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ORIGINAL PAPER

Exploring the adoption of food safety measures in smallholder dairy systems in Ethiopia: implications for food safety and public health

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Abstract

Milk is highly perishable and can be a conduit for the transmission of zoonotic foodborne pathogens. This cross-sectional survey involving 159 farming households and 18 participant observations in participating farms was undertaken in Addis Ababa and surrounding areas in Oromia, Ethiopia to assess the adoption of food safety measures in smallholder farms. Adoption of food safety measures at the farm level influences milk quality and safety across the entire milk value chain, from "grass to glass". This study considered the adoption of 36 different food safety measures (FSM) including animal health, milking hygiene, hygienic milk storage, and hygienic milking premises. A weighted food safety index (FSI, ranging from 0 to 100) was calculated for each household based on FSM adopted. Ordinary Least Squares linear regression was used to quantify the factors of FSM adoption by smallholder farmers. The overall food safety index ranged between 59.97—60.75. A majority of farmers may be classified as moderate adopters of FSM (index ranging between 30–70%). Farm and farmers' characteristics such as herd size, farmer's education level, farmer's expertise in dairying, and participation of the farm in the formal milk value- chain, were shown to positively influence the level of adoption of FSM. Low farm-level adoption of FSM has food safety and public health implications as it can lead to milk contamination and, therefore, expose consumers to foodborne diseases. There is an imperative for policymakers to design and implement policies and intervention strategies that lead to increased farmer training related to livestock production and awareness of the important role that FSM adoption can play in improving food safety and public health.

Keywords Milk quality · Fresh milk · Food security · Dairy farmers · Good agricultural practices (GAPs)

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1 Introduction

Milk is an important animal source food (ASF) that is cheap, easily accessible, and balanced with abundant macro and micronutrients (Häsler et al., 2018; Lemma et al., 2018). Milk is, however, highly perishable and easily contaminated by unhygienic handling and storage (Ledo et al., 2020). Contaminated milk is one of the riskiest food products due to the associated public health risks and can be a conduit for pathogen transmission for zoonotic foodborne diseases (FBDs) (Dongol et al., 2017; Groot & van't Hooft, 2016). Microbial food safety is a public health challenge of global importance (Jacxsens et al., 2009). Ensuring compliance with food safety standards has been a persistent challenge in low- and middle-income countries (LMICs) (Dongol et al., 2017). In sub-Saharan Africa, food safety is a major public health concern due to weak institutions and poor attitudes of food handlers towards compliance with food safety regulations (Roesel & Grace, 2015).

Food safety spans the entire agri-food system from inputs, production, and distribution to consumption (Gereffi & Lee, 2009). Ensuring compliance with food safety measures (FSM) is important for minimising public health risks and mitigating the impact of foodborne diseases (Dongol et al., 2017). There is a growing consensus that integrated food safety through the entire food production chain " from grass to glass"—is needed, to address the numerous food safety hazards in food supply chains (Kumar et al., 2011).

Public health concerns and consumer willingness to pay for improved food safety have led to calls for improved milk quality (Amenu et al., 2019b; Lemma et al., 2018). There is increasing attention to FSM compliance at the farm level, considering it is one of the important stages affecting the overall food safety of dairy products consumed at the end of value chains (Kumar et al., 2011). Increasing compliance with food safety at the farm level could contribute to reducing milk contamination and associated public health risks (Kumar et al., 2017b). Compliance with food safety and quality standards is, however, a challenge for smallholders due to the costs of compliance, and the extra labour and time required (Kumar et al., 2017b).

The links between farm-level unhygienic food handling and storage practices, and food safety risks are well known (Amenu et al., 2019a; Kamana et al., 2014; Makita et al., 2019) and there have been numerous studies exploring food safety risks at the farm level in East Africa. However, there is limited literature on the assessment of FSM at the farm level in LMICs (Kumar et al., 2017b). There is a paucity of studies that explore the adoption of FSM that mitigate the food safety risks, particularly for FBDs, and the drivers of food safety compliance at the farm level in smallholder dairy systems in wider East Africa (Ledo et al., 2019; Mwambi et al., 2020; Nyokabi et al., 2021).

This study used Ethiopia as a case study for several reasons. Milk production is dominated by smallholder farmers (Abebe et al., 2020; Kebebe et al., 2017; Lemma et al., 2018). The Ethiopian dairy sector is segmented into formal (modern) and informal (traditional) outlets. The modern outlets include dairy cooperatives and private processing firms including domestic and multinational companies that have high milk quality demands. However, the traditional outlets include local milk traders, milk bars, artisanal processing, small-scale dairy processors, and consumer households with low milk quality demands (Lemma et al., 2018). In parallel, milk and milk products contaminated by zoonotic and animal pathogens are public health hazards in Ethiopia and a reason for an urgent need for improved FSM in dairy farming systems (Abebe et al., 2020; Amenu et al., 2019a; Kemal et al., 2019; Tschopp et al., 2022).

The majority of studies in developing countries focus on the intermediate level of the food chain, especially on exporters, processors, manufacturers and supply chains that are globally orientated due to sanitary and phytosanitary requirements for exports that exist at the global level (Humphrey, 2009; Kumar et al., 2017b). Although milk contamination and FBDs risk factors have been studied extensively, only a handful of studies have explored the adoption of FSM at the farm level, even fewer in the context of emerging countries in sub-Saharan Africa (Kumar et al., 2017b; Ledo et al., 2019; Mwambi et al., 2020; Nyokabi et al., 2021). Therefore, the main objective of this study was to understand the status and identify the drivers of FSM adoption by smallholder dairy farmers in Ethiopia.

