21 d, pasteurized milks made from low SCC milks were still considered to be high quality, while defects, including rancid and bitter, were detected in pasteurized milk made from high SCC raw milk. One postinfection trial had a high bacteria count (>10,000,000 cfu/mL) at 21 d that was taken into account when interpreting the data.

In another study that included more realistic SCC levels, Santos et al. (2003a), from the same research group, evaluated HTST pasteurized (76°C for 30 s) 2% fat milks made from raw milk obtained from cows grouped at 4 different SCC levels, with mean values at 26,000, 376,000, 726,000, and 1,113,000 cells/mL (2 replicates). Indicators of proteolysis (CN%TP) and lipolysis (FFA) were measured up to 61 d in milks held at 0.5°C and 6.0°C to determine when milks reached previously established threshold values for the detection of off-flavors (Santos et al., 2003b). A 4.76% decrease in CN%TP was used as a threshold for proteolysis related off-flavors (e.g., bitter), while a FFA level of 0.25 mEq/kg was used as a threshold for off-flavors associated with lipolysis (e.g., rancid). Pasteurized milks were preserved with potassium dichromate to eliminate the risk of microbial spoilage. Based on the predetermined threshold value for proteolysis, the potential for off-flavors was reached after 61 d and at 54 d for the low SCC milk (26,000 cells/mL) and at 54 d and 19 d for the high SCC milk (>1,113,000 SCC), at 0.5 and 6.0°C, respectively. Pasteurized milk made from raw milk with the SCC at 340,000 cells/mL, which is closer to average US BTSCC values, reached the bitterness threshold after approximately 28 d at 6.0°C. For lipolysis, pasteurized milks made from raw milk of all SCC levels remained below the FFA threshold level when held at 0.5°C up to 61 d, while milks held at 6.0°C reached threshold values just beyond 61 d and at 35 d for the low SCC (26,000 cells/mL) and high SCC milks (>1,113,000 SCC), respectively. Pasteurized milk made from the raw milk with mean SCC at 340,000 cells/mL reached the lipolysis threshold after approximately 50 d at 6.0°C. These results demonstrate that as raw milk SCC increase, protease and lipase activity increase such that defects in pasteurized milk held under refrigeration are possible. The risk of SCC-associated defects, however, is likely only when SCC are high (>340,000 cells/mL) and when the pasteurized milk is held for extended periods beyond current sell-by dates (e.g., >14–21 d). The authors suggested that fluid milk operations striving for extended shelf-life might consider economic incentive programs for low SCC milk (Barbano et al., 2006). Other quality defects associated with high SCC milk that have been reported include reduced whipping properties of cream and frothing capability of milk (Auldist and Hubble, 1998), likely due to increased lipolysis and FFA levels, although other factors may be involved.

From a commercial processing perspective, Martin et al. (2011) sampled raw milk supplies of 4 dairy plants monthly over a 1-yr period and evaluated the shelf-life of the corresponding pasteurized milks. They used a range of raw milk tests, including SCC, to assess raw milk samples collected from dairy plant storage tanks and compared the results to shelf-life evaluations of pasteurized 2% fat milk made from the sampled raw milk. Pasteurized milks were stored at 6.0°C and tested for total bacteria count (SPC) and evaluated by a trained sensory defect panel after 21 and 17 d of storage, respectively (no sensory at 21 d). The reported R^2 values for raw milk SCC to pasteurized milk SPC and sensory scores were low (<0.16). However, the raw milk SCC values were relatively low and in a narrow range for all samples tested (160,000–280,000 cells/mL), thus they provided no conclusive information on the influence of raw milk SCC values on pasteurized milk quality. In general, the existing data suggest that under typical conditions of raw milk quality, dairy plant HTST processing and milk-handling parameters and shelf-life expectations (e.g., code dates <21 d) SCC will have a limited effect on pasteurized milk quality and shelf-life unless SCC are very high (e.g., exceeding the PMO limit).

High-Heat Fluid Milks

High-heat fluid milks are processed and packaged for extended shelf-life. These include UHT milks that are aseptically processed and packaged to be shelf-stable (e.g., shelf-life >180 d) and ultrapasteurized (**UP**) milks that are heated at greater than 138°C for 2 s and packaged in extended shelf-life fillers (nonaseptic) but are required to be refrigerated (e.g., shelf-life of 60–120 d). For UHT shelf-stable milk, increased SCC in raw milk may increase the risk of enzyme-associated defects such as age gelation (protein gel formation or coagulation during storage), protein sedimentation, bitterness, and rancidity, although data correlating defects to specific SCC levels are limited (Ismail and Nielsen, 2010). Auldist et al. (1996b) evaluated UHT (140°C for 4 s) processed milks made from raw milk from dairy herds with low (**L**) and high (**H**) SCC from both early (**E**) and late (**Lt**) lactation herds. Mean SCC for LE, LLt, HE, and HLt herds were 121,000 (n = 3), 252,000 (n = 4), 687,000 (n = 2), and 1,463,000 (n = 4), respectively. Bacteria counts were relatively low in all raw milks used (<100,000 cfu/mL). The UHT processed milks were held at 20°C for up to 9 mo. The researchers found that UHT milks made from early lactation milk (LE, HE) showed increased viscosity after 4 mo and gelled more quickly than late-lactation UHT milk (LLt, HLt), regardless of SCC, but high SCC milks

(HE, HLt) gelled sooner than low SCC milks (LE, LLt) at similar stages of lactation. The HLt milks gelled at 9 mo, but the LLt milks did not gel in this period. The authors found the rate of proteolysis was greatest in the HLt milks, followed by the HE milks. The authors concluded that age gelation was not directly related to SCC levels or plasmin proteolysis of the milk. While the difference between early and late lactation milk raises questions to the mechanisms involved, this would rarely be a concern in most US dairy cow herds where milk is commingled across lactation. Fernandes et al. (2008b) evaluated 15 batches of UHT milk (142–145°C for 2 s) made in a commercial dairy plant from farm raw milk supplies with 3 levels of SCC (197,000–316,000, 379,000–560,000, and 600,000–800,000 cells/mL); these batches were assessed throughout a 120-d incubation at room temperature. Bacteria counts were not performed on raw milks used for these trials. Although the authors observed increases in FFA, decreases in CN%TP, and slight increases in apparent viscosity over time in UHT milks made from raw milk at all SCC levels, they found no significant difference of these parameters between SCC levels except for CN%TP at 120 d. This finding suggested that proteolysis related to higher SCC levels may be a factor in UHT milk quality later in shelf-life. HPLC revealed that β-casein and α_S-casein were most affected, which is consistent with plasmin proteolysis (Fernandes et al., 2008a). In a single trial experiment, Topçu et al. (2006) evaluated UHT milk made from bulk raw milk with SCC at 212,000, 315,000, and 621,000 cells/mL and found that higher SCC UHT milk had higher plasmin activity and corresponding levels of proteolysis, resulting in bitterness, gelation, and sedimentation at room temperature, but the 2 higher SCC UHT milks studied also had high bacteria counts before UHT processing (>1,000,000 cfu/mL compared with 350,000 cfu/mL for low SCC milk), which could have affected the processed milk quality. The ability of plasmin to cause age gelation has been demonstrated in studies in which plasminogen was added directly to UHT milk. Kelly and Foley (1997) in a single experiment found little plasmin activity in UHT milk (processed through indirect heating at 138°C for 2.4 s) made from either low (140,000 cells/mL) or high (630,000 cells/mL) SCC milk. They found sedimentation but no gelation in the high SCC milk after 150 d. When plasminogen was added, gelation occurred in both high and low SCC milks, but it was more pronounced in the high SCC. The authors suggested that a heat-stable plasminogen activator was present in higher levels in the high SCC milk. Although evidence suggests that using raw milk with high SCC is more likely to result in defects in UHT processed milk, the likelihood of milk with SCC below US PMO limits causing defects is low.

