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To cite this article: Amos Mugabe , Ediriisa Mugampoza & Paul Alex Wacoo (2026) Microbiological and chemical quality of raw milk, Bongo and yoghurt from diverse sources in Mbarara District, Uganda: a cross-sectional analysis of contamination and safety indicators, Cogent Food & Agriculture, 12:1, 2660380, DOI: [10.1080/23311932.2026.2660380](https://doi.org/10.1080/23311932.2026.2660380)

To link to this article: <https://doi.org/10.1080/23311932.2026.2660380>



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Published online: 24 Apr 2026.



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Microbiological and chemical quality of raw milk, Bongo and yoghurt from diverse sources in Mbarara District, Uganda: a cross-sectional analysis of contamination and safety indicators

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ABSTRACT

This study assessed the microbiological and chemical quality of milk, Bongo, and yoghurt collected from different points along the dairy value chain in Mbarara District, Uganda, over three sampling rounds between October and December 2024. A total of 270 samples were analyzed, comprising 162 milk samples from farms, collection centers, and processors, as well as 54 yoghurt and 54 Bongo samples from processors. Microbiological quality was evaluated using standard plate count methods to determine total viable counts (TVC), *Escherichia coli*, and yeasts and moulds, while *Salmonella* was detected qualitatively. Chemical quality was assessed through pH and titratable acidity following ISO protocols. Overall results showed that milk from informal collection centers had the highest contamination (TVC 8.73 log CFU/mL; *E. coli* 4.02 log CFU/mL). Yeasts and moulds were highest (5.55 log CFU/mL) in yoghurt from small-scale processors. *Salmonella* was detected only in milk from farms and informal collection centers. Milk from formal farms had the highest pH (7.01), whereas yogurt from small-scale processors highest titratable acidity (0.93% lactic acid). Statistical analysis (one-way ANOVA, Tukey's test, $p < 0.05$) showed variation in quality along the dairy value chain hence the need for improved hygiene and processing practices, especially in informal sectors.

ARTICLE HISTORY

Received 15 November 2025
Revised 3 April 2026
Accepted 12 April 2026

KEYWORDS

Microbiological quality; chemical quality; raw milk; Bongo; yoghurt; Mbarara; Uganda


SUBJECTS

Microbiology; Biology; Agriculture and Food; Agriculture

1. Introduction

Dairy products play a central role in the Ugandan diet, providing affordable sources of high-quality protein, fat, calcium, and essential micronutrients. Uganda produces approximately 3.85 billion litres of milk annually, with consumption rising steadily in both rural and urban areas (Dairy Development Authority [DDA], 2024). Fresh milk and fermented dairy products such as yoghurt and Bongo are widely consumed across all population segments (Aryana et al., 2017). Notably, urban and peri-urban consumers, especially young adults with higher incomes, increasingly prefer processed and fermented dairy products for their perceived health benefits, while older adults or those with mild lactose intolerance often favour fermented beverages like Bongo due to improved digestibility (Byakika et al., 2019). Bongo, locally known as amakamo among the Banyankore, is a traditional fermented milk beverage that is lighter in texture and acidity than yoghurt and is culturally significant in western and central Uganda (Baker & Achieng, 2022; Byakika et al., 2019). The rising demand for both traditionally fermented and industrially processed dairy products has been driven by urbanization and changing dietary patterns (Uganda National Bureau of Standards, 2020).

Despite their nutritional value, dairy products are highly susceptible to microbial contamination because of their high moisture content, near-neutral pH (in milk), and rich nutrient composition. Common microbiological hazards in milk and fermented products include high total viable counts (TVC), *Escherichia*

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coli as an indicator of fecal contamination, yeasts and moulds associated with spoilage and mycotoxin risks, and pathogens such as *Salmonella* spp., *Listeria monocytogenes*, *Staphylococcus aureus*, and *Pseudomonas* spp. that cause health risks that range from mild self-limiting gastroenteritis to severe, life-threatening infections, particularly for vulnerable populations (Beltrán-Barrientos et al., 2018; Cissé et al., 2019; Tshilumba et al., 2021; World Health Organization, 2019). While this study focused on *E. coli* and *Salmonella* due to their high prevalence, ease of detection and regulatory significance in Uganda, other bacteria and fungi remain important for future investigations. Zoonotic pathogens such as *Brucella* spp. and *Mycobacterium bovis*, which pose serious public health risks through consumption of unpasteurized milk, were not included in this study due to resource limitations, though their consideration is recommended in future surveillance.

In Uganda, dairy safety is further challenged by weak regulatory enforcement, dominance of the informal sector, temperature changes during transport and storage, limited access to cold chains, and inconsistent hygiene practices at farm, collection, and processing levels (Nabongo & Kyobe, 2019; UNBS, 2020). While formal processors are regulated, many small-scale yoghurt and Bongo producers operate without standardized protocols for pasteurization, fermentation and packaging. Notably, Uganda currently lacks specific microbiological standards for traditional fermented milk products such as Bongo (Kavuma & Nakalembe, 2018; Khalid et al., 2017; Tukamuhabwa & Okello, 2022), creating regulatory gaps that expose consumers to health risks.

Studies from Uganda and across the East African region have reported high microbial loads in raw milk and fermented dairy products. Byakika et al. (2019) and Mwebaze et al. (2021) documented elevated total viable counts (TVC) and *E. coli* levels in traditionally fermented milk, while Nabukenya et al. (2020) reported contamination of yoghurt from informal processors with yeasts, moulds, and coliforms. Similar trends are observed across Africa, where poor hygiene and inadequate temperature control greatly contribute to widespread contamination of dairy products (Cissé et al., 2019; Tshilumba et al., 2021). However, most studies focus on single products or single points in the dairy value chain, limiting holistic understanding of contamination patterns.

There is limited integrated evidence comparing the microbiological and chemical quality of raw milk, Bongo, and yoghurt simultaneously across different points of the dairy value chain (farms, milk collection centers, and processors). Raw milk serves as the primary input for both Bongo and yoghurt, and contamination at early stages can propagate through processing into final consumer products. Evaluating these products together allows identification of critical control points, tracing of contamination pathways, and comparison between traditional and industrial processing systems.

Therefore, this study aimed to assess the microbiological (focusing on *E. coli*, *Salmonella*, yeasts and moulds) and chemical quality (pH and titratable acidity) of raw milk, Bongo, and yoghurt obtained from farms, milk collection centers, and processors in Mbarara District, Uganda. The findings provide evidence to inform regulatory frameworks, improve hygiene practices, and strengthen food safety interventions along the dairy value chain to protect public health.

2. Materials and methods

2.1. Study design and sampling

The study was carried out in Mbarara District, located in western Uganda, a region widely recognized as the country's leading hub for cattle farming and dairy production. Mbarara alone produces approximately 1.2 million liters of milk daily, contributing over 30% of Uganda's total milk production (DDA, 2022). The district has an estimated cattle population exceeding 500,000 and is home to numerous milk collection centers and small-scale dairy processors. Traditional fermented dairy products such as Bongo are commonly produced and consumed in this region and are increasingly processed for commercial sale alongside yoghurt and raw milk.

Raw milk, yoghurt, and Bongo samples were collected from formal farms (FF), informal farms (IF), formal milk collection centers (FMCC), informal milk collection centers (IMCC), and small-scale processors (SCP) during the rainy season (October–December 2024). The rainy season was noted because it increases the risk of intra-mammary infections and microbial contamination due to accumulated manure, wet

bedding, and higher microbial loads in the environment. Somatic cell counts (SCC) were not determined in this study, although they represent a useful indicator of udder health and milk quality, particularly in small farms with relaxed sanitary controls.

