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Dairy Innovations over the Past 100 Years

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The dairy industry in the United States has undergone many changes over the past century. Adulteration and contamination of milk were rampant before the passage and enforcement of the Pure Food and Drug Act of 1906, and the introduction and eventual acceptance of certified and pasteurized milk have provided consumers with a consistently safe product. Homogenization and advances in the packaging and transport of milk gradually took hold, improving the milk supply. Other developments included the concentration of milk and whey, lactose-reduced milk, and the popularization of yogurt. Consumers have benefited from advances in butter packaging, low-fat ice cream, cheese manufacture, and yogurt technology, which has helped create the large demand for dairy products in the United States. Current trends and issues, including the increasing popularity of organic and artisanal products and the use of rBST, will shape the future of the dairy industry.

KEYWORDS: Milk; safety; cheese

INTRODUCTION

One hundred years ago, the greatest issue facing the American dairy food industry was the wholesomeness of the nation's milk. Infant mortality rates in some large cities exceeded 30%, and adulterated and contaminated milk were to blame for some of this staggering loss (*1*). Legislation and pasteurization solved these problems, and the industry was able to turn toward developing more and better products (**Table 1**). The advances in safeguarding milk in the United States and the improvements in dairy products over the past century are the subjects of this paper.

ADULTERATION

Adulteration of food is defined as adding unsafe amounts of preservatives, adding color to conceal defective or deteriorating products, or mixing or substituting lesser products (*2*). Before the end of the American Civil War, food was grown and processed locally, and consumers received personal guarantees about quality. However, by 1875, the national railroad system allowed for the long-distance transport of food to consumers who were not close to farms, creating preservation issues. State laws did not cover interstate commerce, and fraudulent practices arose (*3*). Most food was adulterated at the turn of the 20th century (*2*), especially milk, which passed through many hands on the way to city dwellers and was often watered down every step of the way (*4*). Milk was also skimmed and whitened with chalk and thickened with emulsions of almonds or animal brains (*4*). To prevent spoilage, milk was tainted with formaldehyde (*2*), and butter was adulterated with borax (*5*).

The first key figure in the field of safeguarding food in the United States was Harvey Washington Wiley. He was born in a log farmhouse in Indiana in 1844 and went on to receive an M.D. degree, but he did not go into the field of medicine; instead, he obtained a B.S. degree at Harvard and became a chemistry instructor at Purdue University in 1874, the year the school opened (*6*, *7*). Wiley became interested in providing the scientific background in food analysis to minimize adulteration of food and in 1883 began serving as Chief Chemist at the U.S. Department of Agriculture's Bureau of Chemistry (*6*), the forerunner of the U.S. Food and Drug Administration (*7*). He started to conduct laboratory research on food adulteration, including milk and butter, and along the way helped found the Association of Official Analytical Chemists in 1884, served as American Chemical Society President in 1893, and chaired the ACS Section on Agricultural and Sanitary Chemistry, the predecessor of the Division of Agricultural and Food Chemistry, in 1905 (*8*). He set up what became known in the press as the Poison Squad: 12 healthy male volunteers who consumed some of the adulterants found in food to observe their effects (*3*). Starting with borax, the tests continued until most of the men became ill (*5*). Wiley testified before Congress about these results in February 1906, the same month Upton Sinclair's novel *The Jungle* outraged the public about slaughterhouse practices. Wiley's long crusade for the passage of the Pure Food and Drug Act, which forbade the manufacture, sale, or transportation of adulterated food products, culminated four months later when the Act was signed into law by President Theodore Roosevelt (*6*). The first federal food and drug inspections, conducted by the Bureau of Chemistry, began the next year.

CONTAMINATION

The efforts of Wiley and others raised the public's awareness of less-than-healthful food products, especially milk. Many cows were being fed waste grain mash from distilleries, resulting in low-grade "swill milk" (*9*). Almost all of the milk consumed in large cities arrived by rail (*10*) and became a vector for *Mycobacterium*

