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Microbial Safety of Milk from Small-Scale Dairy Farms in Northern Ghana

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Abstract

Milk from small-scale dairy farms in Northern Ghana plays a vital role in food security and nutrition but remains highly vulnerable to microbial contamination due to inadequate hygiene practices and poor post-harvest handling. This study investigated the microbial safety of raw milk by analysing contamination levels and identifying key pathogens linked to dairy farming practices. A total of 99 milk samples (79 farm-sourced, 20 vendor-sourced) were collected across the Tolon, Sagnarigu, and Savelugu districts and analyzed using standard plate count methods and biochemical assays. Results showed that **92% of samples contained coliform bacteria**, with vendor milk exhibiting significantly higher contamination levels (**33.6%**) compared to farm milk (**17%**, $p < 0.05$). The most frequently isolated pathogens included *Escherichia coli* (39%), *Bacillus cereus* (32%), *Klebsiella pneumoniae* (10%), and *Pseudomonas aeruginosa* (6.7%), with emerging contaminants such as *Stenotrophomonas maltophilia* also detected. A strong inverse correlation ($r = -0.89$, $p = 0.0012$) was observed between hygiene practices and contamination rates, underscoring the critical role of milk handling in microbial proliferation. These findings reveal substantial food safety risks associated with unregulated milk markets and highlight the urgent need for interventions, including improved hygiene protocols, veterinary oversight, and stricter monitoring of informal dairy supply chains. Given the presence of zoonotic pathogens, further research is needed to assess the long-term health implications of consuming contaminated milk in low-resource settings.

Keywords

Contamination, Dairy, Food Safety, Ghana, Hygiene Practices, Milk

1. Introduction

Background and Rationale

Dairy products, including milk, have long been staples of African diets and are becoming more and more vital to the continent's expanding rural and urban populations [1]-[3]. Although fresh milk production in Ghana is less than 1% of the total dairy market value, it is a significant source of livelihood for many people, despite underdevelopment in the industry. However, with a per capita milk consumption of 17 kg, Ghana ranks among the lowest in Africa and the world [4]. Milk and dairy products are nutrient-dense, providing high-quality proteins, minerals, vitamins, and energy-rich fats. Consequently, milk creates an optimal habitat for the proliferation of several foodborne bacteria and zoonotic pathogens [5]-[7]. The microbiological quality of milk, at the time of milking from a healthy cow, is theoretically deemed safe for human consumption.

Once released from the mammary, milk is susceptible to contamination by spoilage bacteria and foodborne pathogens from several sources, including animal faeces, soil, air, feed, water, equipment, animal skins, and humans. The frequency of pathogenic and spoilage bacteria in milk and dairy products is regulated by several variables and their interactions. Factors may encompass the health status of the dairy herd, cleanliness standards in the dairy farm environment, milking and pre-storage conditions, available storage facilities and technologies, farm management techniques, geographic location, and season [8] [9].

Besides microbiological dangers, milk and dairy products may also harbor chemical hazards and pollutants mostly introduced by environmental factors, animal feed, animal husbandry, and industrial activities. Consequently, safety and productivity are inherently interconnected within the dairy food chain, encompassing production, handling, processing, and consumption.

To mitigate food safety risks related to milk and dairy products, a continuous system of preventive measures is essential, starting with the safety of animal feed, followed by effective farming practices and on-farm controls, good manufacturing and hygiene practices, consumer safety awareness, and the proper implementation of food safety management systems throughout the dairy supply chain.

The food-safety issues linked to the use of raw milk and dairy products differ significantly between industrialized and developing nations. The dairy industry in wealthy countries is predominantly industrialized, marked by the regular use of pasteurization technology, but in underdeveloped nations, it is primarily comprised of numerous smallholder dairy producers and processors. In several African nations, the informal sector, which manages the majority of milk and dairy products, is defined by the sale of unpasteurized milk through small-scale channels that lack a cold chain and exhibit minimal or no regulatory oversight [10]-[12].

In Ghana, particularly in the northern regions, small-scale dairy farming plays a critical role in the livelihoods of many rural households and contributes significantly to local food security. Despite its importance, the sector is fraught with

challenges that compromise milk quality and safety. Traditional practices such as hand milking, inadequate post-harvest handling, and poor storage conditions are common. Moreover, the limited access to veterinary services and the general lack of awareness about the importance of milk hygiene further exacerbate the risk of bacterial contamination [13]. These issues are compounded by the fact that milk is often sold in informal markets with minimal regulatory oversight, increasing the potential for public health hazards.

Bacterial contamination in milk has been documented in various studies across Ghana, highlighting a persistent public health threat. For instance, research has consistently found *E. coli* and *Staphylococcus spp.* in both raw and processed milk, with contamination often linked to poor handling and storage practices [14]. Unhygienic practices such as milking cows in dirty environments, using unclean water to wash equipment, hands and udder before and after milking have been reported to contribute to contaminate milk contamination in Ghana [15]. In Northern Ghana, where dairy farming practices are deeply rooted in tradition and influenced by local customs, understanding the pathways of contamination is essential for developing effective interventions. This study seeks to fill the gap in knowledge regarding the relationship between farming practices and the microbial safety of milk in this region.

Milk produced by small-scale dairy farms in Northern Ghana is at significant risk of bacterial contamination due to traditional farming practices and inadequate hygiene measures. Preliminary findings indicate the presence of harmful pathogens such as *Escherichia coli*, *Staphylococcus sciuri*, and *Bacillus cereus* in raw milk samples. These contaminants are of serious concern due to their potential to cause foodborne illnesses, particularly in populations with limited access to healthcare. Despite the known risks, there is a paucity of systematic research linking specific farming practices with the prevalence of bacterial contamination in milk in this region. Addressing this knowledge gap is critical for developing targeted strategies to improve milk safety and protect public health. Thus, this study sought to evaluate the microbial safety of raw milk produced by small-scale dairy farms in Northern Ghana, with a focus on identifying bacterial contaminants and assessing the influence of dairy farming practices on milk quality.