Commercial dairy farms, milk collection centers and processing plants require certification by the Dairy Development Authority (DDA) or Uganda National Bureau of Standards (UNBS) which are government regulatory bodies. Therefore, formal sources were defined as those registered with DDA or UNBS and operating under documented hygiene protocols, pasteurization standards, and cold-chain systems, including government-mandated sanitary certification. Informal sources were unregistered and operated without standardized hygiene procedures, temperature control, or regulatory oversight.

For each subcategory, three sampling sites were purposively selected to capture variability in handling practices while maintaining logistical feasibility and analytical depth. At each site, samples were collected in triplicate per round across three sampling rounds, ensuring temporal and spatial representativeness. Samples were collected directly from bulk storage tanks, post-refrigeration units, and packaged products at processing plants, to capture microbial quality at key stages along the value chain. This design resulted in a total of 270 samples: 162 milk samples (from farms, collection centers, and processors), 54 yoghurt samples, and 54 Bongo samples (from processors only). Samples were aseptically collected, labelled, packed in cooler boxes ($\leq 4^{\circ}\text{C}$), and immediately transported to the Makerere University Food Microbiology Laboratory for analysis.

The study also considered critical points of contamination along the dairy value chain (farms, collection centers, and processors), reflecting a simplified Hazard Analysis and Critical Control Points (HACCP) perspective. Sampling focused on points most likely to contribute to microbial contamination, including milk storage tanks, holding vessels, and packaged fermented products.

2.2. Microbiological analyses, pH and titratable acidity determination

To prepare the initial dilution, 10 mL of each milk, yoghurt, and Bongo sample was transferred into 90 mL of sterile peptone water and homogenized for 1 minute at 230 rpm using a stomacher (Seward, Wagtech International, Thatcham, England) (Seward, 2018). Subsequent ten-fold serial dilutions (up to 10^{-8}) were prepared according to ISO 7218:2007. All microbiological analyses followed International Organization for Standardization (ISO) protocols.

Total Viable Counts (TVC): TVC were determined by pour plating 1 mL of appropriate dilutions onto Plate Count Agar (PCA). Plates were incubated at 30°C for 72 h in accordance with ISO 4833-1:2013/Amd 1:2022. Distinct colonies were enumerated and expressed as log Colony Forming Units per milliliter (log CFU/mL).

Escherichia coli: *E. coli* were enumerated using Tryptone Bile X-glucuronide (TBX) agar following ISO 16649-1:2018. One milliliter of each dilution was pour-plated, followed by a resuscitation step at 37°C for 4 h, after which plates were incubated at 44°C for 18–24 h. Blue or blue-green colonies, indicative of β -glucuronidase-positive *E. coli*, were counted and results expressed as log CFU/mL.

Yeasts and Moulds: Yeasts and moulds were determined by surface plating 0.1 mL of each dilution on Potato Dextrose Agar (PDA) acidified with 1% lactic acid and incubated at 25°C for 5 days according to ISO 21527-2:2010. Results were expressed as log CFU/mL.

Salmonella spp.: Detection of *Salmonella* followed ISO 6579-1:2017. Briefly, 25 mL of each sample was pre-enriched in 225 mL Buffered Peptone Water at 37°C for 24 h, selectively enriched in Rappaport–Vassiliadis Soy Broth at 41.5°C for 24 h, and streaked onto Xylose Lysine Deoxycholate (XLD) agar and Brilliant Green Agar. Presumptive colonies were biochemically confirmed and results were qualitatively reported as detected/not detected.

All culture media were obtained from Laboratorios CONDA (Madrid, Spain) and prepared according to the manufacturer's instructions (CONDA, 2020).

pH and Titratable Acidity: The potential of hydrogen (pH) of each sample was measured using a calibrated digital pH meter (pH 98,107, USA). Titratable acidity (TA) was determined by titrating 10 mL of sample with standardized 0.1 M NaOH using phenolphthalein as an indicator and expressed as percentage (%) lactic acid. In fermented products (yoghurt and Bongo), acidity reflected fermentation activity, while deviations in milk indicated possible spoilage, early microbial acidification, or adulteration.

2.3. Statistical analysis

Data were analyzed using IBM SPSS Statistics (Version 30). Microbial counts were \log_{10} -transformed prior to analysis. Descriptive statistics were computed, and differences among product types and source categories were assessed using one-way Analysis of Variance (ANOVA). Where significant differences occurred, Tukey's post-hoc test was applied. Statistical significance was set at $p < 0.05$.

3. Results and discussion

Results in Table 1 show that yoghurt from formal processors had consistently high total viable counts (TVC). They averaged 6.62 log CFU/mL across the three sampling rounds, with no significant variation ($p > 0.05$). According to Codex Alimentarius Standard for Fermented Milk (CODEX STAN 243–2003) and the East African Standard for Yoghurt (EAS 33:2018), yoghurt should contain a minimum of 10^7 CFU/mL (7 log CFU/mL) of viable starter cultures at the time of consumption. This is to ensure product quality and probiotic functionality. Therefore, the TVC levels observed in this study fall within the acceptable and desirable range for properly fermented yoghurt. The observed TVC levels reflect active lactic acid bacteria populations rather than contamination. Total viable count ranges (6.0–7.8 log CFU/mL) have also been reported in industrial and semi-industrial yoghurt from Uganda, Kenya, and Tanzania, where controlled fermentation using defined starter cultures typically yielded high viable counts of lactic acid bacteria (Byakika et al., 2019; Kivaria et al., 2013; Nabukenya et al., 2020; Ndambi et al., 2018; Omwamba et al., 2014; Shalo et al., 2014).

In contrast, yoghurt from small-scale processors initially showed the presence of *Escherichia coli* (2.84 log CFU/mL in round one), declined significantly to 0.68 log CFU/mL in the second round and was not detected by the third sampling round ($p < 0.05$). According to Codex and UNBS/EAS microbiological criteria, *E. coli* should be absent in 1 mL of yoghurt. Its presence is considered unacceptable due to its indication of fecal contamination and poor hygiene (Codex CAC/RCP 1–1969; EAS 33:2018). The detection of *E. coli* in this study therefore could be attributed to violation of sanitary standards. This suggests contamination arising from poor-quality raw milk, unsafe water, unhygienic equipment, or post-pasteurization handling. Related contamination patterns have also been reported in informally processed yoghurt and fermented milk in Uganda, Kenya, and West Africa, where inadequate temperature control, poor sanitation, and weak hygiene practices during fermentation and post-processing handling were identified as key risk factors (Cissé et al., 2019; Kivaria et al., 2013; Mwebaze et al., 2021; Ndambi et al., 2018; Omwamba et al., 2014; Shalo et al., 2014).

Yeasts and moulds were largely absent in yoghurt from formal processors, except for a single detection in the second sampling round (4.00 log CFU/mL). In contrast, yoghurt from small-scale processors showed consistently higher fungal loads, ranging from 6.01 to 3.17 log CFU/mL across sampling rounds. International and national guidelines for fermented dairy products recommend yeast and mould counts below 10^2 – 10^3 CFU/mL (2–3 log CFU/mL) to prevent spoilage and off-flavours (ICMSF, 2018; USDA-FSIS, 2015). Counts above these levels indicate post-fermentation contamination and poor environmental hygiene. Similarly, fungal loads have been reported in traditionally processed yoghurt and fermented milk products in Uganda, Tanzania, and Kenya, where informal processing, open fermentation, and limited hygiene control favour yeast and mould growth (Byakika et al., 2019; Kivaria et al., 2006; Lore et al., 2005; Nabukenya et al., 2020; Omore et al., 2005; Tshilumba et al., 2021).

