

Major Advances in Fresh Milk and Milk Products: Fluid Milk Products and Frozen Desserts

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ABSTRACT

Major technological advances in the fluid milk processing industry in the last 25 yr include significant improvements in all the unit operations of separation, standardization, pasteurization, homogenization, and packaging. Many advancements have been directed toward production capacity, automation, and hygienic operation. Extended shelf-life milks are produced by high heat treatment, sometimes coupled with microfiltration or centrifugation. Other nonthermal methods have also been investigated. Flavored milk beverages have increased in popularity, as have milk beverages packaged in single-service, closeable plastic containers. Likewise, the frozen dairy processing industry has seen the development of large-capacity, automated processing equipment for a wide range of products designed to gain market share. Significant advancements in product quality have been made, many of these arising from improved knowledge of the functional properties of ingredients and their impact on structure and texture. Incidents of foodborne disease associated with dairy products continue to occur, necessitating even greater diligence in the control of pathogen transmission. Analytical techniques for the rapid detection of specific types of microorganisms have been developed and greatly improved during this time. Despite tremendous technological advancements for processors and a greater diversity of products for consumers, per capita consumption of fluid milk has declined and consumption of frozen dairy desserts has been steady during this 25-yr period.

Key words: fluid milk, ice cream, major advancement

ADVANCES IN PRODUCTS AND PROCESSES

Fluid Milks

The last 25 yr of science and technology devoted to milk and milk products have led to major advances in mechanization, automation, and hygiene within the

processing plant, quality and safety, extensions in shelf life, and new product introductions that have brought variety and convenience for the consumer. Perhaps this quarter-century has been one of adaptive change and slow evolution rather than one of paradigm shifts; however, the diligence and effort of dairy researchers and technologists in bringing about these changes continues at an all-time high. The consumer has greatly benefited in ways that often seem transparent; for example, in the improvement of quality and shelf life of milk and milk products. Certainly this quarter-century has been marked by consolidation within the milk and milk products industries, as will be evident in the presentation of production statistics. Consolidation allows for improvements in mechanization and automation, so that today's milk processing plant would be hardly recognizable to the practitioners of 25 yr ago.

Of the 74.3 billion liters of milk produced in the United States in 2003, 39% or 29 billion liters were consumed as fluid milk. The average price paid to the farmer was \$14.24 per hundredweight at 3.5% milkfat, Class I, and \$12.11 at 3.5% milkfat, blend price. This compares to a total milk production of 61 billion liters of milk 25 yr ago, with 26 billion liters going into fluid milk (42.6% of total milk production). In Canada, milk production in 2002 stood at 7.4 billion liters, with 38% sold as fluid milk. In 2002, the United States ranked second only to India in terms of total milk produced (Table 1). Concentration in the industry is illustrated by US census data. The 1,924 plants existing in 1977 produced an average of 13.2 million liters of fluid milk. There were only 612 such plants in 1997 but they had an average yearly output of 43.8 million liters. Similar consolidation has occurred in Canada and in many other countries.

Advances in fluid milk processing over the last 25 yr can be traced by comparing state-of-the-art textbooks on the subject then and now. Books written by Harper and Hall in 1976, Campbell and Marshall in 1975, and Kessler in 1981 are appropriate benchmarks from approximately 25 yr ago, and the book written by Walstra and his coworkers in 1999 is an appropriate benchmark for a discussion of the modern state-of-the-art. The major unit operations involved remain clarification and

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Table 1. Cow milk production in selected countries in the world (2002)¹

Country	Production (million L)
India	79,855
United States	74,343
Russia	32,304
Germany	26,930
France	24,298
Brazil	21,848
New Zealand	13,513
China	12,546
Poland	11,367
Italy	10,932
Netherlands	10,422
Australia	9,942
Mexico	9,542
Argentina	8,200
Canada	7,300

¹Source: Agriculture and Agri-Food Canada, Ottawa, ON, Canada.

separation by centrifugation, standardization of fat content, pasteurization, homogenization, and packaging. However, each of these unit operations has benefited from significant technological developments. The modern centrifuge is self-cleaning of sludge with minimal loss of milk. Standardization involves online rapid analysis of milkfat with automated feedback adjustment so that fat content can be maintained within 0.05% of set-point. Improvements in HTST plate pasteurization have focused on energy efficiency, with regeneration (heat reclamation) rates of 94% being possible. Homogenization improvements have also focused on energy efficiency, including the use of homogenization valves capable of producing the same fat globule size distribution with less than half the operating pressure of standard homogenizing valves. Milk pasteurization plants can now produce volumes of 200,000 L/h.

