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PERSPECTIVE

Milk and Dairy Products in the 21st Century

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Dairying into the 21st century will largely continue with the trends seen in the past few decades, although there is always the possibility of an unlikely but disruptive event. The politics of globalization will potentially be important in freeing up global trade in dairy products. Production on the farm will become increasingly efficient, resulting in continuing price benefits to the consumer. At the same time, increasing attention will be paid by the consumer, producer, and manufacturer to safety and quality issues. Environmental concerns will increase in importance, and the issue of methane production may be important for the industry over the next two decades. It is unlikely that genetically modified milk will be introduced soon, even if public acceptance ceases to be an issue; however, the use of genetic markers for accelerated genetic improvement of cows will have rapidly increasing importance. Despite increasing pressure from nonmilk alternatives, milk and dairy will still be the best sources of nutrition for the young and for traditional dairy products. Consumer concerns will be of overriding importance for the industry, and the safety of dairy foods must become absolute. Recent advances in the chemical, physical, and information sciences and technologies will be utilized to gain greater understanding of the increasingly complex food systems and to support the consumer objectives.

KEYWORDS: Dairy; genetic modification; environment; consumer concerns; food safety

A number of distinct influences have affected the shape of world dairying as we know it over the 20th century, and it is reasonable to suppose that these will continue in the 21st. Probably the two largest influences are not scientific or even technological at all. The biggest influence earlier in the 20th century was the mechanization of dairy processing aided by the decreasing cost of energy, whereas later in the century, this influence was wielded by the increasing power and preferences of the consumer, and of the retail chains on behalf of supposed consumer opinion, and the efforts of governments, also on behalf of the consumers.

There have also been major advances in milk production and processing, often in response to one or another of the two influences noted above. Major importance has been attached to clearly targeted selection and breeding of cows and their feed. The availability of relatively simple technological advances, such as refrigeration, large-scale transport by road and sea, and high-speed routine business communication, has led to larger scale manufacturing and wide-ranging and complex warehousing and distribution systems, thus allowing targeted production and distribution of a large number of specialist products. In turn, this has resulted in increased globalization, technological complexity, standardized milk quality, and lower product prices. As production costs decreased, the relatively high price (in real terms) of all animal products steadily fell over the past century. Consequently, the consumption of dairy and dairy-based foods has increased, and the industry has provided consumers in most socioeconomic groups with high-quality nutritious foods. This trend is predicted to continue worldwide over the next 20 years with almost all of the growth being in the developing world (*1*).

THE PAST 50 YEARS

Looking back over the past 50 years of dairy science and technology has been an interesting experience because much of the basic science and technology that supports the current practices were known and used at the beginning of that era.

Milk was known to contain milk sugar (lactose), triglycerides, and other lipids in globular structures stabilized by a protein

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film, small (0.1−0.3 μm) particles (casein micelles) composed of a group of phosphoproteins known as caseins, and there were some globular proteins that existed in the aqueous "whey" fraction. During the following years the sequences of the proteins were elucidated, and the placement of the disulfide bonds was determined in the whey proteins. A number of genetically different (generally single amino-acid substitutions) milk proteins were identified and characterized. More recently, the three-dimensional structures of β-lactoglobulin, α-lactalbumin, immune globulins, lactoferrin, and serum albumin were determined using X-ray crystallography and high-resolution NMR spectroscopy. The important role of α-lactalbumin as a modulator of lactose synthesis was established, and β-lactoglobulin was found to bind amphiphilic and hydrophobic ligands. This was explored for practical applications. Although β-lactoglobulin is now considered to belong to a large group of carrier proteins with similar structures and important biological functions, its role in milk is unclear. The protective roles of immune globulins, lactoferrin, and the peroxidase systems, probably for the neonate as well as the mammary gland, were established. The more recent nucleotide technologies enabled the sequencing of the milk protein genes and thus allowed the cloning of a range of mutant proteins.