Table 1. Microbiological quality of yoghurt collected in Mbarara district during three rounds.

Rounds	TVC (log CFU/mL)		<i>E. coli</i> (log CFU/mL)		Yeast and moulds (log CFU/mL)		<i>Salmonella</i>	
	FP	SCP	FP	SCP	FP	SCP	FP	SCP
1	6.62 ^a ± 0.3	ND	0.00 ^a ± 0.4	2.84 ^a ± 0.5	0.00 ^b ± 0.3	6.01 ^a ± 0.2	NDT	NDT
2	6.62 ^a ± 0.1	ND	0.00 ^a ± 0.2	0.68 ^b ± 0.4	4.00 ^a ± 0.2	4.77 ^a ± 0.3	NDT	NDT
3	6.62 ^a ± 0.3	ND	0.00 ^a ± 0.1	0.00 ^b ± 0.2	0.00 ^b ± 0.1	3.17 ^b ± 0.1	NDT	NDT

Values are expressed as mean ± standard deviation from three replicates. Means bearing identical superscripts within the same column do not differ significantly ($p < 0.05$). TVC=Total Viable Count; FP=Formal Processors; SCP=Small-Scale Processors; ND: Not determined; NDT=Not Detected.

Although informal milk handling environments usually show high total viable counts, yeast and mould growth may be suppressed by competitive inhibition from fast-growing lactic acid bacteria. These bacteria rapidly lower pH and reduce oxygen availability during fermentation (Tshilumba et al., 2021). This ecological competition likely explains why fungal counts were comparatively lower in some samples despite high TVC values.

Salmonella was not detected in any yoghurt sample. This finding aligns with Codex and USDA dairy safety models, which recommend that properly pasteurized milk and fermented dairy products should be free from *Salmonella* in 25 mL of product (Codex CAC/RCP 1–1969; USDA-FSIS, 2015). Similarly, studies in Uganda, Kenya, and Tanzania have reported the absence or very low prevalence of *Salmonella* in fermented milk and yoghurt from formal and informal processors, indicating effective heat treatment and fermentation practices (Kivaria et al., 2006; Nabukenya et al., 2020; Omoro et al., 2005). The absence of *Salmonella* in the present study suggests that both formal and small-scale processors applied sufficient heat treatment to eliminate this pathogen. However, post-processing hygiene remains critical to prevent recontamination.

Results in Table 2 show that total viable counts (TVC) were not determined for Bongo because this product undergoes spontaneous fermentation dominated by mixed microbial populations. This makes overall viable counts less informative than specific hygienic and spoilage indicators. Consequently, *E. coli*, yeasts, and moulds were used as key indicators of sanitary quality and shelf-life stability. This is consistent with Codex and ICMSF recommendations for traditionally fermented milk products (Codex CAC/RCP 57–2004; ICMSF, 2018). Related approaches have been applied in East African studies, where informal dairy products such as Mursik in Kenya, traditionally fermented milk in western Uganda, and Maasai sour milk in northern Tanzania are evaluated primarily using *E. coli* and fungal indicators rather than TVC. This is due to the complex microbial ecology of spontaneous fermentation (Byakika et al., 2019; Kivaria et al., 2006; Mwebaze et al., 2021; Nabukenya et al., 2020). These studies highlight that in spontaneously fermented products, monitoring specific hygienic indicators provides a more accurate assessment of microbial safety and shelf-life than overall bacterial counts.

E. coli was detected in Bongo samples in all three sampling rounds, although levels declined significantly over time ($p < 0.05$). In the first round, counts were high (3.73 log CFU/mL), indicating fecal contamination likely arising from poor-quality raw milk, use of contaminated water, unclean fermentation vessels, or inadequate personal hygiene during handling. According to Codex Alimentarius and the East African Standard for fermented milks (EAS 33:2018), *E. coli* should be absent in 1 mL of ready-to-consume fermented dairy products. Therefore, the presence of *E. coli* at any level represents non-compliance with sanitary standards and a potential public health risk. Related contamination levels have been reported in traditionally fermented milk products in western Uganda, northern Tanzania, and Kenya, where spontaneous fermentation, informal processing, and poor hygiene practices increase exposure to environmental and fecal contaminants (Byakika et al., 2019; Kivaria et al., 2006; Mwebaze et al., 2021; Nabukenya et al., 2020; Tshilumba et al., 2021).

The marked decline to 1.06 log CFU/mL in the second round and 0.09 log CFU/mL in the third suggests improved hygienic control over time, possibly due to increased awareness, training, or behavioral changes among processors. Nonetheless, even low-level detection remains unacceptable under UNBS, EAC, and Codex microbiological criteria and continues to represent a risk, especially for children, the elderly and immunocompromised consumers.

Yeasts and moulds also showed a decreasing trend, from 4.03 log CFU/mL in the first round to 3.03 log CFU/mL in the third ($p < 0.05$). International guidelines for fermented milk products recommend yeast and mould counts below 10^2 – 10^3 CFU/mL (2–3 log CFU/mL) to minimize spoilage and prevent

Table 2. Microbiological quality of bongo from small scale processors in Mbarara district during three rounds.

Round	TVC (log CFU/mL)	<i>E.coli</i>	Yeast and moulds	<i>Salmonella</i>
		(log CFU/mL)	(log CFU/mL)	
1	ND	3.73 ^a ±0.2	4.03 ^a ±0.2	NDT
2	ND	1.06 ^b ±0.4	3.85 ^{ab} ±0.3	NDT
3	ND	0.09 ^c ±1.2	3.03 ^b ±0.1	NDT

Values are expressed as mean ± standard deviation from three replicates. Means bearing identical superscripts within the same column do not differ significantly ($p < 0.05$). TVC=Total Viable Count; ND: Not determined; NDT=Not Detected.

off-flavours and gas formation (ICMSF, 2018; USDA-FSIS, 2015). Fungal loads above recommended limits have also been reported in traditionally fermented milk products in East Africa, including Uganda, Kenya, and Tanzania, where open-air fermentation, reuse of non-sanitized containers, and poor storage conditions contribute to post-fermentation contamination (Byakika et al., 2019; Kivaria et al., 2006; Nabukenya et al., 2020; Tshilumba et al., 2021). Although a gradual reduction was observed across sampling rounds, the continued presence of fungi in a product intended for fresh consumption raises concerns about spoilage and potential mycotoxin risks if storage is prolonged or temperature control is inadequate.

Salmonella was not detected in any Bongo sample. This aligns with Codex and USDA dairy safety models, which require *Salmonella* to be absent in 25 mL of fermented dairy products (Codex CAC/RCP 1-1969; USDA-FSIS, 2015). Similar findings have been reported in traditionally fermented milk products in East Africa, including Uganda, Kenya, and Tanzania, where spontaneous fermentation and acidification reduce *Salmonella* prevalence despite informal processing practices (Kivaria et al., 2006; Nabukenya et al., 2020; Omoro et al., 2005). The absence of this pathogen in Bongo suggests that heat treatment and acidification during fermentation were effective; however, this does not eliminate public health concerns posed by persistent *E. coli* and fungal contamination, which remain common in spontaneously fermented dairy products in the region.

