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Predisposing risk factors to milk quality and safety in smallholder dairy enterprises in Kenya

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Abstract
The unhygienic milk handling practices along the value chain predispose it to microbial and chemical contamination. This study aimed to investigate the on-farm practices related to animal health management and milk handling predisposing risk factors to milk quality and safety in Githunguri. A cross-sectional survey using a pre-tested questionnaire was administered to randomly selected smallholder dairy farmers (n= 457). Most farmers have enhanced standard measures for clean and safe milk production. However, a portion of them do not adhere to recommended practices such as screening workers for zoonotic diseases (82.8%), striping of milk for mastitis test (47.1%), teat dipping after milking (68%), feeding mouldy feeds to animals (35.2%) and observe withdrawal period after drugs administration (23.3%). The use of untreated water for sanitation and plastic containers for milk storage poses a threat to the quality and safety of milk. Furthermore, variations of farmers' demographic characteristics on milk collection routes influenced hygienic milk handling practices ($p<0.05$). Hence, a need to develop programmes to educate farmers on good agricultural practices, surveillance and control of hazards at the production level.

Keywords: contamination, hygiene, milk, quality, safety

1. Introduction
Smallholder farmers from low-to-middle-income countries have embraced dairy production enterprises as an essential source of livelihood, contributing to food and nutrition security (Grace *et al.*, 2020; Banda *et al.*, 2021) [7, 2]. Kenya has one of the most developed dairy sectors in sub-Saharan Africa, whereby smallholder dairy farmers account for 80% of the estimated 4 to 5 billion litres of national milk production (King'ori, 2022) [8]. However, producing good quality milk remains a challenge to smallholder farmers due to unhygienic handling practices and non-adherence to food safety standards (Nyokabi *et al.*, 2021) [13]. Hence, an integrated approach to milk quality and safety is needed to guarantee its integrity from farm to glass.

Milk contamination usually begins at the production level; the microbial safety of raw milk in low to middle-income countries originating from small-scale farmers has been a concern for decades (Mogutu *et al.*, 2020). For instance, the report on post-harvest losses at the farm level in Kenya is more than 6% of total production (Ndungi *et al.*, 2021) [12]. Post-harvest losses harm farmers' economic well-being, food security, and national gross domestic product (GDP) (Dudi, 2014) [4]. Lack of efficient monitoring and proper enforcement structures has resulted in processed milk products from smallholder dairy farmers being non-compliant with national, regional, and international quality and safety standards despite the increase in demand (Mogutu *et al.*, 2020). Processing low-quality raw milk results in low-quality products, so there have been attempts to offer monetary premium incentives to dairy farmers that provide high-quality milk to processors (Murphy *et al.*, 2016) [11].

Besides these on-farm practices that cause contamination at the farm level resulting in quantitative and qualitative losses, another concern is the safety of consumers of milk and milk products. Milk has become a vehicle for consumers of foodborne pathogens, antibiotic residues, mycotoxins, and zoonotic diseases.

According to Grace *et al.* (2020) [7], harmful microorganisms may originate from the animal, environment, milking equipment, milk handlers or introduction by an adulterant such as contaminated water. Accidentally or deliberately, the feeds and veterinary drugs for animal treatment may lead to chemical contamination. Cattle can act as reservoirs for zoonotic diseases either directly or indirectly. Brucellosis and Campylobacteriosis are transmitted through handling of the animal and environments contaminated with animal manure, respectively. (McDaniel *et al.*, 2014) [10]. Milk quality and safety concerns on consumer health and nutrition need public health surveillance to prevent foodborne diseases, food poisoning and zoonosis risk from raw milk and fresh dairy products (Velázquez-Ordoñez *et al.*, 2019) [18].

The objective of this study was to establish whether smallholder dairy enterprises in the area have embraced the standard practices recommended for producing quality and safe milk.

