

Determinants of increased microbial contamination of milk among dairy farmers in Bugesera District, Rwanda

*^{1,2}SIBOMANA Ephrem, ¹Maurice B. Silali, ²Munyaneza Celestin, ²Munyampuhwe Severin, ²Bizimana Ferdinand

¹Department of Public Health, Mount Kenya University, Rwanda

²Rwanda Institute for Conservation Agriculture (RICA)

DOI: <https://doi.org/10.5281/zenodo.17454389>

Published Date: 27-October-2025

Abstract: This study explores the factors contributing to milk contamination, a continuing public health issue in developing countries. The research aimed to assess the prevalence of microbial contamination, hygienic and handling practices, milk quality testing methods, dairy feed management, and the knowledge, attitudes, and practices (KAP) of farmers regarding milk safety. A mixed-methods, cross-sectional design was used, involving 217 dairy farmers supplying milk in Bugesera District. Data were collected using surveys, interviews, and focus group discussions. Quantitative data were analyzed using descriptive statistics, Fisher's exact test, and odds ratios (OR) at a 95% confidence interval, while qualitative data were examined through content analysis. Ethical approval was obtained from Mount Kenya University and Bugesera District authorities. Findings revealed a 24% prevalence of milk contamination (n=52), significantly associated with poor hygiene practices (p=0.034). While 77.9% of farmers reported washing their hands and 71.9% cleaned udders before milking, the OR (3.7; 95% CI; p=0.0345) indicated these practices had a protective effect against contamination. Concerning feed hygiene, 52% stored feed properly, and 53% inspected it regularly, yet 68% were unaware of mycotoxin risks from fungal contamination. In milk quality testing, 33.6% relied on simple organoleptic assessments, whereas advanced tests like the California Mastitis Test (CMT) were conducted only at milk collection centers, with notable gaps in antibiotic residue and aflatoxin testing—posing significant health risks. The study also found that proper milk storage in aluminum containers reduced contamination (RR = 3.0–3.88; p=0.043), while plastic containers increased risk (OR = 4.1) due to poor sterilization and micro-cracks. Overall, the findings demonstrate that microbial contamination in milk is driven by inadequate hygiene practices, poor feed management, limited farmer knowledge, and insufficient milk testing procedures. The study recommends targeted farmer training to improve milk hygiene, feed safety, and diagnostic testing at both farm and milk collection center levels to ensure safe milk production and protect public health.

Keywords: Milk contamination, Safety, Hygiene Practice, Milk Testing, Mycotoxins, Antimicrobial resistance.

I. INTRODUCTION

Milk from dairy cows is a vital source of essential nutrients, including proteins, energy, minerals, and vitamins, which are crucial for growth, development, and tissue maintenance (Aliyo & Teklemariam, 2022). However, milk safety and quality can be significantly compromised by various biological and chemical contaminants arising from the complex interactions between animals, humans, and the environment, a concept addressed within the One Health framework. Contaminants found in dairy products, such as milk, can lead to various health issues in humans, including allergic reactions, weakened immune function, cancer, birth defects, genetic mutations, damage to genetic material and human antimicrobial resistance (Baydan et al., 2017). The risk of contamination mainly arises from the milking process, because the udders are exposed to external environmental conditions, along with poor sanitation of equipment, improper storage, unclean pipes, improper handling and preservation of animal feed, non-compliance with drug withdrawal periods, and other factors (Nyokabi et al., 2021). The research conducted in Tanzania regarding microbial quality of cow's milk and antimicrobial susceptibility indicated that

33.9% of respondents consume milk from animals that are under medication, 94.6% of them did not adhere to withdrawal periods raising significant public health concerns which is antimicrobial resistance.(Kanyeka.,2014)

Veterinary antibiotics, hormone treatments, agricultural pesticides, additives, heavy metals from processing and packaging, mycotoxins, and environmental pollutants poses significant risks to human health, potentially affecting both well-being and nutritional status (Claeys et al., 2014).According to WHO, 57500 illnesses occurred due to consumption of raw milk, 55deaths, and 3870 disability adjusted life year (Sapp et al., 2023).The reported proportion of contaminants were 22% of Chemical contaminants, 22.05 % of heavy metal, 22.05 of pesticides, 22.18% antibiotics and mycotoxin report in milk were 9.97% due to bad agriculture practices and livestock farm management. Mycotoxins are of greater importance as they are a source of carcinogenic substances (Calahorrano-Moreno et al., 2022).