Milk-Based Beverages

Flavored milks have become more popular in recent years; these include vanilla, strawberry, chocolate, banana, and coffee. Flavors that appeal to children have also been introduced. Packaged, single-service portion milk shakes, which contain milk, enhanced milk solids, sugar, and stabilizers for thickening and aeration upon shaking, are also readily available from many processors, to compete in the convenience store with other beverage choices. These shakes have similar flavors to the flavored milks. Milk-based beverages, in which milk has been combined with another beverage such as a fruit juice, are available in limited quantities. Although appealing, there is a large technological challenge to stabilize milk protein, particularly the casein micelles, outside of its normal range of pH and ionic strength.

Extended Shelf Life and Shelf-Stable Milks

Extension of the shelf life of milk has been a prime objective of the dairy industry for many years to meet the demands of increasing distribution times and distances. Extended shelf life (ESL) products, with shelf life of 21 to 28 d at refrigerated temperature, are available through normal pasteurization, although at slightly elevated heat treatments, accompanied by aseptic packaging. Such packaging machines have been developed within the last 25 yr with adoption of some of the technologies used in the production of UHT sterilized products (filling heads enclosed from the atmosphere, sanitizer sprays, UV light), although standard packaging is used and a headspace exists within the container. Extended shelf life products can be manufactured with the use of microfiltration membranes. In this procedure, skim milk is passed through membranes that concentrate bacteria in the retentate, which is then pasteurized with elevated heat treatments and used elsewhere. The permeate is then standardized for fat, and pasteurized at minimal time-temperature conditions to produce an ESL milk with high flavor quality. The microfiltration process leads to reduction in counts of about 4 to 5 log cycles but mandatory pasteurization regulations require that microfiltration be accompanied by thermal pasteurization. It is not possible at present to meet fail-safe engineering requirements on membrane systems, as it is on thermal pasteurization equipment. Another means of reducing bacterial numbers in pasteurized milk is through the use of high-speed centrifugation (so-called bactofugation), followed by minimal pasteurization, although this process is not used as much as membrane processing. Other nonthermal techniques for pasteurization of milk such as pulsed electric field and high pressure processing have been investigated but have not found practical application.

Shelf-stable milk products are processed by UHT continuous flow sterilization followed by aseptic packaging. Sterilization is achieved most successfully by direct heating systems, steam injection, or steam infusion, in which the temperature of milk is rapidly raised to 140°C by direct mixing with steam, followed immediately by rapid cooling through flash vacuum evaporation of water that condensed in the product from the steam. Systems can be designed to operate at 2,000 to 30,000 L/h. The sterilized milk is then aseptically packaged within multilayer paperboard, plastic, and metal film with no headspace. Ultra-high temperature sterilized milk is widely used in many countries of the world where inadequate refrigeration limits widespread distribution or home use of fresh milk. It is also used as a convenience product for traveling or baking. However, the excellent

refrigerated-distribution and retailing system in place in North America, coupled with flavor limitations from the intense heating, have precluded widespread acceptance of UHT-sterilized milk here.

Frozen Dairy Desserts

In 2003 in the United States, 5,333 million liters of regular, light, and low-fat ice cream were manufactured. Production has increased from 4,591 million liters in 1980 and from 3,104 million liters in 1955. The frozen dairy desserts industry utilizes 10% of total milk production and 16% of manufactured milk production in the United States. In Canada, frozen dairy dessert production in 2003 was 380 million liters, of which 79% was ice cream and light ice cream, 9% was ice milk, and 4% was frozen yogurt. Consolidation can be readily seen by looking at the number of plants producing hard ice cream in the United States. In 2003, there were 400 registered manufacturers, compared with 950 in 1980 and 3,500 in 1955. Similar trends have occurred in Canada and Europe. As with fluid milk, consolidation has allowed for improvements in mechanization and automation as well as plant sanitation and hygiene.

A comparison of ice cream science and technology described in the book written by Arbuckle in 1977 compared with that in Marshall, Goff, and Hartel written in 2003 provides a good look at developments that have occurred during the last 25 yr. Many major scientific advances have focused on ice cream structure and colloidal properties: understanding and control of ice recrystallization, recognition of the importance of the glass transition in stability of the frozen product, development of stabilizers, and the latest developments in the area of ice structuring proteins from natural sources, advances in understanding and control of fat destabilization and emulsifier functionality, and enhanced knowledge of the air bubble interface and air bubble stability. These studies have been published in highly respected physical chemistry journals and reviews of this progress are available, indicating the advanced level of knowledge that has been developed.