2. Methods

2.1 Study area

The study was conducted in the Githunguri sub-county, Central Kenya, about 1600 m above sea level. It lies between latitude 1° 05" and 1° 06" South of the Equator and longitude 36° 53" and 36° 55". The annual average rainfall is 1065 mm, with the mean maximum monthly temperature varying from 22.4 °C to 27.6 °C, while the mean minimum temperature range from 11.3 °C to 14.9°C (Alaru, 2019).

2.2 Study design and data collection procedures

Using a structured pre-tested questionnaire, a cross-sectional survey was used to collect data on dairy cattle health management and milk-handling practices. The sample size was determined using a formula by Cochran (1963):

$$n = \frac{Z^2 pq}{e^2}$$

Where: n = sample size; Z^2= abscissa of the normal curve, which is 1.96 for 95 confidence interval; p= estimated proportion of an attribute; q= (1-p) and e= desired level of precision set at 0.05. A total of 457 households distributed along the eight-milk collection routes: Kiairia, Githunguri town, Ikinu, Komothai, Githinga, Ngewa and Gitiha combined with Kiambaa, were interviews.

2.3 Data management and analyses

Descriptive statistics was used to describe sources of water, milk handling practices and dairy cattle health management. Chi-squared analyses assessed the relationship between the farmers' characteristics (Age, education and membership in farmers' organizations) and the milk collection route. Inferential analyses employed analysis of variance (ANOVA) to determine the influence of farmers' characteristics on milk quality and animal health management practices. *Post-hoc* analysis was performed using Tukey's method to separate means. Linear regression models were used to identify the determinants of farmers' demographic characteristics on farm-level practices affecting animal health and milk quality. Non-significant terms were eliminated from the model. The regression model used is explained as follows:

$$y_i = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n$$

Where yi in the farm-level indicator is for farmers' i^{th} practice (animal health management and milk handling), β_o is the intercept, $\beta i \ldots \beta n$ are coefficients to be estimated and $Xi \ldots Xn$ is a vector of farmers' demographic characteristics. Data was collected from the cross-sectional survey using the open data kit (ODK) version 2022.3.6. Data were then coded and analyzed using the statistical package for social sciences (SPSS) statistics software version 26 at a 95% confidence level.

3. Results

3.1 Hygienic milk handling practices

Sources of water used for sanitation are in Figure 1. Most farmers (51.68%) obtained water from boreholes, 28.59% from rain, 12.75% from rivers, 2.28% used tap water and the remaining from vendors, dams and shallow wells.