Several factors other than SCC level may influence the potential for age gelation and other defects in UHT milk (Datta and Deeth, 2001) including cow factors (e.g., age, stage of lactation), milk composition, milk preheating steps before UHT, and the type of UHT treatment (e.g., direct or indirect).

Milks that fall under the definition of UP in the PMO (FDA, 2013) are more popular in US markets than UHT milks, primarily for niche products (e.g., organic milks). Ultrapasteurized milk is heated similarly to UHT milk (138°C for ≥2 s) and packaged for extended shelf-life. Because UP milks are not aseptically packaged, they are required to be stored refrigerated (FDA, 2013). Under extended shelf-life processing, UP milks typically have a shelf-life of 60 d or more. Plasmin has an optimum temperature of 37°C, but it has been shown to be active at refrigeration temperatures; however, the extent of activity in UP milks is poorly defined (Ismail and Nielsen, 2010). Specific research on UP products related to raw milk quality is lacking.

Yogurt and Cultured Dairy Products

Yogurt is manufactured in a variety of styles including traditional cup-set, blended, and strained. The limited available research suggests that SCC levels have little effect on the manufacturing properties of unstrained yogurts (Le Maréchal et al., 2011), although some evidence indicates that yogurt manufactured from high SCC milk may show decreased sensory quality. Oliveira et al. (2002) manufactured yogurt (7 lots, 1 per month) from raw milk with SCC at <400,000, 400,000–800,000, and >800,000 cells/mL collected from grouped cows. Raw milk bacteria counts were higher in the high SCC milks (540,000 vs. 100,000 cfu/mL). Sensory evaluation by a trained panel found lower consistency scores on initial testing and decreased flavor scores after 30 d of storage at 5°C for yogurt made with raw milk with SCC >800,000 cell/mL. Bitter or rancid notes were not detected. Hachana and Paape (2012) observed increased proteolysis, decreased pH, and increased viscosity in cold stored yogurt made with raw milk with a mean SCC of 400,000 cells/mL compared with 100,000 cells/mL. High FFA levels were only found in yogurt made from milk with very high SCC (1,150,000 cells/mL). Bacteria counts of the raw milks used in this study were not determined. In a study that evaluated yogurt made from raw milk with mean SCC of 147,000, 434,000, and 1,943,000 cells/mL collected from grouped cows (6 trials), Fernandes et al. (2007) also found significantly higher FFA levels in the yogurt made from the highest SCC milk compared with yogurt made from the low SCC milk. Although the intermediate SCC yogurt had higher FFA levels than the low SCC yogurt, the differ-

ence was not statistically significant. No significant differences were noted in proteolysis in the yogurts made from raw milks with different SCC levels in this study. Bacteria counts of the raw milks used in this study were not determined. None of the researchers noted any influence on yogurt manufacture (e.g., set time), and conflicting reports exist on the influence of SCC on yogurt starter culture activity (Tamine and Robinson, 2007). In traditional yogurt, yield is not affected, but this outcome may differ for strained yogurts, which have the potential for loss of protein in the whey as is seen with cheese; published reports on this possibility are lacking and further work in this area is needed. An SCC limit of 400,000 cells/mL has been suggested as an upper limit for yogurt manufacture to maintain quality over shelf-life (Oliveira et al., 2002; Fernandes et al., 2007). Based on the presented research this level appears to be reasonable, although more research in this area is warranted, especially in regard to strained yogurts. It should also be noted that plasmin is most active at pH 7.5 to 8.0 and at a temperature of 37°C (Ismail and Nielsen, 2010), suggesting that plasmin proteolysis would be greatest during the initial culturing phase of yogurt products, although it is not clear to what extent plasmin may remain active at set yogurt pH values (e.g., pH 4.4 or lower).

For cultured products other than yogurt, only 1 study was found. Klei at al. (1998) evaluated cottage cheese curd made from milk collected from the same 8 cows before and after an induced *Streptococcus agalactiae* infection with mean (n = 4) SCC of 83,000 and 872,000 cells/mL, respectively. The authors found decreased yield efficiency (4.3%), higher moisture, and increased proteolysis in cottage cheese curd made with the postinfection high SCC milk.

Milk Powders

Auldist et al. (1996c) evaluated the influence raw milk SCC and stage of lactation on the quality of whole milk powders manufactured in a pilot plant using the same raw milk used for the UHT milk study cited previously (Auldist et al., 1996b). Mean SCC for LE, LLt, HE, and HLt herds were 121,000 (n = 3), 252,000 (n = 4), 687,000 (n = 2), and 1,463,000 (n = 4), respectively. Although compositional differences were noted for powders processed from raw milks in the different SCC and lactation milk categories, all powders met product specifications for titratable acidity and solubility index (**SI**) as determined by centrifugation of reconstituted powders. Significant differences related to powder quality and performance noted included (i) a lower SI in powders made from the LE milk compared with powders made from the high SCC, HE milks and (ii) poor

heat stability (based on viscosity of sterilized reconstituted powder) and the development of organoleptic defects (e.g., "cheesy") after 4 mo of storage at 20°C for powders made from HLt milk, the highest SCC. Rogers and Mitchell (1989) evaluated high-heat skim milk powder made from raw milk from cows grouped into SCC categories of <250,000, 250,000–500,000, 500,000–1,000,000, and >1,000,000 cells/mL collected from 2 farms (87 milks total). Although they also found compositional differences in the powders, no association existed between raw milk SCC levels and heat stability, SI, or organoleptic assessment of the powders. No recommendations for SCC levels in raw milk used for powders were provided in the cited research. Additionally, no available research has assessed the potential for further development of defects once the powder is used in formulation and processed; additional work in this area is warranted.

SCC Levels and Producer Incentive Programs

Overall, current research suggests that raw milk with lower SCC provides for improved dairy product quality, and in the case of cheese, improved yields. Based on USDA data (USDA-APHIS, 2015), BTSCC values have decreased dramatically over the past several years with weighted and unweighted means for 2014 at 193,000 and 229,000 cells/mL, respectively (Table 3), compared with 296,000 and 320,000 cells/mL, respectively, in the year 2000. Although this outcome can be attributed to improved production practices in general, cooperative-based incentive programs, the inclusion of BTSCC in the USDA-FMMO multiple component pricing (**MCP**) system in the year 2000, and more recently, the European Union (**EU**) Health Certification Program (**EUHCP**) have likely played significant roles. The FMMO-MCP system provides for positive and negative adjustments in producer payments based on BTSCC below or above 350,000 cells/mL, respectively. The EUHCP requires that US processors exporting dairy products to the EU use a milk supply that is in substantial compliance with the EU SCC limit of 400,000 cells/mL (USDA-AMS, 2016).

Aside from incentives paid for quality milk, reduced SCC values and improved herd health enhances profitability for dairy farmers with increased production levels and reduced animal health care and replacement costs (Auldist and Hubble, 1998). From a public health perspective, increased SCC are associated with higher incidence of mastitis, which increases the risk of illegal levels of drug residues in milk (van Schaik et al., 2002). Milk found with illegal drugs can also result in economic loss to the producer (e.g., dumping contaminated milk and associated penalties). In general, the current status suggests a low risk of reduced quality due to high SCC for most dairy processing operations in the United States, but continued and fair incentives for dairy producers will likely be instrumental in keeping the risks low.

The SCC is currently our best industry indicator for milk quality related to udder health, but the quality of the raw milk supply and changes in that quality with respect to variation in heat-stable native milk protease levels are difficult to evaluate, and a need exists for more information on this parameter, particularly in studies of UP fluid milk shelf-life. Heat-stable native milk protease activity in milk will be higher when milk SCC is high, but once milk SCC decreases, this activity does not necessarily decrease in a corresponding manner (Saeman et al., 1988). Thus, dairy product shelf-life studies of flavor and texture changes should always include a measure of the starting levels of native milk protease activity in the milk in addition to milk SCC and bacterial counts. Without this baseline information, causes of off-flavor development during shelf-life will not be able to be parsed with respect to microbial or native heat-stable enzyme origin. Also, with increasing cow age, proteolytic damage to casein caused by heat-stable native milk protease activity increases (Barbano, et al., 1991). This outcome underscores the fact that milk SCC is not a direct indicator of milk quality with respect to the level of heat-stable native milk protease activity in milk and nothing in current regulations, which are based on public health protection, or metrics measured in milk quality incentive programs (other than the practical relationship with milk SCC) addresses control of this source of heat-stable enzymes in milk.