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Table 1. Innovations in the Dairy Industry since 1908

year	event	reference
1908	butter sold in sticks wrapped in paper	Parker (*32*)
	pasteurization made compulsory in Chicago	Straus and Straus (*14*)
1910	commercial cheese starters become popular	Price (*38*)
1910s	spray-drying of milk begins	Johnson (*20*)
1919	homogenized milk first sold	Trout (*18*)
1920s	ice cream filling and packaging machines and continuous ice cream freezer invented	Marshall et al. (*36*)
	industrial process for yogurt production developed	Fuller (*47*)
1921	processed cheese first marketed	Price (*38*)
1929	paper milk cartons introduced	Richmond and Stine (*22*)
1920s−1930s	copper in dairy equipment replaced by stainless steel and nickel−chromium alloys	Johnson (*20*)
1930s	truck hauling of milk replaces railroad cars	Lockhart (*17*)
	vitamin fortification of milk begins	Holik (*23*)
1933−1937	evaporation and spray-drying of whey begins	Tunick (*30*)
late 1940s	instant milk products first sold to consumers	Johnson (*20*)
1950	prepackaged processed cheese slices introduced	Eldred (*34*)
1950s	continuous butter churning starts	Frede (*33*)
	fruit first added to commercial yogurt	Welch and Mitchell (*46*)
	polysaccharide stabilizers first added to ice cream	Marshall et al. (*36*)
	whipped butter becomes popular	Eldred (*34*)
early 1960s	frozen starter cultures for cheese introduced	Høier et al. (*40*)
1961	ultrahigh-temperature pasteurization introduced	Robinson (*16*)
1964	plastic milk jugs first used	Richmond and Stine (*22*)
1970s	mildly cultured butter and spreadable butter with modified triglycerides invented	Frede (*33*); Walker et al. (*35*)
1971	membrane filtration of whey begins	Tunick (*30*)
1979	lactose-reduced milk introduced	Guy et al. (*27*)
1988	reduced fat and nonfat milk sales exceed whole milk sales for first time	USDA (*25*)
1990	genetically engineered chymosin approved for cheesemaking	Maryanski (*41*)
1994	recombinant bovine somatotropin for increasing milk production introduced	Bauman (*50*)
2004	slow- and double-churned ice cream introduced	Moskin (*37*)

tuberculosis (*11*), typhoid, and other pathogens. Tuberculosis and other infectious diseases were the scourge of American cities 100 years ago, and a call to action was given by Allen in 1909:

"We now know that no law will ever stop the present frightful waste of infant lives, counted in thousands annually, unless dairies are frequently inspected and forced to be clean; unless milk is kept at a temperature of about 50 degrees on the train, in the creamery, at the receiving station, and in the milk shop; unless dealers scald and thoroughly cleanse cans in which milk is shipped; unless licenses are taken from farmers, creameries, and retailers who violate the law; unless magistrates use their power to fine or imprison those who poison helpless babies by violating milk laws; and unless mothers are taught to scald and thoroughly cleanse bottles, nipples, cups, and dishes from which milk is fed to the baby" (*12*).

One solution to "the milk problem" was the production of certified raw milk, which was originated by pediatrician Henry L. Coit in 1892. The American Association of Medical Milk Commissions would (and still does) conduct periodic examinations of the animals, workers, dairies, and equipment and certify the milk as having low bacterial counts and being free of pathogens (*13*). Another solution was pasteurization, which was championed by Nathan Straus, co-owner of Macy's Department Store in New York (*14*). Holder pasteurization has been used commercially in the United States since 1893 (*11*) and was first made compulsory in Chicago in 1908 (*14*). In holder pasteurization, later known as batch or vat pasteurization, milk is held at 62.8 °C for 30 min, which was found to be sufficient to kill *M. tuberculosis* and other dangerous microorganisms. Later, plate heat exchangers were developed, leading to high-temperature−short-time (HTST) pasteurization at 71.7 °C for 15 s (*11*). However, heat treatment of milk was not generally accepted for a number of years, partly due to a lack of faith in technology (*9*) and partly because some felt it gave farmers a license to be unsanitary (*15*). Many companies adopted pasteurization in secret. Eventually, pasteurization won out over certification because purchasing the equipment once was less expensive than paying for frequent inspections (*10*). Milkborne epidemics virtually disappeared in the United States by World War II (*9*). A further development, ultrahigh-temperature (UHT) pasteurization at 130−150 °C for 2−3 s followed by aseptic packaging in paperboard cartons, was developed and introduced in Switzerland in 1961, allowing consumers the convenience of storing unopened milk at room temperature (*16*).

