Chapter 30

Dairy production: microbial safety of raw milk and processed milk products

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Abstract

Dairy production is important for the survival of billions of people across the globe who consume milk and dairy products every day. Milk and its products are a source of essential nutrients, such as proteins, fats, vitamins, and minerals necessary for human health. The production and consumption of dairy products are increasing worldwide. As the single most important raw material in dairy production, the quality of raw milk is central to the quality and safety of all dairy products. Owing to its highly nutritious nature, milk serves as an excellent growth medium for a wide range of microbes. Microbial contamination of milk and dairy products along the value chain remains a daunting task for the dairy industry. Notwithstanding the different process technologies (both conventional and novel) that have been adopted by the dairy industry, microbial spoilage of milk and its products still causes major losses in the industry. Furthermore, several foodborne disease outbreaks have been implicated in milk and dairy products around the world. Enteric pathogens such as *Salmonella* serovars, *Campylobacter* spp., Shiga toxin-producing *Escherichia coli*, *Listeria monocytogenes*, and enterotoxin producing *Staphylococcus aureus* are the most commonly implicated organisms in dairy-borne disease outbreaks. In order to manage food safety in the dairy industry, any approach to food safety reform must be proactive and risk-based. However, this approach is still posing a challenge in developing countries where the dairy sector is predominated by the informal value chains. Irrespective of the scales of production (large or small scale) and sector (formal or informal), the dairy industry should apply principles of good hygiene practices and good manufacturing practices, coupled with identification and management of possible sources of contamination, in order to curb the challenges of quality and safety.

Keywords: Dairy value chain; microbial contamination; food safety; hygiene; risk-based approach

30.1 Introduction

Milk is an essential component of the human diet consumed by approximately 80% of the world's population.[1] It is a source of essential nutrients, such as proteins, fats, vitamins, and minerals necessary for human health.[2] Milk is one of the most produced and valuable agricultural commodities accounting for 27% of the global added value of livestock and 10% of the global added value to agriculture.[3] Globally, about 881 billion liters of milk are produced annually, most of it (81%) coming from cattle, and the remainder coming from other dairy species such as buffaloes, goats, camels, and sheep.[1]

As the single most important raw material in dairy production, the quality of raw milk is central to the quality and safety of all dairy products. The highly nutritious nature of milk makes it an attractive medium for microbial growth. Several contamination sources and risk factors expose raw milk to microbial hazards at the farm level and along the dairy value chain.[4] At the farm, contamination of raw milk can emanate from within the udder (in the case of infected animals suffering from mastitis), the milking environment and from milk handling and storage equipment. Bioaerosols and dust in milking parlour environments can be sources of contamination with soilborne organisms, fecal and animal skin microflora. In addition, bacterial biofilms in milking machines, and milk pipelines can be another source of raw milk contamination. With so many sources of contamination, the microflora of raw milk is very diverse. It includes soilborne and waterborne microorganisms such as *Curtobacterium* spp., *Bacillus* spp., *Corynebacterium* spp., *Aerococcus* spp., *Staphylococcus* spp. and *Pseudomonas* spp. The microflora also include

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animal-derived commensal bacteria such as lactic acid bacteria (LABs) and pathogenic bacteria such as Shiga toxin-producing *Escherichia coli*, *Salmonella* serovars, *Campylobacter* spp., *Listeria monocytogenes*, *Staphylococcus aureus*, and *Yersinia enterocolitica*.[5]

The presence of microorganisms in milk has two main consequences. The growth of spoilage organisms that secrete hydrolytic enzymes can cause spoilage and quality defects in milk. Microbial spoilage of milk is a major cause of losses in the dairy industry. The deterioration in quality is exacerbated by inadequate cooling conditions in the storage of raw milk and inadequate cold chain post-milking. The second consequence of microbial presence in milk is the health risk to consumers arising from the growth of foodborne pathogens. Enteric pathogens such as *Salmonella enterica*, *Campylobacter* spp., Shiga toxin-producing *E. coli* (STEC), and *L. monocytogenes* are common fecal contaminants of raw milk.[5] Other zoonotic pathogens such as *Mycobacterium* spp., *Brucella* spp., *Coxiella burnetii*, *S. aureus*, and *Streptococcus* spp. can also be transferred into raw milk from infected animals.[6,7] Unlike spoilage organisms that cause noticeable quality deterioration in milk, the growth of pathogenic organisms may not produce any discernible effects on quality. Thus, contaminated milk poses a great public health risk as it can be consumed without any objectionable quality defects.

Microbial growth in milk is a major risk factor limiting the shelf life of raw milk. Hence, milk is frequently processed into fresh dairy products such as pasteurized milk, ultra-high temperature (UHT) milk, and extended shelf life (ESL) milk. Of these processes, pasteurization (heat treatment at 72°C for 15 s) is considered the most fundamental step in milk processing. It is a process designed to keep the microbial load of milk low, before further processing into other value-added dairy products such as cheeses and yogurt, butter, and sour cream.[8] Although pasteurization has been effective as a primary step in controlling the microbial load in milk, the spoilage and safety of pasteurized milk are still a major issue in the dairy industry.[9] Moreover, some heat-resistant (thermoduric vegetative) bacterial species and spore-formers can survive the pasteurization processing and cause spoilage of the pasteurized milk.[9] Because of the low-temperature storage of pasteurized milk, the spoilage is often a result of psychrotolerant spore-formers such as *Bacillus* spp. and *Paenibacillus* spp. that survive the thermal processing conditions.[10] Besides the psychrotolerant spore-formers, heat-labile psychrotolerant Gram-negative bacterial species introduced into the product through post-pasteurization contamination are also a significant factor in the spoilage of pasteurized milk.[9] Among the psychrotolerant post-pasteurization contaminants, *Pseudomonas* species are typically the most common causes of spoilage of pasteurized milk. Their adaptation and rapid growth rate under low-temperatures favors their growth in refrigerated pasteurized milk.[9]

As most pathogens associated with milk and dairy products are susceptible to pasteurization, most dairy-borne disease outbreaks are often due to consumption of raw milk or raw-milk-derived products.[11] Notwithstanding the bactericidal effectiveness of pasteurization, incidents of illnesses and outbreaks linked to the consumption of pasteurized milk and its products are still common.[12] Hence, the control and management of microbial hazards in dairy foods is a matter that must incorporate all stages of the value chain. These include farm-level good hygiene practices (GHP) involving animal hygiene, hygiene of the milking environment, the milking equipment and cow health- as well as hazard analysis critical control point (HACCP) systems during processing.[13] In addition to the implementation of GHP and HACCP, risk-based approaches can provide a way of limiting the risk of illnesses associated with pathogens in dairy foods. Using risk-based approaches, processes and operations where a higher probability of contamination, cross-contamination and pathogen growth exists, are given more attention.