Table 3. Geometric mean of bulk tank SCC of representative US farm supplies[1]

Year	Geometric mean	
	Weighted mean	Unweighted mean
2014	193,000	229,000
2013	194,000	231,000
2012	194,000	230,000
2010	224,000	259,000
2008	247,000	294,000
2006	249,000	293,000
2004	263,000	296,000
2002	290,000	322,000
2000	296,000	320,000

[1]Determined from Federal Milk Market Order (FMMO) data from 4 of 10 FMMO (Central, Mideast, Southwest, and Upper Midwest). From USDA-APHIS (2015).

RAW MILK BACTERIA COUNTS EXCLUDING HEAT-RESISTANT ORGANISMS AND PRODUCT QUALITY

The reference method for bacteria counts in grade A raw milk, as outlined in SMEDP, 17th ed. (Laird et al., 2004), is the SPC method, which is performed by plating the sample on standard methods agar (**SMA**) followed by aerobic incubation at 32°C for 48 h. Modifications of the SPC procedure approved by the NCIMS for grade A raw milk include the Petrifilm aerobic count, the plate loop count, the spiral plate count methods, and others. In 2001, the NCIMS approved the Bactoscan FC (Foss North America, Eden Prairie, MN) for raw milk bacteria counts. Similar to SCC instruments, the Bactoscan FC is a flow cytometry system that provides results in 10 min. Currently, most producer milk samples are tested with the Bactoscan FC by cooperative and other major laboratories. The system has allowed for rapid turnaround of results and more frequent testing, which can be advantageous in farm-based quality programs. Manufacturing grade milk that might be used for non–grade A dairy products has a higher bacterial limit of 500,000 cfu/mL compared with the PMO grade A limit of 100,000 cfu/mL and is tested by the same methods (USDA, 2011). In addition to total bacteria counts, the preliminary incubation count (**PIC**) of raw milk is used widely in the industry as an indicator of sanitation deficiencies on the farm and has been used in quality incentive programs. The PIC is determined by performing an SPC (or alternative method) on a raw milk sample after incubating the milk at 12.8°C for 13 h (Messer et al., 1985). Other microbiological tests that might be used on raw milk include coliform bacteria counts, psychrotolerant bacteria counts (i.e., those capable of growth at low temperatures; also referred to as psychrotrophic), and specific culturing methods to detect causative agents of mastitis (Murphy and Boor, 2000). Methods that detect thermal resistant bacteria will be discussed later in this article.

Bacterial defects typically become apparent in raw milk and processed dairy products only when bacterial numbers are high, generally >1,000,000 cfu/mL, depending on the specific microorganisms present and their metabolic states (Cousin, 1982; Champagne et al. 1994; Boor and Murphy, 2002). As microbial numbers reach critical mass for sufficient enzyme activity, defects can occur as the result of fermentation pathways (e.g., lactic acid), protease action on proteins (e.g., bitter peptides and protein destabilization), lipase (e.g., rancidity from increased FFA) and esterase (e.g., fruity odors) activity on lipids, and other enzymatic pathways. Generally, initial contamination levels of farm BT raw milk can be kept low through proper production and management procedures, although significant sanitation deficiencies (e.g., soiled cows or dirty equipment) can result in higher levels of bacteria due to contamination during milking. Occasionally, cows with mastitis shedding the infectious bacterial strain or strains can cause an increase in BT bacteria counts (Murphy and Boor, 2000). Once in the farm BT, prolonged or marginal refrigeration storage of raw milk will select for psychrotolerant microorganisms, which have been estimated to be less than 10% of the initial contaminants in milk produced under good hygiene conditions (Cousin, 1982), but they may be much higher when farm sanitation conditions are inadequate. Under cold storage, psychrotolerant microorganisms will multiply over time, often becoming the dominant microflora in raw milk at the farm BT and in transit to and during storage at processing plants. Most psychrotolerant bacteria found in raw milk are gram-negative rods, with *Pseudomonas* species most common (Cousin, 1982). Unless microbial numbers are very high, gram-negative bacteria in raw milk are generally destroyed by pasteurization and other heat treatments. Proper cooling restricts bacterial growth, but cooling failures on the farm or during further raw milk handling can allow microbial proliferation of other microbial groups such as lactic acid bacteria (e.g., *Lactococcus* spp.), some of which are associated with acid or malty defects in milk (Alvarez, 2009).

In raw milk, several strains of *Pseudomonas* and other psychrotolerant microorganisms are known to produce extracellular heat-stable enzymes, primarily proteases and lipases, which can further degrade milk components after the heat process (e.g., UHT) even though the organism itself is destroyed. Heat-stable microbial enzymes have been suggested as a concern for many dairy products and have been extensively reviewed (Fairbairn and Law, 1986; Mottar, 1989; Sørhaug and Stepaniak, 1997; Datta and Deeth, 2001). Psychrotolerant bacteria capable of producing heat-stable proteases have been reported in up to 70 to 90% of raw milk samples tested (Mottar, 1989). Microbial growth in the milk is generally required because extracellular heat-stable enzymes are thought to be secreted primarily at the end of logarithmic growth phase and can be produced under refrigeration temperatures (Sørhaug and Stepaniak, 1997). In contrast to the native milk protease plasmin, κ-casein is a preferred substrate along with β-casein and to a lesser extent α_{S1}-casein, of many extracellular microbial proteases studied; reported activity on whey proteins ranged from little to substantial (Mottar, 1989; Datta and Deeth, 2001). Optimum temperatures for activity for heat-stable enzymes of pseudomonads and other gram-negative bacteria have been reported to range from 30 to 45°C, whereas reduced activity (e.g., 30%) below 7°C has been reported for enzymes from

some strains. Optimum pH values reported ranged from 6.0 to 9.0 (Fairbairn and Law, 1986; Mottar, 1989). As stated previously, when defects characteristic of enzymatic activity develop over time in pasteurized or other heat-treated dairy products (e.g., UHT) that are free from defects initially and free from microbial contamination and growth after the heat treatment, heat-stable enzymes are likely responsible.

From a processor standpoint, the raw milk bacterial content at the time of processing is likely to have the most influence on product quality (e.g., compared with producer BT counts). The extent of the influence on quality will depend on the types, numbers, stage of growth, and enzymatic activity of the bacteria present. Because of the diversity of microorganisms present in raw milk, direct association of bacterial numbers (i.e., SPC values) to quality can be challenging. Most bacteria in raw milk are destroyed by pasteurization, and with the exception of a few select heat-stable spoilage bacteria (e.g., psychrotolerant spore-formers), those that survive are of little concern in most products. Based on thermal death curves, very high counts of less heat-resistant bacteria in raw milk must be considered to result in some survival after conventional pasteurization (e.g., 63°C for 30 min or 72°C for 15 s). With the exception of a few very heat-resistant spore-formers, any bacterial survival is less likely in UHT or UP processes (e.g., 138°C for 2 s). If bacteria counts are already high in raw milk at the time of processing, defects must also be considered already present, even though the bulk of the bacterial load will be destroyed by pasteurization. Enzymatic changes that result in quality defects in processed products may conceivably be initiated in the raw milk and can worsen after processing because of heat-stable enzymes. Although high bacteria counts in raw milk are known to result in inferior products, limited research addresses minimum numbers needed before defects are apparent, especially in regard to activity of heat-stable enzymes after pasteurization.