The detailed structure of the casein micelle has been debated at length, although the fundamentals, κ-casein on the outside and calcium phosphate clusters throughout the inside, have been known for at least 20 years. For both the caseins and β-lactoglobulin, the effects of genetic variants on production and processing are now well-known and partially understood.

The effects of processing on the milk components and their subsequent interaction have also been a matter of enlarging the knowledge of 40 years ago. Clearly heat, pressure, and shear all affect the proteins in similar but different ways. The quantitative and probably the qualitative differences have still to be elucidated and are difficult to deal with.

The basic techniques of polyacrylamide gel electrophoresis, liquid chromatography, nuclear magnetic resonance, mass spectrometry, and X-ray crystallography were all developed before 1970. The steady improvement in the accuracy, sensitivity, and reliability of laboratory instruments together with the data storage and processing capability of modern computers has revolutionized the way science is done. This trend will continue. A consequence of this is likely to be fewer and larger research facilities.

In the product areas, a great deal of work will continue in efforts to tailor products that have predictable and invariant functionality (flavor and texture under particular conditions). There will be substantial efforts to try to substitute instrumental estimation for sensory and other subjective assessment.

Over the past 50 years, the dairy industry has also changed considerably, although the basic technological processes, milk tankering, milk pasteurization, milkfat separation, evaporation and spray-drying, and casein precipitation, are all essentially the same. Continuous churning, tubular washing, microfiltration, and sterilization of products are among the widely used newer technologies that required some innovation. Modern large-scale cheese making is very different from that of 50 years ago through mechanization. Generally speaking it is not obvious that milk is being processed in a modern dairy plant: tankers arrive and discharge their contents, and at the other end, bags of products leave the factory unseen and untouched by human eye or hand and controlled all the way by computer.

In the remainder of this paper, the driving forces that are likely to generate future change are described.

GLOBAL PERSPECTIVE

Because of the importance of dairy products in the nutrition of the population, the importance of short-life products and a farm lobby, most developed countries foster their own dairy industries. Indeed, only ∼2% of global dairy production is freely traded internationally, with another ∼3% traded under quota arrangements.

Taking a global view, the economics of dairying are quite complex. In most countries, there are overriding governmental controls and guidelines. From the government point of view, there are three important and distinct roles: (1) to protect the food supply for the population, for example, in times of pestilence, drought, or war; (2) to protect the individual citizen from exploitation, for example, by the use of cow milk instead of sheep milk for Pecorino cheese; and (3) to control public health hazards, for example, contracting tuberculosis from milk or listeriosis from dairy products.

Governments can also intervene to protect local industries, balancing sector or regional funding and supporting external political alliances.

Codex (The Codex Alimentarius Commission of the Food and Agricultural Organization and the World Health Organization) is responsible for the international harmonization of food standards, with the objective of removing unnecessary obstacles to trade. Codex is responsible for developing a risk analysis framework for controlling dairy food safety (*2*). Emphasis is placed on the outcome, that is, safe food, rather than the mandatory use of particular processes. Its implementation will require an increased understanding of the effect of traditional and alternative processing technologies on milk-associated zoonotic pathogens and more knowledge of the factors that influence the human dose response. Codex requirements will inevitably involve additional compliance costs for nations trading dairy foods internationally.

Given the tension between the cost-efficient production of milk in some countries and the protection mechanisms of many developed countries, future developments in world trade (or not, as the case may be) are likely to strongly influence the future shape of international dairying.

MILK PRODUCTION

On the farm, there are five key issues that will drive changes in dairying over the next 50 years. These are as follows.

- Opportunities for breeding, driven by biotechnology.
- A continuing drive for efficiency as the commodity value of milk continues to decrease.
- Potential costs of greenhouse gases.
- Further development of specialized milks.
- Potential costs of animal disease eradication/control programs.