Ice recrystallization is still recognized as one of the major quality defects in ice cream that limits its shelf life and brings forth consumer complaints. This is perhaps exacerbated by the global shipments of ice cream occurring regularly and by the long distribution chains and mass distribution in modern supermarkets. These market conditions place higher demands than before for heat shock stability due to temperature fluctuations. Stabilizer functionality has been extensively studied by many groups who have provided good understanding of how stabilizers behave. However, the ability to predict whether a macromolecule will be a good stabilizing

agent has not yet been obtained. Also lacking is a full understanding of the relationship between structure and mouthfeel—these relationships between the physical and sensory sciences need further development. Glass transitions have been extensively studied with regards to shelf life. However, rapid, inexpensive, reliable, and accurate methods for measurement of the glass transition are still needed, as is a better understanding of how to manipulate the glass transition temperature without negatively affecting texture at consumption temperatures. Interactions between all the discrete phases of ice cream are increasingly being studied in more complex systems, leading to an appreciation of such things as the effect of air bubble size distribution on ice recrystallization. The importance of protein polysaccharide phase separation in the freeze-concentrated unfrozen phase and its effect on ice recrystallization has been recognized. There is a clear trend toward studying various factors related to ice recrystallization in the complex milieu of ice cream rather than in model systems, taking into account structural effects such as emulsifier action, fat destabilization, air distribution, and phase separations, interactions that were previously not considered; this is undoubtedly the way progress will be made.

Processing advances have included sophisticated, automated continuous freezers that can process volumes of 3,000 to 4,000 L/h, equipped with filtered air, exact control of overrun, and dosing of particulate ingredients. Production rates of freezers can be automatically tied to those of filling machines. Recent research has made the important link between processing parameters and structure. Advances in rapid hardening equipment have also reduced energy costs, increased turnaround time, and improved product quality. Sophisticated and novel processing technology for manufacture of hand-held impulse products is readily available, giving rise to a myriad of new product introductions around the world. Extrusion processing, a technology that was in its infancy 25 yr ago, has enabled a vast array of product shapes and sizes. Fluting, layering, and other fancy molding are widely seen in both single-serving products and in ice cream cakes, much of it from automated, continuous processes. High-quality production of three-dimensional molded products with high definition detail is possible with new molding processes. Extruded and molded products can be shaped in postextrusion or molding processes with deep cooled, nonstick tools with high definition. There is no doubt that the modern ice cream plant, with its level of automation and hygiene, could not have been envisaged by the early ice cream manufacturing pioneers.

Packaging

A comparison of today's milk packaging with that of 25 yr ago suggests that this, too, has been an area of major development. Currently, areas of greatest development are in convenience for home-use packaging and in single-service packaging. Paperboard gable-top containers for 1-quart and half-gallon portions and blow-molded, low-density polyethylene plastic containers (jugs) for 1-gallon portions are the most widely used packages in the United States. In Canada, the 4-L bag from low-density polyethylene film (3×1.33 -L individual bags within a printed outer bag) is the most popular container for home use. The development of resealable, screw-cap plastic closures for gable-top, paperboard, half-gallon containers has been a big improvement for convenience, compared with opening the paperboard itself at the gable, and has led to a resurgence in popularity of this container. For single-serving portions, the 8-ounce (250 mL) paperboard gable-top container was the standard 25 yr ago and is still widely used; however, there have been a number of introductions of single-serving portions to broaden this category. Single-serving containers are now available in 12- and 16-ounce portions, as well as 8-ounce portions, and in recloseable plastic bottles in a variety of convenient shapes. Single-serving portions are now being sold in vending machines and in grocery stores in multipacks, to compete with the convenience and availability of carbonated drinks, juices, and flavored or unflavored waters. These plastic bottles also provide the opportunity for printing with high quality graphics and colors, and the introduction of heat-shrinkable plastic sleeves has provided enhanced eye-appeal to these new packages.

ADVANCES IN SENSORY SCIENCE

A thorough description of the off-flavors in milk and milk products, their sources, and control has been available from the American Dairy Science Association for all of the last 25 yr. Some improvements in understanding the basic chemistry of milk oxidation has occurred, but for the most part, this information has been well known. However, sensory science has advanced tremendously over this period, and these advances are now being applied to dairy products, particularly cheeses. Rather than a focus on off-flavors, much work has been conducted using multivariate statistics in quantitative descriptive analysis and flavor and texture profiling. The objective of this work has been to quantify the intensities of specified sensory characteristics (using a descriptive and standardized lexicon developed by highly trained panelists) to understand minor changes in cheese flavor and relate these to both objective chemical measurements of flavor components and to con-

sumer perceptions in a quantitative way, to elucidate the major inputs that affect sensory quality. In flavor or texture profiling, both signal intensity and duration, or mechanical and geometrical responses, are monitored and quantified. As this sensory science and collaboration with flavor chemists develops further in the dairy industry, the same principles will undoubtedly be applied to understand subtle changes in fluid milk flavor.