Cheese

Although several cheeses can be made from manufacturing grade milk, which has a higher acceptable SPC limit of 500,000 cfu/mL (USDA, 2011), cheese operations often process and sell grade A whey as a by-product of the cheese, thus they are required to use a grade A raw milk supply (FDA, 2013). Reviews on the influence of psychrotolerant bacteria on dairy product quality suggest that high numbers (e.g., >1,000,000 cfu/mL) in raw milk used to make cheese are needed to cause flavor defects and reduce yields (Cousin, 1982; Fairbairn and Law, 1986; Mottar, 1989; Champagne et al., 1994; Sørhaug and Stepaniak, 1997). Greater loss

of nitrogen in cheese whey from cheese made from high count milks was considered evidence of increased proteolysis and potential loss of yield (Cousin, 1982; Mottar, 1989; Champagne et al., 1994). In general, these reviews suggest variability of research findings on the influence of bacterial numbers on cheese quality and yield, which is to be expected because natural microflora vary in regard to their enzyme systems and activities. In addition, the research cited in these reviews contained no discussion of the potential influence of native milk enzymes (i.e., plasmin) or increased enzyme activity associated with mastitis or increased SCC. Most studies cited were with milks stored to promote growth of psychrotolerant populations in the raw milk used to make cheese. For example, Ellis and Marth (1984) evaluated cheese made with raw milk inoculated with psychrotolerant strains of *Pseudomonas* and *Flavobacterium* stored at 7°C for up to 7 d before pasteurization and cheese manufacture. They determined that cheese yield was approximately 3 to 4% lower when using milks stored for 7 d in which populations exceeded 10,000,000 cfu/mL compared with cheese made from the same milks without storage and with low bacteria counts. SCC levels or the potential for plasmin activity in the milk used for these studies were not determined. Banks et al. (1988) evaluated cheese made from raw milk (6 trials using commercial plant commingled milk and 6 trials using farm BT milk) stored at 2.0 and 6.0°C for 2 and 4 d to develop a natural psychrotolerant population before pasteurization and cheese manufacture. After 4 d, levels of psychrotolerant organisms were approximately 100-fold higher in raw milks held at 6°C with mean counts exceeding 10,000,000 and 1,000,000 cfu/mL for commingled and farm BT supplies, respectively. The researchers found no significant effect of milk storage temperature and levels of psychrotolerant bacteria on cheese yield or texture, but they did find more off flavors (after 3 and 6 mo aging) in cheese made with milks that were stored at 6°C and had higher bacterial counts. Cheese yields declined slightly (approximately 1%) over the 4 d storage of milk; this effect was seen in samples stored at both 2 and 6°C. SCC levels of the raw milk used and proteolysis due to native milk enzymes were not determined in this study. In a similar study, Leitner et al. (2008) made cheese from BT milks from 15 farms stored for 0, 24, and 48 h at 4°C. SCC were approximately 230,000 cells/mL in milk from 14 of the 15 farms, while SCC in milk from one farm exceeded 1,000,000 cells/mL. Although the authors observed average total bacteria counts increase from 68,000 to 24,000,000 cfu/mL and an average decrease in cheese curd yield of 7% after 48 h, they found no significant correlation of cheese curd yield with the increase in bacteria counts. They also found no significant correla-

tion of cheese curd yield to SCC because most milk SCC were similar, but they suggested that present and previous herd udder health could be a factor.

Evidence that the influence of psychrotolerant bacterial growth in milk on cheese yield and quality is likely strain dependent was presented by Law et al. (1979) who determined the extent of proteolysis in raw milk inoculated with 5 psychrotolerant proteolytic strains of pseudomonads and in the cheese made from that milk after storage for up to 72 h at 7.5°C. The authors compared this milk with uninoculated control milk and found detectable proteolysis in cheese milk with only 3 of the 5 strains studied for which counts approached or exceeded 10,000,000 cfu/mL after 72 h storage; they concluded this was insufficient to influence cheese yield. No proteolysis was detected with any of the strains studied in milks stored for 24 h in which counts ranged from 470,000 to 1,200,000 cfu/mL. When cheeses made from the pasteurized stored inoculated raw milks were evaluated at 6 and 22 wk, the increased proteinases activity detected in the inoculated raw milks did not appear to have a major influence on the rate or extent of protein breakdown in the cheese compared with the control milks. Although SCC were not determined in the source milk, all comparisons were made to uninoculated control milk held under the same conditions.

In general, existing data suggest that using milks with very high bacteria counts can result in yield loss or defects in cheese. Variability based on the presence of different microbial strains in raw milk used to make cheese and the lack of assessment of other enzyme systems (e.g., SCC or plasmin) makes selecting a microbial cutoff for quality difficult. Based on reviewed literature however, using raw milk with bacteria counts of <100,000 cfu/mL (i.e., PMO producer limit) would be unlikely to have a negative effect on cheese manufacture and quality.

Pasteurized Fluid Milks

Pasteurized fluid milks (e.g., 72°C for 15 s or 63°C for 30 min) are most susceptible to microbial or other flavor defects related to raw milk quality. Typical microbial defects in pasteurized fluid milk include acid, malty, bitter, coagulated, rancid, unclean, fruity, and fermented (Alvarez, 2009). Many of these defects are commonly associated with milk spoilage as a result of postprocessing contamination (**PPC**) but could develop in the raw milk before pasteurization. Published studies on the effects of using raw milk with high bacteria counts on pasteurized milk quality are relatively limited. Patel and Blankenagel (1972) evaluated the flavor of 72 raw milk supplies (farm and plant storage and a few

individual cows) that were laboratory pasteurized fresh and after storage at 7°C for 2 and 4 d for a total 216 samples. Pasteurized milks were assessed after 7 and 14 d of storage at 7°C. Flavor was scored on a 4-point scale (i.e., good, fair, poor, very poor). The SPC of the raw milk samples ranged from <100 to >100,000,000 cfu/mL. Fifty-three raw milk samples had total counts >10,000,000 cfu/mL before laboratory pasteurization. A majority (29 samples) of the laboratory-pasteurized milks made from these 53 high-count raw milks were graded as poor or very poor at 7 d, while 14 were good and 10 were fair. At 14 d, only 7 laboratory-pasteurized milks were graded as good and 6 as fair, indicating further degradation of the milks during refrigeration storage. Bitter was a common defect. For milks that were scored poor to very poor at 7 d, some may have been defective at the time of processing; the authors did not evaluate the milk after initial pasteurization. Several pasteurized milks made from low-count raw milk (<10,000 cfu/mL) were also scored as poor but were characterized as having "oxidized" or other nonmicrobial off-flavors. Somatic cell counts were not reported for the milks used in this study. This study did not specifically address heat-stable enzymes of psychrotolerant bacteria or native heat-stable enzymes, but the further development of off-flavors over shelf-life suggests the activity of heat-stable enzymes, although other mechanisms may have been involved.

In general, specific research on the influence of heat-stable microbial enzymes on the quality of refrigerated pasteurized milk is lacking. Most microbial heat-stable enzymes studied have been reported to have optimum activities above 30°C with reduced activity under refrigeration. Although the potential effect of microbial heat-stable enzymes on pasteurized milk quality is reduced by proper refrigeration, the possibility for further development of defects exists and would be more likely as shelf-life expectations increase (Mottar, 1989). From a standpoint of quality testing, the number of bacteria in raw milk needed for the development of sufficient enzymes to cause defects after pasteurization is likely high (>1,000,000 cfu/mL), but it would undoubtedly depend on the specific strains and metabolic state of the bacteria present. In addition to proteases and lipases associated with psychrotolerant bacteria, other microbial groups and enzyme systems should also be considered. For example, in one instance, a malty defect in pasteurized milk resulting in consumer complaints and product withdrawal was associated with high numbers of *Lactococcus lactis* in the raw milk supply (J. Huck and N. Martin, Cornell University, unpublished data). Because the off-flavor was not detected in the fresh-pasteurized product at the plant, the possibility exists that it developed or further developed during

storage postpasteurization, although the off-flavor may have been present initially and missed.

