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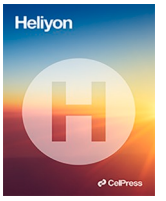

Review article

Review on quality attributes of milk and commonly produced dairy products in Ethiopia

Kedir Awol Assen [a,*], Mohammed Assen Abegaz [b]

[a] Animal Science Department, College of Agriculture and Natural Resources, Raya University, Maichew, P O Box: 92, Ethiopia
[b] Afar Pastoral and Agro-Pastoral Research Institute, Dalifage Research Center, Dalifage, Ethiopia

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ABSTRACT

Raw milk and processed dairy products are among the primary important sources of nutrients and have significant roles in the world's dietary practices. However, the safety and quality of both milk and dairy products are critical issues that should be given more attention, especially from the nutritional and health perspectives. Comprehensive evidence on milk and commonly produced dairy products general quality characteristics in Ethiopia is limited. So, this review was meant to present an overview of the most vital quality measures for milk and dairy products. Previous research revealed that the microbiological characteristics of milk and milk products in different parts of Ethiopia are below accepted standards with high counts of microbial load. The physical quality indicators also did not meet the acceptable standards. Studies supported that the production and handling of milk and various dairy products take place under unsanitary conditions, which in turn attributed to higher microbial counts. This comprehensive review also revealed that the lack of hygienic preparation approaches, uncontrolled fermentation, and the lack of knowledge and awareness of small-holder dairy producers and dairy value chain actors are the main reasons for the inconsistent quality and safety challenges. Thus, designing relevant trainings and the introduction of strategies on hygiene practices are essential to being efficient in reducing the microbiological loads or contamination of raw milk and processed products. Generally, dairy producers must maintain milk quality throughout the whole production process in order to achieve the requisite raw milk input and high-quality processed products.

1. Introduction

For thousands of years, dating back to 4,000 BC, milk and milk products have been recognized as substantial staples in human diets. Both milk and milk products hold crucial positions in global dietary practices [1]. Particularly in low-to-middle-income nations, dairy production serves as a crucial means of income for smallholder dairy farmers [2].

Likewise, in Ethiopia, milk production is one of the livestock production systems that are practiced, and it involves small, medium, or large-scale farms, whether for subsistence or market-oriented purposes [3]. Ethiopia holds large potential for dairy development. Milk is produced and usually supplied to consumers in raw form [4]. In both urban and rural areas, milk is processed using traditional methods. Throughout Ethiopia, various dairy products such as fresh milk, traditional butter, buttermilk, cottage cheese, whey, and ghee were widely consumed [5,6].

* Corresponding author.
E-mail address: kedir.awol44@gmail.com (K.A. Assen).

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A study by Abebe et al. [7] presented that nearby 44.6 % of milk produced was used for domestic processing, and from this, nearly 75 % and 25 % also goes to the manufacturing of butter and the making of Ethiopian cottage cheese/*Ayib*, respectively. About 40 % of the country's total milk production is processed into butter [8]. The advent of modern milk processing techniques, the country has also started producing yogurt, diverse types of cheese, and other products through defined fermentation, heat treatment, and enzymatic use of milk, especially for the domestic market [9]. Although Ethiopia is known with huge dairy potential and diverse dairy products, per capita milk consumption is very low, estimated at about 20 L [10]. This is tremendously less than 200 L of per capita consumption recommended by the World Health Organization, the 62.5 kg recommended by FAO as a minimum level to be kept for a balanced diet, and the world's per capita average of about 100 Liters/year [11]. A recent an umbrella review by Bekele et al. [12] revealed that the recommended amount of milk and dairy foods is 200–300 g per day.

Definitely, milk and dairy products are known as the most cost-effective animal source foods in low-to middle-income countries [2,13,14]. In addition, milk and processed products are crucial in diversifying plant-based diets, promoting child growth, and serving as essential components in therapeutic feeding for undernourished children [15]. From a nutritional perspective, milk is often regarded as the closest to a "perfect food," making it an indispensable part of the daily diet, particularly for expectant mothers and growing children [16]. Milk is biologically complex fluid, and it is the main source of animal-based protein used for enriched nutritional and health benefits in developing countries, predominantly for children [17].

Dairy products high-quality protein content may assist avoid overconsumption due to its satiating effects and can play a substantial role in weight loss as it contributes to muscle protein synthesis and the maintenance of lean body mass during calorie restriction [18]. Fermented dairy products potential benefits for type 2 diabetes may stem from their impact on gut microbiota [19]. Studies directed that dairy products improve bone metabolism, increase bone mineral density, and slow down bone loss [20]. Indeed, in Ethiopia, milk and milk products have additional functions besides their nutritional value. Traditional Ethiopian butter and ghee/*Niter Kibe* are important components of the Ethiopian traditional diet [6]. Butter is also used to treat wounds and apply hair dressings. Ghee/*Niter Kibe* is commonly used for culinary, social and therapeutic purposes [8]. Butter and fresh whole milk are also thought to neutralize toxins. Women apply butter to their heads, and it's believed to have two basic uses: dressing hair and relieving headaches [21].