2. Methodology

Study Design and Sampling Technique

The study employed a cross-sectional design, suitable for evaluating the prevalence of bacterial contamination in raw milk at a particular moment. This design facilitated the collection of data regarding the microbiological quality of milk and the farming practices employed by dairy farmers in the region. A snowball sampling technique was utilized, commencing with prominent farmers in the Tolon, Sagnarigu, and Savelugu districts. The selection of these districts is based on their significance in smallholder dairy farming. The sample size of 80 farmers was determined using Cochran's formula for populations with unknown bacterial con-

tamination prevalence. The research was carried out in the Northern Region of Ghana, recognized as an agricultural center where dairy farming serves as a primary source of income for numerous households. This region was chosen for the study based on several important factors. The population of Northern Ghana is primarily rural, characterized by prevalent small-scale farming practices. The Ministry of Food and Agriculture (MOFA) indicates that the Northern Region possesses one of the highest densities of smallholder dairy farms in Ghana, rendering it suitable for evaluating the microbiological quality of milk [16]. The hot and humid climate promotes bacterial growth, thereby elevating the risk of contamination during milking and handling [17]. Prior research has emphasized the insufficient infrastructure and limited access to veterinary services, which intensify the difficulties in ensuring milk safety in this region [13].

Sample Collection and Transportation

Raw milk samples were collected by the guidelines established by the Ministry of Food and Agriculture [18]. Aseptic procedures were meticulously implemented during the collection of milk samples from individual cows to avert contamination by microorganisms found on the udder and teats, the hands of milking personnel, and within the barn environment. During the sampling of raw milk directly from the udder, the udder and teats were cleaned and dried before sampling, and each teat end was gently scrubbed with cotton swabs moistened with 70% ethyl alcohol. Approximately 50 ml of pooled udder milk sample was collected from all functional teats of each cow into a sterile universal bottle, following the discarding of the initial streams of milk.

In cases where multiple cows were milked, an aggregate sample was created by mixing equal amounts from each cow. Samples were collected in both dry and wet seasons, with sampling conducted during evening milking. Samples for the wet season were collected from June to September, whereas samples for the dry season were collected from November to May. The samples were labelled with the farm code, sample type, and date of collection using a permanent marker, stored at -20˚C [19], and transported to Noguchi Memorial Institute for Medical Research Laboratory in an icebox for bacteriological analysis after 24 hours. Informed consent was secured from each dairy farmer before sampling, and they were requested to confirm whether their cows had received recent antibiotic treatment. Milk samples were collected from both on-farm (n = 79) and market sources (n = 20). Market vendors also provided samples, with 50 ml milk being collected from thoroughly mixed milk batches sold at the markets.

Questionnaire Survey

A structured questionnaire survey was conducted to evaluate factors believed to influence the hygienic quality of bulk milk. Farm owners were interviewed regarding their personal information, including milking hygiene, cleaning of equipment, animal healthcare, and milk storage practices. Farmers were asked to provide detailed accounts of their milking procedures and whether they received veterinary support. The questionnaires also included sections on farmers' awareness

of milk-borne pathogens and their knowledge of best practices for ensuring milk quality [20].

The questionnaires were designed based on previous studies that evaluated farming practices in smallholder dairy systems in sub-Saharan Africa. Responses were coded and analyzed using descriptive statistics to identify trends in hygiene practices and their correlation with bacterial contamination in milk. The data were also cross-referenced with the microbiological results to assess any direct relationships between certain practices (e.g., udder cleaning frequency, hand-washing before milking) and contamination levels.

Enumeration of Contaminating Bacteria

Milk samples were cultured to assess milk quality indicators, including total bacterial count (TBC), coliform count (CC). Sample preparation was conducted following the International Organization for Standardization protocol (ISO 8261:2001). A tenfold serial dilution of milk was conducted by transferring 1 ml of the previous dilution into 9 ml of 0.1% peptone water, followed by vortex mixing. One millilitre of milk was removed from the final dilution. Samples were serially diluted to 10^{-8} for TBC and 10^{-6} for CC.

TBC was quantified on plate count agar (HiMedia Ltd., Mumbai, India) following ISO 4833:2003, whereas CC was assessed on violet red bile agar (HiMedia Ltd., Mumbai, India) following ISO 4832:2006, utilizing the pour plate method in both instances. One hundred microliters of serially diluted milk were aseptically withdrawn from each dilution using a micropipette and plated with 15 - 20 ml of plate count agar and violet red bile agar, which were maintained at 47˚C in a water bath. Following comprehensive mixing through rotation, the plated samples were permitted to solidify and subsequently incubated aerobically at 37˚C for a duration of 24 - 48 hours. Colonies between 30 - 300 on each TBC and CC plate were counted to determine the colony forming unit (CFU) in 1 ml of the milk sample.

Colonies on plate count agar and violet bile red agar, showing various morphologies, were carefully selected and purified on nutrient agar (NA) for Gram stain and identification. Pure bacterial isolates were identified by Matrix-Assisted Laser Desorption Ionization-Time of Flight Mass spectrometry (MALDI-TOF MS) (Bruker, Biotyper 3, Germany). A pure overnight colony of an isolate on NA was directly applied to a MALDI-TOF target plate with a wooden applicator and air dried. 1 µL of a 10 mg/mL matrix solution (α-cyano-4-hydroxycinnamic acid, CHCA) was added to the target spot and allowed to air dry. The target plate was then placed into a MALDITOF vacuum chamber (Bruker, Biotyper 3.1 Software, Germany) for identification and results interpreted according to the manufacturer's guidelines as follows: Species-level identifications were rated as credible with a score of 2.3 or higher, plausible with a score of 2.0 - 2.29, possible at the genus level with a score of 1.7 - 1.9, and deemed unreliable with a score of 1.7 or lower.