From a commercial perspective, Martin et al. (2011) used a range of raw milk bacterial tests, including SPC and PIC, as well as SCC (described previously) to assess raw milk samples collected from storage tanks at 4 fluid milk HTST processing plants and compared the results to shelf-life evaluations of pasteurized 2% fat milk made from the sampled raw milk. Samples were collected monthly throughout a 1-yr period. Pasteurized milks were stored at 6.0°C and tested over shelf-life out to 21 d for total bacteria count (SPC) and evaluated by a trained sensory defect panel over shelf-life out to 17 d. The data analyses included all pasteurized milk samples but focused on milks with no evidence of gram-negative PPC, which included 32 of the 43 pasteurized milks tested. The R^2 values were low for all comparisons of the of raw milk test results to the pasteurized milk shelf-life results, suggesting no significant correlation of any of the raw milk tests to the pasteurized milk shelf-life parameters studied. The R^2 values for raw milk SPC and PIC values were <0.20 for all comparisons to pasteurized milk SPC values (21 d) and sensory scores (17 d). Overall, the raw milks tested in this study were of good quality, with mean SPC of 15,800 cfu/mL (range 4,000–126,000 cfu/mL) and 28% of the supplies below 10,000 cfu/mL. This study thus suggests that for raw milk meeting PMO grade A standards (<100,000 cfu/mL), the effect of raw milk microbial levels on finished product quality would likely be minimal under normal storage conditions (e.g., ≤6°C) and holding times (e.g., ≤21 d).

High-Heat Fluid Milks

Most of the research on raw milk bacteria counts and heat-stable microbial enzymes has focused on UHT aseptically processed milk, in which heat-stable microbial enzymes have been associated with age gelation, protein precipitation, and bitter and rancid off-flavors, as reviewed extensively by Fairbairn and Law (1986), Mottar (1989), and Datta and Deeth (2001). These enzyme systems are more likely to result in defects in UHT products due to ambient product storage temperatures (e.g., >20°C), which are closer to the reported enzyme activity optimum, and the extended shelf-life (e.g., >180 d) of the products. Proteases and lipases from *Pseudomonas* spp. have been implicated and studied most often, whereas proteases tend to be more significant in product spoilage as compared with lipases (Champagne et al., 1994). Depending on the producing bacterial strain, significant activity remains after UHT treatments at and above 135°C for 2 s (Datta and Deeth, 2001). Raw milk bacterial counts gener-

ally need to exceed 1,000,000 to 10,000,000 cfu/mL to cause defects. For example, UHT milk made from raw milk in which levels of *Pseudomonas fluorescens* NSDO 2085, a specific strain known to produce a heat-stable protease, grew to 50,000,000, 8,000,000, and 800,000 cfu/mL gelled at 10 to 14 d, 56 to 70 d, and not by 140 d (still liquid) at 20°C, respectively (Law et al., 1977). Some reports have suggested that levels of enzyme sufficient to cause damage may develop with counts of 250,000 cfu/mL or less; these reports appear to be the exception, and further study in this regard is warranted (Mottar, 1989; Sørhaug and Stepaniak, 1997). The influence of SCC and of native milk enzymes should also be considered, but these were not covered in the reviews.

The effect of heat-stable enzymes on UP milks, which are processed similarly to UHT milks but are not aseptically packaged, if present, may be limited over product shelf-life because of reduced enzyme activity under required refrigeration storage. Similar to conventionally pasteurized milk, although specific research is lacking, when raw milk meeting grade A standards (<100,000 cfu/mL) is used, the effect of microbial levels on UP milk product quality would likely be minimal.

Yogurt and Cultured Dairy Products

Limited research is available on the influence of total bacterial numbers or the presence of heat-stable microbial enzymes on yogurt and other cultured dairy products. Cousin and Marth (1977) found increased levels of proteolysis in cottage cheese and yogurt made from raw milk with total bacteria numbers at >10,000,000 cfu/mL. Aylward et al. (1980) found decreased yields of cottage cheese curd made from raw milk stored up to 12 d at 5°C, but only after bacterial counts exceeded 1,000,000 cfu/mL. With pH optimums above 6.0, heat-stable enzymes associated with psychrotolerant bacterial growth in raw milk may have a limited effect on cultured dairy products, especially yogurt that typically has a pH value below 4.6.

Milk Powders

In a study that evaluated increasing raw milk bacteria counts during cold storage of raw milk on the properties of both low-heat (6 trials) and high-heat (4 trials) dried milk products, SI and heat stability were unaffected by raw milk bacterial numbers when they were less than 1,000,000 cfu/mL (Muir et al., 1986). Use of stored raw milk with higher bacteria counts, however, did affect the properties of the powders made. The mean SI as determined by centrifugation of reconstituted powders, increased from 0.37 to 0.62 mL in

high-heat powders made from raw milk stored for 24 and 72 h at 6 to 10°C, respectively, in which mean bacteria counts increased from 2,500 to >10,000,000 cfu/mL. Solubility index values of the low-heat powders were lower (0.14–0.16 mL) than for high-heat powders and did not appear to be influenced by raw milk storage and increased bacteria counts as high as 80,000,000 cfu/mL. The heat stability of powders expressed as the clotting time of powders reconstituted to 9 and 22% solids with distilled water and heated to 140 and 120°C, respectively, were also affected (reduced clotting time, lower stability) by storage and increased bacteria counts in the raw milk for both low-heat (at 9 and 22%) and high-heat powders (22% only). Although SI and heat stability are accepted criteria for assessing powder quality, both are based on reconstitution in distilled water and may not necessarily reflect performance or predict potential defects (or lack thereof) in product formulations (e.g., powder fortified skim milk). Consequently, powders should be evaluated in the specific products for which they will be used. Based on their findings, Muir et al. (1986) suggested that using raw milk with total bacterial counts over 2,000,000 cfu/mL for milk powder manufacture would be imprudent. This study did not evaluate the potential for organoleptic defects associated with high bacteria counts and did not determine SCC or native milk enzymes in the raw milk tested.

Producer Bacteria Counts and Incentive Programs

Although most research suggests bacteria counts in raw milk may need to be very high (>1,000,000 log cfu/mL) to have a direct effect on product quality, raw milk bacteria counts should not exceed the PMO grade A limit for commingled raw milk supplies (bulk milk tank truck or plant storage) of 300,000 cfu/mL at the time of processing. Further, because pasteurization delivers a defined log reduction of bacterial populations, raw milks with lower bacterial counts will reduce the number of surviving bacteria present after heat treatment. With producers supplying high-quality raw milk off the farm, the risk of raw milk at processing approaching this regulatory limit or levels at which quality or processing defects will occur is reduced dramatically. Evidence, both industry and research based, shows that dairy producers are providing raw milk with excellent microbiological quality. Bacteria counts of producer milks of <10,000 cfu/mL are not uncommon, and milks exceeding the grade A limit of 100,000 cfu/mL are relatively rare (Boor et al., 1998; Costello et al., 2003; Gillespie et al., 2012). In a study of 855 farm samples collected in New York between 1993 and 1996, the mean SPC was 11,000 cfu/mL, with 50% of the samples having SPC

values of <10,000 cfu/mL and only 5.5% having SPC values above 100,000 cfu/mL (Boor et al., 1998).