Opportunities for Breeding, Driven by Biotechnology. For the past 50 years, breeding has been based on sire proving by daughter testing and widespread artificial insemination based on a relatively small number of sires. Over the past decade, there has been increasing use of specific genetic markers for breeding purposes. These have included markers for the various polymorphic forms of the major milk proteins, so that the variants of these proteins are now listed in many semen catalogs. Some of these are associated with the economic value of milk for specific products [such as β-lactoglobulin B for cheese milk (*3*)]. The breeding industry has also identified markers for specific genetic defects, such as bovine leukocyte adhesion deficiency (BLAD), maple syrup urine disease, deficiency of uridine monophosphate synthase (DUMPS), complex vertebral malformation (CVM), and citrullinemia, for which routine tests are now commercially available.

The tools of biotechnology, primarily being developed for the human health industry, will be used increasingly to support herd improvement through genetics. The complete genome sequences of a number of species, including human, rat, and mouse, are now known. It has been variously estimated that it will take another 10−20 or even up to 50 years for the full functional implication of the human genetic sequence to be understood. Knowledge of the cow genome and its implications will not be far behind. The high degree of genetic homology between mammalian species means that genetic discoveries from the human genome can often be quite quickly applied to other species. This will, in principle, enable us to target genes for milk production and cow metabolism that can not only improve efficiency on the farm but also select for the exact type of milk the industry wants. The challenge to the dairy industry will then be to more precisely define what it wants in milk and to develop suitable testing and payment schemes to reward the dairy farmer.

The use of the tools of molecular biology to identify and manage natural variation in milk composition will accelerate the breeding process and give geneticists greater control over the production and composition of milk. The recent identification of a specific genetic polymorphism of a gene involved in milkfat synthesis that appears to modify milk composition may be an important early example of what may be achievable (*4*).

Leaving aside genetic modification for the production of nutraceuticals in milk, it seems unlikely that transgenic modification of milk for functional or nutritional purposes will occur in the foreseeable future. There are several reasons for this.

• Consumer acceptance of genetically modified (GM) foods is still variable, throughout the world, with some countries having strict labeling requirements. Because milk is a liquid product handled in large volumes during processing, maintenance of batch identity and keeping GM milk separate is more difficult than with discrete products.

• Furthermore, milk is an animal product and strongly targeted at the health of babies and young people. This has been identified in consumer surveys as a very sensitive area (e.g., compared with the acceptability of GM fruit and vegetables), and milk will probably be one of the last foods in which genetic modification is accepted.

• The cost of producing herds of GM cows would be very high, and progress very slow unless expensive cloning and embryo transfer methods are used. This is not justified by a small premium for improved nutrition or functionality arising from genetic modification.

• More importantly, a switch to genetic modification will severely limit genetic gain, because the gene pool will be restricted to the genetics of the donor animals for the original GM parents. This segregation from the global bovine gene pool will prevent, or at best, severely limit participation in the ongoing genetic improvement of the species, currently occurring at ∼2% per annum.

• Modification to make milk more suitable for a specific product is unlikely to make it beneficial for all other products.

Pastoral Farming Economics. Traditionally, farmers have invested in their land and relied on capital growth, or at least stability, for their future. The push to attract farmers into dairying has relied on this aspect, and much dairy land can become a poor monetary investment when dairy prices stabilize.

The trend of commodity milk to ever decrease in economic value means that dairy farming has to continually become more efficient simply to survive. Economy of scale provides an obvious way of reducing costs. In developed countries, and excepting those where the small farm unit is being maintained by subsidies for cultural and other reasons, the single-family farm is becoming economically nonviable. The trend is either for a larger farm based around a family unit, with additional labor, typically milking from 200 to 500 cows, or for farms run as a milk production business based on herd sizes of 1000−5000 cows. Future trends will undoubtedly see a decrease in single-family units and migration to a larger herd format.

As farm size increases, labor to milk cows becomes an important issue. In some cases, farmhands are employed specifically to cope with milking, but, in countries where labor costs are high, this poses its own problems. One way of dealing with this is to reduce milking frequency to once a day. Work in this area (*5*) has indicated a substantial loss in production per cow (30%) compared with twice daily milking; however, the loss per hectare (or acre) was less (18%), indicating lower energy requirements for cows milked once a day. It was also noted that the Jersey breed is much more able to cope with once-a-day milking, probably because of the higher milk solids concentration of Jersey milk.