Milk contaminated with aflatoxin poses severe health risks, including liver cancer, growth retardation in children, and immune suppression. Acute symptoms can involve nausea, vomiting, and liver injury, while long-term exposure is linked to hepatocellular carcinoma (a type of liver cancer) and other chronic complications. Children are especially vulnerable, with high exposure potentially leading to stunting and other developmental issues (Massahi et al., 2024). In Turkey, a study on antibiotic residues in milk, specifically tetracycline and streptomycin, revealed that 77.8% of the samples showed a positive result for streptomycin residues (Colak et al., 2007). These drug residues in animal products are known to cause serious health problems, including antibiotic resistance, allergic reactions, and even cancer. Pathogens that can be transmitted from animals to humans, like Brucella, Mycobacterium, and *E Coli*, may also be found in raw milk, posing further health hazards, particularly for groups at risk such as children, the elderly, and individuals with compromised immune systems (Mosalagae et al., 2011; Omore et al., 2004). Despite the recognized dangers, these contaminants are often difficult to detect and regulate, making them a major public health challenge. In Rwanda, the contamination of dairy products continues considered as a public health issue, as 85% of milk is sold through informal, unregulated markets, while only 15% is distributed via formal channels, this leads to a decline in milk quality.

II. METHODOLOGY

2.1 Study Design

This study employed a cross-sectional research design to assess key determinants contributing to milk contamination among dairy farmers in Bugesera District, Rwanda.

2.1 Target Population

The study population involved dairy farmers delivering milk in different milk Collection centers of Bugesera District.

2.3 Sample Size

For calculating the sample size, we used Fisher's formula (Fisher, 1998). For those working in the livestock industry and in veterinary medicine, this tool is invaluable for gauging the current and future health of a population and identifying potential problem areas. There are fewer than 10,000 households in the Bugesera district, so the formula was adjusted using a finite population adjustment formula to acquire the correct study sample size. The target population is 500, while the study population is less than 10,000. Fisher's formula states:

Fisher's Sample Size Formula:

$$n = \frac{Z^2 \cdot p \cdot (1-p)}{E^2}$$

n = sample size

Z = Z value (a standard normal variable corresponding to the desired confidence level)

p = estimated proportion of the population (0.5 is often used for maximum sample size)

E = margin of error (expressed as a decimal, 5% = 0.05)

$$n = \frac{1.96^2 \cdot 0.5 \cdot (1-0.5)}{(0.05)^2}$$

$$n = \frac{3.8416 \cdot 0.5 \cdot 0.5}{0.0025}$$

$$n = \frac{0.9604}{0.0025}$$

$$n = 384.16$$

Adjusted sample size

$$nf = \frac{n}{1 + \left(\frac{n}{N}\right)}$$

$$nf = \frac{384.16}{1 + \left(\frac{384.6}{500}\right)}$$

$$nf = \frac{384.16}{1.76832}$$

$$nf = 217$$

2.4 Sampling Technique

The study has utilized purposive sampling and convenient random sampling techniques to select participants with firsthand information from the target population, which consists of farmers supplying milk at milk collection Center.

2.5 Data Collection Instruments

This study utilized three primary data collection tools: a questionnaire with closed-ended questions, interviews, and documentary reviews.

III. RESULTS

3.1 Socio-Demographic Characteristics of Respondents

The study opined that the majority of gender respondents, 73% (158), were male, and a minority 27% (59) were female of the 217 respondents in the Bugesera District, with RR (0.2, 0.7), (0.37). Consistence gender protection in milk contamination



Figure 1: Gender Participation in Prevention and control of Milk products Contamination

The study showed that the most active age in the study was 67% (145), from the cohort of 35 to 55years and least cohort 16% (34) was from the age cohort of 23 to 35years consisting of mainly youth generations

3.2 Presentation of Findings

3.2.1 Prevalence of Milk Contamination in Bugesera Milk Collection Centers

The prevalence of milk contamination in Bugesera District, based on data from 217 farmers across five sectors, showed significant between sectors in both milk contamination and non-milk-related contamination experiences at milk collection centers (MCCs). Overall Prevalence of Milk Contamination was only 52, (24%) with significant P values of 0.034, milk farmers and were only associated with limited hygiene practices when handle milk for human consumption at the collecting center in the district. Such unclean cow pens, poor personal hygiene of milkers, and inadequate cleaning of milking equipment, many farmers were unaware that contamination could also result from residues of veterinary drugs administered to livestock or from pesticide and other agricultural input. Used for crops that can be used for feeding dairy cows.