30.2 Dairy value chain

The microbial quality and safety of dairy products are a cumulative function of the contamination risks and the growth or inactivation probabilities of the contaminating microorganisms and pathogens from the point of milking up to the consumer. The contamination risks and growth probabilities of the contaminant microflora are influenced by hygiene practices and the handling of milk at the farm level, storage and transportation of raw milk to processing facilities, processing conditions, handling and storage of processed products at the wholesale, retail, and consumer stages. The main stages of the dairy value chain and their associated microbial quality and safety risk factors are shown in Fig. 30.1.

In developed countries (and some developing countries), dairy value chains are formal and are characterized by large commercial farms with modern production technology implementing global standards on good agricultural practices. Although the implementation of food safety standards at different stages of the formal value chains aims to reduce the risk of microbial hazards, many cases of dairy-based foodborne diseases continue to be reported worldwide.[12,14] Several risk factors are associated with every stage of the value chain (summarized in Fig. 30.1). Hence, food safety failures at any stage of the value chain can result in a magnified risk along the chain.

Unlike the situation in developed countries, dairy value chains in most developing countries are predominantly informal. For instance, more than 80% of the milk

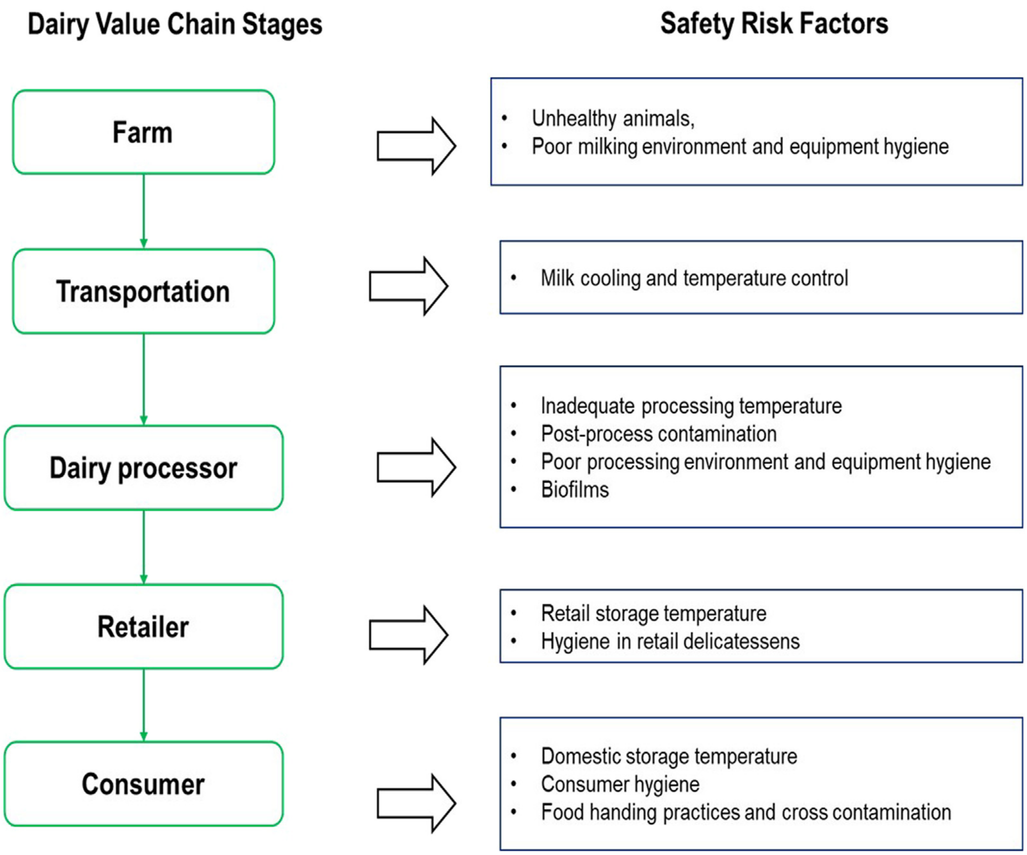

FIGURE 30.1 Dairy value chain and associated risk factors of microbial contamination and growth.

supply in Zambia and Kenya is from informal milk producers and is supplied through informal value chains.[15,16] The informal milk supply chains depend on traditional rural farmers (usually producing milk from indigenous non-dairy breeds for subsistence and family income) and small-holder dairy farms that keep small (3–15) herds of dairy cows and informal milk traders as a supply line to the consumers.[16] In countries where informal rural and smallholder farmers are the predominant raw milk suppliers, the milk can also be channeled to formal processing plants through milk collection centers and dairy cooperatives.[15] Milk collection centers provide facilities for cooling and further distribution to commercial processors. The several nodes of such informal milk value chains and their cross intersection with formal value chains make such supply chains a major safety risk even for products produced through formal commercial processors.

Depending on regulations in each county, milk collection in formal systems is usually done by certified collectors who sample the milk for quick testing to check for compliance with standards such as antibiotic residues. If the milk complies with the required standards, it is pumped from the bulk tanks at farms into the milk trucks.[17] A truckload may contain milk from several farms when it is delivered to the processing plant. Before unloading at the processing plant, the milk passes through a series of preliminary analytical tests such as acidity, antibiotic residuals, added water, fat, and protein content. Compliance failures especially with antibiotic testing would normally result in rejection of the entire truckload. However, failure to comply with other tests would normally result in the classification of the milk load as low-grade which can be used for the processing of low-value dairy products.[18] In some instances, raw milk can be pasteurized at the farm before transportation to processing plants, and in some cases, milk processing can also be conducted on-site.

30.3 Microbiology of raw milk

Milk is a sterile fluid as it is secreted into the alveoli of the udder of healthy animals. However, depending on the level of milking hygiene, milk is almost immediately contaminated at the point of milking. Because of its high nutrient content and nearly neutral pH, it is a good medium for microbial growth. The immediate sources of milk contamination include the exterior of the udder, and the milking and storage equipment. The microflora of raw milk is very diverse; it consists of organisms that are part of the natural flora of healthy animals (skin and gastrointestinal tract commensals), and organisms that cause systemic and gastrointestinal tract infections in dairy animals.[5,19] The microflora also includes soilborne and waterborne organisms as well as organisms from animal feed and vegetation. Animal feed and feed ingredients have been implicated as an important source of microbial contamination of milk at farm level.