It is essential to provide children with not only a nutritious but also safe and quality diet to support their growth and development and prevent diseases in adulthood [22]. Despite being incredibly nutritious and a valuable source of essential macro- and micro-nutrients for human health, milk and dairy products pose significant health concerns, particularly for infants and children [23]. The safety and quality of these products remain significant challenges, as highlighted by studies conducted in low-to-middle-income countries, including Ethiopia, where weak food safety management systems and low compliance with safety standards are prevalent [16,24–26].

Since milk and milk products are associated with foodborne illnesses, consumers are concerned about the quality of dairy products and the production condition [4,9]. There is an overbearing for smallholder producers to produce milk that meets food quality and safety criteria to take opportunity of this raising demand for milk and dairy products [27]. Ensuring the quality and safety of milk and processed products requires control of the various stages of the milk processing chain, from milking the cow to consumption [28,29]. There is a necessity for evolving the hygienic status of locally produced milk and processed dairy products through the provision of information to rural producers on good hygiene practices [30–32]. According to Ref. [33], microbiological contaminants are mostly introduced into milk during the milking practices and at subsequent milk processing chains. Farrell [34] also stated that unsanitary practices and insufficient cleaning contribute heavily to contamination during milking. These problems exist in Ethiopia; where there are enormous challenges in acquiring appropriate milk handling equipment and limited access to clean water [4].

Hence, considering the quality and safety of milk and its products are of utmost importance worldwide [2], particularly in developing countries like Ethiopia [31]. In order to ensure the production of high-quality milk products with a suitable shelf life and to provide consumers with safe and wholesome products, it is essential to start with raw milk that meets hygienic standards [35,36]. To effectively address these issues, it is necessary to organize comprehensive and up-to-date information. Therefore, the purpose of this review is to present organized and updated information on the quality characteristics of milk and the most common consumed milk products in Ethiopia. Additionally, the review assessed the major challenges that interrupt safe milk production and processing practices with their respective possible solutions.

2. Methodology

This review article is based on a thorough consideration of published scientific literatures. Scopus, Directory of Open Access, JSTOR, Google Books, Google Scholar, Science Direct, PubMed, and ResearchGate were the main academic databases and information sources used for the writing of this review. Databases were search using the keywords Ethiopia, dairy, milk, major challenges, milk contaminations, quality, and safety. Moreover, the compilation of information was basically relies on the microbiological, chemical composition, and physical characteristics of milk and the most common milk products.

3. Foremost dairy products in Ethiopia

The country is known for its indigenous milk products and the methods used to process them. A diverse range of dairy products are produce during milk processing. In Ethiopia, the most commonly processed and consumed milk products include traditional butter (*Kibe*), naturally fermented milk (*Ergo*), cottage cheese (*Ayib*), spiced cheese (*Meteta Ayib*), *Ititu*, defatted sour milk (*Arerra*), and traditional Ethiopian ghee (*Nitir Kibe*) (Fig. 1) [37,21,6].

Ergo, a traditional Ethiopian fermented milk product bears a striking resemblance to set yoghurt. It boasts a semi-solid, thick

consistency, a smooth and uniform appearance, a white color and a delightful flavor. Interestingly, the fermentation process does not necessitate the addition of any specific starter culture. Instead, natural lactic acid bacteria spontaneously ferment the milk using traditional utensils in a non-hygienic environment. The raw milk is either left at the room temperature or placed in a warm location to ferment before further processing. The temperature and duration of incubation vary depending on the prevailing environmental condition in different regions [41].

Itittu, traditional concentrated fermented milk, is produced by Borana pastoralists in the southern region of Ethiopia [42].

Ayib, also known as cottage cheese, is made by heating buttermilk in either an iron or clay pot until it forms a curd mass. The curd is then cooled to allow it to coagulate. Afterward, the curd is separated from the whey using a fine mesh cloth or sieve [4].

Butter, known as *Kibe*, is produced through the process of churning ergo, which is sour milk that has been accumulated over a period of several days. Once a sufficient quantity of milk has been gathered, it is then transferred into a churn that is typically made from a clay pot and made of gourd. In Ethiopia, butter holds a significant position as one of the primary dairy products available on the market. It possesses a high nutritional value and is exclusively derived from cow's milk [7]. Apart from its dietary benefits, butter also serves other purposes. Women utilize it as hair oil, believed to have dual functions of hairdressing and alleviating headaches [21].

Nitir Kibe, also known as ghee, is a type of clarified butter that is commonly used in Ethiopian cooking. It is a key ingredient in various traditional dishes, including *Kitifo*, which is made from minced beef and served either raw or partially cooked. Additionally, ghee is often incorporated into sauces made from cereals, pulses, and meat. In Ethiopian culture, it is customary to serve ghee with coffee and tea, mostly when hosting esteemed guests and celebrating holidays [43].