A potential solution to the labor problem may be robotic milking. Prototype milking robots have been around for a decade, and currently seven types of automatic milking systems are commercially available, with an estimated 1000 herds worldwide being milked using automated systems, the majority in The Netherlands (*6*). The high capital cost of milking robots is a deterrent to their widespread adoption, but prices will undoubtedly decrease as manufacturing volumes increase and production becomes more efficient. The impact of robotic milking on production under various farming regimes is not yet well understood, and there is a dearth of information relating to large-scale farms.

Feed sources are another important cost on farm. They take the form of the direct cost of feed purchase in the feedlot form of farming and the cost of land, fertilizer, and supplements in pastoral farming. A number of approaches are being used to decrease the cost and increase the effectiveness of feed for dairy cows. GM plants are already having an impact on nonpastoral dairy farming and, hence, the potential to significantly reduce the cost of milk production. GM pasture plants are still in the future for the dairy farmer but may offer some real benefits:

• Pest resistance has already been engineered into many cropping species and could presumably be incorporated into pasture species. Although this may be relatively straightforward to do, the gain may be small.

• Changing pasture composition is probably the area where most gain could be made. It is well established that, for cows grazing pasture, metabolizable energy is the limiting nutritional factor (*7*). Pasture species with a higher energy content are clearly desirable.

• Drought resistance is an important factor for farming in many parts of the world, and pasture species with more deeply penetrating root systems that can withstand drought are desirable.

• Salt resistance is likely to become important in a number of areas as irrigation increases soil salinity.

Against these desiderata must be put the present public attitude against genetic modification in the food arena. Until public concerns in this area (*8*) are allayed, widespread use of GM pastures is unlikely. It is noted that there is already public concern over the use of GM products in concentrates and supplements being fed to dairy cows, and some markets are requiring audit to show that cows have not consumed GM product.

Another potential way of increasing production is by modification of the reactions that occur in the rumen; for example, removal of the microorganisms that cause methane production can also be expected to improve the energetic efficiency of the cow (see below).

Potential Costs of Greenhouse Gases. Cattle produce substantial amounts of methane as a byproduct of rumen digestion. This is normally released by eructation. Methane is recognized as a greenhouse gas and is rated as having a global warming potential 21 times that of carbon dioxide on a 100-year time scale. It has been estimated that methane is second only to carbon dioxide and is responsible for ∼10−15% of the greenhouse gas effect in the atmosphere. Domestic livestock account for ∼25% of all methane production [Environmental Protection Agency (EPA) estimate, see http://www.epa.gov/ghginfo/topics/topic2.htm for more detail], cattle being the major contributor. Most governments recognize the need to limit greenhouse gases, and some standard will probably be reached. This could have serious implications for the dairy industry, as penalties or costs of compliance could become prohibitively high. Research efforts to specifically target the removal of methanogenic organisms from the rumen could be an important contributor to the future economic viability of the industry. Because these organisms are believed to have an important role in managing the hydrogen concentration in the rumen, it may be necessary to find or create a microorganism that can transfer hydrogen into a product other than methane.

Further Development of Specialized Milks. As our detailed knowledge of the bovine genome develops, and the effects of different feeds and interventions become better understood, the potential to develop specialized milks becomes more of a possibility. The most common form of specialized milk available today is so-called "organic" milk. Standards for organics vary widely, but there is a common theme of not using chemical interventions for farm management. Consumer support for organics is probably driven by concerns about safety from chemical residues and a general support for environmental issues. The future of organics is unclear, but some standard for a "clean green" dairy source is clearly desirable and a genetically engineered (GE)-free label is a perceived benefit for organic milk. Interestingly, a bovine somatotrophin (BST)-free milk has been in the U.S. market for a number of years but does not have a significant market share.