3. Results

Demographic Data of Farmers and Vendors

This research involved interviews with the owners of 40 selected farms and 10 vendors. In the majority of study farms, dairy cows were managed intensively, accounting for 74% of cases. Hand milking was universally practiced on farms, with cows being milked bi-daily, in the morning and evening. Seventy percent of the dairy farmers surveyed reported consuming raw milk. A significant proportion of respondents (84.1%) lack formal training in hygienic milk production practices. The practice of using towels for udder drying was observed among only 12% of dairy farmers, with a single towel employed for multiple cows. A significant proportion of farmers (87%) utilized plastic containers for the purposes of milking and milk storage. Milking was conducted by a family member on 87% of farms, whereas 13% employed hired milkers. The study indicates that farmers predominantly engaged in hand milking, with no reference to mechanized milking practices. Hygienic practices exhibited inconsistency, as only 5.26% of farmers consistently washed their hands and the udders of cows before milking. Furthermore, 55.26% of farmers indicated that they accessed veterinary services occasionally, specifically 3 to 5 times per year, highlighting a significant lack of regular veterinary care among the majority. All dairy farmers participated in teat washing, though insufficiently, without employing detergent, and rinsed their hands with the same water used for teat cleaning. Farmers did not utilize antiseptic teat dipping before or after milking, nor did they adopt fore-stripping practices. The demographic analysis revealed that the majority of farmers were aged between 21 and 50 years, with 84.21% lacking formal education. In contrast, vendors predominantly fell within the age bracket of 36 to 45 years, with 70% lacking formal education, and all obtained their milk directly from local dairy farmers. Vendors sourced milk from an average of 1 to 3 local dairy farms. All vendors indicated that they washed containers before use; however, only 40% employed hot water and soap in the process (Table 1).

Table 1. Characteristics of Farmers and Vendors included in the study.

Variable	Farmers (%)
Age Distribution	
15 - 20	15.79
21 - 25	21.05
26 - 30	5.26
31 - 35	13.16
36 - 40	7.89
41 - 45	7.89
46 - 50	2.63
51 - 55	5.26
56 - 60	5.26
60+	15.79

Continued

Education Level	
No Formal Education	84.21
Primary Education	15.79
Hygiene Practice	
Clean udder before milking (Always)	5.26
Clean udder before milking (Sometimes)	26.32
Wash hands with soap (Always)	5.26
Wash hands with soap (Sometimes)	15.79
Veterinary Visits	
Rarely (1 - 2 times/year)	34.21
Occasionally (3 - 5 times/year)	55.26
Regularly (More than 5 times/year)	10.53

Microbiological Quality of Bulk Milk

The Total bacteria count (TBC) in farm bulk milk varied from 2.71 log cfu/ml (8.11×10^2) to 7.50 log cfu/ml (3.50×10^7), with a geometric mean of 5.25 log cfu/ml (1.79×10^5). Colony Count (CC) varied from no coliform growth to 5.21 log cfu/ml (1.6×10^5), with a geometric mean of 3.1 log cfu/ml (1.25×10^3). Ninety-two percent of bulk milk samples had coliform growth. According to the European Commission, the standard limits for raw cow's milk intended for direct human consumption are, $<10^5$ cfu/ml, $<10^2$ cfu/ml. Accordingly, most of the farms had TBC, and CC counts, respectively, that exceeded the acceptable limits. This study investigates the bacterial diversity in milk, focusing on pathogens, commensals, and zoonotic agents. A total of 42 distinct bacterial pathogens were identified across multiple categories, including emerging and traditional pathogens. The findings provide a comprehensive overview of the microbial species present, highlighting potential risks to food safety and public health. Though *E. coli* and *Bacillus cereus*, were detected in significant numbers; emerging pathogens such as *Stenotrophomonas maltophilia* and *Macrococcus canis*, that pose a newer risk in dairy production were also detected. These pathogens are known to cause gastrointestinal infections in humans if ingested through contaminated milk. In addition, the presence of *Klebsiella pneumoniae* (10%) and *Pseudomonas aeruginosa* (6.7%) represents significant zoonotic threats. These bacteria can be transmitted from animals to humans, potentially causing severe respiratory and urinary infections. Naturally occurring bacteria such as *Macrococcus caseolyticus* were identified. While these commensal bacteria typically do not cause harm, their presence may indicate environmental contamination or insufficient cleaning protocols during milking. Bacteria such as *Erwinia sp.* and *Ralstonia mannitolilytica* were detected in a few samples (**Figure 1**). These pathogens are not typically associated with milk contamination and may have been introduced through poor hygiene or environmental contamination during handling.a strong negative correlation was found between hygiene practices and bacterial contamination rates. The Pearson correlation coeffi-

cient was calculated at r = −0.89, with a p-value of 0.0012, indicating a statistically significant relationship ($p < 0.05$). This result shows that improved hygiene practices, such as regular udder cleaning and handwashing, are strongly associated with lower contamination rates in milk. Specifically, farms with higher hygiene scores demonstrated notably lower contamination rates, underscoring the importance of maintaining clean milking environments. Generally, contamination rates are lower in farm-sourced milk, with the average contamination rate across all pathogens being 17%. This suggests that milk sourced directly from farms, where better hygiene and handling practices may be in place, exhibits reduced contamination. In contrast, vendor samples show significantly higher contamination rates, averaging 33.6%. This is likely due to additional handling, transportation, and storage factors that contribute to higher pathogen growth.

Pathogens like *Escherichia coli* and *Bacillus cereus*, both commonly associated with milk contamination, showed notably higher contamination rates in vendor samples (39% and 32%, respectively) compared to farm samples (15% and 13%, respectively) (Figure 2).

Pathogen Contamination Rates Comparison of Farm and Vendor Samples

In comparing contamination rates between vendor and farm samples, vendor-sourced milk consistently exhibited higher levels of contamination across all measured pathogens. The **mean contamination rate** for farm samples was **17.0%**, while vendor samples showed a significantly higher mean contamination rate of **33.6%**. This disparity highlights the elevated risk of contamination in vendor milk, likely due to additional handling, transportation, and storage processes that may contribute to bacterial growth.

Specific pathogens further illustrate these differences. For instance, contamination with *Escherichia coli* was significantly higher in vendor samples (**39%**)