In addition to quantitative descriptive analysis, advances in oral processing of dairy products have been made. Understanding the way that food components interact with the tongue and palate provides great insight into those attributes that have the greatest impact on texture. For example, the perception of fat as it relates to emulsion characteristics has been the subject of considerable recent work, particularly as it relates to the development of low-fat products that do not sacrifice perceived textural attributes. A great deal of research on emulsions has focused on stability issues; phenomena such as flocculation, coalescence, creaming, sedimentation, and the emulsion attributes that lead to instability are, for the most part, well understood. Stability is often the primary goal of product development work related to emulsions. But how those attributes affect texture or mouthfeel of emulsions, and how changes due to instability might affect texture, are less well understood. It would pose a serious dilemma to the food technologist to learn that the attributes leading to optimal emulsion stability were not those leading to optimal texture. Emulsion attributes can be divided into factors associated with the discrete phase (phase volume, droplet size distribution), those associated with the adsorbed layer (composition, quantity), and those associated with the continuous phase (viscosity, solution composition, and properties). Of these, we know that droplet size distribution and composition of the adsorbed layer are very important stability issues. But the effect these have on texture is almost unknown. Flavor partitioning between the discrete and continuous phases, although not important for stability, must also play a role in perception of flavor of the emulsion.

There is a large difference in texture between skim milk and 1% fat milk, but we do not fully understand how the fat globules in the latter can interact with the mouth at such low concentration. Current research is focused on understanding the relationship between droplet size distribution in homogenized milk (a controllable parameter) and creaminess, understanding the relationship between quantity of adsorbed protein in homogenized milk (a controllable parameter) and creaminess, and interactions between food constituents and the mouth. Fat contributes greatly to the flavor and texture of ice cream. Recent research has focused

Table 2. Outbreaks of food- and milkborne infectious intestinal disease in England and Wales, 1992–2000¹

Year	Foodborne ²	Milkborne (%) ³
1992	232	4 (1.7)
1993	243	3 (1.2)
1994	239	4 (1.7)
1995	233	4 (1.7)
1996	202	4 (2.0)
1997	249	3 (1.2)
1998	142	1 (0.7)
1999	116	2 (1.7)
2000	118	2 (1.7)
Total	1,774	27 (1.5)

¹Gillespie et al., 2003.²Foodborne outbreaks and foodborne outbreaks followed by person-to-person transmission.³As percentage of all outbreaks of foodborne origin.

on flavor and textural aspects of various sources of fat, other nonfat ingredients to provide fat-like properties (“fat replacers”), and the effect of fat on sensory properties and flavor perception of ice cream. This ongoing research is providing new understandings of the effects of ingredients and processes on the texture and flavor of dairy foods.

QUALITY AND SAFETY ISSUES

Incidence and Outbreaks of Milkborne Illness

Pasteurization has been a “guarantee” of safety of dairy products for many years. However, certain consumer groups continue to press for access to unpasteurized milk, despite the vast literature that indicates the effectiveness of pasteurization in the reduction of milkborne illness. Outbreaks related to milk still occur but these are primarily associated with failures in the pasteurization process or postprocess contamination. From January 1, 1992, to December 31, 2000, 27 milkborne outbreaks of infectious intestinal disease were reported to the Public Health Laboratory Service Communicable Disease Surveillance Centre in England and Wales (Table 2). These outbreaks represented about 2% of all outbreaks of foodborne origin reported to the centre, but were characterized by significant morbidity. Unpasteurized milk (52%) was the most commonly reported vehicle of infection in milkborne outbreaks, with milk sold as pasteurized accounting for the majority of the rest (37%; Table 3). *Salmonella* (37%), enterohemorrhagic *Escherichia coli* (33%), and *Campylobacter* (26%) were the most commonly detected pathogens, and most outbreaks were linked to farms (67%). This highlights the importance of *E. coli* O157 as a milkborne pathogen and the continued role of unpasteurized milk in human disease.

Even in jurisdictions where milk is of very good quality, milk can be contaminated with potentially pathogenic bacteria. For example, in Ontario, producers routinely ship milk with bacterial counts $<1.5 \times 10^3$ cfu/mL. However, when 1,720 raw milks were tested for the presence of pathogens, *Listeria monocytogenes*, *Salmonella* spp., *Campylobacter* spp., and verotoxigenic *E. coli* were isolated from 2.73, 0.17, 0.47, and 0.87% of the samples, respectively.

As well as the more usual pathogens associated with milk, there has been concern about the prevalence of *Mycobacterium paratuberculosis* (MAP) in the pasteurized milk supply of several developed countries. It has been proposed that this organism is the etiological agent of Crohn’s disease, but this remains to be substantiated. During the period from March 1999 to July 2000, a survey was undertaken to determine the prevalence of MAP in raw and pasteurized milks in the United Kingdom. The organism was detected in milk using an initial rapid screening procedure involving immunomagnetic separation coupled to PCR. Conventional culture was used to confirm viability of the isolates. Viable MAP was found in 1.6% (4 of 244 samples) of raw milk samples and 1.8% (10 of 567 samples) of pasteurized milk samples. The presence of MAP in pasteurized milk has generated speculation that the organism can survive HTST pasteurization and prompted calls for the minimum pasteurization temperature to be increased. However, work has shown that current HTST treatments are sufficient to control the organism.