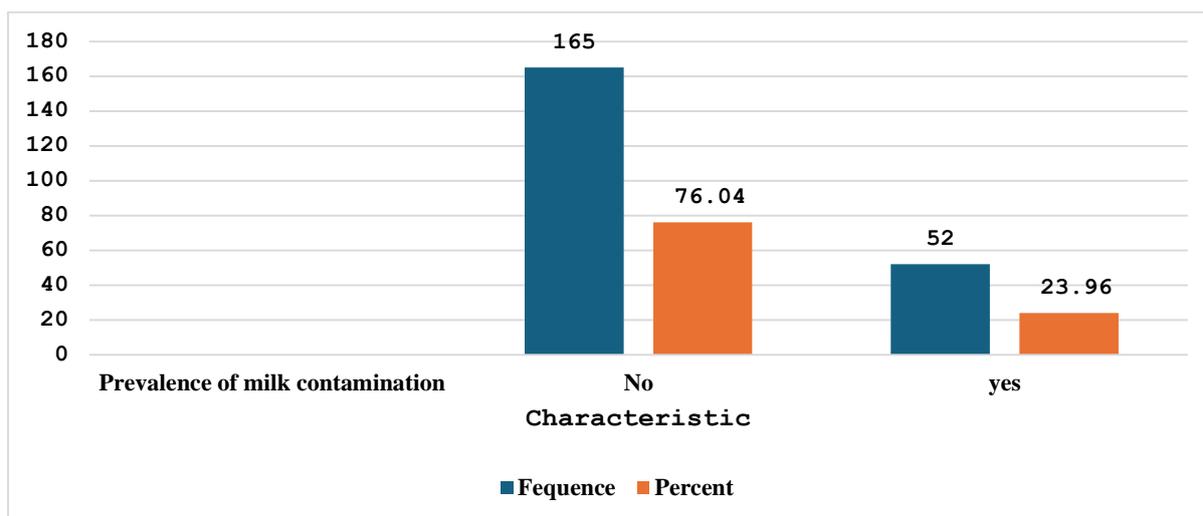


Figure 2: Prevalence of Milk Contamination in the study area

3.2.2 Hygienic practices used by Dairy farmers to control milk contamination in Bugesera District

The results indicate that while many farmers 169, (77.9%) wash their hands and clean the udder 156, (71.9%) before milking both crucial practices for maintaining milk hygiene there remains a notable proportion who do so inconsistently or not at all. About 22% of farmers either neglect or only occasionally wash their hands or clean udder, posing a contamination risk, RR (0.21, 0.78) OD (3.7) signify protective association of 95% CI, pvalue of 0.0345 but chance to contaminate rest of milk in collection being harmful because share same storage containers,

These was also seen during FGD discussion with farmers in who revealed that

“we usually adherence to standard hygienic protocols during milk production and handling was generally low. Due to several barriers such as; limited access to clean and safe water, financial constraints. Farmers expressed that they often could not afford detergents or sanitizing agents required for proper equipment cleaning, But the cost of purchasing appropriate milking containers, such as stainless-steel cans forcing them to rely on less hygienic alternatives like plastic containers, which are harder to clean and more likely to harbor bacteria. FGD held on the 10th/8/2025.

Table 1: Opined Main Hygiene Practices Utilized to Prevent and Control Milk Contaminations When Handling Milk or Human Consumption in the Study Area District

Variable assessed	Categories	Frequency	%
Equipment used for cleaning milking tools	Cooled water and Detergent	109	50.2%
	Cooled water only	82	37.8%
	Hot water, detergent and Towel	26	12.0%
Hand washing before milking	No	22	10.1%
	Sometime	26	12.0%
	yes	169	77.9%
Udder cleaning before milking	No	22	10.1%
	Sometime	39	18.0%
	yes	156	71.9%
Milk storage containers	Aluminum container	129	59.4%
	Plastic container	88	40.6%
Time from farm to MCC	15-30 Min	82	37.8%
	31-60 Min	135	62.2%

3.2.3 Types of Testing Methods Used to Prevent Milk Contamination

This study reveals a significant limited control challenges in the milk production system, between farm-level and Milk collection center practices, where at farm-level contamination could minimal with only 72 (33.6%) of farmers and herders conduct any milk testing relies heavily on basic methods organoleptic assessment (18.4%) and clot-on-boiling tests (14.3%) Advanced diagnostic tools like the California Mastitis Test (CMT) are virtually unused (0.5%), while at Milk Collection Centers (MCC) there is implementation comprehensive standardized testing.

Standard protocols include alcohol tests (acidity), lactometer tests (density/adulteration), and CMT (mastitis detection) but there is notable Safety gap on antibiotic residue testing which is a serious food safety concern.