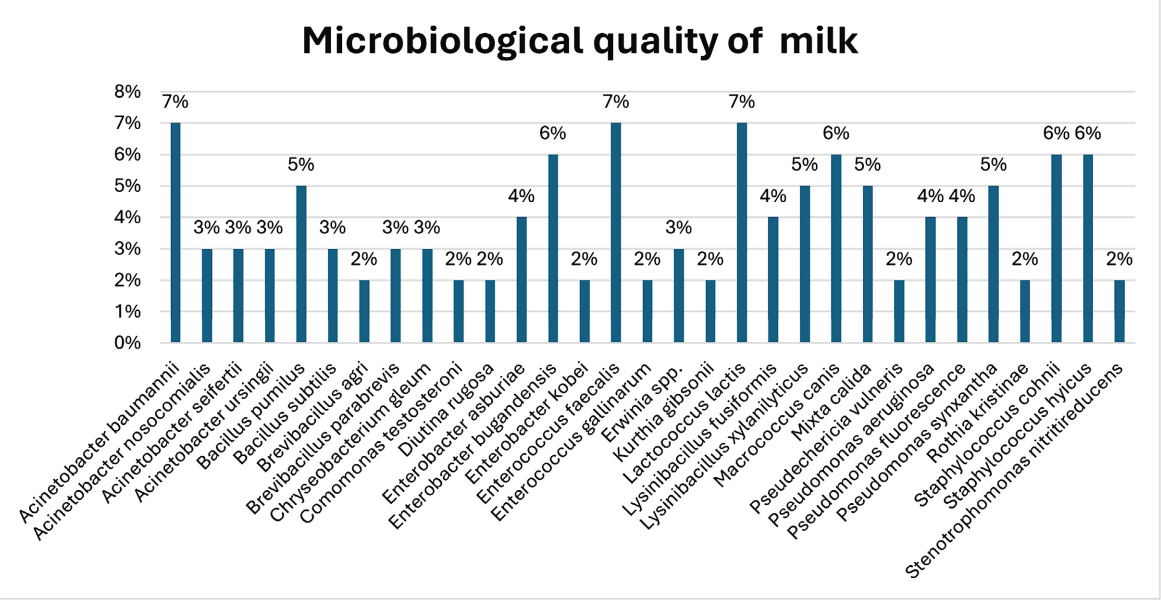

Figure 1. Microbiological quality of milk.

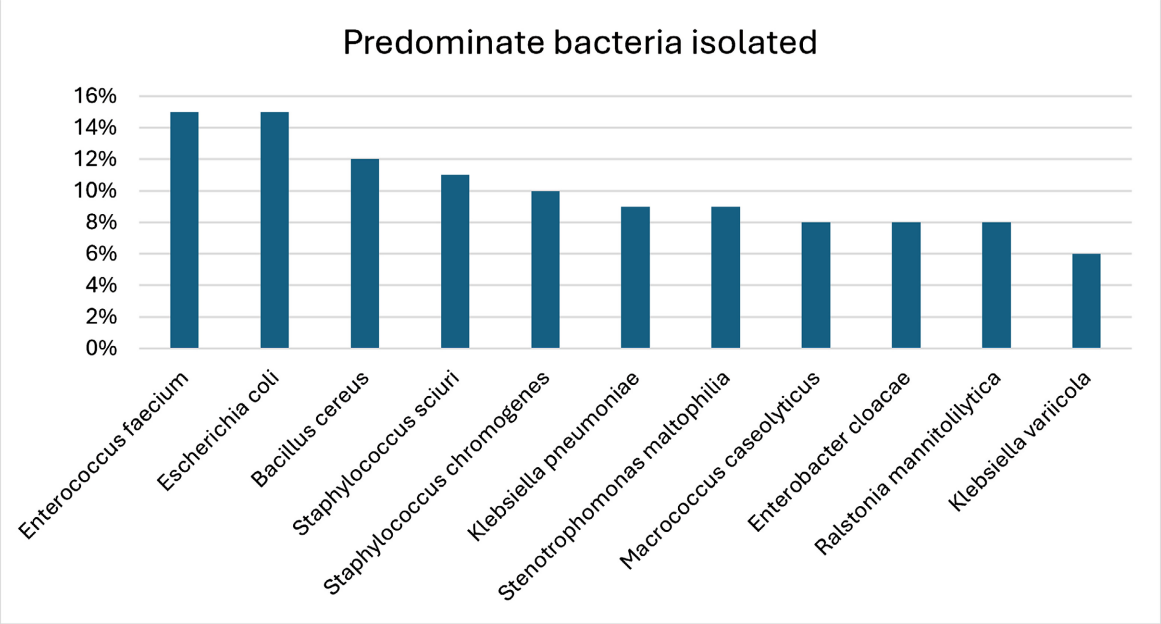

Figure 2. Predominate bacteria isolated.

compared to farm samples (**15%**), suggesting that post-farm handling is a critical factor in controlling the spread of this pathogen. Similarly, *Bacillus cereus* contamination was **32%** in vendor samples, more than double the **13%** rate observed in farm samples (Figure 3). These findings emphasize the need for stricter hygiene controls, particularly in the stages after milk leaves the farm. Overall, the analysis confirms that vendor milk is more likely to be contaminated, posing a greater

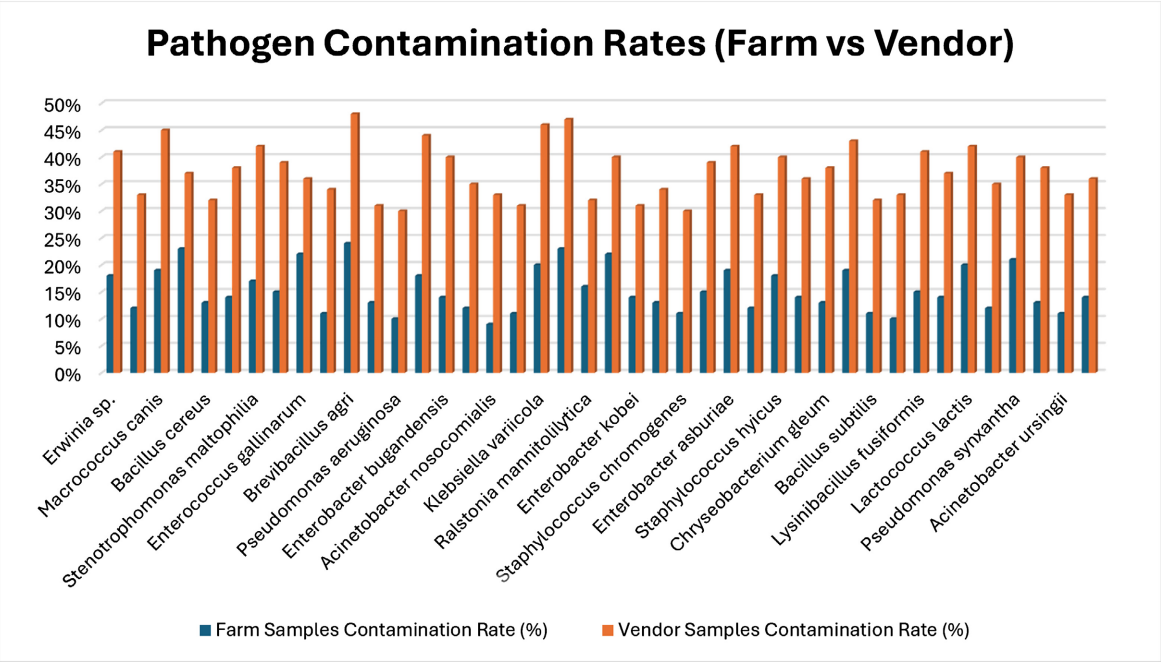

Figure 3. Pathogen contamination rates (farm vs vendor).