Other examples of specialized milks already on the market include breed-specific milks, such as the niche "Gold Top" and "Fountains Gold" Jersey and Guernsey milk products marketed in the United Kingdom; hyperimmune milks such as "Stollait" milks marketed by NZMP, which can confer passive immunity against gut infections (*9*); milk with elevated levels of conjugated linoleic acid (CLA) for cheese such as that sold by Northern Meadows in the United States; so-called "A2 milk", which is claimed to have health benefits in relation to diabetes or heart disease, although these claims are under dispute (*10*). There is rapidly growing interest in the use of probiotics and prebiotics in milk and dairy products. Probiotics are living microorganisms that, upon ingestion in sufficient numbers, exert health effects beyond basic nutrition. Substantiated health claims include enhanced immune performance, alleviation of diarrhea, and improved lactose utilization. Prebiotics are nondigestible food ingredients including oligosaccharides and dietary fiber that are able to modify the intestinal flora in favor of health-promoting bacteria. A range of possible further modifications to milk composition has been described by Boland et al. (*11*).

Potential Costs of Animal Disease Eradication/Control Programs. A commentary on the recent foot and mouth disease (FMD) outbreak in Europe used the term "global farm" to describe the fact that the animal husbandry practice of moving animals within and between countries is also a very efficient means of spreading both animal and human pathogens (*12*). Outbreaks such as FMD and bovine spongiform encephalitis (BSE) have heightened biosecurity awareness worldwide and traceability of individual animals. Government regulatory authorities play an important role in controlling the import of biological materials to ensure freedom from disease-causing organisms.

Animal diseases are also being seen in the context of animal health and welfare. Consumers will increasingly demand safe milk and dairy foods produced by healthy animals. This will lead to more pressure for programs to control or eliminate bacterial or viral diseases. Such measures will be either a direct or an indirect cost to milk producers.

FOOD SAFETY

Pasteurization was established to ensure that milk contaminated with bacteria or viruses responsible for animal diseases, particularly bovine tuberculosis, was safe for human consumption. Bovine tuberculosis and brucellosis have been subjected to eradication programs in many countries. Bovine tuberculosis is difficult to control when the pathogen becomes established in wild animals, providing a reservoir of infection. Brucellosis is also endemic in sheep and goats in many countries. If raw milk from these species is used for traditional cheese varieties, certified brucellosis-free herds are essential to ensure product safety.

Another disease with a worldwide distribution is Johne's disease or paratuberculosis. The mycobacteria responsible have been claimed to survive pasteurization. Recent studies using a strictly controlled commercial-type pasteurizer, however, show that this organism is effectively eliminated using the traditional pasteurization time and temperature (*13*). Pasteurization and/or other means (see above) will always be essential to ensure the absence of animal and environmental pathogens from milk and milk products.

Traditional methods of preservation—increased acidity, lowered water activity, and lowered redox potential—were used to preserve both butter and cheese. With easy sterilization of products, aseptic packing, and good refrigeration, a wide range of fluid products can now be made, distributed, and sold.

Throughout the world, awareness of foodborne disease has risen in response to the high level of publicity that such outbreaks receive (*14*). The toll exacted in human and economic terms is considerable. Notable dairy outbreaks in recent years include *Salmonella* in ice cream (United States, 1994, 224,000 cases of illness) and staphylococcal enterotoxin in milk (Japan, 2000, 15,000 cases). Contaminated soft cheeses and raw milk are often in the news. Whereas most dairy products, processed to modern standards of hygiene, have an excellent safety record, consumers are demanding increased surveillance and control of all foods, including dairy. The contamination of animal feed with dioxin in Belgium (1999) highlighted that consumers place the absence of toxic chemicals in their food alongside microbiological safety in importance. There will be no lessening in the demands on food producers to control risks and deliver assurances of safety. The increased costs associated with providing this assurance through effective process control will become the norm for dairy businesses in the future.