30.3.1 Pathogenic organisms

Most milk-borne pathogens are either zoonotic organisms that infect dairy cows or commensal organisms that are part of the natural flora of healthy animals. In some instances, milk-borne pathogens can be environmental saprophytes introduced into the milk from the milking environment while some can be introduced into the milk by personnel during milking. Among the systemic infections, mastitis has the greatest influence on the microbiology of raw milk. Mastitis is an inflammation of the mammary gland primarily caused by bacterial intramammary infections. Based on the extent of inflammation, mastitis can be clinical (with visible signs such as a swollen udder and watery milk with clots) or subclinical which is asymptomatic. Because of its asymptomatic nature, subclinical mastitis is a major risk factor in the transmission of milk-borne pathogens as infected animals shed the pathogens into the milk together with somatic cells. The most identified causes of subclinical mastitis are *S. aureus* and *Streptococcus agalactiae*.[20] These bacterial species are part of the natural flora of the cow's udder and teat skin that can colonize and grow into the teat canal. Other pathogens include *E. coli*, *Klebsiella* spp., *Enterobacter* spp., *Pseudomonas* spp., *Streptococcus uberis*, and *Bacillus* spp.[21] Thus, milk from infected animals is considered to be a main source of milk-borne pathogens with enterotoxigenic *S. aureus* as the leading risk in raw milk and raw milk-derived products.[21]

In addition to mastitis, raw milk consumption has for a long time been known to be a risk factor for the transmission of other zoonotic pathogens that cause systemic infections in dairy animals. These include *Mycobacterium bovis* and *Mycobacterium avium* subspecies *paratuberculosis* (MAP),[22] which cause bovine tuberculosis (TB) and Johne's disease respectively. Due to the universal implementation of pasteurization, zoonotic TB outbreaks are now rare in developed countries. However, sporadic cases still occur due to on-farm consumption of raw milk. Notwithstanding the well known success of pasteurization in attenuating the human risk of zoonotic TB, low levels of MAP have been detected in retail pasteurized milk.[23,24] The reason for this has not been clearly understood. Intracellular MAP within the somatic cells may be protected against heat inactivation during pasteurization.[24] Several milk-borne human MAP infection outbreaks have been reported across the globe. Table 30.1 presents some of the disease outbreaks traced to the consumption of some milk and dairy products since 2000 in Europe and United States.

Like many other livestock animals, dairy animals can be asymptomatic carriers of several enteric pathogens such as *Salmonella* serovars, *Campylobacter* spp., *E. coli* O157:H7, and *L. monocytogenes*.[41] Most commonly, these organisms are harboured as commensals in the gastrointestinal tracts and are introduced into milk during milking through fecal contamination of the udder. Milking hygiene is a key factor in modulating the risk of fecal contamination. Since the udder of the dairy animals can come into direct contact with the dung, cleaning the udder before milking is one of the most important hygienic practices to reduce the transmission of pathogens through fecal contamination. A 90% reduction of teat contamination can be achieved with good udder preparation before milking.[42]

30.3.2 Spoilage organisms

While it is not a food safety risk factor, the deterioration in milk quality as a result of microbial growth is a major concern for the dairy industry. Milk spoilage is a result of microbial growth and enzyme production that result in the degradation of lipids and proteins leading to the release of metabolites that have negative effects on milk quality. If raw milk is kept unrefrigerated, the most common spoilage problem is souring due to mesophilic LABs. However, the greatest challenge is attributed to the growth of psychrotrophic organisms in raw and pasteurized milk stored at low temperatures. The low-temperature spoilage is mainly due to the growth of psychrophilic *Pseudomonas* spp. and *Acinetobacter* spp. as raw milk contaminants or as post-pasteurization contaminants.[9] Moreover, spoilage can also result from heat-stable enzymes produced by *Pseudomonas* spp. during growth of the organisms in low-temperature stored raw milk before pasteurization.[43] As a ubiquitous environmental saprophyte, contamination with *Pseudomonas* spp. can emanate from water, bulk milk tank surfaces, udder teats, and milking equipment.[44]

Apart from psychrotrophic vegetative bacterial species, psychrotolerant spore-forming bacteria also represent a major challenge in the spoilage of thermally processed dairy products. The Gram-positive psychrotolerant spore-formers include *Bacillus* spp. (*B. licheniformis*, *B. cereus*, *B. pumilus*, *B. sporothermodurans*, *B. weihenstephanensis*), and *Paenibacillus* spp. (*P. odorifer*, *P. graminis*, and *P. amylolyticus*).[10,45] In terms of ecology, the spore-formers are ubiquitously found around the dairy farm

TABLE 30.1 **Disease outbreaks traced to consumption of some milk and dairy products since 2000 in Europe and United States.**

Pathogen	Country	Year	Implicated dairy products	Number of cases	Reference
Salmonella serovars	France	2018	Raw goats' milk cheese	153	Robinson et al.[25]
	France	2017	Infant milk products	22	Jourdan-Da Silva et al.[26]
	France	2015–2016	Raw milk cheese	83	Ung et al.[27]
Escherichia coli (STEC)	France	2019	Soft raw cow's milk cheeses	13	Jones et al.[28]
	USA	2014	Aged raw milk Gouda cheese	41	Mccollum et al.[29]
	Canada	2013	Aged raw milk Gouda cheese	29	Currie et al.[30]
Campylobacter spp.	Italy	2018	Cheese	222	Sorgentone et al.[31]
	England	2016	Raw milk	69	Kenyon et al.[32]
	USA	2012	Unpasteurized milk	81	Longenberger et al.[33]
Listeria monocytogenes	Austria and Germany	2009–2010	Acid curd cheese "Quargel"	14	Fretz et al.[34]
	Canada	2008	Pasteurized cheese	38	Gaulin et al.[35]
	United States	2009	Mexican-style cheese	8	Jackson et al.[36]
Staphylococcus aureus	Switzerland	2014	Soft cheese made from raw milk	14	Johler et al.[37]
	Germany	2013	Ice cream	13	Fetsch et al.[38]
	Japan	2000	Powdered skim milk products	13 420	Asao et al.[39]
	Austria	2007	Pasteurized milk products	40	Schmid et al.[40]

STEC, Shiga toxin-producing *Escherichia coli*.

environment, being abundant in soil, vegetation, silage, and the gastrointestinal tracts of dairy animals. Apart from the contamination of raw milk at the farm, spore-formers present a big challenge along the dairy product processing continuum as they are hard to eliminate once such organisms colonize storage tanks, pipework, and product packaging lines.

30.4 Dairy processing and safety of processed products

Raw milk is a very perishable commodity with a short shelf life. The usable life of milk can be extended for several days through techniques such as cooling, pasteurization and fermentation. Milk is further processed into high-value dairy products with longer shelf lives. Dairy processing involves the conversion of raw milk into fluid milk products, fermented milk products like yogurt and cheese, evaporated and condensed milk, dry milk products, whey and whey products, ice cream, and butter and spreads.