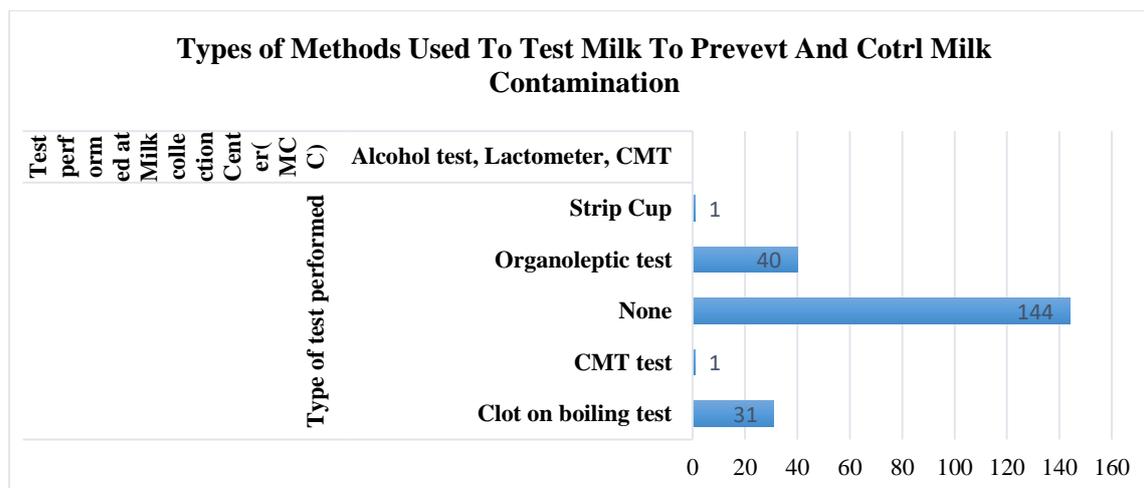


Figure 3: Opine Types of testing methods used to prevent milk contamination

Limited awareness on various methods to be used to test milk contamination was also discussed in KII, at Nyamata, Mayange, Rweru, Ruhuha and Gshora milk collection centers, who said “Most farmer are not aware of the modern testing method on the market to prevent and control milk contamination for human consumption”. These was also discussed and triangulated in FGD discussions:

We are not aware of simple on-farm milk testing methods, such as alcohol tests, lactometer use, or clot-on-boiling (COB) tests, which are commonly used to assess milk quality before delivery to collection points. Their lack of exposure to these methods suggests a significant knowledge and training gap in quality control at the production level. Focus group Discussion held on the 13th of August 2025

3.2.4 Level of Hygiene Level in Handling Dairy Feeds for Milk Production and formation

The study opined that the hygiene level of handling dairy feed at household level to control milk contamination was 52%, (112) respondent covered under the shed and 53% (115), respondents inspected the quality of feeds before given livestock to feed. Also, majority of famers 68%, (149) were not aware that mycotoxin microbes from fungi Which is zoonotic if you feed animals on poor moistures feed.

Table 1: The evaluation of hygiene level in handling dairy feeds by farmers supplying milk in Bugesera District, Rwanda

Variable to assess	Categories	Number (%) of respondent
Use of dairy supplement	No	157(72.4%)
	yes	60(27.6%)
Feed storage location	Covered shed	112(51.6%)
	Nonspecific area	105(48.4%)
Feed inspection frequency	Before feeding	115(53%)
	Rarely	96(44.2%)
	Weekly	6(2.8%)
Handling of contaminated feed	Discarded	61(28.1%)
	Mixed with other feed	80(36.9%)
	Used for other animals	76(35%)
Knowledge about mycotoxin	No	149(68.7%)
	Yes	68(31.3%)
Source of dairy feed	Local market	111(51.2%)
	Own production	106(48.8%)
Checking feed quality	No	108(49.8%)
	Yes	109(50.2%)

The research findings highlight significant hygiene concerns in how dairy farmers handle animal feeds where most farmers (72.4%) do not feed dairy supplements, which may impact milk yield and quality. Feed storage is almost evenly split, with 48.4% storing in nonspecific (often unhygienic) areas, this increases the risk of contamination and spoilage. Only 53% of farmers inspect feed before feeding, while 44.2% rarely inspect it, suggesting poor feed quality control practices. Only 28.1% discard contaminated feed, while the rest either mix it (36.9%) or give it to other animals (35%), posing potential health risks across the herd. 68.7% of farmers are unaware of mycotoxins, harmful compounds in spoiled feeds, and about half (49.8%) do not check feed quality at all. This knowledge gap underscores a serious vulnerability in feed safety and animal health management.

3.3 Inferential Statistics

Examination on knowledge, attitudes, and practices (KAP) is associated with milk contamination among dairy farmers in Bugesera District

The study found there is a strong association between trained farmers and non-trained farmers, where 77% more less likely to experience milk contamination compared to those who had not received training. The odds ratio (OR) for untrained farmers was 0.33 (95% CI: 0.118–0.457; $p < 0.001$), indicating a significant association. The study found that appropriate milk storage using aluminum containers were 3.88 times less likely to experience contamination compared to those using plastic or other materials (OR = 3.88; 95% CI: 2.012–7.493; $p < 0.001$). In contrast, plastic containers were associated with higher contamination risks (OR = 1.402; 95% CI: 1.172–1.678), likely due to micro-cracks and poor sterilization. The compliance with the antibiotic withdrawal period. were 112.5 times less likely to experience milk contamination (OR = 112.5; 95% CI: 25.927–488.151; $p < 0.001$). In contrast, non-compliant farmers had an OR of 2.628 (95% CI: 1.979–3.489), indicating higher contamination risks.

Farmers' perceptions of the health risks posed by contaminated milk showed no significant association with actual contamination outcomes. Both those who agreed and those who strongly agreed that contaminated milk can cause human diseases had approximately the same odds of experiencing contamination (OR = 1.056 and OR = 1.013, respectively; $p = 1.0$). Those who never separated sick animals were 17.88 times more likely to experience milk contamination (OR = 17.883; 95% CI: 0.8359–38.262; $p < 0.001$).