Once milk leaves the farm it is commingled with other milks in a bulk milk tank truck (**BMTT**), at the processing plant, or both, and it may be subject to additional contamination (e.g., dirty tank truck or loading equipment) and microbial growth during handling. Milk in a BMTT must be <7°C (FDA, 2013) when off-loaded at the plant, but colder is ideal (<4°C). Depending on the season and region, empty BMTT may be warm at their first pick-up, potentially increasing the farm milk temperature. Bulk milk tank trucks are only required to be washed every 24 h, allowing the hauler to pick up several loads in a day but also increasing the risk for additional microbial growth and contamination. Within that 24-h period, no limit exists for how long a load of milk may be stored in a BMTT as long as the milk temperature is <7°C and bacteria count remains <300,000 cfu/mL. Once off-loaded at the dairy plant, milk can be stored for up to 72 h in a dairy plant storage tank before the tank is required to be washed, allowing for increased numbers of psychrotolerant bacteria and the potential for the development of microbial heat-stable enzymes, as well as allowing continuous activity of native milk enzymes. Inadequate cleaning, sanitation, or both of dairy plant raw milk storage and handling equipment can promote microbial growth and contribute to the final microbial load of raw milk. How milk is handled even during processing needs to be assessed, such as when hot milk is returned to the raw balance tank during divert flow allowing the temperature to rise. Starting with high-quality producer milk, keeping raw milk cold (<4°C) and using it as soon as possible reduces the risk of increased microbial numbers and milk degradation at the time of processing and beyond. Maintaining low bacteria counts at the plant is achievable as evident in the summary statistics of monthly test results for raw milk collected from NCIMS-listed dairy plants in New York for 2004, 2009, and 2014 (Table 4). The overall numbers show improvement in bacteria counts for 2009 and 2014 compared with 2004, while values were similar for 2009 to 2014. For 2014, the overall median SPC value of 430 samples was 11,000 cfu/mL. Only 5 samples (1.2%) exceeded the 300,000 cfu/mL PMO standard, while 46% of all samples tested in 2014 were <10,000 cfu/mL. From a standpoint of bacteriological quality, these results indicate that overall, the producer raw milk supply going into New York plants is exceptional. Producer incentive programs are likely to play a significant role in this level of quality. Although these bacterial numbers may not be representative of all regions of the United States, they provide an achievable benchmark for raw milk bacteriological quality.

RAW MILK BACTERIA COUNTS OF HEAT-RESISTANT ORGANISMS AND SPORE-FORMERS

Thermotolerant bacteria that survive conventional pasteurization (i.e., 72°C for 15 s or 63°C for 30 min) include those that do so in the vegetative state and those that survive as bacterial endospores (spore-formers). The laboratory pasteurization count, which requires performing a SPC on a raw milk sample heated to 63°C for 30 min (Frank and Yousef, 2004), is a method that detects heat-resistant aerobic mesophilic vegetative cells as well as most aerobic mesophilic spore-formers. The laboratory pasteurization count, also referred to as a "thermoduric count" (Frank and Yousef, 2004), is often used as an indicator of sanitation deficiencies on the farm, but it is rarely relevant to processed product standards or quality, except when results exceed the regulatory limit based on SPC (i.e., >20,000 cfu/mL for pasteurized milk). Bacteria that survive minimum pasteurization are typically gram-positive and include non–spore-forming strains of *Microbacterium*, *Micrococcus*, *Streptococcus*, and *Lactobacillus*, among others as well as spore-forming bacteria including strains of *Bacillus*, *Paenibacillus*, *Clostridium*, and others (Boor and Murphy, 2002).

Bacteria belonging to specific spore-forming groups have become more of a concern to the dairy industry because their endospores survive minimum pasteurization temperatures as well as higher temperatures, and they have been associated with product defects. Because of the diverse nature of spore-forming bacteria, various methodologies are used to determine spore counts in raw milk. Frank and Yousef (2004) describe methods for determining counts of (1) psychrotolerant and mesophilic aerobic spores, and (2) mesophilic anaerobic spores. The first method, which includes a heat treatment at 80°C for 12 min followed by enumeration on SMA or brain heart infusion agar at 7°C for psychrotolerant or 32°C for mesophilic aerobic spore-former counts is commonly used on raw milk, fluid milk, and dairy powders. The second method for determining anaerobic spore count, specifically of those organisms that cause late blowing in some cheeses (i.e., *Clostridium tyrobutyricum*), consists of a heat treatment followed by a 3 tube anaerobic most probable number procedure (Frank and Yousef, 2004). Although these 2 methods are commonly used, other methods are employed to determine counts of the different categories of spore-formers (i.e., psychrotolerant, mesophilic, thermophilic, highly heat resistant, and anaerobic). Additional methods include (i) heating the milk sample at 100°C for 30 min followed by plating and subsequent aerobic incubation at 55°C (Burgess et al., 2010) to select for highly heat-resistant thermophilic spore-formers or (ii) heating the milk at 106°C for 30 min followed by plating and subsequent aerobic incubation at 55°C to select for specially thermoresistant spore-formers (i.e., *Anoxybacillus* spp. and *Geobacillus* spp.; ISO-IDF, 2009). Regardless

Table 4. Summary statistics of SPC values for monthly commingled raw milk samples collected from dairy plant storage tanks for New York State National Conference on Interstate Milk Shipments (NCIMS)-listed plants for 2004, 2009, and 2014[1]

Year	Measure	Plant type			
		Cheese	Fluid milk	Cultured	All samples
2004	Mean cfu/mL[2]	32,000	20,000	23,000	23,000
2009		18,000	12,000	14,000	14,000
2014		13,000	11,000	14,000	12,000
2004	Median cfu/mL[2]	25,000	16,000	20,000	20,000
2009		17,000	8,900	13,000	12,000
2014		14,000	10,000	12,000	11,000
2004	Minimum cfu/mL	570	810	2,500	810
2009		3,500	1,100	1,400	1,100
2014		1,200	2,000	2,500	1,200
2004	Maximum cfu/mL	42,000,000	2,000,000	760,000	42,000,000
2009		880,000	1,600,000	930,000	1,600,000
2014		79,000	2,000,000	410,000	2,000,000
2004	Percentage ≤10,000 cfu/mL	14.3	30.5	22.2	24.5
2009		29.2	59.0	37.1	46.1
2014		37.7	51.8	42.7	45.8
2004	Percentage >300,000 cfu/mL	5.7	3.9	2.0	3.7
2009		1.2	2.4	1.4	1.9
2014		0.0	1.6	1.2	1.2
2004	Total samples	70	154	99	323
2009		82	205	140	427
2014		77	189	164	430

[1]Data provided by New York State Food Laboratory; represents large NCIMS-listed dairy plants.

[2]Logarithmic (log 10) mean and median.

Table 5. Milk heat activation treatments and enumeration methods for select spore-forming groups

Spore-forming group	Milk heat treatment	Enumeration method[1]
Mesophilic[2]	80°C/12 min	SMA or BHI agar; 32°C/48 h
Psychrotolerant[2]	80°C/12 min	SMA or BHI agar; 7°C/10 d[5]
Thermophilic[2]	80°C/12 min	SMA or BHI agar; 55°C/48 h
Highly heat-resistant thermophilic[3]	100°C/30 min	SMA or BHI agar; 55°C/48 h
Specially high heat-resistant thermophilic[4]	106°C/12 min	SMA or BHI agar; 55°C/48 h
Anaerobic lactate-fermenting clostridia (late gas defect)[2]	80°C/10 min	RCM-L tubes, sealed; most probable number[6]; 32°C/48 h

[1]SMA = standard methods agar; BHI = brain heart infusion; RCM-L = reinforced clostridia medium with lactate. Aerobic incubation is normally used for all but the RCM-L method.

[2]Frank and Yousef (2004).

[3]Burgess et al. (2010).

[4]ISO-IDF (2009).

[5]To detect low levels of psychrotolerant spore-formers, incubate the heat-treated milk at 6 to 7°C for 7 to 10 d before plating; longer incubation of 14 to 21 d may be needed.

[6]Example of one available method. Several others have been published and used.

of the specific spore-former targeted, each spore-former test includes a heat treatment that eliminates vegetative cells from the sample and activates germination of the surviving spores. Subsequent differentiation of spore-forming groups is achieved through use of different incubation temperatures, different oxygen levels, or both. A summary of common methods is presented in Table 5.

Endospores are capable of surviving various harsh conditions including heat, UV radiation, oxidizing agents, chemicals, and others (Nicholson et al., 2002). In spore form, spore-forming bacteria are able to survive processing conditions commonly encountered in the dairy industry and subsequently germinate and grow to spoilage levels (Scott et al., 2007; Ranieri and Boor, 2010; Ivy et al., 2012). Reducing dairy product spoilage from spore-forming bacteria relies on 2 primary methodologies: (1) removing spores or reducing outgrowth or both through processing technology, and (2) reducing transmission from farm environments into raw milk.