HOMOGENIZATION

Another development in the early 20th century was homogenization of milk. Milk is an oil-in-water emulsion in which fat globules, which are less dense than water, rise to the top. Starting in the late 1920s, consumers could purchase milk in a cream top bottle with a bulb in the neck and then extract the cream that collected in the bulb (*17*). In 1899, August Gaulin of France patented a homogenizer, where milk passes through a tiny orifice under high pressure (*18*), breaking up the fat globules and increasing their number by a factor of 600. The surface area of homogenized milkfat increases 9-fold, preventing the fat globule membrane from covering most of the larger surface (*19*). The casein in the milk sticks to globules, weighs them down, and prevents clumping. Homogenized milk was first sold in 1919 and started to become popular in the 1930s as consumer preferences changed (*18*).

OTHER ADVANCES IN MILK

Processing, Transport, and Storage. Most dairy equipment was made from copper and its alloys in the early 20th century, but the metal would corrode and cause fat in the milk to oxidize, imparting off-flavors. Research in the 1920s and 1930s led to the adoption of stainless steel and nickel−chromium alloys, which are still in use (*20*).

In the past many small-town residents owned a cow or bought milk from a neighbor who did. In the bigger communities raw milk was transported from farm to home in cans on a horse-drawn wagon, and then dipped or poured from the can into a receptacle provided by the consumer (*21*). This arrangement was phased out in favor of the more convenient home delivery of milk in glass bottles with cardboard disk closures, which was first available in larger cities (*17*). The cost of purchasing and cleaning the bottles led to the adoption of the less expensive option of paper milk cartons, which were introduced in 1929 and became popular by the mid-1940s. Plastic jugs, which first became commercially available in 1964, are a more effective barrier to the transfer of moisture, air, and some flavor compounds (*22*).

As previously mentioned, long-distance hauling of milk was originally performed by railroad, which accounted for 98% of milk deliveries to New York City in 1916 (*21*). Advances in automotive engineering caused tank trucks to become the preferred mode of transporting milk, and by the mid-1930s many areas had all of their milk hauled to them by truck (*21*).

Addition of Vitamins and Removal of Fat and Lactose. By the 1930s vitamin D was identified as a preventative of the bone disease rickets, and vitamin A was known to be essential for vision and bone growth. Fortification of milk with synthetic vitamin D was begun, and rickets was eradicated in developed countries as a result (*23*). Vitamin A is found in whole milk at 249 IU per 8 oz (244 g) serving, but being a fat-soluble vitamin it is present in nonfat milk at only 17 IU per serving (*24*). To prevent vitamin deficiencies, milk in the United States is now fortified with 100 IU of vitamin D and 500 IU of vitamin A per serving.

Whole milk, which contains at least 3.25% fat, was the preference of consumers until dietary concerns caused reduced-fat milk to become popular. Skim milk represented 0.42% of total milk sales in 1909 and 15.3% in 2006, and 2 and 1% fat milks became popular in the 1950s and 1960s, respectively (*25*). Sales of whole milk have been exceeded by sales of reduced-fat and skim milk starting in 1988 (*25*).

Milk contains 5% lactose, but most of the world's adult population is lactose-intolerant, ranging from $<25\%$ of people of northern and central European ancestry to $>80\%$ of Asians and Native Americans (*26*). The USDA laboratory in Wyndmoor, PA, developed a lactose-reduced milk containing lactase enzyme extracted from *Kluyveromyces* yeast and *Aspergillus* fungi (*27*), and the product was introduced commercially in 1979. Pills and drops containing the enzyme can also be used in conjunction with dairy products, but have been shown to be less efficacious than lactose-reduced milk (*28*).

Milk Protein Research. The identification of the various caseins in milk and the existence of the casein micelle have been determined over the past 70 years. Casein was originally thought to be a pure protein, but α-, β-, and γ-caseins were found in 1939 (*29*) and fractionated in 1956 (*30*). The existence of κ-casein was also revealed in 1956, by David Waugh and Peter von Hippel (*31*), and α-casein was later found to be a mixture of α_{s1}- and α_{s2}-caseins (*32*). In 1934, whey proteins were found to be a mixture of what was later denoted α-lactalbumin and β-lactoglobulin (*33*). Some milk proteins have more than 10 genetic variants (*34*).

The use of "casein micelle" to denote the calcium caseinate–calcium phosphate particle took hold in the 1950s, especially after Waugh and von Hippel pioneered new theories about its structure (*35*). The structure of the casein micelle is still being investigated, as there is some disagreement about whether micelles are made up of submicelles or casein molecules joined by colloidal calcium phosphate crystals and hydrophobic bonds (*36*).