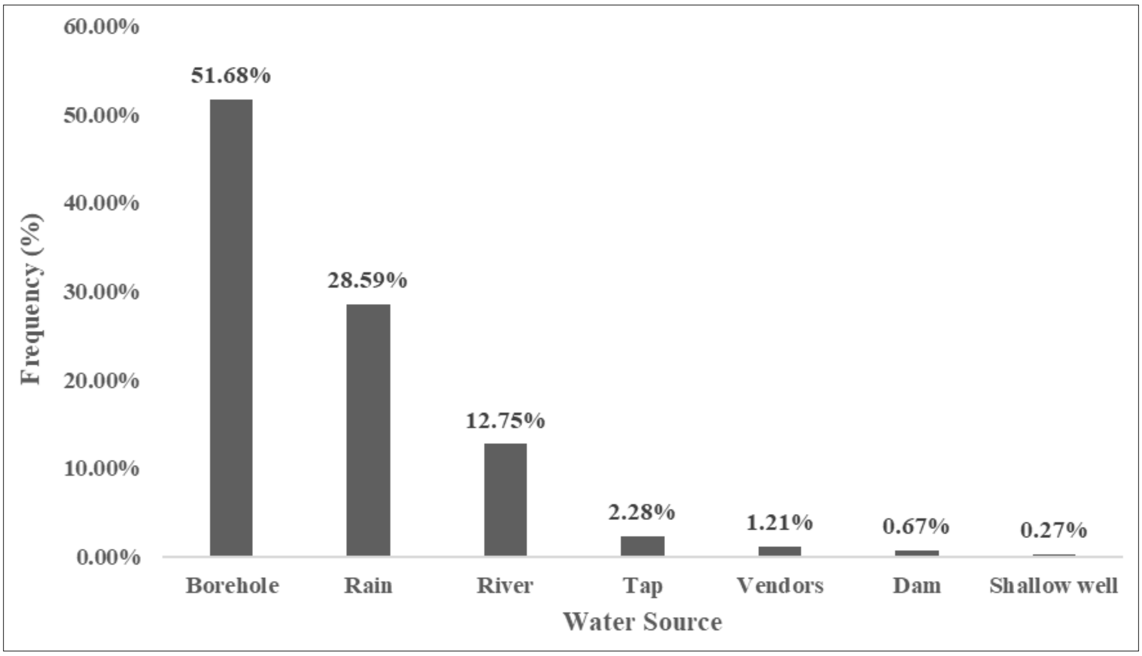

Fig 1: Sources of water used by Githunguri dairy farmers for sanitation

Hygienic milking and milk handling practices are in Table 1. Most farmers implemented standard hygienic milk handling practices; where 94.7% milk their cows in the parlour, 98.6% cleaned the milking area, and 90.0% delivered milk to collection centres within 2 hours. However, a smaller proportion is engaged in unhygienic practices such as mixing morning and evening milk (19.4%), use of plastic containers to store and transport milk (30.8%) and milk in the sleeping area (4.6%), which can compromise on milk quality and safety.

3.2 Dairy cattle health management and safe milk production practices

Dairy cattle health management practices are in Figure 2. Only 52.9% of the farmers practice striping of milk for mastitis testing, 31.7% practice teat dipping after milking, 35.2% encountered incidences where they had to feed cattle on mouldy feed, and 82.8% of farm workers are not tested for zoonotic diseases. Among the farmers who practised testing for zoonotic diseases, only 20.5% tested every three months as per the public health guidelines. Furthermore, 23.5% of the farmers did not observe the recommended withdrawal period after administering antibiotics to lactating cows.

