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Evaluation of Microbiological Quality and Physicochemical Properties of Raw Cow Milk

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Abstract

Milk is a nutritionally important animal-source food that plays a crucial role in human health, livelihoods, and food security. In Ethiopia, the Yelemat Tirufat initiative has been introduced to improve dairy productivity and milk quality, particularly in emerging urban production systems. However, empirical data on the quality of raw milk produced under this program remain limited. This study aimed to evaluate the physicochemical properties and microbiological quality of raw cow milk produced in Maya City, eastern Ethiopia. A total of 40 raw milk samples were randomly collected from four kebeles Adele, Damota, Xiniqe, and Finqile and analysed using a completely randomised design with triplicate measurements. Physicochemical parameters, including temperature, pH, specific gravity, fat, and protein content, were determined using standard laboratory methods, while microbiological quality was assessed through total bacterial count, total coliform count, and yeast and mould enumeration. Data were analysed using one-way ANOVA at $p < 0.05$. The results showed that milk temperature (19.0–20.3 °C) and pH (6.60–6.73) were within acceptable ranges. Fat (4.16–4.76%) and protein (3.33–3.50%) contents met Ethiopian quality standards, although specific gravity variations suggested compositional differences among kebeles. Microbiological analysis revealed generally low contamination levels, except in Xiniqe, which showed significantly higher bacterial counts. Overall, raw milk produced in Maya City met acceptable quality standards, although targeted hygiene interventions and routine monitoring are recommended to ensure sustained milk safety and public health.

Keywords: Raw Cow Milk, Physicochemical Properties, Microbiological Quality, Yelemat Tirufat Initiative, Urban Dairy Production, Ethiopia

Introduction

Milk is a highly nutritious food that plays a critical role in human diets worldwide, providing essential proteins, fats, vitamins, and minerals necessary for growth and overall health (Giller

et al., 2021). As an animal-based food, milk offers high-quality and bioavailable protein, which is particularly important for reducing undernutrition among children and supporting human development (Krebs et al., 2015). Beyond its protein content, milk supports immune function, bone health, and disease prevention, and supports general wellness throughout adulthood (Turck et al., 2016).

It is also a rich source of minerals such as calcium, potassium, phosphorus, and magnesium, as well as vitamins including D and B12, all of which are essential for maintaining healthy bones, metabolic functions, and effective defences against pathogens (Leblanc et al., 2018; Dixit et al., 2023). Collectively, these nutritional attributes highlight milk's role not only as a staple dietary component but also as a functional food that supports human health and development.

In addition to its nutritional value, milk production is a critical source of livelihood for smallholder farmers in developing countries. It provides a steady source of income, contributes to household food security, and can help alleviate poverty in rural communities where livestock farming is a primary livelihood (Paudel et al., 2017). In regions facing food insecurity, promoting milk production aligns with global health and nutrition objectives, as emphasised by the World Health Organisation and other food security agencies (Cavallo et al., 2020).

Despite these benefits, milk production in Ethiopia has not fully met domestic demand. Ethiopia possesses the largest cattle population in Africa, yet challenges persist in providing sufficient quantity and quality of milk for its population (Tegegne & Feye, 2020). In 2018, approximately 4.4 billion litres of milk were produced in the country, of which only 3.08 billion litres (70%) were available for human consumption (Mustefa, 2023). Per capita milk consumption remains relatively low at less than 66 litres, indicating limited accessibility despite the considerable production potential (Tegegne & Feye, 2020).

Rapid population growth and urbanisation have further increased the demand for dairy products, creating a pressing need for enhanced production systems (Abu et al., 2019). To address this challenge, the Ethiopian government launched the "Yelemat Tirufat" initiative in 2022, led by Prime Minister Abiy Ahmed. This national program seeks to boost productivity and production of dairy, eggs, poultry, honey, and related agricultural products to achieve food self-sufficiency and improve household nutrition. Urban dairy production programs, such as those emerging in Maya City, reflect this strategic effort to meet the growing demand for high-quality dairy products.