Arrera, which is a by-product of butter making, is utilized for the production of *Ayib*. It possesses an analogous color to *Ergo*, but its texture is somewhat smoother and its consistency is thinner, even though thicker than that of fresh milk. Additionally, it boasts a delightful aroma and taste. *Arrera* is widely consumed throughout the entire country [5].

Metata Ayib, a type of traditional fermented cottage cheese, is crafted in the northwest region of Ethiopia. The production process of this cheese entails the incorporation of various spices and allowing it to undergo spontaneous fermentation for a duration of 15 days [44].

Fig. 1. The major well-known milk products in Ethiopia [25,38–40,6].

3.1. Quality attribute measures of milk and dairy products

The overall quality of food, including milk and milk products, is closely tied to various factors such as its physical, chemical, microbiological, sensory, organoleptic, physical characteristics (Fig. 2). It is fundamental to conduct physicochemical and microbiological studies, as they serve as valuable tools for monitoring and assessing their quality [45–47]. Milk quality assessments are intended to confirm that the processed products fit the accepted standards for nutritional composition, cleanliness, and, and levels of a variety of microorganisms [48].

3.1.1. Microbial quality

The quality of milk and milk products is primarily determined by their microbiological quality [49]. The sources of microbial contamination in raw milk can be categorized into three main groups: the environment, the udder, and the milking equipment. Pathogenic organisms such as coliform counts, Staphylococcus, Mycobacterium, Brucella, Escherichia, Corynebacterium, and others, which are known to cause diseases in animals and humans, can also be present in milk [36,50,51]. The microbial content of milk reflects the hygiene levels during milking, including the cleanliness utensils, proper storage and transportation, as well as the health of the cow's udder [27]. The most frequently used tests to assess the microbial quality of milk and processed dairy products are the total bacterial count or standard plate count, the coliform count, and the yeast and mold count. The standard plate count is particularly widely used. Additionally, the estimation of yeast and mold counts is valuable in evaluating sanitary practices [52].

Assembly of data was made on the bacteriological characteristics of milk and milk products that have been studied yet in Ethiopia (Table 1). Some research findings suggest microbial quality of raw milk from dairy farms is generally in line with accepted standards. However, milk samples and processed products collected from various regions of Ethiopia often fall below the standards and are measured substandard. This also poses a possible consumers health risk [30]. Studies conducted by Haile et al. [53] and Zelalem [4] indicated that the cleanliness of milker, the udder, the milking surroundings, and the materials used in traditional milking practices can be the primary sources of milk contamination.

The total viable count serves as a reliable indicator of milk handling practices, spanning from the milking process to consumption. It is synonymous with the total aerobic mesophilic bacterial count or total viable count. Previous research conducted in Ethiopia has demonstrated that the microbial count in milk often exceeds the tolerable limits of 5 cfu/ml. For instance, various regions across the country have reported average total counts ranging from 6 to 9.28 log cfu/ml for raw milk. Notably, Zelalem [4], Bruktawit [58], and Debela [59] have reported higher total bacterial counts of 9.10 log cfu/ml, 8.6 log cfu/ml, and 8.149 log cfu/ml, respectively.

Total coliform bacteria found in milk and dairy products are often an indication of fecal contamination. The presence of a significant number of coliforms not only suggests poor sanitary conditions during milk production but also raises concerns about the potential presence of pathogenic coliforms that can pose a serious health risk to consumers. The coliform counts varied among the samples, as highlighted in a study conducted by Bruktawit [58], where a coliform count of 6.15 log cfu/ml was observed in raw milk. Similarly, Zelalem and Faye [63] conveyed a coliform count of 6.57 log cfu/ml in raw milk. On the other hand, studies by Deginet [54] and Eshetu et al. [55] reported relatively lower coliform counts (4.49 log 10 cfu/ml) and (4.96 log 10 cfu/ml), respectively. However, it is important to note that the coliform counts recorded (Table 1) exceed the acceptable levels set by the East African Standards (EAS 67: [68]) (4.7 log 10 cfu/ml) and the European Union Standards (2.0 log 10 cfu/ml).

Yeast and mold can be present in a food product due to insufficiently sanitized equipment or as contaminants in the air. The occurrence of yeast and mold in food, such as milk, is a significant factor in spoilage and reduced shelf life. Various types of fungi can be found in soil, barn dust, animal feed, dung, and unclean utensils. These fungi have the ability to produce toxic substances, withstand freezing conditions, and cause unpleasant odors and flavors in food. This can lead to spoilage and a decrease in the shelf life of milk, as well as potential health risks for consumers due to mycotoxins, which are secondary metabolites produced by fungi. Molds, in particular, are capable of producing mycotoxins that can cause food poisoning in humans. Studies have reported high yeast and mold counts in raw cow's milk, ranging from 4.363 log cfu/ml to 5.06 log cfu/ml [59,55,64,69–72].