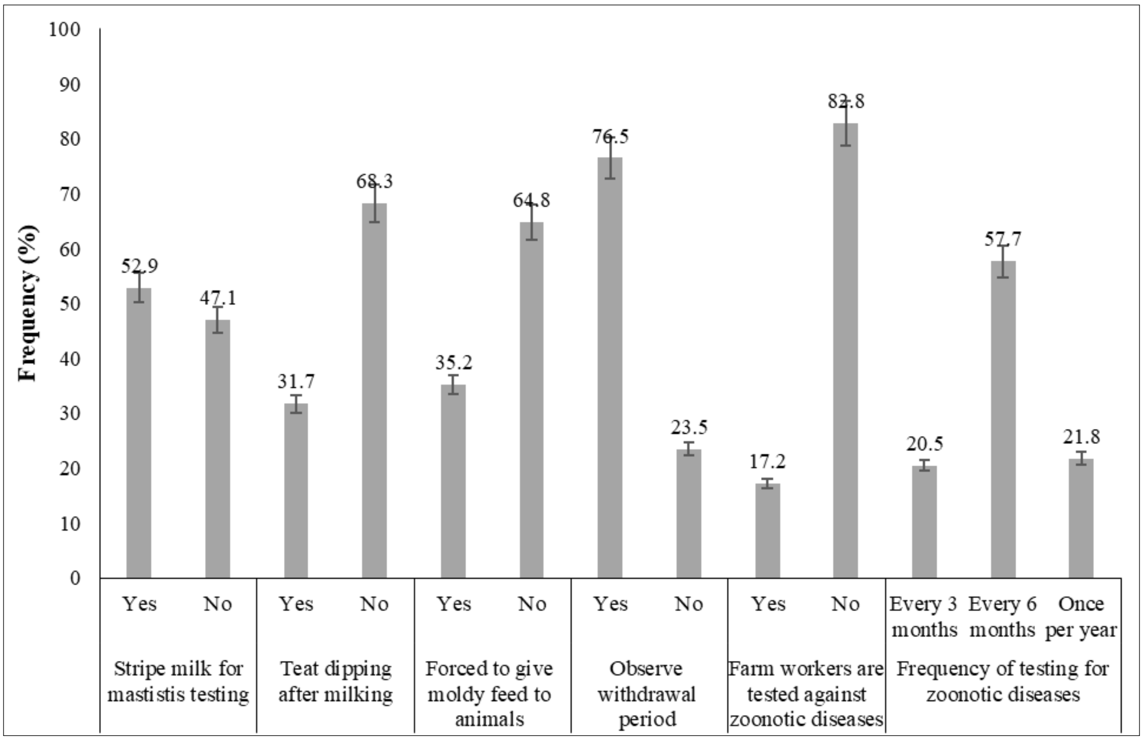

Fig 2: Dairy cattle health management in Githunguri Sub-county, Kenya

Influences of the farmers' demographic characteristics that predict farm-level practices affecting animal health and milk quality are in Table 2. From the regression model, the milk collection route was a significant predictor for the use of jelly/salve during milking, teat dipping, frequency of zoonotic disease testing, stripping of milk for mastitis testing and observation of withdrawal period after administering antibiotics to lactating cows. The household head's education level and age influenced the possibility of a farmer giving mouldy feed to cows and milk cooling before delivery to the collection centre.

Table 1: Milk handling practices in smallholder dairy enterprises in Githunguri Sub-county, Kenya

Risk factor		Levels	Frequency (%)
Milking place	Where	Milking parlour	94.7
		Sleeping area	4.6
		Both the milking parlour and sleeping area	0.7
	Cleaning	Yes	98.6
		No	1.4
	Frequency	After every milking	35.9
		Every morning and evening	22.2
		Every morning	27.5
		Once per week	1.6
		After every two days	9.2
		Every evening	3.7
Udder	Cleaning	Yes	98.2
		No	1.8
	Use of salve/jelly	Yes	87.8
		No	12.2
Equipment	Type	Stainless steel	64.8
		Plastic	30.8

		Both stainless steel and plastic	4.4
	Cleaning	With warm water and soap	89.0
		With cold water and soap	6.4
		Both warm and cold water with soap	4.6
	Covering after milking	Yes	72.7
		No	27.3
Milking	Method	Hand	98.2
		Machine	1.6
		Both hand and machine	0.2
	Duration	1-3 minutes	7.3
		4-7 minutes	60.9
		Beyond 7 minutes	31.8
After milking	Mixing	Yes	19.6
		No	80.4
	Time to deliver	Within 2 hours	90.0
		3- 4 hours	9.3
		Above 4 hours	0.7
	Cooling before deliver	Yes	6.0
		No	94.0
	Cooling method	Natural convective cooling	25.0
		Fridge/deep freezers	75.0

Table 2: Regression models on farmers' demographics' characteristics in predicting farm practices affecting animal health

A. Dairy cattle health management						
Predictors	**Use of jelly/salve**			**Teat dipping**		
	B	**Stderr.**	**p-value**	**B**	**Stderr.**	**p-value**
Intercept	1.257	0.119	0.000	1.520	0.171	0.000
Milk Route	-0.049*	0.008	0.000	0.040*	0.012	0.001
HHD age	-0.030	0.022	0.172	-0.033	0.032	0.301
HHD education	0.030	0.022	0.181	-0.008	0.032	0.795
FO Membership	0.030	0.061	0.620	0.097	0.087	0.264
Predictors	**Zoonotic testing**			**Frequency of zoonotic Testing**		
	B	**Stderr.**	**p-value**	**B**	**Stderr.**	**p-value**
Intercept	1.637	0.139	0.000	2.692	0.526	0.000
Milk Route	0.005	0.010	0.589	-0.117*	0.053	0.030
HHD age	-0.029	0.026	0.263	0.019	0.108	0.861
HHD education	0.049	0.026	0.064	-0.053	0.108	0.626
FO Membership	0.082	0.069	0.235	-0.157	0.392	0.691
Safe milk production practices						
Predictors	**Use of mouldy feed**			**Stripe milk for mastitis**		
	B	**Stderr.**	**p-value**	**B**	**Stderr.**	**p-value**
Intercept	1.836	0.175	0.000	1.107	0.172	0.000
Milk Route	-0.012	0.012	0.328	0.092*	0.012	0.000
HHD age	0.073*	0.032	0.024	-0.039	0.032	0.220
HHD education	-0.097*	0.033	0.003	0.006	0.032	0.847
FO Membership	-0.014	0.089	0.874	0.075	0.088	0.390
Predictors	**Observe withdrawal period**			**Milk cooling**		
	B	**Stderr.**	**p-value**	**B**	**Stderr.**	**p-value**
Intercept	0.672	0.135	0.000	2.101	0.087	0.000
Milk Route	0.109*	0.009	0.000	0.010	0.006	0.085
HHD age	0.028	0.025	0.259	-0.003	0.016	0.837
HHD education	0.007	0.025	0.797	-0.035*	0.016	0.032
FO Membership	0.056	0.070	0.423	-0.083	0.044	0.061