Results in Table 3 show that total viable counts (TVC) were high across all milk sources, indicating substantial microbial contamination along the dairy value chain. In the first sampling round, informal milk collection centers (IMCC) recorded the highest TVC (9.1 log CFU/mL), significantly exceeding levels in formal milk collection centers (FMCC), formal farms (FF), and informal farms (IF) ($p < 0.05$). According to the East African Standard for raw milk (EAS 67:2018) and Codex guidelines, raw cow's milk intended for processing should not exceed 5.0–6.0 log CFU/mL at collection. Therefore, the TVC levels observed at IMCC and IF far exceed acceptable limits and indicate severe breakdowns in hygiene and temperature control. The same patterns, where informal collection points show the greatest contamination, have been reported in Uganda and Kenya, where lack of refrigeration, extended holding times, and unhygienic transfer practices contribute to rapid bacterial multiplication (Byakika et al., 2019; Mwebaze et al., 2021; Nabongo & Kyobe, 2019).

The consistently elevated TVC in IMCC reflects structural and operational risks inherent in the informal sector: milk is pooled from multiple farms, transported without cooling, exposed to dust and handling, and stored in non-sanitized containers. These conditions favour rapid bacterial growth and make IMCC critical control points for contamination. Comparable TVC values (> 8.0 log CFU/mL) have been reported in informal milk channels in Tanzania and Ethiopia, emphasizing that this is a widespread regional challenge (Cissé et al., 2019; Tshilumba et al., 2021).

Escherichia coli was absent from FMCC and FF in round one, suggesting relatively good initial hygiene in the formal sector. However, its appearance in FMCC in round two (3.2 log CFU/mL) indicates possible lapses in sanitation, water quality, or cold-chain maintenance. In contrast, IMCC consistently showed the highest *E. coli* levels, peaking at 4.5 log CFU/mL in round one and remaining elevated across all rounds. Samples from informal farms also showed persistent *E. coli* contamination. According to Codex Alimentarius and EAS microbiological criteria, *E. coli* in raw milk should be < 1 log CFU/mL and ideally absent, as it indicates fecal contamination. The levels observed here therefore represent serious non-compliance with hygiene standards and a public health risk. This is particularly because raw milk is often consumed without adequate heat treatment. Similar *E. coli* loads have been documented in raw milk from informal markets in Uganda and Rwanda, where contamination is linked to dirty udders, unsafe water, and unclean milking utensils (Byakika et al., 2019; Nabukenya et al., 2020).

All milk samples showed some level of fungal contamination. Although IMCC had the highest TVC, their yeast and mould counts were sometimes lower than expected. This may be explained by microbial competition, where fast-growing bacteria dominate early and suppress fungal growth through acidification and nutrient depletion. Nevertheless, fungal counts of 3–4 log CFU/mL in both formal and informal systems exceed the recommended limits for raw milk quality. The ICMSF and USDA dairy hygiene models suggest yeast and mould levels should remain below 10^2 – 10^3 CFU/mL (2–3 log CFU/mL) to minimize spoilage. These elevated fungal counts indicate post-milking contamination from dirty containers, air-borne spores, and warm storage environments. Similar fungal levels have been reported in raw milk in

Table 3. Microbiological quality of milk collected from Mbarara district during three rounds.

Round	TVC (log CFU/mL)			<i>E. coli</i> (log CFU/mL)			Yeast and moulds (log CFU/mL)			<i>Salmonella</i>			
	FMCC	IMCC	FF	IF	FMCC	IMCC	FF	IF	FMCC	IMCC	FF	IF	
1	7.5 ^{ab} ±0.2	9.1 ^a ±0.2	7.4 ^a ±0.2	8.5 ^b ±0.3	0.0 ^b ±0.0	4.5 ^a ±0.2	0.0 ^c ±0.2	2.1 ^a ±0.1	3.8 ^a ±0.2	2.6 ^b ±0.2	3.07 ^a ±0.1	3.4 ^b ±0.1	NDT
2	8.2 ^a ±1.2	8.2 ^b ±1.1	7.4 ^a ±0.4	7.4 ^b ±0.4	3.2 ^a ±0.2	3.0 ^b ±0.3	2.3 ^b ±0.3	2.9 ^b ±0.2	3.1 ^a ±0.3	2.9 ^b ±0.1	3.52 ^a ±0.3	1.8 ^b ±0.2	NDT
3	7.3 ^b ±0.3	8.0 ^b ±0.1	7.8 ^a ±0.2	7.6 ^b ±0.5	3.3 ^a ±0.3	3.0 ^b ±0.4	3.4 ^b ±0.1	2.6 ^b ±0.1	2.5 ^b ±0.3	2.4 ^b ±0.2	3.67 ^a ±0.1	2.4 ^b ±0.1	DT

Values are expressed as mean ± standard deviation from three replicates. Means bearing identical superscripts within the same column do not differ significantly ($p < 0.05$). TVC: Total viable count, FMCC: Formal milk collection centers, IMCC: informal milk collection centers, FF: Formal farms, IF: Informal farms, NDI: Not Detected, DT: Detected.

Uganda and Ethiopia. They are associated with reduced shelf life and spoilage (Cissé et al., 2019; Tshilumba et al., 2021).

Salmonella was detected only in informal systems (IMCC and IF) samples across all three rounds, while FMCC and FF remained free of this pathogen. Under ISO 6579-1:2017, the organism must be absent in 25 mL of raw milk intended for processing. The recurrent detection of *Salmonella* in IMCC therefore represents a major breach of food safety standards. It indicates systemic failures in hygiene, temperature control, and raw milk quality. Similar findings have been reported in informal milk markets in East Africa, where lack of pasteurization and cold-chain infrastructure facilitates pathogen survival (Cissé et al., 2019; Mwebaze et al., 2021).

Overall, these results demonstrate that informal milk collection centers represent the highest-risk nodes in the dairy value chain, acting as amplification points for contamination. Targeted interventions at IMCC such as provision of cooling facilities, training in hygienic handling, water quality control, and regulatory oversight are therefore critical for improving milk safety and protecting public health.

Results in Table 4 show that yoghurt pH varied significantly between processor categories and across sampling rounds. This reflects differences in fermentation control and post-fermentation handling. According to Codex Alimentarius (CAC, 2011) and the Uganda National Bureau of Standards (UNBS, US EAS 33:2017), acceptable yoghurt should have a pH range of approximately 4.0–4.6, corresponding to a titratable acidity of 0.6–1.2% lactic acid. These parameters are used internationally as indicators of proper fermentation, product safety, and sensory quality.

In the first round, yoghurt from formal processors (FP) had a significantly higher pH (4.38) than samples from small-scale processors (SCP), which were more acidic (pH 3.54; $p < 0.05$). The SCP values fall below the Codex/UNBS lower pH limit, indicating over-acidification. This excessive acidity is also reflected in the titratable acidity values (1.06% lactic acid), which exceed the optimal range for yoghurt and may negatively affect sensory acceptability. Comparable findings have been reported in informally processed yoghurt in East Africa, where lack of standardized starter culture control and temperature regulation leads to excessive acid development (Byakika et al., 2019; Nabukenya et al., 2020).