Despite its importance, milk quality can be compromised by microbial contamination and inadequate handling during production and transportation (Jaffee et al., 2018). Studies assessing the microbiological and physicochemical properties of raw milk in Ethiopia have focused on regions such as Worabe Town (Musema, 2022), Sibu Sire districts in Eastern Wollega Zone (Adugna & Eshetu, 2021), Borena Zone (Tegegn & Soboka, 2020), and Girar Jarso District (Eshetu et al., 2019).

However, limited research exists on the quality of milk produced in urban centres such as Maya City, particularly under the newly established "Yelemat Tirufat" program. Evaluating milk quality in this context is crucial for safeguarding public health, optimising nutritional benefits, and supporting sustainable urban dairy production. The primary objective of this study, therefore, was to assess the microbiological quality and physicochemical properties of raw milk collected from four kebeles in Maya City.

Specifically, the study aimed to determine microbial load and safety, analyse physicochemical characteristics such as fat, protein, and mineral content, and identify factors affecting milk quality in the urban production setting. By generating empirical evidence on the quality of raw milk, this research provides a foundation for interventions that enhance food safety, improve nutritional outcomes, and support the sustainable growth of urban dairy production under Ethiopia's national "Yelemat Tirufat" initiative.

Methods

Study Area Description

The study was conducted in four purposively selected kebeles (villages) within Maya City, a sub-city of Haramaya Town in eastern Ethiopia, where organised dairy production has recently been introduced under a national milk production initiative (Figure 1). The kebeles were selected based on their active participation in the milk production program, presence of smallholder dairy farms, and accessibility for sample collection. Maya City is one of the rapidly emerging urban centres in the region, characterised by increasing population density and growing demand for animal-source foods, particularly milk and dairy products. Geographically, the study area is located at approximately 9°22′ N latitude and 42°10′ E longitude, at an elevation of about 1,980 meters above sea level, and lies roughly 515 km east of Addis Ababa, the capital city of Ethiopia. The elevation and agro-climatic conditions of the area are generally favourable for dairy production, supporting mixed crop–livestock systems that rely on both natural pasture and crop residues for feed. The urban and peri-urban setting of Maya City provides proximity to markets, veterinary services, and extension support, which can influence milk handling practices, hygiene standards, and overall milk quality. The selection of Maya City as the study site is particularly relevant given its recent integration into policy-driven dairy development efforts. As an emerging production hub, the area offers a unique opportunity to assess the physicochemical and microbiological quality of raw cow milk within a newly established urban dairy system, thereby providing insights into how early-stage production environments and institutional support shape milk quality outcomes.