Irrespective of prior pasteurization, milk arriving at the dairy processing plant should be transported at temperatures between 4°C and 6°C.[17] Having passed the preliminary analytical tests, the milk is subsequently processed into different value-added products. Although the dairy industry is still employing conventional processing technologies, different new processing techniques have evolved over time, bringing with them new and unforeseen quality and safety consequences.[46] Potential threats to human health can arise from errors in pasteurization and emergence of heat-resistant pathogens. Cross-contamination of finished products with raw material, inadequate sanitation procedures in the plant environment, or inadequately sanitized equipment has resulted in dairy products with reduced shelf life. Other critics have pointed out the lack of a system involving good laboratory methods for detecting and tracing sources of microbial contamination in the dairy plant environment as the main limitation to achieving an acceptable level of food safety with prolonged shelf life.[46]

The size or scale (large or small) of production influences the operating practices and safety of dairy products.[47] In most developing countries, dairy industries that process more than 10,000 L of milk per day are classified as large-scale.[47] Apart from scales of production, large-scale industries have fairly adopted and implemented food safety management systems (FSMS) while small-scale dairy industries generally lack such management systems.[47,48] Due to the lack of FSMS, small-scale dairy industries have been being characterized by poor dairy product quality.[48]

30.4.1 Thermal processing and quality of fresh milk products

Thermal processing of milk is arguably the principal method of eliminating pathogenic and spoilage organisms, and ensuring safety and long shelf life. The intentional heating of milk above 50°C for a sufficient time such that there is a reduction in the concentration of one or more microorganisms is considered heat treatment. Thus the heat treatment concept covers an infinite number of time–temperature combinations. Although heating has the beneficial effect of reducing microbial load, it results in some inevitable negative consequences such as the loss of nutritional value, loss of bioactive compounds (such as antioxidant, antithrombotic, antitumor, and antiinflammatory activities), and loss of the sensory qualities of milk. A range of novel thermal processing techniques have been developed to improve the quality of foods, at the same time minimizing the negative impacts associated with thermal degradation. Numerous investigations on dielectric heating (which includes microwave heating and radio-frequency heating), ohmic heating, inductive heating, and infrared heating have demonstrated their effectiveness in ensuring product safety, quality, and acceptability.[49] Although efforts have been made to improve milk processing to inactivate microorganisms, there is no ultimate technology that eliminates pathogens from the food supply chain. A combination of multiple thermal and nonthermal interventions also known as the hurdle approach, has shown some potential in improving food safety. Moreover, while novel thermal processes have been partially adopted in dairy industries, the processing of milk is still largely dependent on the conventional thermal processes such as thermization, pasteurization, and ultra-heat treatment.

30.4.1.1 Pasteurized milk

Pasteurization is the oldest and yet still the most widely used technology in dairy processing. The modern process of milk pasteurization [high-temperature, short-time (HTST) process] is based on continuous plate pasteurizers in which the milk is heated to a temperature of 72°C for 15 s in a holding tube followed by rapid cooling.

Except for spore-formers, the time-temperature conditions of HTST pasteurization are considered sufficient to eliminate most bacterial pathogens found in raw milk. With the decimal reduction times (*D*-values) for pathogens such as *E. coli* O157:H7 (16.2 s at 63°C), *L. monocytogenes* (33.3 s at 63°C), *M. bovis* (6.6 s at 64°C), *Campylobacter* spp. (0.12–0.14 min at 60°C), and *Salmonella* serovars (0.11 min at 62.8°C), the HTST process can achieve >5 log reduction of these pathogens in milk.[50]

Although the HTST pasteurization process greatly reduces the safety risks associated with milk and dairy products, infections and outbreaks resulting from consumption of contaminated products derived from pasteurized milk continue to be a challenge for the dairy sector.[51] Most of the safety challenges of pasteurized milk products are attributed to post-pasteurization contamination emanating from filling machines and bacterial biofilms on milk post-pasteurization contact surfaces.[50] Apart from post-pasteurization contamination, the presence of pathogens directly associated with raw milk such as *L. monocytogenes*, *E. coli*, and MAP, could be an indication of faulty pasteurization.[50] Besides the issues of microbial safety risks, pasteurized milk generally has a short shelf life of 2–20 days under refrigerated storage.[52] The major limiting factor to the shelf life is spoilage due to psychrotrophs, principally *Pseudomonas* spp. These organisms are frequent post-pasteurization contaminants and can multiply at refrigeration temperatures. Moreover, the growth of psychrotrophs in refrigerated raw milk before processing has a significant impact on the quality and shelf life of pasteurized milk as heat-stable proteases and lipases secreted at this stage can cause quality deterioration post-pasteurization. Therefore, the total microbial load and the types of organisms present in the raw milk, have a substantial influence on the quality and shelf life of the pasteurized milk.[50]

30.4.1.2 Ultra-high temperature (UHT) processed milk

UHT milk is milk that has been processed at ultra-high temperatures and filled under aseptic conditions into hermetically sealed packaging, thus producing a commercially sterile product. Typically, UHT milk is processed at 125°C−154°C for 1−8 s, followed by quick cooling to ambient temperature.[53] As a commercially sterile product, UHT milk has a shelf life of 4−9 months unrefrigerated. Notwithstanding the ultra-high heat sterilization treatment, some heat-resistant spore-forming bacteria such as *B. cereus*, *B. sporothermodurans*, and *Geobacillus stearothermophilus* have been isolated from UHT milk.[54] Their presence in UHT milk has been attributed to several factors that include intrinsic high heat resistance, survival of clean in place (CIP) procedures, and post-sterilization contamination.[54,55] With respect to intrinsic heat resistance, *B. sporothermodurans* spores have been found to possess a very high thermal resistance, with *D*-values at 140°C (D_{140}) ranging from 3.4 to 7.9 s.[56] In a survey of UHT milk brands sold in South Africa, Tabit[56] found that 50% of them were positive for *B. sporothermodurans* with counts ranging from 2.25 to 4.11 $\log_{10}$ CFU/mL.

30.4.1.3 Extended shelf life (ESL) milk

ESL or ultra-pasteurized milk is produced by thermal processing using temperature conditions that are between the HTST pasteurization and the UHT sterilization processes. There is no consensus in the dairy sector on the shelf life of ESL milk, although, the product can have a refrigerated life span of 21−45 days.[57] Some manufacturers, however, claim that the product can stay up to 90 days if properly refrigerated.[58] Although ESL milk has a shorter shelf life as compared to UHT milk, it is more superior in terms of sensory properties, having less pronounced cooked or scorched flavors. The precise definition of ESL milk and its manufacturing processes varies in many national jurisdictions. Generally, the product is manufactured using two principal technologies (thermal treatment alone or a combination of heat treatment and membrane filtration). The widely used method is a thermal process in which conditions are more severe than pasteurization but less severe than UHT processing (direct or indirect heating at 123°C−127°C with a holding time of 1−5 s).[57] In the alternative method, nonthermal processes such as microfiltration through ceramic membranes with an average pore diameter of 0.8−1.4 μm and bactofugation are usually combined with a final thermal pasteurization treatment.[57] The later process is reported to achieve a spore reduction of 3−5 $\log_{10}$ CFU/mL.[57]