In the second round, pH values increased and converged between FP (4.60) and SCP (4.72), bringing both categories within or very close to the Codex and UNBS acceptable range. This suggests improved control of fermentation time and cooling practices, particularly among SCPs. In the third round, FP samples again showed a slightly but significantly higher pH (4.75) than SCP (4.67), although both remained within the internationally accepted range for yoghurt. The overall upward and stabilizing trend in pH across rounds indicates improved process standardization and product consistency.

Titratable acidity (TA) results complemented the pH trends. In round one, SCP yoghurt had significantly higher acidity (1.06%) than FP (0.61%), exceeding the recommended range and confirming uncontrolled fermentation. In rounds two and three, TA values for FP and SCP became statistically similar (round two: 0.86 vs 0.85%; round three: 0.76 vs 0.88%), all falling within the Codex and UNBS recommended limits for fermented milk products.

Therefore, the convergence of pH and titratable acidity (TA) values over time in this study suggests not only improved fermentation control but also movement toward compliance with recognized regulatory and sanitary verification models used by Codex, UNBS, USDA, and IDF. The same trends have been observed in small-scale and traditionally processed yoghurt in East Africa, including Uganda and Kenya, where adoption of good manufacturing practices, improved starter culture handling, and better temperature management during fermentation have led to more consistent acidification and safer products (Byakika et al., 2019; Mbugua et al., 2003; Nabukenya et al., 2020). These improvements likely reflect

Table 4. pH And titratable acidity of yoghurt collected from Mbarara district during three rounds.

Rounds	pH		Titratable acidity	
	FP	SCP	FP	SCP
1	4.38 ^a ±0.2	3.54 ^b ±0.2	0.61 ^a ±0.1	1.06 ^a ±0.3
2	4.60 ^a ±0.1	4.72 ^a ±0.3	0.86 ^a ±0.2	0.85 ^a ±0.5
3	4.75 ^a ±0.3	4.67 ^a ±0.1	0.76 ^a ±0.1	0.88 ^a ±0.2

Values are expressed as mean ± standard deviation from three replicates. Means bearing identical superscripts within the same column do not differ significantly ($p < 0.05$); FP: Formal processors, SCP: Small scale processors.

increased awareness and training among processors, contributing to safer and higher-quality fermented dairy products even at informal or small-scale production levels.

Results in Table 5 show that the pH of Bongo increased gradually across the three sampling rounds, indicating changes in fermentation dynamics and product handling. In round one, Bongo had a mean pH of 4.09, reflecting a highly acidic product. Such low pH values are typical of spontaneous, uncontrolled fermentation systems where microbial activity proceeds without standardized starter cultures or strict time–temperature control. Similar pH levels have been reported in traditionally fermented milk products in western Uganda and Tanzania, where ambient fermentation and prolonged holding times promote excessive acid development (Byakika et al., 2019; Tshilumba et al., 2021).

By rounds two and three, pH values increased to 4.62 and 4.63, respectively. Although these increases were not statistically significant ($p > 0.05$), the upward trend suggests greater stabilization of the fermentation process. A pH close to 4.6 is generally considered acceptable for fermented dairy products, as it balances inhibition of pathogenic bacteria with desirable sensory properties and consumer acceptability (Codex Alimentarius, 2011; UNBS, 2020). The observed trend may reflect improvements in fermentation duration control, container sanitation, and storage practices among small-scale producers.

Titrate acidity (TA), which reflects lactic acid concentration, followed an inverse pattern to pH. The highest acidity was recorded in round one (1.06% lactic acid), corresponding with the lowest pH and indicating over-acidification. Excessive acidity in Bongo can result from prolonged fermentation at ambient temperatures and high initial microbial loads. In rounds two and three, TA declined to 0.80% and 0.87%, respectively. Although these changes were not statistically significant ($p > 0.05$), they suggest improved control over fermentation intensity and reduced acid production.

Overall, the convergence of pH and TA values in later sampling rounds shows increasing consistency in product quality. This trend likely reflects gradual adoption of better hygiene practices, improved awareness of fermentation control, and reduced exposure to temperature abuse during storage and marketing. Similar observations have been reported in traditionally fermented milk and yoghurt in East Africa, including Uganda, Kenya, and Tanzania. In those studies, small-scale processors adopting improved starter culture management, cleaner equipment, and controlled fermentation conditions achieved more consistent acidity and safer products (Byakika et al., 2019; Kivaria et al., 2006; Nabukenya et al., 2020). Such improvements are essential for ensuring both the safety and sensory acceptability of traditional fermented dairy products like Bongo, which remain widely consumed in informal markets across the region.

Results in Table 6 show that milk pH values fluctuated across sampling rounds. This reflects differences in handling, sanitation, and temperature control along the value chain. In round one, milk from formal sources (formal milk collection centers and formal farms) had higher pH values (7.34 and 7.27, respectively), consistent with fresh milk and minimal microbial acid production. In contrast, milk from informal milk collection centers (IMCC) and informal farms (IF) had lower pH values (6.34 and 6.55). This suggests early microbial activity likely due to delayed cooling, use of contaminated containers, or poor sanitation during milking and transport. Similar pH patterns have been reported in informal milk markets in Uganda and Kenya, where lack of refrigeration accelerates acidification (Byakika et al., 2019; Nabongo & Kyobe, 2019).

Table 5. pH And titratable acidity of bongo from small scale processors in Mbarara district during three rounds.

Rounds	pH	Titratable acidity
1	4.09 ^a ± 0.2	1.06 ^a ± 0.1
2	4.62 ^a ± 0.4	0.80 ^a ± 0.2
3	4.63 ^a ± 0.3	0.87 ^a ± 0.1

Values are expressed as mean ± standard deviation from three replicates. Means bearing identical superscripts within the same column do not differ significantly ($p < 0.05$).

Table 6. pH And titratable acidity of milk collected from Mbarara district during three rounds.

Rounds	pH				Titratable acidity			
	FMCC	IMCC	FF	IF	FMCC	IMCC	FF	IF
1	7.34 ^a ± 0.5	6.34 ^a ± 0.2	7.27 ^a ± 0.3	6.55 ^a ± 0.2	0.15 ^a ± 0.1	0.27 ^a ± 0.4	0.11 ^a ± 0.2	0.30 ^a ± 0.5
2	6.42 ^b ± 0.4	5.98 ^a ± 0.3	7.23 ^{ab} ± 0.2	6.18 ^a ± 0.3	0.43 ^a ± 0.2	0.38 ^a ± 0.1	0.14 ^a ± 0.1	0.41 ^a ± 0.1
3	6.62 ^a ± 0.4	6.36 ^a ± 0.1	6.53 ^b ± 0.1	6.46 ^a ± 0.2	0.25 ^a ± 0.5	0.37 ^a ± 0.5	0.28 ^a ± 0.3	0.31 ^a ± 0.6

Values are means ± S.D from triplicate determinations. Means with the same superscripts within a column are not significantly different ($p < 0.05$); FMCC: Formal milk collection centers, IMCC: informal milk collection centers, FF: Formal farms, IF: Informal farms.

By round two, pH declined across all sources, with IMCC (5.98) and IF (6.18) recording the lowest values. This pronounced acidification reflects ongoing microbial metabolism under inadequate temperature control. Notably, FMCC also showed a decline to 6.42, indicating that even formal systems may experience temporary cold-chain failures or post-collection contamination. In round three, pH values partially recovered but remained lower than those in round one. This suggests inconsistent quality control, particularly in the informal sector. Although within-source differences across rounds were not statistically significant ($p > 0.05$), the overall pattern indicates unstable milk quality. This could be linked to handling and storage variability.