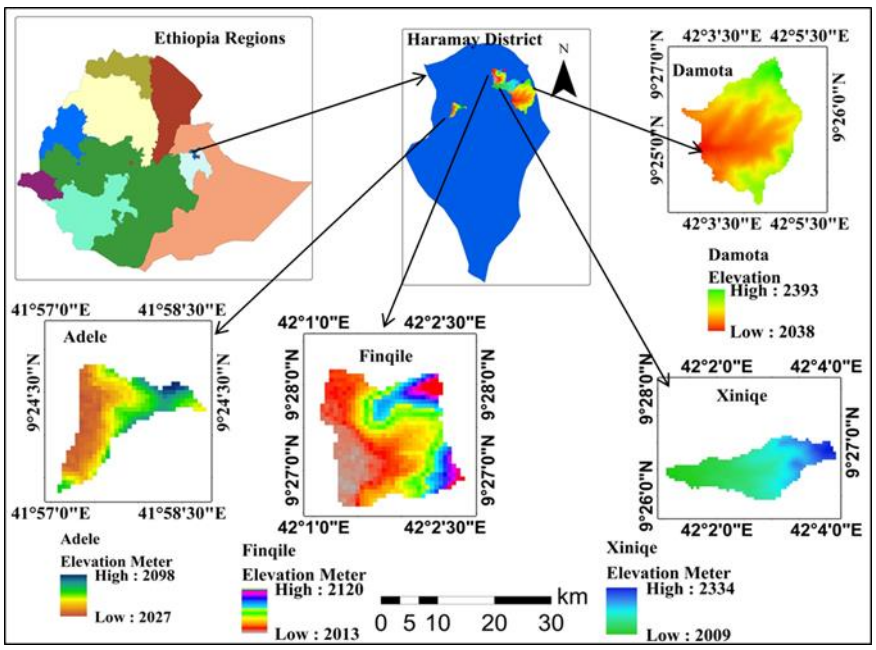

Figure 1. Study the Map Area

The detailed name of the kebele (village) was shown in legend (Papaya whip = Adele, Moccasin = Dmota, Pink = Xiniqe, Purple = Finqile and Blue = Maya (Haramaya sub-city))

Sample Collection

Raw cow milk samples were collected using a simple random sampling design from four kebeles Adele, Damota, Xiniqe, and Finqile with ten samples per kebele, yielding a total of 40 samples. Approximately 200 mL of raw milk was aseptically collected from each selected dairy farm into sterile sampling bottles. Samples were immediately placed in an ice-packed cooler to minimise microbial proliferation, following standard procedures described by Belli. The samples were then transported without delay to the Haramaya University Dairy and Microbiology Laboratory, where they were stored at 4°C until analysis. All physicochemical and microbiological analyses were initiated within 24 hours of collection to preserve sample integrity. Each kebele sample was analysed in triplicate to ensure analytical reliability and reproducibility.

Physicochemical Analysis

Milk samples were analysed for key physicochemical attributes, including temperature, pH, specific gravity, fat content, and protein content. These parameters are widely recognised indicators of milk freshness, compositional quality, microbial stability, and nutritional value, and they collectively influence milk's suitability for human consumption and processing.

Determination of Milk Temperature

Milk temperature was measured in situ at the point of sampling using a calibrated digital thermometer. The thermometer probe was directly immersed in the milk sample, and the temperature was recorded immediately to reflect handling and environmental conditions at the time of collection, following the procedure outlined by Tadesse et al. (2023).

Determination of pH

Milk pH was determined in the laboratory using a digital pH meter calibrated with standard buffer solutions of pH 4.0 and 7.0. After calibration, the electrode was immersed in a beaker containing the milk sample, and the pH reading was recorded once stabilised. The pH meter was recalibrated before and after measurements to ensure accuracy and consistency, as recommended by Amenu.

Determination of Specific Gravity

The specific gravity of milk samples was measured using a lactodensimeter (SIW, Germany) according to standardised procedures (Erdem et al., 2023). Fresh milk samples were poured into a 100 mL glass cylinder, and the lactometer was gently inserted and allowed to float freely until equilibrium was achieved. The lactometer reading was taken at the lower meniscus, after which milk temperature was recorded to allow for appropriate correction of specific gravity values.

The following formula was used to calculate the specific gravity of the milk.

$$Specific\ gravity = \frac{L}{1000} + 1$$

Where:

L = corrected lactometer reading at a given temperature, i.e., for every degree above 6600°F, 0.2 was added to the lactometer reading, but for every degree below 6600°F, 0.2 was subtracted from the lactometer reading.

Fat Content Determination

Milk fat content was determined using the Gerber method, a standard and widely accepted procedure for dairy analysis (Tadesse et al., 2023). Briefly, 10 mL of sulfuric acid, 10.75 mL of raw milk, and 1 mL of iso-amyl alcohol were sequentially added into a butyrometer, which was then securely sealed with a rubber stopper. The mixture was thoroughly homogenised and centrifuged at approximately 1,200 rpm for 5 minutes to facilitate fat separation. Following centrifugation, the fat content was measured directly from the calibrated stem of the butyrometer as a clear, straw-yellow column and recorded as a percentage.