Given that ESL milk is usually not packaged under aseptic conditions, spoilage challenges are also reported.[45] Spoilage of ESL milk can occur as a result of spore-forming bacteria whose spores are not destroyed by the heating process or by post-pasteurization contamination due to poor hygiene practices or by process biofilms especially around the filler nozzle and other parts of the processing equipment.[45,59] Among the spore-formers, *Bacillus* spp. (in particular psychrotrophic strains) have been identified as a major challenge. The most common and problematic post-process contaminants of ESL milk are the Gram-negative psyschrotrophs, principally Pseudomonads. Studies have also shown the presence of mesophilic organisms in ESL milk stored under refrigeration.[45] These mesophiles include the *Bacillus* spp. and *Paenibacillus* spp. which harbour genes for cold adaptation and growth.[45] Other common spoilage organisms in commercial ESL milk include *Rhodococcus* spp, *Anquinibacter* spp. *Arthrobacter* spp. *Microbacterium* spp. *Enterococcus* spp. *Staphylococcus* spp. *Micrococcus spp.* and coryneforms.[57] A further consideration that can affect ESL milk is the initial bacterial load in the raw milk received for processing. The higher the bacterial count in the raw milk, the higher will be the residual count in the heated milk.[53,58] For good quality ESL milk, the total count in the raw milk should not exceed 10^5 CFU/mL.[57]

30.4.2 Quality of fermented dairy products

Preservation of food by fermentation has been practiced since time immemorial and fermented milk is one of the oldest examples of fermented foods. Until now, fermented dairy products continue to contribute to the socio-economic development and food security of people in both rural and urban communities across the globe. Fermented dairy products are produced using spontaneous fermentation or starter cultures. Spontaneous fermentation uses the natural microflora associated with raw milk. Spontaneous fermentation has occasionally been associated with pathogens, predominantly, because of poor hygiene.[60] Using certain strains of starter cultures (LAB, yeasts, and molds), a lot of commercial fermented dairy products such as cultured buttermilk, sour cream, yogurt, and cheeses are among the most common dairy products produced across the globe. Other, less known products include *kefir*, *koumiss*, acidophilus milk, and new yogurts containing *Bifidobacterium* spp. are also consumed in different parts of the world.[60]

With a rising consumer demand for additive-free and minimally processed foods, innovative food processing technologies are gaining more attention and are increasingly being adopted within the dairy industry.[61] Of interest is the application of new starter cultures (probiotics, *kombucha*), as well as quality improving ingredients like transglutaminase, milk protein fractions, and functional components of plant origin.[61] Other novel processing technologies of interest to dairy fermentations are high-pressure processing, high-pressure homogenization, and ultrasonic processing because of their potential to achieve a specific and/or novel functionality or to improve efficiency.[61] Certainly, novel trends in fermented dairy technology contribute to the creation of various products with high nutritive value. However, new food safety challenges arising from the introduction of novel processing techniques need to be recognized.

30.4.2.1 Microbial quality of cheese

Cheese is a fermented dairy product that can be made using pasteurized or raw milk. Cheese made from raw milk imparts different flavours and texture characteristics to the finished cheese. The product comes in different varieties, ranging from soft, and semi-soft to hard cheeses. In terms of macrostructure, cheese is a stabilized curd of milk solids produced by coagulation of the milk caseins. The coagulum entraps fats, proteins, vitamins, calcium, and phosphorus. Microbial contamination of the cheese is intrinsically linked to the dairy value chain, from production through handling and processing to consumption. The various sources of microbial contamination that have been implicated in cheese processing include raw materials (milk and cheese ingredients), personnel, packaging material, and the processing environment.[62] As ready-to-eat (RTE) foods, cheeses are high-risk products with respect to human listeriosis outbreaks due to their ability to support the growth of *L. monocytogenes* through a long refrigerated shelf life and the lack of further treatment before consumption.[62,63]

Soft and semi-soft cheeses have previously been associated with outbreaks of listeriosis and most of these outbreaks were from cheeses made from unpasteurized milk. However, for cheeses made from pasteurized milk, post-process contamination of the product by *L. monocytogenes* and other enteric pathogens has been reported.[62] Soft cheeses are relatively more vulnerable to post-pasteurization bacterial contamination and subsequent outgrowth than hard cheeses.[64] Bacterial contamination of soft cheeses is attributed to low acidity and high moisture content. Soft cheeses like Camembert have a moisture content $> 70\%$ and a pH range of 5.5−5.8, whereas hard cheeses like Cheddar have a moisture content $< 42\%$ and a pH < 5.45.[65] As a result, psychrotrophic pathogens like *L. monocytogenes* can readily multiply in soft cheeses during refrigerated storage. On the other hand, while several pathogens can be inactivated during storage in hard cheeses, *E. coli*, *L. monocytogenes*, *Brucella* spp., and *Salmonella* can still be detected after long ripening periods.[62]

The occurrence of pathogenic and spoilage microorganisms in fermented dairy products is influenced by a number of factors which include the health status of the dairy herd, hygiene level in the farm environment, milking and storage conditions, geographic location, season, and processing of the milk.[60] Therefore, to reduce the risk associated with fermented dairy products, there is a need for a continuous system of preventive measures beginning with the safety of animal feed, through good farming practices and on-farm controls, to good manufacturing and hygiene practices, consumers' safety awareness, and proper application of FSMS throughout the dairy chain.[60]

30.5 Hygiene in dairy processing

Contamination of the milk typically occurs when the raw milk comes into contact with contaminated teats and milking equipment, feed, water, and soil at the farm level. Due to the susceptibility of raw milk to contamination, good hygiene and sanitary conditions of the dairy environment are crucial and imperative matters as they directly impact the quality and safety of the dairy products. The challenge of ensuring the safety and quality of products necessitates the development of FSMS targeted at producers and personnel at all levels of the value chain.

30.5.1 Sources of contamination in dairy processing

Contaminated water, aerosols, and packaging materials are some of the entry points for microbial contamination of dairy products. The microbes may also form biofilms that can persist in the processing environment. This makes the need for GHP in the dairy chain a critical issue that will aid in the production of a safe and quality product. Therefore constant monitoring and improvement of hygiene and safety control measures to meet the rising demands of both regulatory standards and consumers are crucial in the dairy industry.

30.5.1.1 Bioaerosols

Air often serves as a medium for microdroplets and suspended inanimate and biological agents, including viruses, bacteria, parasites, yeasts, molds, skin particles, dust and water droplets.[66] Microbial aerosols can be free-floating bacterial or fungal spores either suspended in droplets or adhered to dust or skin particles. The quality of air inside dairy processing areas plays a vital role in the final quality of processed milk products. This is because milk products are highly susceptible to extraneous contamination by microbes, and the indoor air of the dairy processing plant is a vehicle for such biological aerosols or contaminants.[67] These bioaerosols may harbor pathogenic organisms or spoilage microbes, that affect both safety and product shelf life.[67]

A critical factor in controlling airborne microbial contamination of processing areas is the management of air quality entering processing plants through the use of clean air systems. The air entering the processing plant is usually filtered to remove suspended particulate matters such as microbes, after which it is cooled and gently pumped into processing areas. Nonetheless, factors such as personnel clothing and footwear, structures, ingredients, and food contact surfaces may initiate the release of bioaerosols into the processing environments causing product contamination if uncontrolled.[67] For example, microorganisms such as *L. monocytogenes* and *E. coli* can be dispersed in the aerosols produced by cleaning operations such as applying hoses and spray lances and condensate on the cooling fins of evaporative chillers.[68] Other factors responsible for the generation of aerosols are industry operations such as milling, weighing powdery substances, spray drying, vacuuming, and handling of dry ingredients.[69]

The concentration of microbes suspended in an aerosol is dependent on several factors which include the size of the particulate materials in suspension, location, season, weather conditions, and the level ground covering in the vicinity of processing plants.[70] Furthermore, the size of the suspended particulate matter influences the dispersion of aerosols. For instance, particulate materials of more than 15–20 μm easily fall close to the point of dispersion, while lighter particles can be airborne for an extended period and travel further to the point of dispersion in slow-moving air.[69] Thus a regular monitoring of the microbial load in air within processing environments is an essential tool in management of airborne contamination.