According to the Quality and Standard Authority of Ethiopia [68], the acceptable bacteriological levels for raw cow milk are less than 2×10^5 and 2×10^5-$1x10^6$ cfu/ml for very good and good quality, respectively. However, studies conducted by various researchers indicate that the quality of Ethiopian milk falls below the established standards, with a high presence of microorganisms. This can be attributed to unsafe handling practices, leading to an increased bacterial count, which ultimately results in milk spoilage and reduced yields of dairy products [73]. Moreover, the elevated yeast and mold content in raw milk adversely affects the flavor and physicochemical properties of dairy products [74].

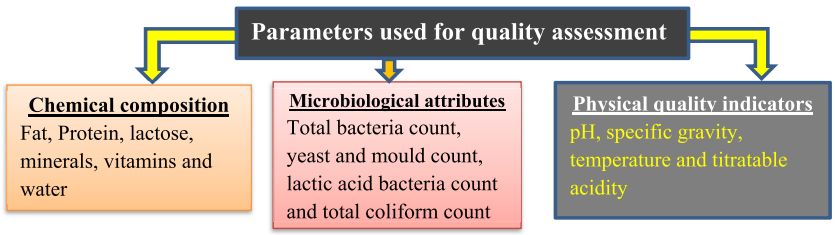

Fig. 2. Layout for the parameters used to measure the quality of milk and milk products.

Table 1
Microbiological profiles of milk and dairy products.

Milk/milk products type	Obtained results	Ref.
Raw milk	The total bacterial counts and coliform counts were 5.675 and 4.41 log10 cfu/ml, respectively.	[29]
	The milk produced exhibited a total bacterial count of 7.58 ± 0.09 log 10 cfu/ml, while the coliform count was 4.49 ± 0.11 log 10 cfu/ml.	[54]
	The total viable count, coliform, and yeast and mold counts were recorded as 5.48, 4.96, and 4.90 log cfu/ml, respectively.	[55]
	The total bacterial count, coliform count, yeast, and mold counts were recorded as 8.13, 5.99, and 7.24 cfu/ml, respectively.	[56]
	The total counts of bacteria, coliforms, and entrobacteria were 7.6, 3.6, and 3.2 cfu/ml, respectively.	[57]
	The counts of aerobic mesophilic, coliform, Staphylococcus bacteria, and lactic acid bacteria were recorded as 6.85, 6.14, 6.13, and 7.19 log cfu/ml, respectively.	[24]
	A total bacteria count of 8.6 log10 cfu/ml, a coliform count of 6.15 log10 cfu/ml, and a somatic cell count of 198 cell/ml were recorded.	[58]
	The total bacterial land coliform counts were recorded as 7.58 ± 0.09 and 4.45 cfu/ml, respectively.	[33]
	The total counts of bacteria, coliforms, spore-forming bacteria, yeast, and mold were 8.149, 6.323, 5.297, and 4.363 log 10 cfu/ml, respectively.	[59]
	The log 10 cfu/ml values for the total viable count, coliform count, spore-forming bacteria count, and yeast and mold count 7.13, 4.99, 4.70, and 4.21, respectively.	[60]
	The log cfu/ml counts for total bacteria, coliforms, yeast, and molds were 6.88, 5.57, and 0.46, respectively.	[61]
	The log cfu/ml for total bacterial count was 9.10, while for Enterobacteriaceae and coliform count; it was 5.49 and 4.58, respectively.	[4]
	The total bacterial and coliform counts were 7.51 and 4.03 log cfu/ml respectively.	[62]
	The counts of aerobic mesophilic, coliform, and lactic acid bacteria were 8.38, 6.57, and 7.68 cfu/ml, respectively.	[63]
	The raw milk exhibited aerobic mesophilic bacteria, coliforms, lactic acid bacteria, and yeast and mold counts of 6.8, 3.5, 2.9, and 5.06 log cfu/ml, respectively.	[64]
Ergo	The aerobic mesophilic count was 5.3 log cfu/ml, while the coliform count was 2.5 log cfu/ml	[64]
	The counts of aerobic mesophilic bacteria, coliform bacteria, Staphylococcus bacteria, and lactic acid bacteria were 6.79, 5.6, 5.55, and 6.13 log cfu/ml, respectively.	[24]
	The mean aerobic mesophilic, coliform, and lactic acid bacteria counts were 8.11, 4.82, and 6.7 log cfu/ml, respectively.	[63]
	The log cfu/ml counts for total bacteria, Enterobacteriaceae, coliform, yeast, and mold were 9.49, 4.95, 4.51, and 8.38, respectively.	[4]
Butter	The log cfu/g counts for total bacterial, Enterobacteriaceae, coliform, yeast, and mold were 6.67, 4.95, 4.58, and 8.32, respectively.	[4]
	The counts of aerobic mesophilic bacteria, coliforms, yeast, and molds, as well as lipolytic bacteria, were recorded as 6.23, 2.5, 4.6, and 3.98 log cfu/mL, respectively.	[64]
	The butter samples collected from the Selale and Sululta areas exhibited an average total bacterial count of 6.18 cfu/g and 7.25 cfu/g, respectively.	[3]
	The aerobic mesophilic bacteria count was 8.71 log cfu/gram, while the total bacterial count is 9.58 log cfu/g, the total coliform count is 5.62 log cfu/g and the yeast and mold count is 6.7 cfu/g.	[59]
	The butter sample exhibits yeast and mold counts ranging from 4.3 to 6.86 log cfu/g	[65]
	The reported yeast and mold count of butter was 7.65 log cfu/g.	[66]
Arerra (Defatted sour milk)	The counts of total bacteria, Enterobacteriaceae, and coliforms were 9.0, 4.7, and 4.2 log cfu/ml, respectively.	[3]
	The *Arerra* sample exhibited a total bacterial count of 9 log cfu/ml and a coliform count of 4.86 log cfu/ml.	[62]
Cottage cheese/*Ayib*	The Ayib had an average yeast and mold count of 6.35 log cfu/g.	[67]
	The log cfu/g counts for total bacterial, Enterobacteriaceae, coliform, yeast, and mold were 7.01, 4.84, 4.42, and 8.26, respectively.	[4]
Metata Ayib	The Metata Ayib sample exhibited a total viable bacteria count ranging from 5.4 to 7.8 log cfu/g.	[44]