Spore-forming bacteria are found in a wide range of dairy-associated environments including soil, water, feed, and manure (te Giffel et al., 2002; Scheldeman et al., 2006; Huck et al., 2007; Ivy et al., 2012; Masiello et al., 2014). The presence of spores in BT raw milk is associated with certain farm management practices that facilitate contamination from these sources. Masiello et al. (2014) reported that some farms produced BT raw milk that did not show growth of psychrotolerant spore-formers during refrigerated storage following heat treatment, while raw milk from other farms showed psychrotolerant spore-former growth. This report suggests that production of raw milk with a lower risk of spoilage due to psychrotolerant spore-former growth in processed pasteurized fluid milk products is possible.

Farm management factors associated with psychrotolerant spore-former presence in BT raw milk were herd size and percentage of cows in the milking parlor with dirty udders (Masiello et al., 2014). Miller et al. (2015) examined the association between farm management practices and mesophilic and thermophilic spore-formers in BT raw milk. Farm management factors associated with fewer mesophilic spores, the most abundant spore type found in BT raw milk, included larger herd size, the use of sawdust bedding, and not fore-stripping during premilking routine. Farm management factors associated with a lower likelihood of thermophilic spores in BT milk were large herd size, spray-based application of postmilking disinfectant, dry massaging the udder during the premilking routine, and use of straw bedding.

Anaerobic spore-forming bacteria, particularly anaerobic butyric acid–producing spore-forming bacteria, or butyric acid bacteria (**BAB**) responsible for late-blowing defect in cheese, are also found in the dairy farm environment. Silage has long been considered a primary source of BAB in farm raw milk (te Giffel et al., 2002; Vissers et al., 2006, 2007a,b). Aerobic deterioration of silage leading to yeast growth and subsequent increase in pH with localized anaerobic niches leads to high concentrations of anaerobic spore-forming bacteria (Vissers et al., 2007a). These high concentrations of BAB in silage consumed by dairy cattle are then further concentrated in manure. Other farm sources include soil and bedding (Julien et al., 2008). Farm management practices essential in reducing risks of contaminating BT raw milk with BAB include controlling anaerobic spore concentrations in silage, controlling the cow's environment (e.g., feed, grounds, and bedding) to reduce udder soiling, and effective premilking hygiene practices.

Cheese

Of the known spore-forming bacteria, anaerobic BAB capable of fermenting lactic acid into butyric acid, acetic acid, hydrogen, and carbon dioxide have long been associated with a defect in some hard and semi-hard style cheeses (e.g., Gouda) known as late blowing (Goudkov and Sharpe, 1965; Klijn et al., 1995). Copious gas production by BAB, which causes extreme body defects in these cheeses, along with flavor defects associated with butyric acid and other byproducts of BAB growth (Cocolin et al., 2004) results in loss of product and economic implications. Butyric acid bacteria most commonly associated with this defect are *Clostridium tyrobutyricum*, along with *Clostridium butyricum*, *Clostridium beijerinckii*, and *Clostridium sporogenes* (Le Bourhis et al., 2007).

Various strategies have been employed to reduce the incidence of late-blowing defect in cheese, starting with control of the presence of these organisms in the raw milk (Vissers et al., 2006, 2007b). As few as 1 BAB spore per milliliter of raw milk can lead to late-blowing in susceptible cheeses, and in certain areas of the world where the economic importance of these cheeses is high, penalty systems are therefore in place for BAB in raw milk (Vissers et al., 2006). In some areas, the use of silage feed is prohibited when the intended use of the raw milk produced is for susceptible cheeses (McClure, 2006). Beyond strategies to reduce the entry of BAB into raw milk, approaches to reducing BAB spoilage include removing spores by centrifugal clarification (Su and Ingham, 2000) and adding lysozyme (Hughey and Johnson, 1987) or using culture microorganisms to control outgrowth of BAB (Bogovic Matijasic et al., 2007; Martinez-Cuesta et al., 2010). For the manufacture of some cheeses, spores can be effectively controlled by using gravity separation to remove spores from the raw milk before cheese making (Caplan et al., 2013; Geer and Barbano, 2014a,b). Currently, testing for BAB is not commonly employed in premium incentive programs in the United States, although some processors of specialty cheeses are using testing as a means of identifying high-risk loads of milk such that they can be diverted to other uses (M. Wiedmann, Cornell University, personal communication). In some countries (e.g., the Netherlands) systems are in place that reward raw milk with low BAB levels (e.g., less than 1,000 BAB spores/L raw milk; Vissers et al., 2007b).

Pasteurized Fluid Milks

Psychrotolerant spore-forming bacteria capable of surviving pasteurization are the most significant spore-forming group associated with raw milk that will influence pasteurized fluid milk quality and shelf-life. In the absence of PPC with gram-negative psychrotolerant bacteria typically associated with reduced pasteurized milk shelf-life, the presence of psychrotolerant spore-formers in raw milk and their survival, outgrowth, and activity after pasteurization are considered key limiting factors in extending pasteurized milk shelf-life (Martin et al., 2012b). If both spore-former outgrowth and PPC are controlled, maintaining acceptable quality of pasteurized milk beyond 21 d is achievable. Common psychrotolerant spore-forming bacteria belong primarily to the genus *Paenibacillus* (Ivy et al., 2012), but some strains within the genera *Viridibacillus* and *Bacillus* (e.g., *Bacillus weihenstephanensis*) also exhibit the ability to grow at refrigeration temperatures (Ivy et al., 2012). Psychrotolerant spore-formers, like many other spore-forming bacteria, are common contaminants of producer raw milk where they are normally present at low concentrations, generally below 10 spores/mL (Masiello et al., 2014). However, only 1 spore/container may be sufficient to cause spoilage of pasteurized milk. Despite low initial levels, *Paenibacillus* and other psychrotolerant spore-forming bacteria, many of which produce lipolytic and proteolytic enzymes (De Jonghe et al., 2010), are capable of germinating at refrigeration temperatures and growing to spoilage levels in approximately 14 d post processing (Ranieri and Boor, 2010). The numbers of psychrotolerant spore-formers in raw milk do not necessarily correlate with outgrowth and spoilage potential in pasteurized milk, suggesting variability in germination and growth rates as well as enzymatic activity (Trmčić et al., 2015). Processing parameters have been shown to influence the outgrowth of psychrotolerant spore-forming bacteria; in particular, higher pasteurization temperatures lead to faster outgrowth of psychrotolerant spore-forming bacteria when present in raw milk (Ranieri et al., 2009; Martin et al., 2012a). Additionally, PPC with these organisms cannot be ruled out. Given that it takes only 1 actively growing psychrotolerant bacteria per container to eventually cause spoilage, detecting psychrotolerant spore-formers in raw milk presents a challenge in regard to sensitivity and ability to predict outgrowth and spoilage. Although current methods for detecting psychrotolerant spore-formers are effective tools in investigating sources of these organisms in the raw milk supply and their influence on product quality, using psychrotolerant spore-former levels in quality incentive programs may not be feasible because keeping levels consistently below a determined acceptable level to minimize eventual spoilage (e.g., 1 spore per 100 to 1,000 mL) remains a challenge at the producer/farm level. Raw milk will always contain some spores. Although the fluid milk processing industry has technologies that can help ex-

tend shelf-life of fluid milk products through removal of spores from milk before thermal treatment such as by centrifugal clarification or microfiltration (Elwell and Barbano, 2006; Caplan and Barbano, 2013), effective control of psychrotolerant spore-formers to allow consistent production of extended shelf-life conventionally pasteurized fluid milk products will most likely require a systems approach that includes control and monitoring of psychrotolerant spore-formers in the raw milk.