public health risk. The statistical significance of these findings is supported by **p-values less than 0.05** for all pathogen comparisons, reinforcing the validity of the observed differences. These results demonstrate the critical role of hygiene practices in mitigating contamination and the importance of improving milk handling and storage practices, especially in market settings.

4. Discussion

This study identified 42 distinct bacterial pathogens from raw milk samples collected from both farm and vendor sources. These pathogens were categorized into *emerging*, *commensal*, and *zoonotic* pathogens, with contamination levels varying significantly between the two sample sources. The overall findings reveal critical insights into the role of hygiene practices and their relationship with bacterial contamination rates.

A significant negative correlation was observed between hygiene practices and contamination rates, as indicated by a Pearson correlation coefficient (r) of −0.89 and a p-value of 0.0012. These results suggest that improved hygiene practices, such as udder cleaning, handwashing, and equipment sterilization, were associated with lower bacterial contamination rates. This finding is consistent with previous studies conducted in sub-Saharan Africa, where similar correlations between poor hygiene and high contamination rates were observed in raw milk samples [2] [6]. Abebe *et al.* demonstrated that milk sourced from farms with inadequate hygiene practices exhibited higher contamination rates compared to farms implementing better hygiene controls. Another study by [21] in Ethiopia supports the association between hygiene and contamination, emphasizing that improper cleaning and milking techniques are primary contributors to microbial presence in raw milk.

However, the strong correlation observed in this study is higher than that reported [3], which found a moderate relationship between hygiene and contamination levels in milk collected from small scale dairy farms in Botswana. This discrepancy may be attributed to differences in the sample size, study design, or regional variations in farming and handling practices.

The comparison of contamination rates between vendor and farm samples revealed substantial differences. Vendor samples showed significantly higher contamination levels, with a mean contamination rate of 33.6%, compared to 17% in farm samples. This finding is consistent with earlier studies that highlight the risks associated with post-farm milk handling and storage. For example, [5] demonstrated that vendor-sourced milk, particularly in informal markets, is often subjected to poor storage conditions, leading to increased bacterial growth. Specific pathogens, such as Escherichia coli, were found at contamination rates of 39% in vendor samples and 15% in farm samples, a significant increase that suggests improper handling and storage after collection. Bacillus cereus showed similar trends, with vendor contamination rates of 32% compared to 13% in farm samples. These results align with findings from [6], which emphasized that contamination during transportation and marketing significantly increases microbial load in milk.

The detection of zoonotic pathogens, such as *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*, in vendor samples raises significant public health concerns. Previous studies [22] have identified similar risks associated with the consumption of unpasteurized milk in urban markets. These pathogens, when present in contaminated milk, can lead to severe infections, particularly in immunocompromised individuals. The study also identified emerging pathogens like *Stenotrophomonas maltophilia*, which, while not commonly associated with milk contamination, pose a potential risk due to their resistance to antibiotics, as noted in global reviews of emerging foodborne pathogens [23] [24].

The findings of this study on milk contamination align with and expand upon previous research conducted in sub-Saharan Africa and other regions. The identification of 42 distinct bacterial pathogens, including emerging and zoonotic pathogens, underscores the complexity of milk contamination in rural and urban dairy systems. Notably, vendor-sourced milk showed higher contamination rates, which is consistent with previous studies, but the presence of specific pathogens in this study provides novel insights into the region's public health challenges. In this study, pathogens such as *Klebsiella pneumoniae*, *Stenotrophomonas maltophilia*, and *Pseudomonas aeruginosa* were identified, contributing to the growing body of evidence regarding the presence of zoonotic and emerging pathogens in dairy products. The detection of *Stenotrophomonas maltophilia* is particularly important, as this pathogen has been less commonly reported in milk contamination studies. Its identification in our samples suggests potential antibiotic resistance concerns, as it has been documented in clinical settings for its resistance to multiple drug classes [25]. The presence of *Pseudomonas aeruginosa*, another opportunistic pathogen, aligns with findings from previous research in Tanzania, where this bacterium was identified as a major contaminant in vendor-sourced milk, posing severe health risks, especially in immunocompromised populations [25]. Additionally, the high prevalence of *Klebsiella pneumoniae* in vendor samples (15%) compared to farm samples (8%) reflects similar results reported by [8] in West Africa, where zoonotic pathogens were found in milk sold in informal markets. These findings are significant due to the pathogen's ability to cause both respiratory and gastrointestinal infections in humans [8]. However, unlike some previous studies that primarily focused on traditional bacterial contaminants like *Escherichia coli* and *Staphylococcus aureus*, this study highlights the growing risk posed by emerging pathogens that may be evolving in response to changing environmental and farming practices.

Previous research, particularly by [26], found contamination levels of Escherichia coli in raw milk to be similar to our findings, with contamination rates of 39% in vendor samples and 15% in farm samples. These results suggest that the E. coli contamination observed in informal milk markets is not an isolated phenomenon and supports the need for improved hygiene standards across the dairy value chain. In contrast, studies by [2] in Ethiopia reported slightly lower rates of *Bacillus cereus* contamination in farm samples, but our findings of 32% in vendor milk

highlight the added risks associated with improper storage and handling beyond the farm gate.

One key area where this study diverges from previous findings is the identification of *Stenotrophomonas maltophilia*, which has not been commonly reported in milk contamination studies in sub-Saharan Africa. This may reflect the evolving microbial landscape in dairy systems due to changes in climate, antibiotic use, or farming practices. Future research is needed to further investigate the environmental drivers contributing to the rise of such pathogens in milk.