NONCULTURED PRODUCTS

Condensed and Evaporated Milk. Sweetened condensed milk, a product with years of shelf life at room temperature if the container is unopened, is made by removing water and adding sucrose. The sugar inhibits bacterial growth and makes the product sweet and thick. Condensed milk was invented by Gail Borden in 1856 and became popular during the Civil War. Evaporated milk, which also has a long shelf life, is produced by removing 60% of the water and adding vitamin D and stabilizers. John B. Meyenberg invented condensed milk in 1884, and it became popular during World War I (*20*). Seven editions of an influential book detailing proper manufacturing procedures for condensed and evaporated milk were published in the first half of the 20th century (*37*).

Dry Milk and Whey. Spray-drying of milk to remove water began in the 1910s, and industry standards were established in the following decade. Many of the manufacturing concepts employed for condensed and evaporated milk were applied to dry milk. Nonfat dry milk solids were originally used exclusively by food processors, but instant milk products were introduced to consumers after World War II (*20*).

The health benefits of whey proteins, primarily α-lactalbumin and β-lactoglobulin, led to the development of processes to isolate whey solids (*38*). The long-tube multiple effect evaporator was applied to whey processing starting in 1933 and the spray dryer followed four years later (*39*). Membrane filtration was first applied to food in 1965 and to whey in 1971 and allows for separation and fractionation of whey proteins while retaining their solubility (*38*). Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis are now used in combination and followed by spray-drying to obtain desired products. Until the 1980s, whey was a mostly unwanted byproduct of cheesemaking and was fed to animals or spread on fields to dispose of it. Now, whey protein concentrate (20−89% protein) and whey protein isolate (at least 90% protein) are used in a large variety of food products because of their functionality and nutritive value.

Butter. Around 1908, paper- and paraffin-lined butter cartons were introduced and the practice of packaging butter in convenient 4 oz (113 g) sticks was begun (*40*). Originally, the only type of butter available was cultured cream butter, made from raw cream collected from several milkings and therefore partially fermented. Commercial cream separation began in the 1890s, which together with refrigeration led to the industrial production of sweet cream butter from pasteurized cream. Continuous butter churning began in the 1950s, replacing the batch process (*41*), and whipped butter, aerated with nitrogen gas, became popular (*42*). A mildly cultured butter, with bacteria introduced after pasteurization, was invented in the 1970s (*41*) along with spreadable butters with modified triglycerides, which were developed in New Zealand (*43*).

Ice Cream. The first ice cream filling and packaging machines, the first continuous ice cream freezer, and the Eskimo Pie, Good Humor bar, and Popsicle were all invented between 1919 and 1926 (*44*). Polysaccharide stabilizers were introduced in the 1950s, replacing gelatin for functional and economic reasons (*44*). Later in the century, companies began to produce low-fat ice cream due to dietary concerns by the public. Carrageenan extracted from algae, monoglycerides, diglycerides, and other ingredients have been used to mimic the texture produced by egg yolks and milk fat. Extra air and water have also been used to reduce the fat and calorie content. Slow- and double-churned low-fat ice cream, introduced in 2004, utilize low-temperature extrusion, which significantly reduces the size of the fat globules and ice crystals in ice cream and leads to a creamy mouthfeel (*45*).

CHEESE

Chemistry. Although cheese has been made for some 10000 years, most of the chemistry and microbiology involved was not investigated until the 20th century. Commercial starter cultures became popular by 1910, replacing the less hygienic practice of using held-over whey and sour buttermilk (*46*). Chymosin, the enzyme responsible for coagulation, was finally crystallized in the early 1960s (*47*). Frozen concentrated starter cultures first appeared around the same time (*48*). Chymosin from genetically engineered bacteria, fungi, and yeasts was approved by the U.S. Food and Drug Administration in 1990 (*49*) and was the first genetically modified food ingredient legalized. It replaced the more expensive version extracted from calf stomach. The chemical origins of cheese flavor were barely known in 1961 (*50*), but cheeses with added enzymes to enhance the flavor profile were introduced over the ensuing 15 years.