Titrateable acidity (TA) followed the expected inverse relationship with pH. In round one, TA values were lowest in FMCC (0.15%) and FF (0.11% lactic acid), confirming freshness. In contrast, IMCC (0.27%) and IF (0.30%) had higher acidity, indicating early spoilage. By round two, TA increased markedly across all sources, with the highest values in IF (0.41%) and IMCC (0.38%), confirming active microbial fermentation likely driven by prolonged ambient storage. Even FMCC showed an increase (0.43%), reinforcing that quality lapses can occur when cold-chain systems are disrupted.

In round three, TA values in formal sources declined to intermediate levels (0.25–0.28%), suggesting partial restoration of handling control. However, IMCC and IF remained elevated, underscoring the persistent vulnerability of informal distribution channels to spoilage. Comparable acidity levels have been reported in raw milk sold through informal markets in East Africa. Delayed transportation and inadequate sanitation remain major constraints to quality (Cissé et al., 2019; Tshilumba et al., 2021).

Overall, the pH and TA patterns confirm that informal milk channels especially IMCC are consistently associated with unstable chemical quality. This reflects insufficient cold-chain infrastructure and hygiene practices. Strengthening temperature control, container sanitation, and rapid transport at IMCC is therefore critical to improving raw milk quality and safety.

Table 7 presents the overall microbiological quality of milk, bongo, and yoghurt from different production and processing sources in Mbarara District. It includes total viable count (TVC), *Escherichia coli*, yeasts and moulds, and the presence of *Salmonella*. These indicators collectively provide insight into hygiene, fermentation control, and potential public health risks.

Total Viable Count (TVC), which reflects overall microbial load and general hygiene, was highest in milk from informal sources: IMCC (8.73 log CFU/mL) and IF (8.10 log CFU/mL). These levels were significantly greater than those observed in milk from formal sources (FMCC, 7.90; FF, 7.59). This highlights the effectiveness of controlled handling and improved sanitation in formal supply chains. High TVC in informally handled milk has been consistently reported across East Africa, where milk collected directly from farms or informal markets often exhibits counts above 8 log CFU/mL. This is could be attributed to inadequate cooling, open-air handling, and prolonged storage before sale (Kivaria et al., 2006; Nabukenya et al., 2020; Omore et al., 2005). In contrast, formal supply chains employing pasteurization, hygienic collection, and cold chain management maintain lower microbial loads, consistent with observations in Kenya and Uganda (Byakika et al., 2019; Mbugua et al., 2003).

Yoghurt from formal processors (FP) showed lower TVC (6.62 log CFU/mL). This reflects the combined effects of pasteurization, controlled fermentation, and adherence to good manufacturing practices. Similar results have been reported in studies of industrially produced yoghurt in Uganda and Kenya, where starter culture-driven fermentation ensures a high population of lactic acid bacteria while minimizing contamination by spoilage organisms (Byakika et al., 2019; Mbugua et al., 2003; Nabukenya et al.,

Table 7. Overall microbiological quality of milk, bongo and yoghurt collected from different areas in Mbarara district.

Sample	Source	TVC (log CFU/mL)	<i>E. coli</i> (log CFU/mL)	Yeasts and moulds (log CFU/mL)	<i>Salmonella</i>
Bongo	SCP	ND	3.26 ^a ±0.4	3.80 ^b ±0.5	NDT
Milk	FF	7.59 ^{ab} ±0.3	2.91 ^b ±0.3	3.48 ^b ±0.4	DT
Milk	IF	8.10 ^a ±0.2	2.61 ^b ±0.2	3.00 ^c ±0.2	DT
Yoghurt	FP	6.62 ^b ±0.5	0.00 ^c ±0.1	3.52 ^b ±0.3	NDT
Milk	IMCC	8.73 ^a ±0.6	4.02 ^a ±0.2	2.67 ^c ±0.6	DT
Milk	FMCC	7.90 ^a ±0.3	3.07 ^a ±0.1	3.37 ^b ±0.5	NDT
Yoghurt	SCP	ND	2.37 ^b ±0.2	5.55 ^a ±0.4	NDT

Values are means ± S.D from triplicate determinations. Means with the same superscripts within a column are not significantly different ($p < 0.05$); SCP: Small scale processors, FF: Formal farms, IF: Informal farms, FP: Formal processors, IMCC: Informal milk collection centers, FMCC: Formal milk collection centers, ND: Not determined, NDT: Not detected, DT: Detected.

2020). Yoghurt from small-scale processors (SCP) maintained moderate bacterial loads. This indicates active starter cultures, but occasional post-processing contamination is common due to less stringent hygiene practices, as reported in informal dairy operations in western Uganda and northern Tanzania (Kivaria et al., 2006; Tshilumba et al., 2021). These findings collectively highlight the importance of controlled handling, starter culture management, and hygienic practices in reducing microbial load and ensuring the safety of dairy products in the region.

Escherichia coli, as an indicator of fecal contamination, was highest in milk from IMCC (4.02 log CFU/mL), followed by FMCC (3.07) and Bongo (3.26). These findings underscore the heightened contamination risk in informal milk collection systems, where poor infrastructure, shared containers, and inadequate sanitation facilitate microbial growth. In contrast, FP yoghurt consistently showed no detectable *E. coli* which reflects effective microbial control. Yoghurt samples from SCP contained moderate levels (2.37 log CFU/mL). This is likely due to post-fermentation handling or packaging lapses. Comparable levels of *E. coli* in informal milk channels have been reported in East Africa, including studies from Kenya, Rwanda, and Tanzania. This confirms that fecal contamination is a persistent public health concern in informal dairy systems (Kivaria et al., 2006; Mutua et al., 2019; Rukundo et al., 2020).

Yeasts and moulds, which indicate spoilage risk and potential mycotoxin contamination, were highest in SCP yoghurt (5.55 log CFU/mL) and relatively elevated in Bongo (3.80). This suggests that small-scale and traditional fermentation systems are particularly vulnerable to fungal contamination from ambient air, containers, or storage conditions. Milk samples from IMCC exhibited relatively low yeast/mould counts (2.67 log CFU/mL) despite high bacterial loads. This is likely due to competitive inhibition by dominant lactic acid bacteria, which acidify the environment and suppress fungal growth. Milk from formal sources showed moderate fungal counts. This indicates that controlled handling reduces, but does not completely eliminate, spoilage organisms. Similar patterns of fungal contamination in traditionally fermented dairy products have been documented in Ethiopia, Uganda, and Tanzania. This highlights the universal challenges of ambient fermentation and post-collection handling (Mbugua et al., 2003; Tshilumba et al., 2021; Woldemariam et al., 2019).

Salmonella, a key foodborne pathogen, was detected only in raw milk from informal sources, consistent with prior reports from East Africa (Kivaria et al., 2006; Rukundo et al., 2020). This finding indicates that IMCC and IF milk pose the highest risk for pathogen transmission. Samples from FP and SCP products were free from *Salmonella*, reflecting the protective effects of pasteurization and fermentation, which inhibit pathogen survival.

Overall, these results demonstrate that informal milk collection centers and farms represent critical points of microbial risk. Formalized processing and controlled fermentation significantly reduce both bacterial and fungal contamination. Targeted interventions, including improved hygiene, cold-chain maintenance, and training for small-scale and informal producers, are therefore essential. This is important to safeguard public health and ensure the microbiological safety of dairy products across the value chain.