Protein Content Determination

Protein content was determined using the Kjeldahl method in accordance with INS No. 639, employing the formaldehyde titration technique. A 10 mL milk sample was treated with 0.4 mL saturated aqueous potassium oxalate and 0.5 mL of 0.5% phenolphthalein indicator, allowed to stand for two minutes, and titrated with N/9 NaOH until a persistent pink endpoint was achieved. Subsequently, 2 mL of neutral 40% formalin was added to discharge the colour, and titration with N/9 NaOH was continued until the pink endpoint reappeared. The volume of NaOH used after formalin addition was multiplied by 1.74 to calculate the percentage of protein in the milk sample.

Microbiological Quality Analysis

The microbiological quality of raw milk samples was assessed by enumerating key microbial indicators, including total bacteria, coliforms, and yeast and moulds. These analyses were conducted to evaluate hygienic quality, potential contamination, and overall suitability of milk for consumption and processing.

Total Bacterial Count (TBC)

The total bacterial count was determined using the method described by Harrigan & McCance (2014). Milk samples were serially diluted (10^{-2} to 10^{-4}) using sterile peptone water. One millilitre of the appropriate dilution was pour-plated onto Standard Plate Count (SPC) agar (Oxoid) and incubated at 37°C for 24 hours. After incubation, visible colonies were enumerated using a digital colony counter (Azeze & Tera, 2015), and results were expressed as colony-forming units per millilitre (CFU/mL).

Total Coliform Count (TCC)

Total coliform counts were determined according to the Bacteriological Analytical Manual procedure. A 1 mL milk sample was aseptically diluted with 9 mL of 1% peptone water and serially diluted up to 10^{-6}. Duplicate aliquots (1 mL) were pour-plated using 15–20 mL of Violet Red Bile Agar (VRBA) and allowed to solidify before incubation at 30°C for 24 hours. Typical dark red colonies were counted as coliforms using a colony counter, and results were expressed as $\log_{10}$ CFU/mL (Tegegn & Soboka, 2020).

Yeast and Mould Count (YMC)

Yeast and mould counts were determined using serial dilution and surface plating techniques. Milk samples were diluted in sterile peptone water up to 10^{-7}, and 0.1 mL of appropriate

dilutions was spread onto pre-dried Sabouraud Dextrose Agar (SDA) supplemented with streptomycin and chloramphenicol. Plates were incubated at 25°C for 3–5 days. Creamy to white or grey colonies were identified as yeasts, while filamentous colonies of various colours were recorded as moulds. Plates containing 10–150 colonies were used for enumeration (Fereja et al., 2023).

Data Analysis

Microbial counts were converted to $\log_{10}$ values prior to statistical analysis. Both transformed microbiological data and physicochemical parameters were analysed using SPSS version 27. Differences among means were evaluated using one-way analysis of variance (ANOVA) at a 95% confidence level ($p < 0.05$), followed by Tukey's post hoc test for mean separation. All analyses were conducted in triplicate, and results were expressed as mean ± standard deviation (SD).

Result and Discussion

Table 1 presents values as mean ± standard deviation (SD) based on ten samples per kebele (n = 10). The measured parameters include milk temperature (T°C), pH, specific gravity (SG), fat content, and protein content, which collectively provide an integrated assessment of milk quality, freshness, and nutritional composition. Differences among kebeles were evaluated using one-way analysis of variance (ANOVA), and mean separation was performed using Tukey's post hoc test. Within each column, values sharing the same superscript letter are not significantly different, whereas different letters indicate a statistically significant difference at $p < 0.05$. This statistical approach allows for the identification of spatial variations in physicochemical attributes across production sites and facilitates comparison with national and international milk quality standards.