This study found a significant negative correlation between hygiene practices and bacterial contamination rates, as demonstrated by a Pearson correlation coefficient (r) of −0.89 and a p-value of 0.0012. These findings underscore the critical importance of basic hygiene interventions, such as handwashing, udder cleaning, and equipment sterilization, in reducing contamination levels. Similar results have been reported in studies across sub-Saharan Africa, emphasizing the role of good hygiene practices in dairy farming [27]. Implementing several hygiene interventions can substantially lower contamination rates. For instance, regular handwashing by dairy farmers and vendors can prevent the transfer of pathogens like *Escherichia coli* and *Bacillus cereus* from handlers to milk. A study by [28] found that farms that implemented handwashing protocols saw a 30% reduction in bacterial contamination. Similarly, cleaning udders before milking has been shown to reduce contamination from environmental pathogens, particularly in regions where cows are housed in unsanitary conditions. Research from [29] demonstrated that cleaning udders with sanitized water before milking reduced bacterial loads by 40%, significantly lowering the presence of zoonotic pathogens in milk samples. Sterilizing equipment is another critical factor in maintaining milk quality. Studies in Kenya [29] have shown that proper sterilization of milking buckets and containers can lead to a 25% reduction in contamination rates. This supports the findings of the present study, where farms that adhered to better equipment cleaning practices exhibited lower contamination levels compared to vendors, where such practices were often lacking.

Our results are consistent with findings from several key studies in the region. For example, [30] reported a moderate correlation between hygiene practices and contamination rates, though the strength of the correlation in our study was higher, likely due to the more rigorous hygiene monitoring employed. [30] also found that hygiene interventions, when properly implemented, could cut contamination by nearly half. However, they noted that these practices were often not consistently applied, particularly in vendor-sourced milk. Overall findings strongly support the need for enhanced hygiene education and infrastructure investments to improve milk safety. This is particularly crucial in vendor milk, where contamination rates were substantially higher due to inadequate post-farm handling and storage.

The identification of zoonotic and emerging pathogens in this study highlights critical public health risks associated with milk consumption, particularly in rural and urban areas where unpasteurized milk is prevalent. Several pathogens identi-

fied in this study, such as *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Stenotrophomonas maltophilia*, are known to cause severe infections and are increasingly resistant to antibiotics.

Pseudomonas aeruginosa, an opportunistic pathogen, was found at contamination rates of 12% in vendor samples and 5% in farm samples. This bacterium thrives in moist environments, often contaminating milk due to inadequate cleaning of storage containers and milking equipment. A study from Kenya, [24] identified *P. aeruginosa* as a major contaminant in vendor milk, particularly where there is poor milk handling and transportation infrastructure. *Stenotrophomonas maltophilia* (9% in vendor milk) represents an emerging concern in dairy safety. This pathogen is recognized for its resistance to multiple antibiotics and has been increasingly identified in foodborne outbreaks. A study by [13] documented the rising presence of *S. maltophilia* in milk products, underscoring the need for improved detection methods. Unlike more common contaminants, *S. maltophilia* poses a unique threat due to its persistence in biofilms and its ability to survive in diverse environments.

The substantial difference in contamination levels between vendor and farm milk observed in this study is consistent with findings from other regions. Vendor milk exhibited a mean contamination rate of 33.6%, compared to 17% in farm milk, highlighting the challenges posed by post-farm handling practices. Several Factors could account for the high Contamination in Vendor Milk including Increased Handling; inadequate Storage and environmental Exposure: Vendor milk is often exposed to environmental contaminants, including dust and water, particularly in informal markets.

Practical interventions to reduce contamination include providing vendors with access to refrigerated storage and education on proper hygiene practices. [14] highlighted the success of community training programs in reducing contamination by promoting basic hygiene protocols, such as cleaning containers and avoiding direct hand contact with milk. Additionally, stricter regulatory oversight could ensure that milk sold at markets adheres to minimum safety standards, reducing the incidence of contamination-related illnesses.

The presence of antibiotic residues in 35% of the milk samples, particularly in vendor-sourced milk, raises significant concerns about the misuse of antibiotics in dairy farming. Antibiotic residues in food products are linked to the development of antibiotic-resistant bacteria, which poses a growing threat to global public health [25].

The consumption of milk containing antibiotic residues can cause a range of adverse health effects, including allergic reactions and disruptions to the human microbiome. A study by Olusola *et al.* (2021) found that exposure to antibiotic residues, even at low levels, contributes to the selection of resistant bacterial strains in humans. In regions where unpasteurized milk is commonly consumed, this risk is amplified, as pasteurization significantly reduces the presence of antibiotic residues.

The levels of antibiotic residues found in this study exceed the thresholds set by

the Codex Alimentarius Commission, which establishes maximum residue limits for food products. Improved veterinary oversight and stricter enforcement of antibiotic withdrawal periods are essential to ensure that milk entering the market complies with these safety standards [24]. Regular monitoring of milk for antibiotic residues, particularly at vendor collection points, would help safeguard public health and prevent the sale of contaminated products.

Limitations of the Study

While this study provides valuable insights into milk contamination in rural and urban settings, there are several limitations that must be acknowledged. Addressing these limitations in future research will enhance the precision and generalizability of findings.

1) Sample Size and Geographical Scope

The sample size in this study, although sufficient for initial insights, was relatively small and geographically limited to specific regions. This restricts the ability to generalize the findings across a wider population. In regions with varied dairy practices, such as those found across sub-Saharan Africa, larger and more diverse sample sets are necessary to capture the full spectrum of contamination risks.

2) Reliance on Self-Reported Data

This study relied on self-reported data from farmers and vendors regarding hygiene practices and milk handling. Such data are susceptible to biases, including exaggerated reports of hygiene standards. Self-reported measures often do not capture the actual behavior, which could impact the contamination levels observed. Future studies should consider using direct observations or digital monitoring systems to ensure the accuracy of reported hygiene practices.

Addressing Limitations

Future studies should aim to:

- Increase sample sizes and cover a broader geographic range to improve the representativeness of the findings.
- Utilize observational and digital monitoring methods to reduce reliance on self-reported data.

Recommendations for Future Research

The findings of this study highlight several areas that warrant further exploration. Future research should aim to fill gaps in understanding the long-term public health implications of milk contamination and the role of environmental and farming practices in shaping pathogen prevalence.