Key: B= regression coefficient; Stderr=Standard Error; HHD= Household head; FO= Farmers' Organization

4. Discussion

4.1 Hygienic milk handling practices

Findings in Figure 1 show that farmers obtained water for sanitation from several sources, but boreholes, rain and rivers constituted the bulk source. The treated tap water supplied by the county government has not reached most homesteads. Therefore, the use of untreated water for sanitation is a predisposing risk factor for microbial contamination of milk. Table 1 shows that most farmers clean the udder and milking equipment and the milkers' hands, mainly using untreated water, thereby compromising milk quality. Poor hygiene in milking and handling practices could result in microbial milk contamination and pathogens dissemination. In addition, udder contamination may occur at milking time between cows, the hands of milkmen, and machines (Velázquez-Ordoñez *et al.*, 2019) [18]. Considering that some farmers use plastic milking equipment, maximum hygienic conditions cannot be attained by their nature. Plastics are difficult to clean, even after thorough cleaning of plastic jerry cans, mean microbial residual load for TVC and TCC levels were found to be 3.84 ± 0.92 and 3.64 ± 0.80 $\log_{10}$ CFU/cm^2 respectively (Alaru *et al*., 2019) [1]. In addition, the scratches on plastic containers harbour bacteria which would contaminate the fresh milk delivered to collection centres. The situation is even worse for the farmers who use cold water to wash equipment and clean the udder. According to Bekuma and Galmessa (2018) [3], water serves as a primary source of microorganism contamination, and if it is obtained from an open water supply, more care is necessary to prevent drainage that may contain both human and animal waste and other contaminants gaining entry into the source.

Besides water that is used in sanitation, the environment is also a predisposing factor for microbial contamination of the milk at the farm. From Table 1, some farmers don't use parlours but sleeping areas for milking. This is a dangerous practice because the cow dung, mud, ammonia gas and dust present in the sleeping area will find their way into the milk. However, even those farmers who use the milking parlour but only clean the place every two days or once per week predispose the milk to environmental contamination. Standard bulking of milk before processing requires dairy farmers to bring all their milk to a common milk collection centre. Any contamination within the milk production unit will compromise on quality and safety of milk at the collection centre. This scenario could negate all the efforts put in by smallholder farmers in ensuring the quality and safety of milk are enhanced. Similarly, a small proportion of farmers in Githunguri do not clean the cows' udder before milking. Considering that the udder is often soiled with cow dung in the sleeping area, cleaning removes soil particles, bedding materials and manure, which prevents the entry of microorganisms into the milk. Mixing the previous day's evening milk; which has a higher microbial load with morning milk was practised in some households thereby compromising on quality. The problem is further aggravated by the practice of farmers taking more than two hours to deliver milk to the collection centres and the lack of cooling facilities that curtails the microbial activity in milk. A small proportion of farmers cool milk before delivery to collection routes; however, some of the farmers that cool milk do not have refrigerators or freezers. They use natural convective cooling, where evening milk is stored in a can and placed outside overnight in either a trough of water or just an open place, where the night breeze causes the cooling.