30.5.1.2 Contaminated water

In the dairy industry, water is used for cleaning equipment during the production cycle, steam generation and cooling systems. The dairy industry consumes vast amounts of water and generates huge volumes of wastewater. Contaminated water used for equipment cleaning can serve as a transmission vehicle for foodborne pathogens in dairy processing. Most dairy processing plants use treated municipal water for their operations. The microbial quality of water supplied from municipality treatment facilities depends on the efficiency of the treatments to remove enteric pathogenic bacteria, viruses, and parasites.[71] Although conventional water treatment facilities are designed to remove pathogens, bacteria growing in pipeline biofilms can be a source of contamination of purified water within the supply system.[71] Additionally, due to corrosion of the piping system (because of pipe aging) or other poor engineering design in municipal reticulation systems, potable water supply systems can be contaminated through leakages. Leakages arising from sewage runoff, overloaded sewage treatment systems, septic systems, and leaking sanitary sewer pipes impose the greatest risk to the contamination of purified potable water.[71] Because of this, most dairy processing plants further treat the municipal water by processes such as filtration. However, depending on the maintenance of the purifying system, it can accumulate sludge, scale, rust, algae, or slime deposits in the water distribution systems and potentially represent a temporary reservoir of undesirable microbial contaminants (some of which can be pathogenic).[72] Therefore a good water supply in dairy production is a principal starting point in controlling microbial contamination dairy products.

30.5.1.3 Personnel hygiene

Poor personnel hygiene is frequently one of the sources of contamination in dairy processing. In most cases, negligence is often cited as the cause of poor personnel hygiene. Critics believe that most foodborne illness outbreaks are caused by food workers' contact with food, particularly those that are ill or chronically infected.[73] As carriers of foodborne pathogens, infected workers can be reservoirs and vehicles for the contamination of dairy products.

Microorganisms can colonize the human external body surfaces such as the skin and hair, and mucosal surfaces such as nose, and mouth, or be excreted from the alimentary tract via faeces.[73] The most implicated microorganisms to increase the risk of cross-contamination from personnel to food products or process environments in the food industry are the microorganisms that reside on the skin. These microorganisms can be transient or resident skin microflora. Gram-negative bacteria such as *Salmonella* spp., *E. coli*, *Pseudomonas* spp., and *Klebsiella* spp. are examples of transient organisms that can be acquired from handling of raw materials, contaminated equipment, contaminated clothing, or touching other body parts or through poor toilet hygiene. In most cases, the transient organisms do not have sufficient residence time to multiply, and are easily removed by hand washing with detergents.[73] Some of the transient organisms like *S. aureus* can reside on localized skin lesions for longer periods, making them temporary residents. Resident skin microorganisms are generally not food pathogens and can live and multiply on the skin and constitute the normal microflora.[73] Although not a common threat in the dairy industry (because they do not multiply in the food), viruses can also be transferred by food handlers to the food via contaminated hands or droplets via coughing or sneezing.

The personnel who often dismantle and reassemble machinery for cleaning procedures and those who maintain the operation of machinery during production are often a source of contamination. Besides such contamination, the movement of personnel from processing areas of low-hygiene to high-hygiene areas increases the risk of product contamination. Arrangements averting the free flow of movement between low- and high-hygiene areas should be installed, such as a hygiene lobby or barriers, where a change of protective clothing should be required if the staff member moves from a low hygiene to a high hygiene area. Other considerations that can be put in place may involve compartmentalizing processing lines and preventing rotation on the job within the same processing day.[74]

30.5.1.4 Biofilms

Biofilms are surface or substratum communities of attached microorganisms surrounded by extracellular polymeric substances, often behaving differently than their planktonic counterparts.[75] Essentially, microbes exist in their natural environments as biofilms and not as single cells as obtainable on culture media in the laboratory. The biofilm structure is dispersed by detaching and re-attaching to another part of the dairy processing line during the downstream process termed "sloughing off."[76] They often grow on different processing equipment parts, such as ultrafiltration membranes etc. Biofilms in the dairy processing plant present a daunting challenge as they are about 1000 times more resistant to disinfection than the planktonic cells, making their control and prevention crucial.[59] Their establishment in dairy processing lines creates a contamination reservoir. Some factors that influence the formation of biofilms include the surface roughness of the equipment, conditioning films such as remnants of milk on equipment, the composition of the processed product, electrostatic charge, and hydrophobicity of the surface.[77]

The quality of the raw milk to be processed is a strong determinant in the formation of biofilms. Some contaminating microbes, such as the spores of *Bacillus* spp., survive the pasteurization process and the cleaning in place (CIP) regimes. They later establish in the processing lines, making their control a challenge. The biofilm structure, especially the inner part, is a well-known zone for high sporulation and formation of persister cells. These spores within biofilms have been demonstrated to be capable of forming fresh biofilms post-CIP.[55]

30.5.1.5 Sanitization and cleaning in place (CIP)

The CIP system involves the automated cleaning of hard-to-reach internal parts of processing equipment and pipelines without them being dismantled. The cleaning solutions that are used are often recycled and reused. The automation of these systems allows for a safe and economic optimization of the process.[78] CIP is an integral part of the food safety systems that are put in place to eliminate potential microbial contaminants in the food industry. Most CIP regimes use various biocides, usually in combination at an appropriate flow rate and temperature. However, the effectiveness of the sanitizing strength of the CIP system is hindered by the resistance of some bacteria, due to repeated disinfectant exposure and a consequent build-up of biofilms on equipment surfaces.[78] The standard CIP regime in a dairy processing plant is given as: water rinse, 1% sodium hydroxide at 65°C for 10 min, water rinse, 1.0% nitric acid at 65°C for 10 min, water rinse. There are other alternatives, such as caustic and acid blends that have effectively removed attached bacteria.[79]

Bacteria become attached when they survive a bactofugation or microfiltration process. The bactofugation and microfiltration processes take place before the pasteurization of milk, which significantly reduces the concentration of the contaminating microbes. Nonetheless, some microbes, especially the thermophilic spore-formers, survive the process or cause post-processing contamination, thus reducing the shelf life of the products.[80] Since the traditional CIP methods may fail to remove vegetative cells, biofilms and spores of these contaminants, this challenge has generated the demand for innovative techniques in the dairy industry. An investigation by Pretorius and Buys[55] revealed that simulated CIP treatment is not very effective when applied against *B. cereus* spores isolated from the filler nozzles, nor did it prevent subsequent germination. High-pressure spray and mechanical scrubbing are highly effective in removing biofilms that develop on exposed surfaces, but not for removing biofilms in crevices within the dairy factory.