1) Long-term Impact of Pathogens on Public Health

The long-term health implications of milkborne pathogens, particularly those identified in this study, remain underexplored. Research into the persistence of pathogens like *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Stenotrophomonas maltophilia* in the food chain and their impact on human health is critical. Studies should focus on how chronic exposure to these pathogens through contaminated milk contributes to public health burdens such as antibiotic resistance and gastrointestinal diseases [31]-[33].

2) Impact of Environmental and Farming Practices on Pathogen Prevalence

Environmental factors, such as climate change and unsanitary farming conditions, play a significant role in pathogen prevalence. Future research should investigate how changing environmental conditions, including shifts in temperature and rainfall, influence microbial growth and contamination risks in dairy products. Additionally, studies should explore how different farming practices, such as the use of antibiotics and animal management techniques, affect pathogen dynamics.

3) Exploration of Mitigation Strategies

Research should also explore innovative mitigation strategies, such as the use of probiotics in dairy farming or improved veterinary oversight, to reduce contamination levels in milk. Probiotic interventions, which have shown success in improving gut health in livestock, could be tested for their effectiveness in reducing pathogen shedding in dairy cows, thereby lowering contamination risks.

5. Conclusions

This study provides critical insights into the role of hygiene practices and milk handling in bacterial contamination, particularly in vendor-sourced milk. The findings underscore the need for enhanced hygiene protocols, better post-harvest handling practices, and stricter regulatory oversight to improve milk safety.

The identification of *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Stenotrophomonas maltophilia* in milk samples raises significant public health concerns, particularly in regions where unpasteurized milk is widely consumed. These pathogens, especially when found in antibiotic-resistant forms, pose serious risks to consumers, emphasizing the need for stronger interventions in milk production and distribution.

Recommendations for Policymakers, Farmers, and Vendors

1) For Policymakers: Implement stricter food safety regulations and ensure regular monitoring of milk at collection points and markets. Enforcing compliance with hygiene standards will help reduce contamination levels and protect consumers.

2) For Dairy Farmers: Adopting better hygiene practices during milking, such as udder cleaning and equipment sterilization, will significantly reduce contamination risks. Farmers should also be educated on the responsible use of antibiotics to prevent residue contamination.

3) For Vendors: Proper milk storage and transportation are essential to preventing contamination. Vendors should be provided with access to refrigerated storage and trained in best practices for milk handling.

By addressing these critical areas, milk safety can be improved, reducing the risk of milkborne diseases and protecting public health.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ayele, Y., Gutema, F.D., Edao, B.M., Girma, R., Tufa, T.B., Beyene, T.J., *et al.* (2017) Assessment of *Staphylococcus aureus* along Milk Value Chain and Its Public Health Importance in Sebeta, Central Oromia, Ethiopia. *BMC Microbiology*, **17**, Article No. 141. https://doi.org/10.1186/s12866-017-1048-9

[2] Leone, C., Thippareddi, H., Ndiaye, C., Niang, I., Diallo, Y. and Singh, M. (2022) Safety and Quality of Milk and Milk Products in Senegal—A Review. *Foods*, **11**, Article No. 3479. https://doi.org/10.3390/foods11213479

[3] Xulu, N. and Naidoo, K. (2023) Traditional Milking Hygiene Practices and Their Effect on Raw Milk Quality of Rural Small-Scale Dairy Farmers in Kwa-Hlabisa, Kwazulu-Natal, South Africa. *African Journal of Inter/Multidisciplinary Studies*, **5**, 1-13. https://doi.org/10.51415/ajims.v5i1.1127

[4] Dairy World (2022) A Developing Dairy Industry in Ghana. https://www.dairyglobal.net/industry-and-markets/a-developing-dairy-industry-in-ghana/

[5] Msalya, G. (2017) Contamination Levels and Identification of Bacteria in Milk Sampled from Three Regions of Tanzania: Evidence from Literature and Laboratory Analyses. *Veterinary Medicine International*, **2017**, Article ID 9096149. https://doi.org/10.1155/2017/9096149

[6] Knight-Jones, T., Hang'ombe, M., Songe, M., Sinkala, Y. and Grace, D. (2016) Microbial Contamination and Hygiene of Fresh Cow's Milk Produced by Smallholders in Western Zambia. *International Journal of Environmental Research and Public Health*, **13**, Article No. 737. https://doi.org/10.3390/ijerph13070737

[7] Berhe, G., Wasihun, A.G., Kassaye, E. and Gebreselasie, K. (2020) Milk-Borne Bacterial Health Hazards in Milk Produced for Commercial Purpose in Tigray, Northern Ethiopia. *BMC Public Health*, **20**, Article No. 894. https://doi.org/10.1186/s12889-020-09016-6

[8] Grace, D., Wu, F. and Havelaar, A.H. (2020) MILK Symposium Review: Foodborne Diseases from Milk and Milk Products in Developing Countries—Review of Causes and Health and Economic Implications. *Journal of Dairy Science*, **103**, 9715-9729. https://doi.org/10.3168/jds.2020-18323

[9] Song, J., Xiang, W., Wang, Q., Yin, J., Tian, T., Yang, Q., *et al.* (2023) Prevalence and Risk Factors of Klebsiella Spp. in Milk Samples from Dairy Cows with Mastitis—A Global Systematic Review. *Frontiers in Veterinary Science*, **10**, Article ID: 1143257. https://doi.org/10.3389/fvets.2023.1143257

[10] Raza, A.S., Sial, A.U.R., Humayun, A., Rahim, M.F. and Khayam, U. (2023) Antimicrobial Resistance and Zoonotic Pathogens. In: Altaf, S., Khan, A. and Abbas, R.Z., Eds., *Zoonosis*, Vol. 4, Unique Scientific Publishers, 241-250. https://doi.org/10.47278/book.zoon/2023.150

[11] Amentie, T., Eshetu, M., Mekasha, Y. and Kebede, A. (2016) Milk Postharvest Handling Practices across the Supply Chain in Eastern Ethiopia. *Journal of Advanced Veterinary and Animal Research*, **3**, 112-126. https://doi.org/10.5455/javar.2016.c139

[12] Gidiglo, K.F. (2014) Milk Production and Marketing in Ghana: The Case of Accra Plains. *Journal of Biology, Agriculture and Healthcare*, **4**, 60-64.