NOVEL PROCESSING

Over the past decade or so, there have been strong trends toward liquid and solid nutritional snack foods with health benefits, which have been brought about as a response to lifestyle changes. Most of the future changes in product characteristics and consequently processing changes will also be driven by the desires of the consumer, albeit modulated by advertising, product price, availability, and perceived value. Despite differences among countries, regions, social classes, and ethnicities, these trends will occur as responses to consumer purchasing choices. Consumer preference for minimally processed and more "natural foods" shows no sign of abating. Processing changes that reduce the effects of the traditional bacteriocidal and bacteriostatic hurdles of salt, acid, and water activity must be treated with caution to avoid compromising the microbiological safety of the product.

Liquid Milk Products. In the fluid milk area, processors have aimed to minimize flavor and texture changes in sterile liquid milk products during storage. This requires the inactivation of not only the bacteria and bacterial spores in the milk but also the indigenous enzymes. Currently, very high temperatures are required to do this with consequential changes to the flavor of the product. Cold pasteurization technologies that can kill most bacteria without compromising flavor include ultrahigh pressure (300−1000 MPa) treatment and pulsed electric fields (PEF) (*15*). The former is currently expensive and suited to small-volume high-value products; PEF, which is showing promise at the experimental stage, is a more economical process. Such procedures, either singly or in combination with other technologies, will be used increasingly for the milk and milk products of the future. The rapidly developing field of risk analysis gives a sound scientific basis for evaluating the safety of both established and new technologies for their use with appropriate dairy foods.

In addition to the traditional forms of liquid milk, manufacturers have altered fat concentrations to differentiate their product range and more recently selected milks from particular herds, breeds, or regions. Examples include so-called "trim milk" (no fat), "cappucino milk" (enhanced foaming properties), and "breakfast milk" (creamier, more fat). Liquid milk has also been differentiated in terms of health benefits by adding minerals and vitamins; its flavor and texture have been modified by the addition of flavorings, thickening agents, and carbonation. Undoubtedly the next few decades will see an extension of this activity to produce a new generation of special milks and milk-containing drinks.

Membrane Filtration. Another technology that is being used and is sure to become better known, at least in the dairy industry, is large-scale molecular filtration to separate various milk protein fractions by size. Thus, skim milk is readily split into a native casein fraction (50−600 nm), a medium-sized fraction (1−60 nm) that is mostly soluble whey proteins, and a salts and sugars (<2 nm) fraction. These fractions can be used to modulate the characteristics of many products, or they can be dried and subsequently used to manipulate product characteristics. A valuable side effect is the ability to remove spores and bacteria (>500 nm) from milk or other dairy streams to give materials with very low bacterial numbers.

On-Farm Milk Concentration. On-farm milk concentration has been studied in the past and, generally, the benefits of lower transport costs because of the lower bulk do not outweigh the equipment and running costs, but this balance could be readily altered in individual cases when long distances and large farms are involved.

Novel Functionalities from GM Milks. The production of milk with significantly different processing properties or functionalities using genetic means has been a possibility for some time (*16*); however, so far no clear-cut monetary or functional advantage has been identified in the milk protein area, and disadvantages in genetic gain (raised earlier) make this avenue unlikely.

COMPETITION FROM NONDAIRY MATERIALS

Milkfat. The dairy fat fraction of milk has already been largely replaced as a spread by peanut butter, mayonnaise, and margarine. In these cases, cheaper plant-sourced oils are generally the basis of the changes, but perceived health benefits have played a part and many spreads are more expensive than butter. Milkfat continues to have a major role in ice cream, dairy desserts, and similar confections and also in high-quality bakery products. It plays an important part in the odor, flavor, and texture of natural cheese.

Protein Products. Many of the important industrial (nonfood) uses of casein products have been displaced by the use of polysaccharide- and petroleum-based chemical polymer materials. However, there has been an increasing and substantial market for various milk protein fractions because of their superior functional properties and the distinctive flavors of most proposed substitutes, such as oilseed protein products or the proteins from microorganisms. In addition, the removal of antinutritional material, such as trypsin inhibitor, and polysaccharides increases the cost of such functional products. Nevertheless, there is an increasing use of soybean "milk", which has a different allergenicity profile and other perceived benefits such as low cholesterol content and the questionable benefit of phytoestrogens. Of greater concern may be the eventual production of nutritional proteins such as "human" β-casein by recombinant organisms such as yeasts (*17*).