The total bacterial count for *Ergo* ranged from 6.79 cfu/ml [24] to 9.49 cfu/ml [4]. Similarly, higher counts of coliform from Ergo samples were reported at 5.6 cfu/ml and 4.82 cfu/ml by Yigrem and Welearegay [24] and Zelalem and Faye [63], respectively. However, relatively lower aerobic mesophilic (5.3 log cfu/ml) and coliform counts (2.5 log cfu/ml) were reported by Abebe et al. [64]. (2018). A higher yeast and mold count was reported by Zelalem [4] at 8.38 log cfu/ml. These counts are much higher than the acceptable value (<10 cfu/g for yoghurt) [75].

With regard to the total bacterial computations of traditionally produced Ethiopian butter (*Kibe*), the counts ranged from 6.18 cfu/g to 7.25 cfu/g. Several studies have consistently shown that these counts exceed the acceptable limit of 5×10^4 cfu/g [75]. In terms of coliform counts, butter samples from different studies exhibited values ranging from 2.5 to 5.62 log cfu/g, which is also higher than the acceptable limit of 2 log cfu/g. Additionally, yeast and mold counts in butter ranged between 4.3 and 8.32 log cfu/g. Research conducted in different regions of Ethiopia also revealed elevated coliform counts in cottage cheese or *Ayib* samples, surpassing the acceptable level of <10 cfu/g [75]. These findings indicate poor hygienic practices during processing and handling. The presence of high microbial counts and potential pathogens can compromise the quality and safety of raw milk and its derived products [64].

The significant inconsistencies observed among studies might be due to a greater range of differences in handling and hygienic conditions, processing techniques, and farm management practices. Consequently, it is decisive to pay close attention to the raw material (milk) used for producing products such as *Ergo*, cottage cheese, and butter, as well as the equipment utilized for processing and storage. Additionally, maintaining personnel hygiene throughout the entire production, consumption, and process is of utmost importance.

3.1.2. Nutritive compositions

According to Ref. [76], milk and dairy products play a significant role in fulfilling nutritional needs. It is crucial to assess their nutritional value and consumer acceptance. The composition and production of milk are influenced by various factors, both internal (within the cow) and external (environmental). The chemical composition of milk and products holds great importance in terms of nutrition [77] and also has a direct impact on the economic value of milk, which is closely linked to its solid content [52].

The higher the solids content, the better its nutritional value and the more of milk products can be made out of it. For example, cheese yields are directly related to the protein content of milk. Nutritional composition of milk and major milk commodity so far done in Ethiopia is presented (Table 2).

Total solid contents of milk ranged (8.59 %) Teshome et al. [83] to (15.47 ± 0.29 %) Debela [59]. The lower average total solid contents of milk from different investigations might be due to the practice of adulteration and fat reduction before taking milk to collection points. The European Union recommends that total solids in cow milk shouldn't be much less than 12.5 %. Except for a few results, most of the milk samples proved to be of an acceptable standard when investigated in Ethiopia.

Fat plays a crucial role in determining the quality of milk, as it provides essential nutrients and energy. According to Debela [59], the fat content of milk was 6.01 ± 0.09 %, while Dessalegn et al. [79] reported a lower content of 3.60 %. These nutritional values are consistently higher than the Ethiopian standard of 3.50 %, as well as the recommended milk fat content of not less than 3.25 % by the Food and Drug Administration (FDA) and the Milk Ordinance and Code of the USA [55]. Table 2 shows that, except for the protein percentages reported by Belay and Janssens [84] at 2.96 % and Hirpha et al. [82] at 3.07 %, all other results indicated higher protein contents than the Ethiopian standard of 3.20 %.