Table 1. Physicochemical Properties of Raw Cow Milk Collected from Four Kebeles in the Study Area

Source of Milk	Physico-chemical properties of Cow milk in the study area (Mean±SE)				
	T^{o}C	pH	SG	Fat	Protein
Adele (n= 10)	19.3±1.15^{a}	6.60±0.05^{a}	1.020±0.10^{a}	4.16±1.03^{a}	3.33±0.15^{a}
Damota(n=10)	19.0±1.00^{a}	6.73±0.11^{ab}	1.030±0.00^{a}	4.69±1.15^{b}	3.43±0.25^{ab}
Xiniqe (n= 10)	20.3±2.08^{ab}	6.71±0.01^{ab}	1.028±0.30^{a}	4.16±1.03^{a}	3.50±0.25^{b}
Finqile (n= 10)	20.0±1.00^{ab}	6.67±0.07^{ab}	1.040±0.20^{a}	4.76±1.03^{b}	3.33±0.15^{a}

N=10 (the number of sample), T^{o}C = (Temperature), pH, SG = (Solid Gravity), Fat, and Protein

The physicochemical characteristics of raw cow milk obtained from the study area are summarised in Table 1. The results indicate relatively low milk temperatures (T°C) and pH values, ranging from 19.0 ± 1.00 to 20.3 ± 2.08 °C and 6.60 ± 0.05 to 6.73 ± 0.11, respectively. These temperature levels are considered unfavourable for rapid bacterial proliferation and suggest that milk handling and collection occurred under relatively controlled conditions (Table 2). Low milk temperature at the point of sampling is a critical factor in slowing microbial metabolism and extending the initial microbiological quality of raw milk, particularly in the absence of advanced cooling infrastructure. The observed temperature and pH values fall within the acceptable limits reported for Ethiopian raw milk standards and are consistent with findings reported by Fereja et al. (2023).

Compared with earlier studies conducted in other regions of Ethiopia, the milk temperatures recorded in the present study were notably lower than those reported by Senbeta & Galmesa (2023), who documented substantially higher temperatures (26.17 ± 1.80 to 30.00 ± 2.78 °C) that are known to favour microbial growth. Elevated milk temperatures have been strongly associated with increased bacterial multiplication during storage and transportation (O'Connell et al., 2016). In contrast, the relatively low temperatures observed in the current study likely contributed to the generally acceptable microbiological quality of milk samples, as reflected in the low bacterial counts reported for most kebeles. Similarly, the pH values observed in this study were within the normal physiological range for fresh cow milk, indicating minimal fermentation and limited microbial activity at the time of sampling.

The specific gravity of the milk samples ranged from 1.020 ± 0.10 to 1.040 ± 0.20. While most samples fell within or close to the normal range for raw cow milk (1.027–1.035), samples from Adele and Finqile deviated from this standard. Such deviations may suggest potential dilution with water, variation in milk composition, or differences in feeding practices and stage of lactation. Specific gravity is a key indicator of milk authenticity and compositional integrity, and deviations warrant closer attention in quality control monitoring.

Significant variation ($P < 0.05$) in milk fat content was observed across the study sites. Milk from Damota and Finqile exhibited higher fat contents (4.69 ± 1.15% and 4.76 ± 1.03%, respectively) compared with samples from Adele and Xiniqe (4.16 ± 1.03%). These differences may be attributed to variations in breed type, feed quality, management practices, and the physiological status of the cows. Fat content is a significant determinant of milk's nutritional and economic value, and the observed levels are comparable to or exceed those reported in several Ethiopian studies.

Protein content ranged from 3.33 ± 0.15 to 3.50 ± 0.25%, aligning closely with Ethiopian standards (ES, 2009) and previous findings by Hawaz. However, these values were slightly lower than those reported in Eastern Hararghe districts, including Babile, Haramaya, Karsa, and Kulubi, where higher protein concentrations have been documented. Such differences may reflect regional variations in feed composition, production systems, and the genetic potential of dairy cows. Overall, the physicochemical quality of milk in the present study indicates satisfactory compositional characteristics, while highlighting localised deviations that require targeted management interventions.