Farmers from different milk collection routes had significantly different practices regarding the frequency of cleaning the milking place, type of milk handling equipment and method of cleaning the milking equipment. Consequently, this can cause differences in milk quality per route resulting from varying levels of awareness of hygienic milk handling. Hygienic handling, cooling and storage, and milk safety monitoring practices are relevant along the dairy value chain. Substandard milk production practices form additional avenues for fresh milk contamination and bacteria proliferation (Ledo *et al.*, 2020) [9]. In addition, farmers of different ages had significantly different practices in cleaning the milking place and the equipment (Table 2). A study by Paraffin *et al.* (2018) [15] established that farmers over 30 years of age were three times more likely to take action concerning hygiene in aspects affecting milk quality.

4.2 Animal health management and safe milk production

The findings indicated that seven out of every ten farmers did not practice teat dipping, as shown in Figure 2, a recommended practice in curbing teat infections such as mastitis, and only one in every two farmers checked for mastitis in milk. Lack of checking for mastitis and teat dipping could lead to the rapid spread of the disease among the herd due to late detections and no control measures. Mastitis infections within the herd lead to low-quality milk due to contaminations, low production, and the high cost of treating the animals. Mastitis is one of the most prevalent diseases affecting dairy animals' production process and is responsible for several production losses (Sharun *et al.,* 2021) [17]. Farmers reported that there were incidences that they fed mouldy feeds to animals and also failed to observe recommended withdrawal period after administering antibiotic treatments. Such practices are harmful as they can predispose milk consumers to chemical hazards from mycotoxins and antibiotic residues respectively. There is a global concern over the increase in antimicrobial resistance in human beings, and the finger points toward consuming foods contaminated with antibiotic residues (Emeje *et al.*, 2022) [5]. Similarly, the occurrence of aflatoxins and their metabolites toxins in the food chain leads to deterioration in animal health and socio-economic losses (Furian *et al.,* 2022) [6]. A relatively small proportion of farm animal handlers undergo routine medical examinations and checkups, as shown in Figure 2. For the smaller percentage that underwent the medical test, the frequency varied between three months and one year, with most tested every six months. This is contrary to the Kenyan Public Health requirement that medical checkups be done quarterly. Żukiewicz-Sobczak *et al.* (2013) [19] suggest that farmers should be subjected to a system of diagnosing occupational diseases and many preventive and educational programs concerning health risks associated with their work. Osoro *et al*. (2015) [14] study revealed that *Brucella* household seroprevalence of 5.0% and herd seroprevalence of 5.6%, which was attributed mainly to natural breeding and acquisition of new animals on a farm. From the regression models in Table 2, the milk collection route significantly influenced farmers' practices on the use of milking jelly/salve, teat dipping, frequency of testing for zoonotic diseases, striping of milk for mastitis checking and observation of withdrawal period. This indicates that on some routes, farmers are aware of recommended animal health management practices, while others are unaware. This variation could be due to limited access to extension services on the routes farmers are not practising as recommended. Apart from the route, the higher the education level of the household head, the fewer chances of them encountering incidences feeding mouldy feeds to cattle and fewer chances of using natural convective cooling of milk before delivery to collection centres. An indication that education level influenced the implementation of good farming practices. On the contrary, the higher the household head age, the higher the chances of encountering incidences of feeding mouldy feed to cattle.

5. Conclusion

Many of the farmers in Githunguri have embraced standard animal health management and clean milk production, but a few have practices that compromise milk quality and safety. These practices were greatly influenced by the milk collection route that the farmer belonged to, an indication of the variation of the knowledge base in the routes. The main problem facing hygienic milk production was the untreated water obtained mainly from boreholes and rivers. Therefore, there is a need for treated water in the area and for farmers to join organizations to benefit from extension services such as good agricultural practices, surveillance and control of hazards at the production level.

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

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