Lactose, also called milk sugar, is the primary carbohydrate found in milk and plays a decisive role in determining its chemical quality. The lactose content in milk varies across different regions of Ethiopia, ranging from 3.79 % according to Hawaz et al. [81] to 5.47 % as reported by Hirpha et al. [82]. The European Union has established a standard for lactose content in unprocessed whole milk, which is set at 4.2 %. Consequently, the majority of milk samples in Ethiopia meet the recommended lactose percentages. In terms of ash content, Debela [59], Legesse [80], Teshome et al. [83], and Hawaz et al. [81] reported higher levels of 0.80 ± 0.015, 0.7 ± 0.07, 0.74 ± 0.00, and 0.68 ± 0.16, respectively.

The variation in chemical compositions observed in various studies could potentially be linked to disparities in feed supply, animal health, and farm management practices. Additionally, the chemical composition of milk is subject to influence from a range of daily factors, including the animal's age, lactation stage, reproductive cycle, time of year, ambient temperature, diet, health condition, and

Table 2
Nutritional composition of milk and dairy products.

Milk/milk product type	Obtained results	Ref.
Raw milk	The percentages of fat, protein, total solids, and lactose were 4.50 %, 3.24 %, 12.78 %, and 4.27 %, respectively.	[55]
Raw milk	The contents of fat, protein, total solid, lactose, and ash were 4.53 %, 3.52 %, 12.97 %, 4.36 %, and 0.64 %, respectively.	[57]
Raw milk	The protein, fat, total solids, and SNF contents were 3.42, 3.86, 12.56, and 8.75, respectively.	[78]
Raw milk	The milk samples had the following composition: total solids 15.47 ± 0.29 %, fat 6.01 ± 0.09 %, solids-not-fat 9.47 ± 0.17 %, protein 3.94 ± 0.07 %, ash 0.80 ± 0.015 %, and lactose 4.35 ± 0.165 %.	[59]
Raw milk	The contents of total solids, fat, SNF, protein, ash, and lactose were 12.87 %, 4.28 %, 8.59 %, 3.43 %, 0.74 %, and 4.43 %, respectively.	[60]
Raw milk	The contents of fat, protein, SNF, total solids, lactose, and ash were 3.60 %, 7.78 %, 11.38 %, 3.93 %, and 0.62 %, respectively.	[79]
Raw milk	A yield of 14.6 % total solids, 0.75 % ash, 3.54 % protein, and 5.54 % fat was acquired.	[80]
Raw milk	The contents of ash, protein, fat, total solids, SNF, and lactose were 0.68 %, 3.51 %, 5.12 %, 13.10 %, 7.98 %, and 3.79 %, respectively.	[81]
Raw milk	The contents of total solids, fat, SNF, protein, ash, and lactose were 14.71 %, 5.46 %, 9.26 %, 3.07 %, 0.72 %, and 5.47 %, respectively.	[82]
Raw milk	The respective contents of total solids, fat, protein, ash, and lactose were 8.59, 4.28, 3.43, 0.74, and 4.43.	[83]
Raw milk	The average contents of fat, protein, lactose, and SNF were 4.38, 2.96, 4.34, and 7.79, respectively.	[84]
Raw milk	Cows' milk contained 4.7 % fat, 3.25 % protein, 13.47 % total solids, 0.73 % ash, and 8.78 % SNF.	[54]
Butter	15.05:82.62:2.09 %,14.26:83.44:2.77 %,14.25:83.30:1.03 %, 14.58:83.82: 3.58 %, and 12.52:83.96:2.82 % were recorded for moisture, fat, and fatty acid contents in samples obtained from farmers, traders, investigators, Tarmaber, and Addis Ababa, respectively.	[35]
Butter	The average contents of ash, fat, protein, lactose, and SNF were 0.10 %, 82.73 %, 2.32 %, 1.18 %, and 4.45 %, respectively. In the Ejere district, the contents of ash, fat, protein, lactose, and SNF were 0.13 %, 84.71 %, 1.87 %, 0.86 %, and 2.19 %, respectively.	[85]
Butter	The composition of traditionally made butter typically consists of about 81.7 % fat, 1.1 % protein, and 0.23 % ash.	[86]
Butter	The butter's moisture content ranges from 20 to 43 %, with total solids comprising 84.82–86.86 %, fat accounting for 80.53–82.53 %, and ash making up 0.12–0.2 %.	[87]
Cottage cheese/*Ayib*	*Ayib* is composed of 76 % moisture, 14 % protein, 7 % fat and 2 % ash.	[88]
Ititu	The fat content of *Ititu* ranges from 3.3 % to 3.7 %, while the protein content ranges from 3.3 % to 3.6 %. Additionally, the lactose content of *Ititu* falls between 3.3 % and 3.5 %.	[89]
Metata *Ayib*	The obtained results were as follows: moisture content was 42.3 %, fat content was 28.7 %, protein content was 43 %, and ash content was 3.2 %.	[44]
Arerra (defatted sour milk)	The obtained results were as follows: 91.5 % moisture content, 3.1 % protein content, 1.4 % fat content, 3.4 % carbohydrate content, and 0.6 % ash content.	[90]
Arerra (defatted sour milk)	Arerra is composed of 91.5 % moisture, 3.1 % protein, 1.4 % fat, 3.4 % carbohydrate, and 0.6 % ash.	[91]

gestation period [92].