Microbiological Quality of Raw Cow's Milk Samples

Table 2. Microbial Counts (Log10 Cfu/Ml) are Shown as the Mean ± SD. The Letter Compares the Means Across the Row and Indicates a Significant Difference at $P < 0.05$.

Microbial Counts	Adele (n=10)	Damota (n=10)	Xiniqe (n=10)	Finqile (n= 10)
TBC	1.501±0.04[a]	1.499±0.34[a]	2.29±0.34[b]	1.503±0.03[a]
TCC	2.13±0.18[a]	2.27±0.18[a]	2.28±0.18[a]	2.28±0.17[a]
YMC	Nil (0.0)	1.000±0.70[a]	1.00±0.40[a]	2.000±0.60[b]

TBC= Total Bacterial Count, TCC= Total Coliform Count, YMC= Yeast and Mold Count, Nil = zero

Total Bacterial Count

Microbial Quality of Raw Cow Milk based on TBC showed marked similarity among milk samples collected from Adele, Damota, and Finqile. The TBC obtained in Xiniqe was high compared to

the acceptable level of 1 × 10^5 bacteria per ml of raw milk. The finding was significantly different ($P < 0.05$) among milk samples collected from Adele, Damota, Xiniqe, and Finqile (Table 1). The obtained Xiniqe result indicated contamination in the milk. In general, the TBC of milk samples from three study areas showed good results; however, the initial kebele sample could be attributed to improper cleaning of the milking containers before and after milking, as the result indicated milk contamination from the containers or the producers' hands (Figure 2).

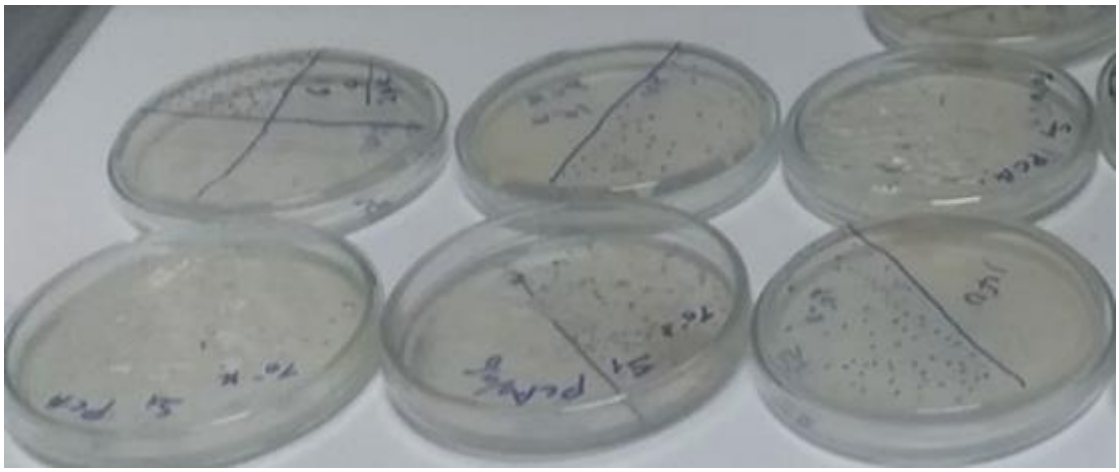

Figure 2. Total Bacterial Counts Colony

Total Coliform Count

The mean of coliform count observed in raw cow's milk samples collected from Damota, Adele, Xiniqe and Finqile were 2.13±0.18, 2.27±0.18, 2.28±0.18 and 2.28±0.17 log10 cfu/ml, respectively (Table .2). The coliform count obtained in the current study was lower than that reported in the district by Eshetu et al. (2019) who found coliform counts of 3.87 ±0.13 and 5.10±0.13 log10cfu/ml. In general, the findings indicated inferior standards from a coliform count perspective according to the East African Standards (EAS 67:2007) (4.7 log10 CFU/mL) (Nyokabi et al., 2023) (Figure 3).