The study found that Vaccination frequency also influenced contamination risk. Farmers who always vaccinated their cows were significantly less likely to experience contamination (OR = 0.193; 95% CI: 0.1–0.378; $p < 0.001$), compared to those who only sometimes vaccinated (OR = 0.636; 95% CI: 0.511–0.793).

Table 2: Examination on knowledge, attitudes, and practices (KAP) is associated with milk contamination among dairy farmers in Bugesera District

Variables	Experienced milk contamination at Milk Collection Center				
	No	Yes	OR	95% CI (RR)	P-Value
No training received on milk quality	60	37	0.33	0.118-0.457	<001
Yes, trained on milk quality	105	15	0.77	0.596-0.38	
Milk stored using aluminum container	111	18	3.88	2.012-7.493	<001
Milk stored using plastic container	54	34	1.402	1.172-1.678	
Do follow antibiotic withdraw period (Always)	135	2	112.5	25.927-488.151	<001
Do not follow antibiotic withdraw period (Never)	30	50	2.628	1.979-3.489	
Agree that contaminated milk causes human Disease	72	22	1.056	0.562-1.983	1
I strongly agree that contaminated milk cause human Disease	93	30	1.013	0.872-1.177	
Do never separate sick cow from health	145	15	17.883	0.8359-38.262	<0.001
Do separate sick cow from health	20	37	2.583	1.808-3.689	
Do you always vaccinate your cows (Yes)	126	32	0.193	0.1-0.378	<0.001
Sometime vaccinate cows	39	20	0.636	0.511-0.793	

IV. DISCUSSION

The results of this study highlight the persistence of microbial contamination challenges within smallholder dairy systems in Bugesera District, reflecting a broader pattern observed across East Africa. Similar contamination trends have been reported in comparable dairy systems in Tanzania and Kenya, where inadequate infrastructure, poor hygiene practices, and limited farmer knowledge have been identified as key contributors (Kurwijila & Bennett, 2011; Tegegne et al., 2013; Lindahl et al., 2018). The relatively high contamination levels underscore the multifaceted nature of milk quality problems in resource-limited settings, where technological and educational constraints converge to hinder safe production and handling.

Farmer education and training emerged as critical determinants of milk quality. The observed association between training and reduced contamination supports evidence from Kenya and Ethiopia, where better-educated farmers were significantly more likely to adopt hygienic milking and handling practices (Makita et al., 2012; Tegegne et al., 2013). This suggests that capacity-building initiatives emphasizing hygiene, equipment sanitation, and awareness of feed-borne contaminants such as mycotoxins could substantially enhance milk safety. The low awareness of mycotoxin risks among farmers in Bugesera mirrors findings from other African contexts and indicates a pressing need for targeted education campaigns (Lindahl et al., 2018; Kagera et al., 2019).

Hygienic practices and infrastructure conditions were also major determinants of contamination. The use of plastic containers, inadequate cleaning methods, and long transportation times expose milk to bacterial proliferation, as established by earlier studies in East African dairy systems (Staal et al., 2008; Grace et al., 2012). Insufficient access to cooling facilities and poor-quality water for equipment sanitation further compound the problem. Moreover, limited on-farm milk testing and the absence of antibiotic residue screening highlight systemic weaknesses in local milk safety management, consistent with observations by Beyene et al. (2016). Addressing these gaps requires coordinated interventions integrating training, improved collection infrastructure, and the promotion of appropriate handling technologies such as aluminum containers and cooling equipment.

Overall, this study reinforces that milk contamination in smallholder settings is driven by a combination of educational, behavioral, and infrastructural factors. Sustainable mitigation demands a holistic approach involving continuous farmer training, stronger extension services, and improved post-harvest infrastructure. Future research should incorporate microbiological testing to identify specific pathogens and adopt longitudinal designs to capture contamination dynamics over time. Such evidence would better inform policy and intervention strategies aimed at ensuring milk safety and protecting public health in Rwanda's growing dairy sector.

V. ETHICAL APPROVAL

Ethical approval for the study was provided by the Mount Kenya University Ethical Review Board REF: MKU 04/ERC/0096, and permission for data collection was obtained from Bugesera District leadership. Respondents were informed about the purpose of the study, how their responses would be used, and their right to withdraw at any time. Informed consent was obtained through signed consent forms from those who agreed to participate.

VI. CONCLUSION

This study establishes milk contamination as a significant public health issue in Bugesera District, Rwanda, largely attributed to inadequate hygiene practices, poor feed management, and limited farmer knowledge. Although basic hygiene measures such as hand and udder washing are practiced, substandard methods and equipment persist, resulting in a contamination rate of 24% in milk collection centers.

Statistical analysis identified strong associations between contamination levels and factors such as container type, hygiene practices, adherence to antibiotic withdrawal periods, and training on milk quality. Farmers lacking training were notably more likely to produce contaminated milk, while the use of aluminum containers, routine vaccination, and isolation of sick animals served as protective measures. The observed gap between farmers' awareness of contamination risks and their actual practices highlights the need for more effective knowledge transfer.