High-Heat Fluid Milks

In contrast to psychrotolerant spore-formers found in HTST fluid milk that is held at refrigeration temperatures, the primary spore-forming bacteria of concern in UHT products are mesophilic and thermophilic. Specifically, *Bacillus sporothermodurans*, which has been shown to survive UHT treatment in spore form (Pettersson et al., 1996) and subsequently grow under the ambient storage conditions of the product (Scheldeman et al., 2006), is of particular concern. *Bacillus sporothermodurans* has been shown to exhibit only weak proteolytic activity in UHT products (Klijn et al., 1997), but it is capable of growing to levels of up to 100,000 cfu/mL at 30°C (Berkeley et al., 2002), compromising the sterility of the product. Klijn et al. (1997) noted that UHT products contaminated with *B. sporothermodurans* are typically found during quality control checks and sometimes exhibit off-odors, off-flavors, and body defects. Although *B. sporothermodurans* is able to grow in UHT products at ambient temperatures, no spore-former has yet been described that can both survive UP or UHT processing conditions and grow at refrigeration temperatures required of UP milks. Despite occurring in the farm environment (i.e., silage), *B. sporothermodurans* is found infrequently in raw milk (te Giffel et al., 2002; Scheldeman et al., 2006; Heyndrickx et al., 2012). Raw milk incentive programs or other strategies to reduce *B. sporothermodurans* loads in raw milk do not currently appear to exist.

Yogurt and Cultured Dairy Products

Although spore-forming microorganisms are abundant in the raw materials used for yogurt and cultured dairy products, little information exists on the effect of spores on these products. Currently, no spore-forming bacteria are known to grow at both refrigerated storage temperatures and the low pH found in these products.

Milk Powders

Spore-forming bacteria have become an increasing area of concern for dairy powder processors because of stringent customer specifications (Bienvenue, 2014). Demand for milk powders with low spore counts (i.e., noncommodity powders) is a fast-growing market that represents economic opportunity for dairy processors (Bienvenue, 2014). Of primary concern in milk powders are the mesophilic and thermophilic spore-formers that originate from the raw milk as well as from the processing environment (Scott et al., 2007; Burgess et al., 2010; Watterson et al., 2014). Studies of the ecology of spore-forming bacteria found in milk powders around the world indicate that the most commonly isolated spore-formers are *Bacillus licheniformis*, *Anoxybacillus flavithermus*, and *Geobacillus* spp. (Rückert et al., 2004; Scott et al., 2007; Burgess et al., 2010; Yuan et al., 2012; Dhakal, 2014; Buehner et al., 2015). Although *B. licheniformis* is frequently isolated from raw milk and farm environmental samples (Ivy et al., 2012), *A. flavithermus* and *Geobacillus* spp. are not commonly found in those samples, suggesting processing plant–associated sources or enhancements. In fact, *Anoxybacillus* and *Geobacillus* have been shown to form biofilms in powder-processing facilities, leading to the contamination of milk powders during production (Scott et al., 2007). Thermotolerant strains of spore-formers as well as non–spore-formers can build up in sections of HTST pasteurization systems and increase in numbers in the product during long processing days (Driessen et al., 1984; Lehmann et al., 1992; Scott et al., 2007), presenting a need for periodic modified washes (e.g., midday flush). These thermophilic spore-formers and others commonly found in milk powders have been shown to produce heat-stable proteolytic and lipolytic enzymes that could cause quality defects in milk powders and even their final product applications (Chen et al., 2004). Interventions at the plant include removal of spores from the raw milk by centrifugal clarification or microfiltration, coupled with methods to control the growth of these organisms during processing, including periodic washes in heat treatment systems. Post-drying treatments of powders with high pressure might also be a possible method to kill spores in products that need to be free from spores.

Current specifications for spore levels in powders vary greatly depending on the customer and product end use. Reducing spore counts in dairy powders requires both farm-level interventions to reduce transmission from the environment into the BT raw milk as well as processing-level interventions to both eliminate spores and prevent biofilm formation. Producer spore count incentive programs may be beneficial for processors with stringent customer spore specifications, specifically if the primary organisms of concern in their products are associated with raw milk (i.e., *Bacillus licheniformis*).

DISCUSSION

Raw milk quality can clearly affect dairy product production, yield, quality, and safety through a variety of different mechanisms. This recognition has led to the use of both regulatory limits and penalty and quality premium systems to require and encourage, respectively, production of high-quality raw milk that facilitates efficient production of high-quality finished products. Beyond this general recognition of importance of raw milk quality, specific and quantitative data on the linkage between raw milk quality parameters and processing efficiency and product quality appear to be more limited than one may assume. One exception to this limitation is the clear and quantifiable linkage between raw milk with lower SCC and improved cheese yields and quality, including the availability of initial, meta-analysis–based models that have attempted to quantify these relationships (Geary et al., 2013, 2014) and thus can facilitate the development of premium payments with a quantifiable return on investment (**ROI**) for the processor offering premium payments. In addition, evidence exists that lower SCC raw milk may provide for improved quality fluid milk and yogurt products as well as milk powder; negative effects of high SCC on fluid milk quality may become more of a concern as the shelf-life of pasteurized milk is further extended. Data for the linkage between SCC and fluid milk, yogurt, and dairy powder quality are typically limited though and often based on data that compared products made from raw milk with low SCC, often below 200,000 cells/mL, to products made with milk at or above the US legal limit of 750,000 cells/mL. Although premium payments for low SCC milk seem prudent even for raw milk designated for these types of products, data do not appear to be currently available to calculate economically justifiable specific premium cutoffs or levels for products other than cheese. Importantly, raw milk SCC is only a weak proxy measure that is correlated with, but does not fully explain, the variations in levels of heat-stable native milk proteases in milk. Better analytical tests are needed to determine the variation both in level and activity of native milk proteases in milk that can be used in milk quality premium payment programs.

With regard to the effects of raw milk bacterial counts on finished product quality and processing efficiencies, indications are again that raw milk with low bacterial counts is likely to be favorable for production of high-quality finished products. While most research available suggests that bacterial counts in raw milk (measured by SPC) need to be very high (>1 million cfu/mL) to have a direct effect on product quality, lower bacterial counts in raw milk may be linked to specific issues if the organisms present are heat tolerant or have

specific characteristics (e.g., highly efficient production of enzymes) that allow them to cause spoilage. In addition, receiving raw milk with low bacteria counts may be economically more valuable to processors because it provides more flexibility in regard to raw milk transport and plant storage, where processing schedules and efficiencies may require extended storage. With producer milk of high quality coming off the farm, the risk of bacterial counts in raw milk at processing approaching levels at which quality concerns will occur is reduced dramatically. Relative to the influence of total bacterial counts on processed quality, further research is warranted in certain areas. With increasing shelf-life expectations such as with fluid milk, lower total bacteria counts may become more significant. Concerning individual producer supplies, no research specifically addresses the potential for heat-stable enzymes related to commingling high-count milk with low-count milk where total bacteria counts may be diluted out or due to native heat-stable milk proteases that originate from the cow that are not well correlated with milk SCC. The possibility of enzyme development related to biofilms or residual milk films in relation to dairy product quality also needs further investigation. In the future, specific bacterial counts (e.g., psychrotolerant spore counts), which have a more direct link to the quality of finished products, are likely to be more commonly used. With this, quantitative data that allow for rational determination of premium levels and cutoffs with economic benefits for the processor will likely follow. In addition to the importance of understanding and quantifying links between raw milk quality parameters and measurable economic benefits for processors of high-quality raw milk, one should not ignore the importance of incentivizing the production of high-quality raw milk even in the absence of a quantifiable ROI for premium payments. Many consumers clearly demand and expect foods including dairy products to be manufactured from "high-quality" raw materials, even if use of higher quality raw materials does not necessarily translate into improved functionality or sensory perception of the finished products. The future of premium payments incentivizing production of high-quality raw milk thus will likely feature a combination of premiums that can be clearly linked to a processor ROI because of improved production efficiency or quality characteristics of the finished product as well as premiums that encourage production of raw milk that consumers may judge to be high quality, where the ROI may be consumer preference for a product and willingness to pay for products produced from higher quality raw materials. One may argue that consumer willingness to pay premiums for finished products made from organic or sustainable sourced raw materi-

als represents an example of a consumer-driven quality parameter.

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