3.1.3. Physical quality indicators

It is a common practice in literature to focus on the chemical composition and microbiological properties when defining the quality of milk and milk products. However, it is important to also consider the physical quality indicators, including lactic acid percentage, pH levels, and sensory properties, in the evaluation of quality. The normal pH range for cow's milk is from 6.2 to 6.6, with an average of 6.5, which is the optimal pH for growth [9]. When the pH of milk drops below 6.7, it indicates bacterial degradation, which typically leads to deterioration. This acidic pH results in the formation of "sour milk," characterized by coagulation or curdling, along with its distinct odor and taste [74].

Milk with high lactic acid percentage suggests that the milk was poorly handled, indicating unsatisfactory hygienic conditions during production and handling. The acidity level of milk provides a general idea of its age and how it was treated. Cow milk is considered normal if it has an apparent acidity of between 0.14 and 0.16 % as lactic acid [93]. Additionally, determining the milk's density is an important method to detect any adulteration [74].

The majority of milk samples examined in Ethiopia displayed pH levels below the minimum range of 6.6–6.8, indicating a higher occurrence of bacterial growth and multiplication (Table 3). In the Yabello District, collected samples exhibited a similar pH value of 6.39 + 0.035 [94]. Slightly higher pH levels (6.47) were in samples assessed from three districts within the Bench-Maji Zone of southern Ethiopia [95]. Similarly, milk samples analyzed from various agro-ecologies exhibited a comparable mean pH value of 6.47 ± 0.42 [56].

The pH values of the milk shown from the studies were found to be outside the recommended range for fresh cow's milk. This could be attributed to inadequate hygiene practices, mastitis, contamination during the milking process, and additional contamination during transportation and storage without proper cooling facilities. Furthermore, the economic motive of adding water and removing fat may have contributed to the deviation in pH values [97].

3.2. Possible solutions to improve the quality of milk and dairy products

Microbiological tests (such as coliform count, total bacteria count, and yeast and mold counts) are used to indicate the hygienic condition of milk production. A coliform count less than one hundred cfu/ml is considered satisfactory for milk intended to be pasteurized before consumption. Counts of 10 cfu/ml or less are achievable and suitable if raw milk will be consumed directly [3]. The total bacterial count on average, aseptically drawn milk from a healthy udder contains between 500 and 1000 bacteria per ml. High preliminary counts ($>10^5$ bacteria per ml) are signal of poor production hygiene [93]. Unfortunately, the microbiological characteristics of milk and dairy products produced and sold in different parts of Ethiopia are also generally below standards [4].

There are multiple factors that can be attributed to the deterioration of milk and processed milk products. These aforementioned limitations have been identified through the compilation of previous research findings (Table 4). The consumption of contaminated milk and dairy products not only poses risks to individual's health and overall well-being but also has detrimental effects on livelihoods and economies. It is imperative for milk producers to guarantee the production of milk that is free from harmful microbial loads, chemical contaminants, antimicrobial residues, residues of veterinary drugs, and improper milk handling practices like adulteration.

The primary hindrance to the production of milk and dairy products that are suitable for consumption is the presence of elevated levels of microorganisms. This issue arises due to inadequate hygienic and sanitation practices, as highlighted by Diriba et al. [98], and a lack of awareness regarding microbiological quality, as emphasized by Babege et al. [29]. These factors significantly contribute to the subpar quality of the products. Similarly, mastitis and udder infections occur when bacteria invade the udder and proliferate within the

Table 3
Physical quality indicators of raw milk and dairy products.