Preservatives. Nisin, a peptide produced by the common starter culture *Lactococcus lactis*, is a broad-spectrum antibiotic that suppresses many spoilage organisms and pathogens and may become more prominent as the food industry tries to combat antibiotic-resistant bacterial strains (*51*). Nisin was characterized in 1947 and has been used as a preservative in cheese since 1951. Sorbic acid and its calcium, potassium, and sodium salts have been added to cheese to prevent fungi, mold, and yeast growth since the 1950s, and natamycin, an antibiotic first isolated from a soil microorganism, has been added as a mold and yeast inhibitor since the 1970s (*51*).

Processed Cheese. Nearly all of the varieties of cheese being produced today have been in existence for over a century. In 1921, James L. Kraft started to market processed cheese, which he developed by grinding aged and fresh Cheddar, adding emulsifying salts, heating, and pouring into forms. This procedure provided an outlet for unsold aged cheese. Kraft also introduced Velveeta, a processed cheese food with added nutrients, in 1928, and prepackaged sliced process cheese in 1950 (*42*).

Mozzarella. The cheese industry has received a boost with the skyrocketing popularity of pizza, resulting in an ever-increasing demand for Mozzarella and, to a lesser extent, Cheddar. The U.S. population increased by 42% from 1974 to 2008, whereas the production of Mozzarella expanded from 0.17×10^6 to 1.46×10^6 kg and that of Cheddar from 0.64×10^6 to 1.42×10^6 kg (*52*). Health concerns have resulted in the growth of various reduced-fat cheeses such as a low-fat Mozzarella for school lunch programs. The texture of these cheeses is modified to mimic the full-fat varieties (*53*). Hispanic (*54*) and artisan cheeses (*55*) are also increasing in popularity.

OTHER CULTURED PRODUCTS

Buttermilk. Buttermilk is the fluid remaining after separated cream is churned. Originally this product was churn buttermilk; the cream was separated during buttermaking on the farm. Sour cream buttermilk is made from raw milk that has been soured naturally or intentionally (*56*). Today, cultured sweet cream buttermilk is made from milk containing $<2\%$ fat, fermented with lactic acid producing bacteria, and frequently labeled as cultured low-fat or nonfat milk. Lecithin from the fat globule membrane is an emulsifier; Pennsylvania Dutch farmers use red buttermilk paint for their barns by mixing buttermilk with red mineral pigment (*56*).

Yogurt. Yogurt was a curiosity in the United States in 1900 when Ilya Metchnikoff isolated cultures for yogurt manufacture (*57*). Isaac Carasso perfected an industrial process for yogurt production in the 1920s and named his company after his son Daniel's nickname, Danone. Daniel Carasso took over the company in the 1930s, moved to the United States during World War II, and Americanized the name to Dannon (*58*). The product began to increase in popularity when fruit was added starting in the 1950s (*57*). Sales of dairy foods with probiotics are increasing 20% a year in the United States due to consumer demand for extra health benefits from their food, and most of the probiotics are from yogurt (*59*). Dannon, for example, adds *Lactobacillus casei immunitas* and *Bifidus regularis* to its yogurt (*15*). The traditional forms of yogurt, set-style (with a firm gel) and Swiss style (with its gel broken), are being joined in the market by yogurt drinks (which are homogenized), Greek style yogurt (strained, with double the protein content) (*60*), frozen yogurt, whole grain yogurt, and other products (*59*).

CURRENT TRENDS AND ISSUES

As an infant's first food, milk has an emotional connection to people. Consumers can easily become mistrustful of the safety and quality of milk, demonstrated in recent years with the 1994 introduction of recombinant bovine somatotropin (rBST, also called bovine growth hormone, BGH). Marketed as Posilac and manufactured by Monsanto until October 2008 and by Eli Lilly since then, it is derived from genetically engineered *Escherichia coli*. rBST prevents mammary cell death and increases milk yield by 15−20%, reducing the number of cows needed, along with the amount of feed and waste output (*61*, *62*). However, many feel that milk produced from cows injected with rBST is unnatural, and its use in dairy herds is illegal in European Union countries (*63*) and other places.

Many Americans are changing their eating habits to include foods they consider to be healthy, better for the environment, or produced by small businesses (*64*). These niche markets include locally grown food, artisanal sources (*9*), milk from grass-fed cows, and raw milk (*15*)—exactly what Americans were consuming at the start of the 20th century. Coupled with recent adulteration and contamination problems with milk produced in China, it seems that the more things change in the dairy industry, the more they stay the same. Many of the concerns and preferences of 100 years ago are still with us.

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