Recently, it has been found that contamination of powdered infant milk formula by *Enterobacter sakazakii* can lead to infant death due to meningitis or neonatal necrotizing enterocolitis. Although the rate of infection is low, with only 48 cases of illness due to *E. sakazakii* reported from 1961 to 2003, the severity of the illness makes it of concern to the dairy industry. The organism has been isolated from 35% of environmental samples taken from a dry niche in milk powder production plants and from up to 12% of cans of infant formulas. However, the source of this organism remains undetermined.

The impact of a major outbreak of milkborne disease on the industry is arguably best illustrated by the events of June and July 2000, when contamination of milk powder by *Staphylococcus aureus* enterotoxin occurred in the Snow Brand plant at Taiki, Hokkaido, Japan. This powder was reconstituted and sold as fluid milk causing more than 14,000 cases of illness and possibly 1 death in 15 prefectures. The contamination was the result of an electrical failure leading to reconstituted milk being held in the line for 3 h at elevated temperatures and the organism was subsequently isolated from a valve at their Osaka plant. The outbreak high-

Table 3. Etiology of milkborne outbreaks in England and Wales (1992–2000) and their association with milk types¹

Pathogen	Number of outbreaks associated with milk type				Total
	Unpasteurized	Pasteurized ²	Mixed ³	Bird-pecked ⁴	
EHEC ⁵	5	3	1	0	9
<i>Campylobacter</i> spp.	4	1	1	1	7
<i>Salmonella</i> Typhimurium	5	1	0	0	6
<i>Salmonella</i> Enteritidis PT4	0	2	0	0	2
Other salmonellae	0	2	0	0	2
Cryptosporidium	0	1	0	0	1
Total	14	10	2	1	27

¹Gillespie et al., 2003.²Milk sold as pasteurized.³In one outbreak, a mixture of milk sold as pasteurized and unpasteurized milk was reported; in the other a mixture of unpasteurized milk and bird-pecked pasteurized milk was reported.⁴Integrity of package compromised by birds pecking at seal.⁵EHEC = Enterohemorrhagic *Escherichia coli*.

lighted several deficiencies in hygiene practices at the Snow Brand sites and led to the closure of all of Snow Brand's 21 dairy plants, plunging the company into an economic crisis.

Hazard Analysis Critical Control Point Systems

Even though our understanding of foodborne pathogens has increased dramatically over the last 3 decades, the dairy industry is still vulnerable. In an effort to maintain the safety of the milk supply, the dairy industry has invested heavily in the implementation of food safety management systems such as Hazard Analysis Critical Control Point (**HACCP**). Although HACCP has been widely adopted, its introduction does not guarantee food safety and the system cannot stand alone. To provide operational targets for regulatory agencies and food plant managers, the concept of Food Safety Objectives (**FSO**) has been introduced by the Codex Alimentarius Commission. This involves setting goals that can be monitored and may be qualitative or quantitative in nature. Meeting these objectives would have an impact on the safety of the food supply. Heggum provided examples of FSO related to the dairy industry. He suggested that a qualitative FSO might be that pasteurization shall significantly reduce microbiological hazards in milk; the quantitative FSO may be that milk intended for human consumption shall contain less than 1 pathogen/L.

Over the past decade it has been recognized that to effectively manage food safety, intervention strategies must be introduced at all points along the food chain. Although it is not possible to introduce strict HACCP programs on farms, because of the difficulty in identifying meaningful critical control points that can be monitored, there has been a move toward the development

of HACCP-like programs for producers. In Canada, commodity groups with financial support from the federal government have developed the Canadian On-Farm Food Safety program to implement national food safety strategies consistent with the HACCP principles of Codex Alimentarius and with those of the Canadian Food Inspection Agency. The program instigated by Dairy Farmers of Canada is known as the Canadian Quality Milk program. Dairy farmers are provided with a reference manual and workbook and must have kept complete records for at least 3 mo before they can apply for registration with the program. Upon completion of a successful audit, the farm becomes part of the Canadian Quality Milk program.

Organic Milk

Because of issues regarding the safety of the food supply, there has been increased consumer interest in organically produced foods. The organic movement has been particularly active in Europe, where some countries have set targets for the production of these foods. The European Union has introduced regulations to standardize organic production of milk. There are only limited data available on the quality of organic dairy products. Decante showed that milk from 264 organic herds was no different in terms of somatic cell count compared with milk produced conventionally.