Figure 3. Total Coliform Counts colony

Yeast and Mould Count

The mean of YMC was observed in raw cow's milk samples collected from Damota, Adele, Xiniqe and Finqile. Adele showed Nil (0.0), 1.000±0.70, 1.000±0.40 and 2.000±0.60, respectively. The mean YMC content of milk samples in the present investigation showed a significant difference ($P<0.05$) between the sample from Damota and all three samples (Adele, Xiniqe, and Finqile). The YMC of the Damota samples showed negative results. The results show positive values for three samples: 1.000±0.70, 1.00±0.40, and 2.000±0.60 (Adele, Xiniqe, and Finqile), except for the Damota sample. However, this result shows very low contamination of YMC when compared with the study result reported by hailu YMC were 3.944±0.346 and

3.762±0.468 log10 cfu/ml, respectively. Based on the microbiological quality findings in some kebele samples, the program needs to properly upgrade awareness on milk production processing (material cleaning and milking) (Figure 4).

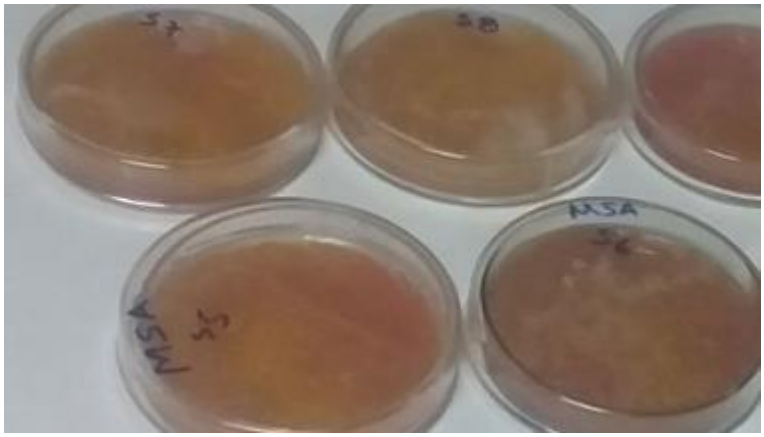

Figure 4. Total Yeast and Mould Counts

Discussion

A growing body of empirical literature has examined the physicochemical properties and microbiological quality of raw cow milk in Ethiopia, reflecting increased concern over food safety, public health, and dairy sector performance. Studies conducted in diverse regions including Borena Zone, Eastern Wollega, Harar milk-shed, Girar Jarso, Worabe Town, and Eastern Hararghe have documented substantial variation in milk quality attributes such as temperature, pH, specific gravity, fat, protein content, and microbial load (Eshetu et al., 2019; Tegegn & Soboka, 2020; Adugna & Eshetu, 2021; Musema, 2022). Collectively, these studies attribute poor milk quality primarily to inadequate hygienic practices during milking, improper cleaning of containers, lack of cooling facilities, and extended storage at ambient temperatures.

Despite their valuable contributions, existing studies share several important limitations. First, the majority focus on traditional rural or peri-urban dairy systems, where long-standing informal market arrangements shape milk production and handling practices. As a result, findings largely reflect systemic constraints typical of subsistence-oriented dairy production, such as limited institutional support and weak regulatory enforcement. Second, most studies treat milk quality as a static outcome, without situating it within the context of recent policy reforms and production intensification initiatives aimed at transforming Ethiopia's dairy sector. Consequently, the literature provides limited insight into whether national programs designed to improve productivity and food safety are yielding measurable improvements at the producer level.