To mitigate contamination, comprehensive training programs on hygienic milking, feed safety, and contamination detection are essential. In addition, policy interventions should enforce the use of hygienic equipment and standardized milk collection protocols. Addressing these determinants will enhance milk safety, improve product quality, and protect public health in Bugesera District and beyond.

REFERENCES

- [1] Aker, J. C. (2011). Dial “A” for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, 42(6), 631–647. <https://doi.org/10.1111/j.1574-0862.2011.00545.x>
- [2] Aliyo, A., & Teklemariam, Z. (2022). Assessment of milk contamination, associated risk factors, and drug sensitivity patterns among isolated bacteria from raw milk of Borena Zone, Ethiopia. *Journal of Tropical Medicine*, 2022, 1–9. <https://doi.org/10.1155/2022/3577715>
- [3] Anto, A., Sugiyanto, S., Yuliati, Y., & Kustanti, A. (2023). Validity and reliability of the adoption questionnaire of agricultural mechanization in the food estate area of Central Kalimantan, Indonesia. *International Journal of Science, Technology & Management*, 4(4), 736–741.
- [4] Bava, L., Zucali, M., Brasca, M., Zanini, L., & Sandrucci, A. (2009). Efficiency of cleaning procedures of milking equipment and bacterial quality of milk. *Italian Journal of Animal Science*, 8(Suppl. 2), 387–389. <https://doi.org/10.4081/ijas.2009.s2.387>
- [5] Baydan, E., Kanbur, M., Arslanbaş, E., Aydın, F. G., Gürbüz, S., & Tekeli, M. Y. (2017). Contaminants in animal products. In S. Sekkin (Ed.), *Livestock Science*. InTech. <https://doi.org/10.5772/67096>
- [6] Bebe, B. O., Udo, H. M. J., Rowlands, G. J., & Thorpe, W. (2003). Smallholder dairy systems in the Kenya highlands: Breed preferences and breeding practices. *Livestock Production Science*, 82(2–3), 117–127. [https://doi.org/10.1016/S0301-6226\(03\)00029-0](https://doi.org/10.1016/S0301-6226(03)00029-0)
- [7] Bertuzzi, T., Rastelli, S., Mulazzi, A., Donadini, G., & Pietri, A. (2018). Known and emerging mycotoxins in small- and large-scale brewed beer. *Beverages*, 4(2), 46. <https://doi.org/10.3390/beverages4020046>
- [8] Beyene, T., Hayishe, H., Gizaw, F., Beyi, A. F., Abunna, F., Mammo, B., ... & Abdi, R. D. (2017). Prevalence and antimicrobial resistance profile of *Staphylococcus* in dairy farms, abattoir, and humans in Addis Ababa, Ethiopia. *BMC Research Notes*, 10(1), 171. <https://doi.org/10.1186/s13104-017-2484-7>
- [9] Bigalke, D. L. (1978). Effect of low-temperature cleaning on microbiological quality of raw milk and cleanliness of milking equipment on the farm. *Journal of Food Protection*, 41(11), 902–906. <https://doi.org/10.4315/0362-028X-41.11.902>
- [10] Calahorrano-Moreno, M. B., Ordoñez-Bailon, J. J., Baquerizo-Crespo, R. J., Dueñas-Rivadeneira, A. A., Montenegro, M. C. B. S. M., & Rodríguez-Díaz, J. M. (2022). Contaminants in the cow’s milk we consume? Pasteurization and other technologies in the elimination of contaminants. *F1000Research*, 11, 91. <https://doi.org/10.12688/f1000research.108779.1>
- [11] Claeys, W. L., Cardoen, S., Daube, G., De Block, J., Dewettinck, K., Dierick, K., ... & Herman, L. (2013). Raw or heated cow milk consumption: Review of risks and benefits. *Food Control*, 31(1), 251–262. <https://doi.org/10.1016/j.foodcont.2012.09.035>
- [12] Claeys, W. L., Verraes, C., Cardoen, S., De Block, J., Huyghebaert, A., Raes, K., Dewettinck, K., & Herman, L. (2014). Consumption of raw or heated milk from different species: An evaluation of nutritional and potential health benefits. *Food Control*, 42, 188–201. <https://doi.org/10.1016/j.foodcont.2014.01.045>
- [13] Codex Alimentarius. (2020). *General principles of food hygiene CXC 1-1969: HACCP system and guidelines for its application*. FAO/WHO. <https://www.fao.org/fao-who-codexalimentarius>
- [14] Colak, H., Hampikyan, H., & Bingol, E. B. (2007). Some residues and contaminants in milk and dairy products. *Asian Journal of Chemistry*, 19(3), 1789–1798.
- [15] Dadar, M., Fakhri, Y., Shahali, Y., & Khaneghah, A. M. (2020). Contamination of milk and dairy products by *Brucella* species: A global systematic review and meta-analysis. *Food Research International*, 128, 108775. <https://doi.org/10.1016/j.foodres.2019.108775>
- [16] De Klerk, J. N., & Robinson, P. A. (2022). Drivers and hazards of consumption of unpasteurised bovine milk and milk products in high-income countries. *PeerJ*, 10, e13426. <https://doi.org/10.7717/peerj.13426>