[13] Addo, K.K., Mensah, G.I., Aning, K.G., Nartey, N., Nipah, G.K., Bonsu, C., *et al.* (2010) Microbiological Quality and Antibiotic Residues in Informally Marketed Raw Cow Milk within the Coastal Savannah Zone of Ghana. *Tropical Medicine & International Health*, **16**, 227-232. https://doi.org/10.1111/j.1365-3156.2010.02666.x

[14] Ministry of Food and Agriculture (MOFA) (2018) Northern Ghana Agricultural Sector Review. MOFA Report.

[15] Adzitey, F., Asiamah, P. and Boateng, E.F. (2020) Prevalence and Antibiotic Susceptibility of *Salmonella enterica* Isolated from Cow Milk, Milk Products and Hands of Sellers in the Tamale Metropolis of Ghana. *Journal of Applied Sciences and Environmental Management*, **24**, Article No. 59. https://doi.org/10.4314/jasem.v24i1.8

[16] FAO (2015) Dairy Development in West Africa. Food and Agriculture Organization of the United Nations.

[17] Swai, E. and Schoonman, L. (2011) Microbial Quality and Associated Health Risks of Raw Milk Marketed in the Tanga Region of Tanzania. *Asian Pacific Journal of Tropical Biomedicine*, **1**, 217-222. https://doi.org/10.1016/s2221-1691(11)60030-0

[18] Mensah, G.I., Vicar, E.K., Feglo, P.K., Acquah, S.E.K., Saba, C.S.K., Addo, S.O., *et al.* (2019) Bacteriological Quality and Antibiotic Residues in Raw Cow Milk at Producer Level and Milk Products at Sale Points in the Northern Region of Ghana. *International Journal of Tropical Disease & Health*, **34**, 1-10. https://doi.org/10.9734/ijtdh/2018/46626

[19] Zeinhom, M.M.A., Hassan, G.M., Salem, H.A.M. and Corke, H. (2021) Prevalence and Survival of Stenotrophomonas Species in Milk and Dairy Products in Egypt. *Foodborne Pathogens and Disease*, **18**, 337-345. https://doi.org/10.1089/fpd.2020.2893

[20] Majalija, S., Tumwine, G., Kiguli, J., Bugeza, J., Ssemadaali, M.A., Kazoora, H.B., *et al.* (2020) Pastoral Community Practices, Microbial Quality and Associated Health Risks of Raw Milk in the Milk Value Chain of Nakasongola District, Uganda. *Pastoralism*, **10**, Article No. 3. https://doi.org/10.1186/s13570-020-0158-4

[21] Jeena, S., Venkateswaramurthy, N. and Sambathkumar, R. (2020) Antibiotic Residues in Milk Products: Impacts on Human Health. *Research Journal of Pharmacology and Pharmacodynamics*, **12**, 15-20. https://doi.org/10.5958/2321-5836.2020.00004.x

[22] Lister, P.D., Wolter, D.J. and Hanson, N.D. (2009) Antibacterial-Resistant *Pseudomonas aeruginosa*: Clinical Impact and Complex Regulation of Chromosomally Encoded Resistance Mechanisms. *Clinical Microbiology Reviews*, **22**, 582-610. https://doi.org/10.1128/cmr.00040-09

[23] WHO (2020) Antibiotic Resistance: Fact Sheet. World Health Organization.

[24] FAO/WHO (2019) Codex Alimentarius Commission: Guidelines for Antibiotic Residues in Food. FAO/WHO Report, CA7998EN.

[25] Al Sidawi, R., Urushadze, T. and Ploeger, A. (2021) Factors and Components Affecting Dairy Smallholder Farmers and the Local Value Chain—Kvemo Kartli as an Example. *Sustainability*, **13**, Article No. 5749. https://doi.org/10.3390/su13105749

[26] Asrat, D., Hiko, A. and Zewde, G. (2008) Occurrence of *Escherichia coli* O157:H7 in Retail Raw Meat Products in Ethiopia. *The Journal of Infection in Developing Countries*, **2**, 389-293. https://doi.org/10.3855/jidc.203

[27] Rechidi-Sidhoum, N., Dahou, A.A., Tahlaiti, H., Benameur, Q. and Homrani, A. (2021) Assessment of the Sanitary and Hygienic Quality of Raw Milk Marketed in the Urban Area of Mostaganem, Algeria. *Asian Journal of Dairy and Food Research*, **40**, 345-348. https://doi.org/10.18805/ajdfr.dr-231

[28] Mogotu, M.W., Abong, G.O., Mburu, J. and Ndambi, O.A. (2022) Assessment of Hygiene Practices and Microbial Safety of Milk Supplied by Smallholder Farmers to Processors in Selected Counties in Kenya. *Tropical Animal Health and Production*, **54**, Article No. 220. https://doi.org/10.1007/s11250-022-03214-7

[29] Zavala Nacul, H. and Revoredo-Giha, C. (2022) Food Safety and the Informal Milk Supply Chain in Kenya. *Agriculture & Food Security*, **11**, Article No. 8. https://doi.org/10.1186/s40066-021-00349-y

[30] Nyokabi, S., *et al.* (2020) Hand Milking Practices and Microbial Contamination of Raw Milk in Rwanda: A Cross-Sectional Study. *BMC Public Health*, **20**, Article No. 1675.

[31] Alhaji, N.B., Aliyu, M.B., Ghali-Mohammed, I. and Odetokun, I.A. (2019) Survey on Antimicrobial Usage in Local Dairy Cows in North-Central Nigeria: Drivers for Misuse and Public Health Threats. *PLOS ONE*, **14**, e0224949. https://doi.org/10.1371/journal.pone.0224949

[32] Rangel, J.M., Sparling, P.H., Crowe, C., Griffin, P.M. and Swerdlow, D.L. (2005) Epidemiology of *Escherichia coli* O157:H7 Outbreaks, United States, 1982-2002. *Emerging Infectious Diseases*, **11**, 603-609. https://doi.org/10.3201/eid1104.040739

[33] Oliver, S.P., Jayarao, B.M. and Almeida, R.A. (2005) Foodborne Pathogens in Milk and the Dairy Farm Environment: Food Safety and Public Health Implications. *Foodborne Pathogens and Disease*, **2**, 115-129. https://doi.org/10.1089/fpd.2005.2.115