The perceived reasons for the resistance of biofilms to biocides used in CIP are multifactorial. These may include reduced penetration of the biocide within the biofilm structure due to the complexity and the production of extra polymeric substances, reduced metabolism, stress response, and changes in quorum sensing among the cells within the biofilm.[81] It is therefore important to design the most effective CIP regime for a dairy processing plant.

Another problem associated with the CIP chemicals used in the dairy industry is the transfer of chemical residues from sanitized surfaces to the milk. This has necessitated the need for safe, efficient, and environmentally compatible chemicals for the dairy industry, such as food-grade and edible surfactants. Monitoring fouling during the CIP process is vital in controlling contamination by spoilage and pathogenic microbes in the dairy processing plant.

30.5.1.6 Packaging material

Packaging material in the dairy industry is of critical importance because of its impact on the quality, safety, cost, and marketing of the commodities to consumers. Although interest has shifted towards novel applications such as smart or intelligent packaging, modified atmosphere packaging, active packaging, and sustainability, studies have shown that packaging material can be a source of contamination for various dairy products.[82]

Food packaging material has the potential to affect the quality of food as there are possible interactions between the food and the packaging material, which include permeability of gases and water vapor into or out of the package, and migration of package components into the food. This interaction has a direct bearing on the quality and shelf life of products. The dairy industry is no different; here, packaging materials can play an important role in the microbiological quality of milk and milk products. This can occur by directly influencing the microbial load due to the presence of microbes on their surfaces or indirectly due to the permeable character of the packaging material, thereby allowing the growth of microbes that may be present.[83] Proper selection of packaging material in the dairy industry is therefore essential to provide a barrier that retains the quality of the product and also allows for a reasonable shelf life, among other factors.[83]

30.6 Risk-based preventative approach to dairy food safety

The dairy industry has evolved into one of the largest and most modernized food sectors characterized by large volumes of milk and a wide variety of dairy products in the food market. Partly, the dynamics of the dairy industry are influenced by an increase in the population, changes in food regulations, and consumer demands for safe and healthy milk product selection that is supplemented with a great variety and availability in the market. Although consumer trends are global, the nature and extent of their influence are shaped by geography, cultural norms, government policy, and socio-economic status. In most developing countries, particularly in Africa, the dairy industry is predominated by the informal sector, which is characterized by unregistered milk suppliers and processors who do not apply FSMS.[48]

As the industry is expanding and operating in a globalized environment, new challenges to food safety are continuing to emerge. Globalization of the food industry exposes populations worldwide to entirely new and unique food hazards. Regrettably, the dairy industry remains one of the most implicated food sectors associated with foodborne outbreaks globally. Efforts have been made by the dairy industry to adopt different strategies for managing food safety. However, in most developing countries, the policies are more reactive rather than proactive. A reactive system is hazard-based, which uses the premise that the mere presence of a potentially harmful agent at a detectable level in food (testing food to determine safety) is justification for legislation and/or risk management action.[84] However, it is also well known that the presence of a hazard does not necessarily mean that the product is harmful to human health.

In order to manage food safety amid an expanding dairy industry, any approach to food safety reform must be proactive and risk-based.[85] A risk-based food safety management methodology allows the consideration of exposure in assessing whether there may be any unacceptable risks to human health. When considering a preventive approach to food safety management, all aspects of a food safety system, from farm-to-fork (raw material, distribution, food processing, retail, and consumer behavior), are taken into account, ensuring that the combined efforts of all actors along the food chain provide safe and suitable dairy products rather than separating responsibility for any particular component of the chain. A systematic evaluation of hazards and associated risks at each point in the supply chain is required. Additionally, a risk-based approach tries to answer the following questions: where is the risk highest?, which food safety interventions should be prioritized?, and which risk mitigation measure is the most effective?. Undoubtedly, using a risk-based system, the FSMS in the dairy industry would improve through applying more effort towards managing the greatest risks, while fully understanding the factors that contribute to the risk, and allocating resources appropriately to prevent the risks and their root causes, and truly evaluating the effects of those efforts.[86,87] Apart from benefiting the dairy industry alone, a risk-based approach to food safety is also used by regulatory bodies that monitor food safety. Risk-based resource allocation focuses government efforts on the greatest risks and the greatest opportunities to reduce the risk, wherever they may arise. To promote a risk-based approach to food safety in the dairy industry, concepts such as qualitative and quantitative risk assessments, including HACCP-based FSMS are central.

30.6.1 Microbiological risk assessment and role in dairy food safety

The objective of ensuring safe food for the consumer has been a major preoccupation of governments and international organizations. Globalization of the dairy industry has posed challenges in the management of food safety. Food safety hazards such as microorganisms may enter at various stages along a dairy supply chain. Several interventions have been implemented to control microbial hazard presence in dairy products. These include good manufacturing practices (GMP) and HACCP principles, which are applied at specific stages of the production process, acting as preventive measures, and not the entire food production chain. Foodborne outbreaks from milk and dairy products are still reported regardless of FSMS programmes in place. Food safety management in the dairy industry should be risk-based and focus on the most relevant food safety hazards. The most prominent and central approach to risk-based preventative approaches to dairy food safety is food safety risk assessment. Risk assessment offers a means of improving and managing food safety associated with pathogenic microorganisms as well as chemical hazards. Microbial risk assessment is a valuable tool used to organize and analyze scientific information to estimate the probability and severity of any adverse risk posed by a pathogen in a particular dairy commodity. Risk assessment can be defined as the measurement of risk and identification of factors that influences it. It is an independent scientific process that can be conducted qualitatively (through descriptive measures as high, medium or low probability of contamination) or quantitatively (through numerical measures such as pathogen prevalence and modeling pathogen responses in foods). The process includes four stages: (1) hazard identification, (2) exposure assessment, (3) hazard characterization, and (4) risk characterization as outlined by the Codex Alimentarius Commission.[89] Risk assessment can be used to; review the safety of new products under development; evaluate the most effective control measures to address a particular food safety hazard; and establish food safety priorities. Apart from benefiting the dairy industry and protecting the consumer from food safety hazards, outputs and decisions from risk assessments can be used to facilitate international trade.