The effect of antibiotic use in farming on the prevalence of antimicrobial-resistant human pathogens has been contentious. Although therapeutic use of antibiotics is allowed in organic farming, nontherapeutic applications are not permitted. The antimicrobial susceptibility patterns of *Staphylococcus aureus* isolated from bulk tank milks sampled from 30 organic and 30 conventional dairy farms in the United States and from

Table 4. Aerobic sporeformers in extended shelf life milk (127°C/5 s) isolated at 30°C¹

Organism	No. of isolates	%
<i>Bacillus licheniformis</i>	470	73
<i>Bacillus subtilis</i>	35	5
<i>Bacillus cereus</i>	26	4
<i>Brevibacillus brevis</i>	18	3
<i>Bacillus pumilus</i>	9	1
<i>Bacillus amyloliquefaciens</i>	8	1
Other <i>Bacillus</i> spp.	5	1
<i>Paenibacillus</i> spp.	5	1
<i>Aneurinibacillus</i> spp.	5	1
Unidentifiable	64	10

¹Mayr et al., 2004a.

20 of each farm type in Denmark have been investigated. Only small differences in susceptibility were observed between the 2 farm types; greater differences were found between the agricultural systems of the 2 countries.

ESL Milk

The technology of ESL milk was discussed previously. In Europe, heat treatment of 127°C for 5 s followed by nonaseptic packaging has been used to extend the shelf life of refrigerated fluid milk. Mayr and colleagues reported that shelf life of these milks was limited by non-systematic postprocess contamination by non-spore-forming gram-positive bacteria present in very low numbers. When heat treatments between 100 and 145°C were applied to milk, psychrotrophic *Bacillus* spp. were only isolated from milks processed at temperatures ≤134°C. *Bacillus licheniformis* was the predominant species isolated from ESL milk following incubation of plates at 30°C (Table 4). The average number of sporeformers recovered after incubation at 30°C was 100 cfu/L. *Bacillus licheniformis*, *Bacillus subtilis*, and *Bacillus cereus* have all been associated with foodborne illness.

Thus, the safety issues associated with ESL milk include extended storage time at refrigeration temperatures that may allow the psychrotrophic *Bacillus* spp. remaining after the heat treatment to grow. Indeed, the temperatures used for ESL may activate the spores of *Bacillus* spp. leading to germination and outgrowth. Their growth may be improved because of the lack of competition from other organisms and they may become adapted to this “new” niche.

Advances in Analytical Techniques

With the advent of molecular tools we have a new battery of analytical techniques available for the detec-

tion and identification of microorganisms. Methods such as real-time PCR are revolutionizing the speed and accuracy with which we can detect foodborne pathogens. These new methods for the study of microorganisms have been reviewed by Maukonen and colleagues. Real-time PCR assays have been described for the detection of *Mycobacterium paratuberculosis*, *Bacillus anthracis*, *Salmonella* spp., *Campylobacter jejuni*, *L. monocytogenes*, and *E. coli* O157:H7. Commercial systems based on real-time PCR are now in use in the food industry for routine analysis of products.

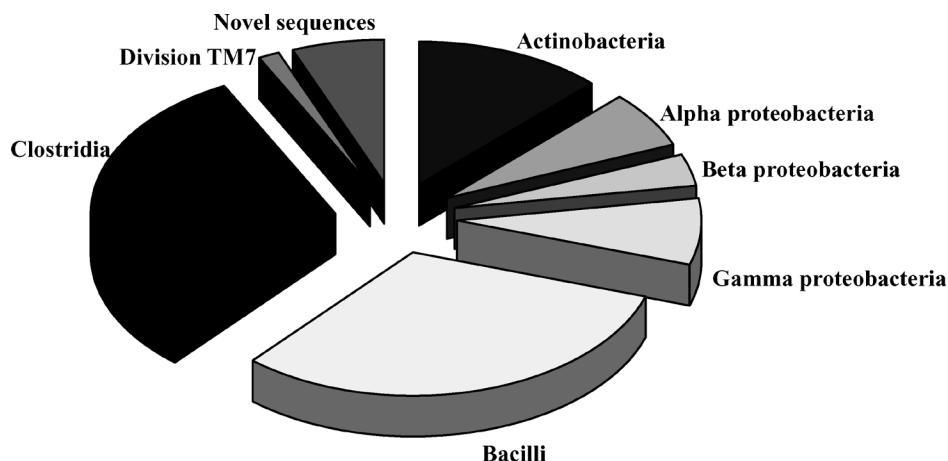
As well as their use in detection, molecular methods can be used to characterize microorganisms. Dogan and Boor, using ribotyping, were able to show that there were multiple sites of contamination for *Pseudomonas* spp. within processing plants, and that the ribotype was related to the spoilage potential of the strain. Denaturing gradient gel electrophoresis and temporal temperature gradient electrophoresis can be used to improve our understanding of the ecology of food systems. In these methods, the total DNA is extracted from the sample and a 16S or 28S rRNA gene sequence is amplified using PCR. The bands are then separated by gradient electrophoresis according to their melting temperatures. Using these techniques, dynamic changes in bacterial populations in raw milk during refrigerated storage have been monitored, allowing simultaneous detection of several pathogens that would be impossible to culture together. In addition, these techniques can be used to identify bacteria that are difficult to culture. For example, Sabour and coworkers have determined the microbial flora associated with the bovine teat canal of beef and dairy cattle using denaturing gradient gel electrophoresis. They showed that the predominant bacteria present in both types of animal belonged to the classes Clostridia and Bacilli (Figure 1). They also identified novel sequences not corresponding to known bacteria in both groups of animals.