Milk/milk product	Obtained results	Ref.
Raw milk	The mean temperature, pH, specific gravity, and titratable acidity of milk were recorded as 24.07 °C, 6.32, 1.03, and 0.20, respectively.	[55]
Raw milk	The specific gravity of raw milk samples obtained from urban dairy farms ranged from 1.023 to 1.030, with an average of 1.027 ± 0.00.	[84]
Raw milk	The pH value from the current finding was 5.963.	[29]
Raw milk	The pH values of whole milk varied between 6.29 and 6.66 while the mean specific gravity was 1.028 and 1.020 from Holetta and Selale study areas, respectively.	[4]
Raw milk	The average values for temperature, pH, specific gravity, and titratable acidity were recorded as 25.93 ± 0.210C, 6.39 ± 0.035, 1.022 ± 0.00, and 0.197 ± 0.004 %, respectively.	[59]
Raw milk	The average values for temperature, pH, specific gravity, and titratable acidity of milk were recorded as 22.83, 6.32, 1.030, and 0.194, respectively.	[60]
Raw milk	The average pH value of raw milk was 6.49.	[24]
Raw milk	Percent lactic acid was 0.23 % ± 0.01.	[54]
Raw milk	The milk obtained from Sebeta region displayed mean pH of 6.28 and a freezing point of −0.619 °C. Conversely, the milk sourced from Bishoftu area exhibited a pH of 6.49 and a freezing point of −0.486 °C.	[96]
Ergo	The average pH value was 4.18.	[24]
Butter	The butter samples from Dire Enchini had an average moisture content of 12.82 %, a melting point range of 34.5–35.40 °C, and a titratable acidity (butyric acid) of 0.28 %. On the other hand, the butter sample from Ejere had an average moisture content of 11.77 %, a melting point range of 35.0–35.70 °C, and a titratable acidity of 0.23 %.	[85]
Meteta Ayib	The samples exhibited mean titratable acidity of 0.43 ± 0.07 % lactic acid and a pH value of 4.0 ± 0.1.	[44]

Table 4
Possible alternative solutions to improve the quality of milk and dairy products.

Constraints category	Reasons	Ref.	Solutions	Ref.
High microbial loads	Poor hygienic and sanitation practices	[98,99, 34]	Promote hygienic practices through training and education	[25,35, 64]
	Lack of Awareness on Microbiological quality	[4,29, 100]	Raising awareness among milk producers and the public about hygienic milk production and processing of milk	[101, 102,6]
	In dairy cows, mastitis is caused by bacteria entering the udder and multiplying in the milk-producing tissues.	[103, 104]	Timely vaccination and maintain udder sanitation	[105]
Highly fluctuated in chemical compositions	Lack of balanced Feed and nutrition	[106]	Enhance the quality of available feed resources	[107]
Unacceptable deviations in physical parameters	Intentional adulteration practices	[3, **82]**	Regulatory institutions need to be strengthened to play their role in setting standards.	[108,6]

milk producing tissues, leading to reduced milk yield accompanied by a high bacterial load [104]. All of these challenges contributed to higher microbial contaminations of milk and dairy products that increase the risk of foodborne diseases [5].

Milkers should wash their hands thoroughly with soap and water before milking each cow [24,25]. Milking utensils should also be cleaned and sanitized before each use [35,64]. Numerous dairy individuals also hold the belief that all types of milk are the same, but this is not the case. So, providing appropriate and timely training should not be ignored [101,102]. Technical advises and timely training can be done through workshops, demonstrations, and the distribution of materials. Improving both the quality and quantity of accessible feed resources through the provision of well-balanced supplementary diets [107] is of utmost significance. This is because the absence of balanced feed and nutrition [106] contributes to the imbalanced chemical composition of milk and milk products. Intentional adulteration practices are also among the major challenges [4,97] to producing ideal raw milk and qualified products. To address this issue, it is crucial to establish robust regulatory institutions that can effectively set standards [108] and regulate detrimental practices [4].

Generally, to protect public health risks and improve the safety of milk and dairy products, stakeholders within the dairy industry must recognize the significance of creating high-quality products and support the implementation of an integrated chain control system [4,109]. All participants involved in the milk value chain should be properly trained [63] and organized to enhance their understanding of dairy animal management, milk handling, and milk hygiene [102,6]. Policies, institutional frameworks and supports for farmers and other stakeholders in the sector must be effectively targeted to encourage the development of the dairy sector [4,108, 109].

4. Conclusion and implication for future works

Milk samples from different studied regions in Ethiopia were found to be contaminated with different types of bacteria and processed under unhygienic conditions, posing a health risk to consumers. Expressly, the microbiological characteristics of milk and processed dairy products in different regions of Ethiopia are generally substandard. Higher total bacterial counts, the coliform counts, and the yeast and mold counts were reported. The high total bacterial load and the presence of pathogenic bacteria in different parts of the country not only affect raw milk and milk products but definitely pose safety issues for consumers. Moreover, the physical quality indicators also did not meet the acceptable standards. Due to inadequate hygienic procedures, uncontrolled fermentation, and a lack of awareness on the part of small-holder dairy producers, milk and traditionally produced milk products are frequently low in quality and safety.

It is therefore essential to minimize milk contamination on the farm and keep contamination levels as low as possible through good hygiene practices, including proper cleaning and disinfection of milking utensils and prompt cooling of milk. An applicable hygienic practices package should be implemented alongside all the actors in milk production and processing chains. Safety measurements to reduce microbiological contamination should be practiced according to food safety regulations. Enhancement in animal husbandry and farm management should not be ignored to increase the quality and safety of milk and dairy products produced in Ethiopia. Finally, designing friendly training and the introduction of hygiene practices are essential to reducing the microbiological loads or contamination of raw milk and processed dairy products.

CRediT authorship contribution statement

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