Traditional Dairy Products. Despite the threats identified above, there will always be a need for liquid milk and for other traditional milk-based products such as varietal cheeses, yogurts and other cultured products, ice creams and other dairy desserts, pastries, and other products to be made from milk. Particularly in the gourmet or luxury categories, it is unlikely that substitutes will ever be considered the equal of those derived from milk. It is noted that, despite more than half a century of competition from margarine, butter is still the gold standard for quality cuisine.

Milks from Other Species. In many countries, the cow is not the principal dairy species: water buffalo are important in the Middle East, India, and parts of the East and sheep's or goat's milk is produced in many European countries. In general, these milks behave very similarly to cow's milk, although issues of adulteration arise because cow's milk is cheaper to produce. Because of the different distribution of vitamin A and carotene the milk is differently colored; the fatty acid distribution and the casein structure and ratio of types are different among the species, leading to different colors, textures, and flavors of the products. Altogether these milks account for a small proportion of world production. Goat's milk is considered by some to have a lower allergenicity than cow's milk, and goat's milk powder has a niche market. Sheep's and goat's milk cheeses are also freely available in specialty stores and increasingly in supermarkets.

CONSUMER CONCERNS

The consumer seems to have the power to bring about change. In reality, it is often the major retailing chains that have the real power, and they base their decisions on what they believe the consumers want. This is of some concern to the dairy industry because the supermarket chains exert enormous power over the dairy value chain, and consumer concerns can be strongly over-represented by vocal minorities. If the buyers for the retail chains do not fully understand this, there is a real chance of retail outlets distorting the true market for dairy (and other) products.

On the positive side, market-led changes will continue to stimulate the development of new products and lead new market opportunities. In contrast, consumer reaction to real or even perceived safety issues is swift and often dramatic in its consequences for those seen to be responsible. When individual companies fail and lose consumer confidence, the fallout can not only seriously damage or even destroy that business but also affect sales of related products made by competing manufacturers. If a government is blamed, as with BSE, then a whole business sector, producers, and suppliers suffer.

In a world where consumers rule and are unwilling to accept any risks associated with their foods (the market forces situation), we can envisage possible scenarios that will have serious national or international repercussions. These include an outbreak of a serious foodborne illness from a microorganism or a toxic material or an exotic animal disease outbreak, such as FMD.

The continuing move to greater volumes of milk from each farm, larger processing facilities, and complex multi-ingredient products, such as composite food gels, means that it will be increasingly difficult to trace any alleged fault back to the responsible ingredient and then to the farm and thence to the cow or its feed. Despite the inherent difficulties in milk traceback and animal traceability, the establishment of practical protocols will be an important dairy industry priority.

The increased perception of a link between some milk component and a serious long-term health risk to themselves or their children would also diminish the status of dairy foods and could result in a gradual shift toward nondairy alternatives. In general, consumers cannot assess the claims by the promoters of all the various products available. It is important for the industry to be fully cognizant of the science (if any) underpinning adverse health claims relating to milk and dairy products and to challenge any inadequately supported assertions. The industry has already lost ground due to claims about milkfat and heart disease that are not properly supported (*18*), and this must not happen again.

CONCLUSION

Dairy products are likely to remain important dietary components because of their nutritional value, flavor, and texture. There will continue to be a demand for traditional, high-quality dairy products, despite increasing competition from non-dairy-based products. Although there is the potential to genetically modify the dairy cow and the milk it produces, the benefits need to be unambiguous and superior to standard breeding practice. Traceability of a problem from product pack to source cow as well as rigorous testing at every step of the process will be necessary to meet consumer requirements for "safe food". New technologies that give dairy products a longer life without any compromise to their sensory properties are likely to arise. Application of sound engineering, technological, and scientific principles and accurate laboratory and statistical analysis will have even greater importance for all of these endeavors.

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