Risk assessment studies have been carried out to quantify the risk posed by pathogenic organisms in milk at national and regional levels by different researchers across the globe.[89] To date, quantitative microbial risk assessment (QMRA) for the major milk-borne pathogens has been conducted. EFSA[90] and Giacometti et al.[91−93] conducted risk assessments for *L. monocytogenes*, *Campylobacter jejuni*, STEC O157, and *Salmonella* spp. in raw drinking milk in Europe. The risk of listeriosis associated with the consumption of milk was also evaluated in the United States.[94] However, few risk assessment studies on pathogen-contaminated foods have been carried out in developing countries such as those in Africa. Among the few studies, Grace et al.[95] and Makita et al.[96] estimated the risk of hemolytic uremic syndrome (HUS) and brucellosis incidence respectively in informally marketed milk in Africa. Ntuli et al.[97] estimated the risk of HUS associated with the consumption of bulk milk sold directly from producer to consumer in South Africa. Most risk assessment studies carried out for pathogen-contaminated raw or pasteurized milk identified that temperature and storage time are the main factors influencing the product safety risk. For preventative measures, especially in countries where the sale of raw milk is permitted (sold via vending machines or outlets), the risk assessors recommended the boiling of milk before consumption.[98] The major shortcoming outlined by researchers who conducted QMRA in developing countries was applying risk-based methods to diverse, nonlinear, shifting, and data-scarce systems in which formal and informal food supply systems coexist and overlap. The major drawback is that risk assessments are expensive and time-consuming and because of the complexity of value chains, the approach has not been widely adopted in developing countries where the informal sector predominates and resources are limited.

A review by Verraes et al.[64] indicated that microbiological hazards and risks associated with dairy products manufactured from raw milk vary with the type of the product. They reported that the main microbiological hazards associated with raw milk soft and fresh cheeses were *L. monocytogenes*, STEC, *S. aureus*, *Salmonella*, and *Campylobacter* spp., whereas the microbiological hazards associated with raw milk butter and cream included *L. monocytogenes*, STEC, and *S. aureus*. They also highlighted that raw milk dairy products may also be contaminated with *Brucella* spp., *M. bovis*, and the tick-borne encephalitis virus. To limit the exposure to pathogens due to consumption of dairy products made from raw milk, several control measures can be applied from farm to fork and these control measures can vary depending on the point/source of contamination across the dairy value chain.[64] Ramos et al.[98] reviewed risk assessment studies conducted from 2015 to 2018 on cheese produced from raw or pasteurized milk. The target organisms in the risk assessments were STEC, *L. monocytogenes*, *S. aureus*, and *Clostridium* spp. In general, the studies reviewed by Ramos et al.[98] noted that the risk of infection was influenced by the initial concentration of the pathogen in the raw material, particularly for raw milk cheeses. The studies also revealed that the storage condition of cheese also influences the risk of consuming contaminated cheeses.[98]

Microbial risk assessment has also been applied as a microbial source tracking tool in the dairy industry. Vissers et al.[99] applied QMRA to the microbial contamination of farm tank milk related to the amount of dirt transmitted to milk via the exterior of teats using spores of mesophilic aerobic bacteria as a marker for transmitted dirt. The authors found that silage was the main source of butyric acid bacteria and *Clostridium spp.* spores in milk.

30.6.2 HACCP −based food safety systems

The establishment of a HACCP system in the dairy industry is the first step towards managing the safety of milk and dairy products. HACCP and its evolution to preventive controls have been hailed as promoting a risk-based approach to food safety. Although not common, the application of HACCP programmes on dairy farms has improved the quality and safety of milk intended for processing for those dairy farms that have adopted the system.[100] On-farm HACCP does not only cover milk safety but has components that improve the welfare of dairy animals and environmental protection as demanded by consumers and retailers. On-farm HACCP is linked to both operational management and food chain quality assurance. Given that dairy animals are one of the main reservoirs of pathogenic microorganisms, the presence of pathogens in milk is because of direct contact with the contamination sources which include the infected udder and fecal contamination. On-farm HACCP systems apply cost-effective, accurate, and reproducible practices to monitor certain points which are contamination routes. However, this system is less effective for small-holder dairy farmers due to the high costs associated with testing methodologies. Other approaches to managing animal health problems and addressing pathogens have been developed specifically for the dairy industry. A joint guidance on Good Dairy Farming Practices (GDFP) was prepared and published by the International Dairy Federation (IDF) and the Food and Agriculture Organization (FAO) in an effort to improve the safety of milk at dairy farms.[100] Good agricultural practices are still applied at dairy farms. However, for the practices to be effective, they should focus on the areas such as animal health, milking hygiene, animal feeding and water safety, animal welfare, and the environment.[100]

In dairy processing, the implementation of HACCP has been primarily reported as an effective approach to improve the safety of dairy products. For effective management of safety in the dairy industry at the processing level, GHP, HACCP-based systems, and other risk management metrics should be applied. An effective HACCP-based programme requires the appropriate expertise.

Dairy manufacturers must understand and be able to document their production practices and demonstrate their understanding of the various biological and other classes of hazards that could be introduced and controlled at each step. Dairy products are susceptible to microbial hazards; therefore temperature treatment is very important for rendering the end product safe. In the dairy industry, temperature−time combinations during processing are considered a critical control point.

Notwithstanding the effectiveness of HACCP-based programmes in dairy safety, the system has not received widespread adoption except in countries where it is mandatory.[47,48] In some countries where such systems are not mandatory, industries implement the HACCP-based FSMS as a response to consumer demand. The process requires a critical multidisciplinary review of existing management systems, the establishment of limits via the identification of critical control points, the use of routine surveillance procedures, effective record keeping, and documentation of standard processes. Because of these confines, several dairy farmers and processors in the developing world have favored alternative approaches such as hurdle technology.[46]

30.7 Gaps and future directions

The dairy industry is diverse and complex. Factors affecting microbiological quality and safety of milk and milk products involve everything from production (farming), processing, distribution, trade (including multinational companies), and strict regulation. Like any other food industry, the dairy sector is battling to adjust and manage the rising global milk consumption as a result of population growth and changing socio-economic dynamics which demand diverse, convenient, safe, and high-quality milk and milk products. On the other hand, food regulations are evolving to meet quality and safety requirements. In view of this, the industry has invested in novel production and processing technologies in order to meet some of the consumer demands as well as changing food regulations. As much as the adoption of novel technologies is showing improvement in quality and the convenience and availability of dairy products, there are safety concerns that still need to be taken into consideration. More research needs to be conducted that provides information concerning source tracking of spoilage and pathogenic organisms at farms and in dairy processing environments. This also includes improvements in dairy farm management and cleaning regimes in processing environments. New technologies such as whole-genome sequencing can assist the dairy industry in surveillance and microbiological source tracking of contaminants.

Many regulatory authorities in developing countries are adopting and implementing a risk-based preventative approach to improve food safety. However, in yet other developing countries where the food supply chain is an interconnection between the formal and informal sector and is predominated by the informal sector, this approach is still in its infancy. Research is still required in order to understand the complexities of the informal sector in order to apply practical risk-based food safety measures that are appropriate for this sector. This includes source tracking of microbial contamination in milk which is produced and supplied in the informal sector. More data are required related to the informal dairy sector so that a HACCP system can be developed that is appropriate in order to improve the safety of milk and milk products in this vast and important sector.

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