- [17] De Oliveira, T. L. C., Soares, R., Piccoli, R. H., & Nero, L. A. (2015). Food safety: Good manufacturing practices and hazard analysis critical control point in the dairy industry. In *Dairy Processing: Improving Quality* (pp. 415–436). Woodhead Publishing. <https://doi.org/10.1016/B978-1-78242-223-5.00016-5>
- [18] Dragomir, N. (2012). Contaminated milk influences human health. *Journal of Environmental Protection and Ecology*, 13(3), 1669–1676.
- [19] Food and Agriculture Organization (FAO). (2019). *Behavioural change strategies for improving food safety compliance*. <https://www.fao.org/3/ca5644en/CA5644EN.pdf>
- [20] Ghose, B., Mishu, M. P., & Islam, M. A. (2021). Contaminants in milk and their health hazards: A review. *Environmental Science and Pollution Research*, 28, 66521–66539. <https://doi.org/10.1007/s11356-021-14637-z>
- [21] Grace, D., Dipeolu, M., & Alonso, S. (2015). The roles of food safety in food and nutrition security. *Food Security*, 7(3), 491–501. <https://doi.org/10.1007/s12571-015-0454-9>
- [22] Grace, D., Mutua, F. K., Ochungo, P., Kruska, R. L., Jones, K., Brierley, L., ... & Ogotu, F. (2012). *Mapping of poverty and likely zoonoses hotspots*. International Livestock Research Institute.
- [23] Grace, D., Wu, F., & 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(11), 9715–9729. <https://doi.org/10.3168/jds.2019-17864>
- [24] Holzhauer, M., & Wennink, G. J. (2023). Zoonotic risks of pathogens from dairy cattle and their milk-borne transmission. *Journal of Dairy Research*, 90(4), 325–331. <https://doi.org/10.1017/S0022029923000506>
- [25] International Livestock Research Institute. (2016). Prevalence of aflatoxin in feeds and cow milk from five counties in Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, 16(3), 11004–11021. <https://doi.org/10.18697/ajfand.75.ILRI04>
- [26] Joseph, E. (2015). *Assessment of microbiological hazards along the milk value chain in Kilosa and Mvomero districts, Tanzania* [Doctoral dissertation, Sokoine University of Agriculture].
- [27] Kabera, J., Nshimiyimana, T., & Habineza, F. (2019). Milk contamination detection methods in Rwanda: Challenges and opportunities. *Rwanda Journal of Science*, 31(4), 98–104.
- [28] Kalunda, E., Mutoni, J., & Ngoga, G. (2020). Hygiene and milk contamination in dairy farming. *Journal of Agricultural Science*, 22(3), 102–110.
- [29] Kanyeka, H. B. (n.d.). *Assessment of microbial quality of raw cow's milk and antimicrobial susceptibility of selected milk-borne bacteria in Kilosa and Mvomero districts, Tanzania*.
- [30] Khan, R., Anwar, F., & Ghazali, F. M. (2024). A comprehensive review of mycotoxins: Toxicology, detection, and effective mitigation approaches. *Heliyon*, 10(8), e28361. <https://doi.org/10.1016/j.heliyon.2024.e28361>
- [31] Lanyasunya, T. P., Wamae, L. W., Musa, H. H., Olowofeso, O., & Lokwaleput, I. K. (2005). The risk of mycotoxin contamination of dairy feed and milk on smallholder dairy farms in Kenya. *Pakistan Journal of Nutrition*, 4(3), 162–169.
- [32] Lowe, N. K. (2019). What is a pilot study? *Journal of Obstetric, Gynecologic & Neonatal Nursing*, 48(2), 117–118. <https://doi.org/10.1016/j.jogn.2019.01.005>
- [33] Massahi, T., Omer, A. K., Habibollahi, M. H., Mansouri, B., Ebrahimzadeh, G., Parnoon, K., Soleimani, H., & Sharafi, K. (2024). Human health risk assessment of aflatoxin M1 in various dairy products in Iran: A literature review. *Journal of Food Composition and Analysis*, 129, 106124. <https://doi.org/10.1016/j.jfca.2024.106124>
- [34] McKinnon, C. H., Rowlands, G. J., & Bramley, A. J. (1990). The effect of udder preparation before milking and contamination from the milking plant on bacterial numbers in bulk milk of eight dairy herds. *Journal of Dairy Research*, 57(3), 307–318. <https://doi.org/10.1017/S0022029900026959>
- [35] Mesfin, Y. M., Mitiku, B. A., & Tamrat Admasu, H. (2024). Veterinary drug residues in food products of animal origin and their public health consequences: A review. *Veterinary Medicine and Science*, 10(6), e70049. <https://doi.org/10.1002/vms3.70049>