More importantly, previous research rarely examines newly established urban dairy production systems, particularly those promoted through coordinated government interventions. This represents a critical knowledge gap, as urban and peri-urban dairy systems are increasingly recognised as strategic entry points for improving milk quality due to their proximity to markets, better access to extension services, and greater potential to adopt improved hygienic practices. Moreover, earlier studies often report aggregated results at district or zonal levels, thereby masking intra-urban heterogeneity and limiting understanding of localised differences in milk handling and hygiene practices.

The present study addresses these gaps by investigating the physicochemical and microbiological quality of raw cow milk in Maya City. In this emerging urban centre, dairy production was recently introduced and supported under the "Yelemat Tirufat" national initiative. Unlike previous studies conducted in other regions of Ethiopia, this research explicitly situates milk quality assessment within a policy-driven production framework, allowing for an evaluation of how institutional support and awareness-raising efforts influence milk safety and quality outcomes. By comparing milk quality across four kebeles within the same urban setting, the study provides a fine-grained analysis of spatial variability, offering insights into how differences in hygiene practices, container sanitation, and handling procedures manifest even under a shared programmatic context.

Furthermore, this study integrates physicochemical indicators with microbiological quality metrics, enabling a more comprehensive assessment of milk safety than studies that focus on a single dimension of quality. The observed patterns particularly the generally acceptable physicochemical parameters alongside localised elevations in microbial counts underscore the importance of linking production-focused initiatives with sustained behavioural change in hygiene and handling practices. In this way, the findings move beyond descriptive reporting and contribute to a more nuanced understanding of the conditions under which dairy intensification initiatives can succeed or fall short in improving food safety.

Overall, this study advances the existing literature by shifting the analytical focus from traditional dairy systems to emerging urban, program-supported production environments. It provides empirical evidence that complements earlier regional studies while highlighting persistent gaps in hygiene practices that require targeted intervention. By doing so, the research offers both scientific and policy-relevant contributions, demonstrating how national agricultural initiatives can influence milk quality outcomes and identifying critical leverage points for improving public health and nutritional security in rapidly urbanising areas of Ethiopia.

Conclusion

This study assessed the physicochemical properties and microbiological quality of raw cow milk produced in four kebeles of Maya City, Ethiopia, within the context of the Yelemat Tirufat dairy development initiative. Overall, most physicochemical parameters, including temperature, pH, specific gravity, fat, and protein content, were within acceptable national and regional standards, indicating generally good milk quality from a compositional and nutritional perspective. These findings suggest that emerging urban dairy production systems supported by policy-driven initiatives have the potential to improve baseline milk quality compared with traditionally reported conditions in many rural settings. Despite these positive attributes, microbiological analyses revealed notable variability across kebeles. While total bacterial and coliform counts were essentially within acceptable limits in most locations, elevated microbial loads in specific kebeles highlight persistent hygiene-related challenges. These variations point to inconsistencies in milking practices, container sanitation, and handling procedures rather than inherent deficiencies in the production system itself. The coexistence of acceptable physicochemical quality with localised microbial contamination underscores the need for integrated quality management approaches that extend beyond production inputs to encompass post-milking hygiene and handling behaviours. The findings have important implications for urban dairy development and food safety policy in Ethiopia. They demonstrate that national initiatives such as Yelemat Tirufat can contribute to improved milk quality. However, their effectiveness depends on sustained training, monitoring, and enforcement of

hygienic practices at the household level. Strengthening extension services, promoting the use of clean and appropriate milking containers, and introducing basic cooling and storage solutions are critical steps for reducing microbial contamination and safeguarding public health.

Suggestion

Future research should expand beyond cross-sectional assessments to include longitudinal monitoring of milk quality across seasons and production cycles, as well as evaluations of consumer-level handling and market chain contamination risks. Additionally, integrating socio-behavioural analyses with microbiological testing would provide deeper insights into the drivers of hygiene practices and inform more targeted, context-specific interventions. Such efforts are essential for ensuring the long-term sustainability and safety of urban dairy systems in rapidly growing Ethiopian cities.

Data Availability Statement

All data generated or analysed during this study are included in this article. This information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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