Spoilage

As we gain more knowledge about the physiology and biochemistry of microorganisms, new approaches to control spoilage become evident. It is now appreciated that bacterial cells communicate with each other and with their host. This cellular communication is mediated by a variety of molecules. Pseudomonads “talk” to each other through the production of acyl homoserine lactones (AHL). These molecules control expression of a variety of genes when the bacterial population reaches sufficient levels to produce threshold concentrations of AHL. This phenomenon is known as quorum sensing. Quorum sensing is involved in biofilm formation and in extracellular protease production in pseudomonads.

A. Dairy herd sample

- 80 sequences
- 48 molecular species



B. Beef herd sample

- 76 sequences
- 47 molecular species

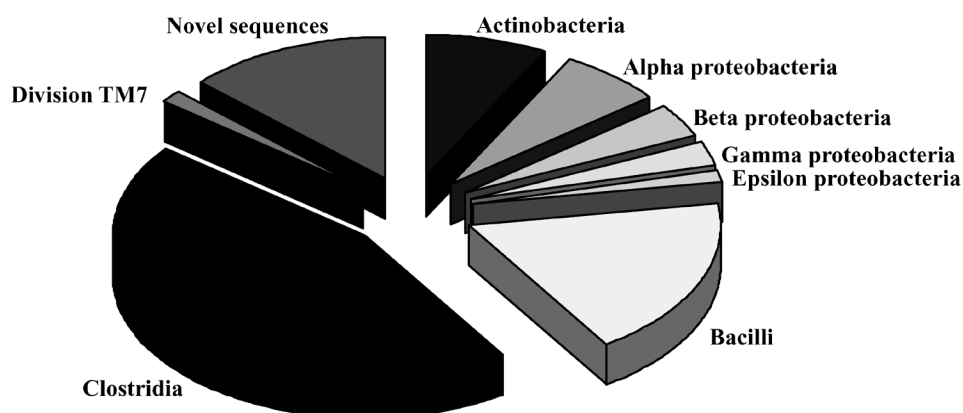


Figure 1. Diversity of bacteria colonizing the bovine teat canal in dairy and beef cows as determined by denaturing gradient gel electrophoresis. Recovered molecular species were sorted by class.

Thus, by disrupting quorum sensing using AHL analogues such as furanones or by the use of lactonases that degrade AHL, it may be possible to control biofilm production and spoilage.

Although we have made great strides in our understanding of the behavior of microorganisms over the past 5 decades and we have at our disposal analytical techniques that allow changes at the molecular level to be recognized, the problems facing the dairy industry are much the same now as they were in the past. The organisms responsible for disease may have changed from agents such as *Mycobacterium tuberculosis* to psychrotrophic pathogens such as *L. monocytogenes* and the incidence of outbreaks may be smaller now than in the past, but illness associated with the consumption of dairy products still occurs. The quest continues for ways to enhance shelf life and reduce our reliance on pasteurization.

CONSUMPTION TRENDS

The food retailing industry has undergone massive consolidations in the last 25 yr, with consumers now

shopping in vast food retailing centers offering a diversity the like of which has never been seen before. The dairy display in a modern food shopping center provides a vast array of choices. Milk consumption in the United States has declined slightly over the last 25 yr, but compares favorably to similar countries such as Australia, New Zealand, and Canada (Table 5). Per capita consumption of total fluid milk in the United States in 2003 was 90 L, compared with 110 L a quarter-century ago. However, there has been a large change within the sector. Consumers have shifted away from full-fat milk toward lower fat products. Consumers are now offered fat-free, 0.5% fat, 1% fat, and 2% fat products. Today, 35% of the fluid milk consumption is whole milk at 3.25% milkfat, whereas 65% is consumed as reduced-fat or nonfat milk at an average fat content of 1.28%, for an average of 1.98% milkfat in fluid milk. If we look back 25 yr, only about 14% of total milk consumption was in low-fat products.

The total per capita consumption of all ice cream in the United States in 2003 was 18.7 L, which has not changed in the last 25 yr. In fact, it represents marginal

Table 5. Fluid milk consumption in selected countries in the world (2002)¹

Country	Consumption (L/capita)
Romania	150.0
Poland	123.2
Australia	97.5
Russia	95.8
United States	91.0
New Zealand	88.0
Canada	85.4
European Union	77.6
Brazil	66.2
Argentina	50.3
Mexico	38.6
Japan	38.1
India	31.4
China	4.2

¹Source: Agriculture and Agri-Food Canada, Ottawa, ON, Canada.

growth over a 50-yr period, with the per capita consumption in 1955 of 17.8 L. However, the consumption in the United States is topped only by New Zealand and is almost double that of Canada (Table 6).