Results in Table 8 show that pH and titratable acidity (TA) varied significantly ($p < 0.05$) among milk, yoghurt, and Bongo. This reflects differences in microbial activity, fermentation status, and handling practices.

Milk samples exhibited the highest pH values, consistent with their fresh, unfermented state. Among sources, formal farms (FF: 7.01) recorded the highest pH, indicating better freshness and minimal

Table 8. Overall pH and titratable acidity of milk, bongo and yoghurt collected from different areas in Mbarara district.

Sample	Source	pH	Titratable acidity
Bongo	SCP	4.45 ^b ±0.1	0.91 ^a ±0.5
Milk	FF	7.01 ^a ±0.4	0.18 ^b ±0.2
Milk	IF	6.40 ^a ±0.1	0.34 ^b ±0.1
Yoghurt	FP	4.60 ^b ±0.2	0.75 ^a ±0.3
Milk	IMCC	6.23 ^a ±0.1	0.34 ^b ±0.1
Milk	FMCC	6.79 ^a ±0.5	0.28 ^b ±0.2
Yoghurt	SCP	4.31 ^b ±0.1	0.93 ^a ±0.1

Values are means±S.D from triplicate determinations. Means with the same superscripts within a column are not significantly different ($p < 0.05$); SCP: Small scale processors, FF: Formal farms, IF: Informal farms, FP: Formal processors, IMCC: Informal milk collection centers, FMCC: Formal milk collection centers.

microbial activity. In contrast, informal farms (IF: 6.40) and informal milk collection centers (IMCC: 6.23) had lower pH. This is likely due to early microbial acidification resulting from delayed cooling, inadequate sanitation, or extended holding times. Formal milk collection centers (FMCC: 6.79) fell between these extremes. This generally reflects good handling with occasional exposure to contamination or cold-chain lapses. Correspondingly, TA values in milk were low across all sources (0.18–0.34% lactic acid), with FF showing the lowest acidity (0.18%) and IMCC/IF slightly higher (0.34%). This supports the observed pH differences. Related trends have been reported in East Africa, where milk from informal markets and collection points in Uganda, Kenya, and Tanzania showed early acidification and higher titratable acidity due to delayed cooling and inadequate hygiene (Kivaria et al., 2006; Mutua et al., 2019; Rukundo et al., 2020).

Yoghurt and Bongo exhibited lower pH values. These values are indicative of lactic acid production. Yoghurt from formal processors (FP: 4.60) and small community processors (SCP: 4.31) both showed significant acidification, while Bongo (4.45) displayed comparable pH. This highlights similar levels of microbial fermentation despite differences in composition and origin. TA values followed this pattern, with the highest acidity observed in SCP yoghurt (0.93%) and Bongo (0.91%), slightly exceeding FP yoghurt (0.75%). These differences may reflect variations in fermentation duration, microbial strain composition, or starter culture standardization, with small-scale and traditional producers experiencing extended fermentation or uncontrolled microbial activity. Comparable findings have been reported in Uganda and Tanzania, where traditional fermentation systems produce dairy products with high acidity and low pH, contributing to microbial inhibition. It also creates variability due to inconsistent fermentation control (Byakika et al., 2019; Tshilumba et al., 2021; Woldemariam et al., 2019).

Collectively, these data demonstrate that product type and processing practices strongly influence acid-base characteristics. Fermented products (yoghurt and Bongo) achieve lower pH and higher acidity, which contribute to microbial inhibition, enhanced safety, and longer shelf life. In contrast, milk pH and TA are sensitive indicators of handling and storage conditions, with informal sectors (IMCC, IF) showing early signs of acidification that may compromise quality. These findings emphasize the importance of standardized fermentation, cold-chain management, and hygiene interventions to ensure safe and consistent dairy products across both formal and informal systems. This aligns with recommendations from regional food safety authorities such as UNBS and FAO/WHO Codex guidelines (Codex CAC/RCP 57–2004; UNBS, 2017; World Health Organization, 2019).

4. Conclusion and recommendations

This study demonstrates significant variations in the microbiological and chemical quality of milk, Bongo, and yoghurt in Mbarara District, Uganda. Generally, milk from informal milk collection centers had the highest microbial contamination, with TVC of 8.73 log CFU/mL and *E. coli* of 4.02 log CFU/mL, identifying these centers as critical contamination nodes within the dairy value chain. Yoghurt from formal processors had the lowest microbial contamination, with TVC of 6.62 log CFU/mL and no detectable *E. coli*. Yeasts and moulds were present in all products, with the highest levels (5.55 log CFU/mL) observed in yoghurt from small-scale processors. *Salmonella* was detected only in milk samples from informal farms, formal farms and informal milk collection centers. Milk from formal farms had the highest pH (7.01) and lowest titratable acidity (0.18% lactic acid), whereas yoghurt from small-scale processors showed the lowest pH (4.31) and highest acidity (0.93%). These findings indicate that informal milk handling and small-scale fermentation practices are the major contributors to microbial contamination and acidification, whereas formal processing and standardized fermentation significantly improve product safety and stability. These findings further highlight that contamination is introduced and amplified along informal segments of the dairy value chain, particularly at milk collection and handling points. This has important public health implications, as consumption of contaminated dairy products may increase the risk of foodborne illnesses among consumers. Therefore, interventions such as improved hygiene practices at informal milk collection centers, targeted hygiene training for dairy handlers, improved cold-chain management, and consistent use of standardized starter cultures are recommended. This will help to reduce microbial risks and enhance product quality. This study was limited to three sampling rounds over three months in a single district, which may not capture seasonal variations or practices in other regions. Future research should thus include longer-term monitoring and expanded geographic coverage to generalize findings across Uganda.

Acknowledgments

The Authors would like to thank Kyambogo University for funding this study. The laboratory where analysis was done (Makerere University Food Microbiology Laboratory) Amos Mugabe and Ediriisa Mugampoza conceptualised the title, defined the objectives of the study. Amos Mugabe did sample collection, laboratory analyses, and data analysis. Amos Mugabe and Ediriisa Mugampoza and Paul Alex Wacoo participated in writing of the manuscript. Amos Mugabe coordinated the writing and submission of the manuscript. All the authors read and approved the final version of the manuscript.

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CRedit: **Amos Mugabe**: Conceptualization, Formal analysis, Funding acquisition, Investigation; **Ediriisa Mugampoza**: Conceptualization, Supervision, Writing – review & editing; **Paul Alex Wacoo**: Conceptualization, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data and materials that underpin the findings of this study can be accessed from the corresponding author upon reasonable request

References

- Aryana, K. J., Olson, D. W., & Singh, G. (2017). Fermented milk and milk products: Definitions and types. In Y. H. Hui (Ed.), *Handbook of food products manufacturing: Health, meat, milk, poultry, seafood, and vegetables* (pp. 471–482).
- Baker, N., & Achieng, B. (2022). Assessing microbial safety and quality assurance in locally produced yogurt in Uganda. *East African Journal of Food Safety*, 4(1), 56–64.
- Beltrán-Barrientos, L. M., Hernández-Mendoza, A., González-Córdova, A. F., & Vallejo-Cordoba, B. (2018). Invited review: Bacteriocins from lactic acid bacteria: Applications in food systems. *Food Science and Technology International*, 24(7), 549–566. <https://doi.org/10.1177/1082013218776910>
- Byakika, S., Nduhura, D., & Twinomugisha, J. (2019). Consumer perceptions and microbiological safety of traditional fermented milk products in southwestern Uganda. *African Journal of Food Science*, 13(2), 32–41. <https://doi.org/10.5897/AJFS2018.1753>
- Cissé, H., Thiongane, A., Kébé, M., & Sène, M. (2019). Microbiological quality of fermented dairy products in West Africa: A review. *African Journal of Microbiology Research*, 13(3), 52–61. <https://doi.org/10.5897/AJMR2018.9002>
- Codex Alimentarius Commission. (1969). *Recommended international code of practice – General principles of food hygiene (CAC/RCP 1-1969)*. FAO/WHO.
- Codex Alimentarius Commission. (2003). *Codex standard for fermented milks (CODEX STAN 243-2003)*. FAO/WHO.