- [36] Meyer, F. M., Schmidt, R., & Richter, M. (2017). Microbiological quality of milk: A review of methods for detection of pathogens. *International Journal of Dairy Science*, 14(2), 145–152.
- [37] Mosalagae, D., Pfukenyi, D. M., & Matope, G. (2011). Milk producers' awareness of milk-borne zoonoses in selected smallholder and commercial dairy farms of Zimbabwe. *Tropical Animal Health and Production*, 43, 733–739.
- [38] Mukasafari, M. A., Mutimura, M., Wredle, E., & Gonda, H. L. (2025). Nutritional quality of feed resources used by smallholder dairy farmers in the Northern Province of Rwanda. *Tropical Animal Health and Production*, 57(7), 301. <https://doi.org/10.1007/s11250-025-04562-w>
- [39] Nyokabi, S., Luning, P. A., de Boer, I. J. M., Korir, L., Muunda, E., Bebe, B. O., Lindahl, J., Bett, B., & Oosting, S. J. (2021). Milk quality and hygiene: Knowledge, attitudes and practices of smallholder dairy farmers in central Kenya. *Food Control*, 130, 108303. <https://doi.org/10.1016/j.foodcont.2021.108303>
- [40] Oliver, S. P., Jayarao, B. M., & Almeida, R. A. (2005). Foodborne pathogens in milk and dairy farm environments: Food safety and public health implications. *Foodborne Pathogens and Disease*, 2(2), 115–129. <https://doi.org/10.1089/fpd.2005.2.115>
- [41] Omore, A. O., Staal, S. J., Osafo, E. L. K., Kurwijila, L. R., Barton, D. N., Mdoe, N. S. Y., ... & Aning, G. (2004). *Market mechanisms, efficiency, processing and public health risks in peri-urban dairy product markets: Synthesis of findings from Ghana and Tanzania*.
- [42] Orwa, J. D., Matofari, J. W., & Muliro, P. S. (2017). Handling practices and microbial contamination sources of raw milk in rural and peri-urban smallholder farms in Nakuru County, Kenya. *International Journal of Livestock Production*, 8(1), 5–11. <https://doi.org/10.5897/IJLP2016.0318>
- [43] Pereira, J., Ramos, D., & Silva, C. (2018). Prevalence of pathogenic microorganisms in milk in rural communities. *Journal of Food Safety and Hygiene*, 25(1), 1–10.
- [44] Phokane, S., Flett, B. C., Ncube, E., Rheeder, J. P., & Rose, L. J. (2019). Agricultural practices and their potential role in mycotoxin contamination of maize and groundnut subsistence farming. *South African Journal of Science*, 115(9–10). <https://doi.org/10.17159/sajs.2019/6221>
- [45] Phuensane, P., Jaroenwanit, P., & Hongthong, P. (2022). Influence of demographic characteristics and extrinsic motivations on farmers' smart farming adoption in Northeastern Thailand. *GMSARN International Journal*, 16, 359–365.
- [46] Rwanda Agriculture Board (RAB). (2019). *Report on dairy farming practices in Rwanda*. Kigali: Government of Rwanda.
- [47] Sapp, A. C., Nane, G. F., Amaya, M. P., Niyonzima, E., Hategekimana, J. P., VanSickle, J. J., Gordon, R. M., & Havelaar, A. H. (2023). Estimates of disease burden caused by foodborne pathogens in contaminated dairy products in Rwanda. *BMC Public Health*, 23(1), 657. <https://doi.org/10.1186/s12889-023-15204-x>
- [48] Sharma, V., Ameta, K. D., & Ameta, R. (2022). Milk contamination and its impact on human health: A review. *Journal of Dairy and Veterinary Sciences*, 13(2), 555859. <https://doi.org/10.19080/JDVS.2022.13.555859>
- [49] Soon, J. M., Baines, R., & Seaman, P. (2012). Meta-analysis of food safety training on hand hygiene knowledge and attitudes among food handlers. *Journal of Food Protection*, 75(4), 793–804. <https://doi.org/10.4315/0362-028X.JFP-11-502>
- [50] Srairi, M. T., El Jaouhari, M., Saydi, A., Kuper, M., & Le Gal, P. Y. (2011). Supporting small-scale dairy farmers in increasing milk production: Evidence from Morocco. *Tropical Animal Health and Production*, 43(1), 41–49.
- [51] Swai, E., & 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(3), 217–222. [https://doi.org/10.1016/S2221-1691\(11\)60030-0](https://doi.org/10.1016/S2221-1691(11)60030-0)
- [52] Vroh, B. T. A., N'guessan, K. E., & Adou, Y. C. Y. (2017). Challenges and opportunities of milk, meat and live animal marketing in Ethiopia: A review. *International