Within the ice cream category, there has not been the same trend toward consumption of low-fat products as has been seen in the consumption of fluid milk. On the contrary, the last quarter-century has seen the development of a range of premium (within the approximate range of 12 to 14% fat) and superpremium (approximately 16% fat) products. Of today's consumption of ice cream in the United States, 70% is standard product (>10% fat), 28% is low fat, and 2% is nonfat. This is very similar to 1980, during which 73% of consumption was regular, standard fat product and 27% was lowfat and nonfat. For comparison purposes, if you go back a half-century to 1955, 88% of consumption was standard fat product and 12% was lowfat.

Table 6. Per capita consumption data for ice cream from selected countries, 2002¹

Country	Consumption (L/capita)
New Zealand	26.3
United States	18.7
Australia	17.8
Finland	13.9
Sweden	11.9
Canada	9.5
Italy	9.2
Ireland	9.0
Denmark	8.7
United Kingdom	7.7
Chile	5.6
Malaysia	2.0
China	1.9
Japan	0.01

¹Source: Agriculture and Agri-Food Canada, Ottawa, ON, Canada.

In addition to ice cream, 197 million liters of sherbet and 302 million liters of frozen yogurt were produced in 2003 in the United States and are part of the frozen dairy dessert industry. These products have been available throughout the last 25 yr, although frozen yogurt has gone through a life cycle during this time: 445 million liters in 1990, 576 million liters in 1995, 330 million liters in 2000, and 302 million liters in 2003. Per capita consumption of frozen yogurt in the United States went from 2.1 L in 1995 to 1 L in 2003. Reasons cited for this trend include consumer confusion as to the presence or absence of live culture in these products, product quality as an alternative to ice cream, and a decline in the marketing effort required to sustain consumption of this product. Retailing shops specializing in frozen yogurt were opened in large numbers but then subsequently closed during this product life cycle. It is also likely that the renaming of frozen desserts in the United States subsequent to the issuance of labeling regulations by the US FDA in January 1993 contributed to the decline in sales of frozen yogurt. Until that time, ice milk was the name of the alternative product in the United States, and this category of frozen dairy products was not marketed or accepted well. Once it became possible for consumers to purchase reduced-fat, light, low-fat, and nonfat ice creams, there was less incentive to purchase frozen yogurt. Thus, the decline in frozen yogurt may be partly attributed to a move on the part of the industry to market lower fat ice cream products rather than frozen yogurt. These factors emphasize the importance of the possible/likely effects of the Nutrition Labeling and Education Act of 1990 and the regulations promulgated by FDA in 1993 on manufacture and sales of ice cream in the United States. In Canada, a category of light ice cream was also introduced during the same period, but the category of ice milk has remained in the definition of standards, and accounted for 9% of the volume of frozen dairy products produced in 2003. Sherbet production in the United States has remained very steady although per capita consumption has fallen marginally to 0.7 L in 2003.

Consumers of frozen desserts have seen a large increase in the variety of flavors offered by processors over the past 25 yr. The current flavor distribution is seen in Table 7. One new trend has been the incorporation of particulates of large size and with defined features (such as chocolate cow shapes or candy superhero shapes). This required technological innovation in ingredient feeding and dosing. Another flavor trend has been experimentation with a range of exotic flavor introductions (e.g., hot and spicy flavors), or flavor combinations involving several types of inclusions (e.g., ribbons), and the adoption of flavor standards from other

Table 7. Supermarket sales of ice cream by flavor in 2001¹

Flavor	Percentage of share
Vanilla	28.4
All nut flavors ²	10.4
Chocolate	8.0
All fruit ³	7.6
Neopolitan	7.4
Chocolate chip	3.7
Candy flavors	3.4
Mint chocolate chip	3.4
Cookies and cream	3.3
Bakery flavors	2.5
Coffee	2.2
Extreme flavors	2.0

¹Source: International Dairy Foods Association, Washington, DC.

²Butter pecan was the most popular at 4.4%.

³Strawberry was the most popular at 3.2%, followed by cherry at 2.0%.

parts of the world (e.g., Mexican dulce de leche or Asian green tea or red bean flavors).

CONCLUSIONS

The fluid milk and frozen dairy dessert processing industries have undergone tremendous improvements in technology in the last 25 yr. Emphases have been on automation, increasing capacity, and improving hygiene while producing a wider range of safe, high-quality, convenient-to-use dairy products for consumers than has ever been seen before. The competition for market share of the consumer's food spending dollar is ever-increasing, which forces the dairy industry to be diligent in its search for new products or for new images for old products; for example, packaging for added convenience. Despite an increasing body of knowledge about foodborne pathogens and disease transmission, keeping dairy products safe for human consumption remains a challenge, due in part to the changing nature of pathogens and their control within today's production and processing environment.

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