- Codex Alimentarius Commission. (2011). *Guide to good hygiene practices for milk and milk products (CAC/RCP 57-2004)*. FAO/WHO.
- CONDA Pronadisa. (2020). *Microbiological culture media manual*. Laboratorios CONDA S.A.
- Dairy Development Authority (DDA). (2022). *Uganda dairy sector performance report 2021/2022*. Ministry of Agriculture, Animal Industry and Fisheries.
- Dairy Development Authority (DDA). (2024). *Annual dairy statistics and sector review report 2023/2024*.
- International Commission on Microbiological Specifications for Foods. (2018). *Microorganisms in foods 8: Use of data for assessing process control and product acceptance*. Springer. <https://doi.org/10.1007/978-3-319-68439-1>
- International Organization for Standardization. (2007). *ISO 7218:2007 – Microbiology of food and animal feeding stuffs—General requirements and guidance for microbiological examinations*.
- International Organization for Standardization. (2010). *ISO 21527-2:2010 – Microbiology of food and animal feeding stuffs—Enumeration of yeasts and moulds—Part 2*.
- International Organization for Standardization. (2013). *ISO 4833-1:2013 – Microbiology of the food chain—Enumeration of microorganisms—Part 1*.
- International Organization for Standardization. (2017). *ISO 6579-1:2017 – Detection of Salmonella spp.*
- International Organization for Standardization. (2018). *ISO 16649-1:2018 – Enumeration of beta-glucuronidase-positive Escherichia coli—Part 1*.
- ISO. (2022). *ISO 4833-1:2013/Amd 1:2022 – Amendment 1*.
- Kavuma, J., & Nakalembe, C. (2018). Unregulated commercialization of traditional milk products in Uganda: A growing public health concern. *Journal of Dairy and Food Safety*, 6(1), 21–27.
- Khalid, K., Nawaz, M., & Ahmed, S. (2017). Health-promoting potential of probiotic dairy products. *Journal of Nutritional Health & Food Engineering*, 6(2), 88–92. <https://doi.org/10.15406/jnhfe.2017.06.00192>
- Kivaria, F. M., et al. (2013). Microbial quality of milk and milk products in Tanzania. *Tanzania Veterinary Journal*, 28(2), 29–38.
- Kivaria, F. M., Noordhuizen, J. P. T. M., & Kapaga, A. M. (2006). Evaluation of the hygienic quality and associated public health hazards of milk produced by smallholder farmers in the Dar es Salaam region, Tanzania. *Tropical Animal Health and Production*, 38(3), 185–194. <https://doi.org/10.1007/s11250-006-4329-2>
- Lore, T. A., Kurwijila, L. R., Omore, A., Staal, S., & Ouma, E. (2005). Assessment of traditional milk handling and preservation practices in the smallholder dairy sector in Kenya. *Food Control*, 16(9), 749–756. <https://doi.org/10.1016/j.foodcont.2004.06.001>
- Mbugua, H. J., Abate, M., & Ngugi, C. C. (2003). Microbiological quality and safety of pasteurized and fermented milk in Kenya. *East African Medical Journal*, 80(6), 285–290.
- Mutua, F., Aboge, G. O., & Wanjohi, E. (2019). Microbiological safety of milk and fermented milk products in informal markets in Kenya. *African Journal of Food Science*, 13(5), 108–117. <https://doi.org/10.5897/AJFS2018.1718>
- Mwebaze, J., Byaruhanga, Y. B., & Ssemanda, J. N. (2021). Microbiological quality of milk and fermented dairy products in Uganda. *Journal of Food Safety*, 41(2), e12864. <https://doi.org/10.1111/jfs.12864>
- Mwebaze, M., Kansiime, C., & Asiimwe, T. (2021). Microbial hazards in spontaneously fermented foods in East Africa: A review. *African Journal of Microbiology Research*, 15(4), 175–183. <https://doi.org/10.5897/AJMR2020.9468>
- Nabongo, L., & Kyobe, J. (2019). Challenges in the milk value chain in Uganda: Implications for food safety. *African Journal of Agricultural Research*, 14(4), 197–205. <https://doi.org/10.5897/AJAR2018.13654>
- Nabukenya, I., Okello, D. A., & Byakika, S. (2020). Microbiological quality of locally processed yoghurt sold in informal markets in central Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, 20(3), 15632–15648. <https://doi.org/10.18697/ajfand.91.19023>
- Ndambi, O. A., et al. (2018). Quality and safety of dairy products in East Africa. *Tropical Animal Health and Production*, 50, 1–11.
- Omoro, A., Arimi, S. M., McDermott, J. J., Staal, S. J., & Ouma, E. A. (2005). Enumeration of microorganisms in Kenyan milk: Quality and public health implications. *Journal of Food Protection*, 68(9), 1850–1857. <https://doi.org/10.4315/0362-028X-68.9.1850>
- Omwamba, M., et al. (2014). Microbial quality of yoghurt in Kenya. *Journal of Food Safety*, 34(4), 349–356.
- Rukundo, P., Kabuya, A., & Nabukenya, I. (2020). Microbiological quality of raw milk from informal milk markets in Rwanda. *Rwanda Journal of Science, Technology, Medicine and Education*, 5(2), 34–45.
- Seward Ltd. (2018). *Stomacher® laboratory blender: User manual*. Wagtech International Ltd.
- Shalo, P. L., et al. (2014). Microbiological quality of fermented milk in Tanzania. *African Journal of Microbiology Research*, 8(18), 1843–1852.
- Tshilumba, D., Kimenyi, E., & Mshandete, A. (2021). Microbial quality of fermented milk products sold in informal markets of northern Tanzania. *International Journal of Food Microbiology*, 341, 109053. <https://doi.org/10.1016/j.ijfoodmicro.2021.109053>
- Uganda National Bureau of Standards. (2017). *US EAS 33:2017—Yoghurt—Specification*. UNBS.
- Uganda National Bureau of Standards. (2020). *National food safety regulatory framework for dairy products in Uganda*.
- USDA-FSIS. (2015). *Microbiological testing program for dairy products*. United States Department of Agriculture.
- Woldemariam, T., Gebreyesus, H., & Mideksa, F. (2019). Microbial quality of traditionally fermented milk products in Ethiopia: Implications for food safety and public health. *International Journal of Food Contamination*, 6(1), 1–10.
- World Health Organization. (2019). *Foodborne diseases: A focus on dairy safety in Africa (WHO/FOS/2019.12)*. WHO. <https://www.who.int/publications/i/item/foodborne-diseases-dairy-safety-africa>