2 Methodology

This study used a mixed-method approach to collect both quantitative and qualitative data. Quantitative data were collected through a cross-sectional farm survey using a pre-tested questionnaire. Qualitative data was collected through on-farm participant observations. The research had ethical clearance from the University College London's Research Ethics Committee (UCL-REC approval number 19867/001), as well as from the Armauer Hansen Research Institute (AHRI) and the ALERT hospital (AHRI/ALERT Ethics Review Committee (AAERC) protocol number 46/14). Informed consent was obtained from all participating farmers who were briefed in the presence of a witness (local experts) before they participated in the study.

2.1 Study area

The study was done in the urban dairy production systems in Addis Ababa city and the surrounding peri-urban and rural dairy production systems in the Oromia region between April and June 2021. The study areas included Bole, Kolfte, Kaliti and Ketema sub-cities of Addis Ababa and Sebeta, Holeta, Sandafa and Debre Zeit in the Oromia federal region. These study areas were selected due to several reasons. First, the study area was part of the region targeted by the Ethiopia Control of Bovine Tuberculosis Strategies (ETHICOBOTS) project, which looked at cattle disease prevention at the farm level. Second, the areas are important milk-producing areas supporting farmers' livelihoods who produce and sell milk to the intermediate peri-urban and urban markets. Third, studies have shown that milk sold in urban markets in and around Addis Ababa is of poor quality and poses a public health risk to consumers. Finally, the area was convenient due to its easy accessibility, considering the travel restrictions caused by the COVID-19 pandemic.

2.2 Questionnaire design

Quantitative data was collected through a farm survey using a pre-tested questionnaire. The questionnaire used in this study was designed based on the literature review of FAO's Good Agricultural Practices (GAP) and farm-level FSM (Dongol et al., 2017; FAO, 2004; Kumar et al., 2017b; Ledo et al., 2019; Mwambi et al., 2020; Nyokabi et al., 2021). The selected FSM were categorised as animal health and biosecurity, milking hygiene, milk storage and hygiene, and dairy environment hygiene based on their perceived contribution to milk quality (Kumar et al., 2017b). The data collected by the questionnaire comprised households' socio-demographic characteristics, labour availability, milk marketing, adopted FSM, access to information, and group memberships, among others.

2.3 Farm selection

For several reasons, dairy farmers in this study were selected through convenience and purposive sampling. First, the study considered the farmers who were previous participants in the ETHICOBOTS project work and were willing to participate freely in the study. Second, due to COVID-19 travel restrictions, the researchers worked in easily accessible areas and within the regulations prevailing at the time of the data collection. In instances where a previous farmer participant in the ETHICOBOTS project declined to participate or the farm had ceased to exist, an alternative farm within the same areas with similar characteristics was selected as a replacement. The questionnaire was administered in Amharic and Afaan-Oromo by a team of trained enumerators fluent in both languages. In total, cross-sectional survey data were collected from 159 farms around Addis Ababa and its surrounding regions.

2.4 Empirical frameworks

This study was part of the ETHICOBOTs research project that looked at ways to reduce the bovine tuberculosis risks in dairy farms in Ethiopia. The studies employ an approach developed by Kumar et al. (2011) and Kumar et al. (2017a, b) to study the adoption of FSM in smallholder dairy farming systems. These FSM need to be adopted to produce safe and hygienic milk at the farm level. A questionnaire survey was undertaken to investigate the status of FSM adoption at the farm level. The questionnaire design was informed by a literature review of "good agricultural practices (GAPs)" as discussed by FAO (2004) and FSM adoption, including Ledo et al. (2019) for Tanzania; by Kumar et al. (2011), Kumar et al. (2017a, b) for India, Dongol et al. (2017) for Nepal; and Mwambi et al. (2020) and Nyokabi et al. (2021) for Kenya.

FSM are important for producing safe and hygienic milk at the farm level. The FSM judged to be relevant for smallholder dairy production systems in Ethiopia were identified through a literature review (including Dongol et al., 2017; FAO, 2004; Kumar et al., 2011; Ledo et al., 2019; Mwambi et al., 2020; Nyokabi et al., 2021). The selected FSM were categorised according to Kumar et al. (2011) and Kumar et al. (2017a, b) into four broad categories, namely; (1) animal health (9 practices); (2) milking hygiene (11 practices); (3) hygienic milk storage (7 practices); and (4) maintenance of hygienic premises and surrounding environment (10 practices).

Responses were recorded for each of the measures as 1 if the FSM was adopted and 0 if not. The binary categorisations were then summed up to the total number of FSM adopted in each category on each farm. This total sum for each category was used as the dependent variable to run an Ordinary Least Squares (OLS) linear regression model to explore the drivers of FSM adoption. The OLS regression model was as shown in Eq. 1:

$$Y = \beta o + x'\beta + \varepsilon \tag{1}$$

where: Y= is the dependent variable which is the sum of adopted FSM (animal health/milking hygiene/ hygienic milk storage/ maintenance of hygienic premises and surrounding environment). The independent variables used in the model were: herd size, number of lactating cows, the proportion of milk sold, other livestock present, the occurrence of cattle diseases in the last two years, farmer knowledge about historical cattle disease outbreaks, farmer trusting information offered by government agencies, farmer trusts government interventions (i.e. vaccination during disease outbreaks), a veterinarian has contacted the farmer regarding vaccination programs, cattle breed, milk marketing channel, farming system (zero-grazing or semi-zero grazing), the type of veterinarian farmer uses (private or public), and ε is the column vector of error terms, assumed to be independently distributed.

For each farm, a weighted food safety index was calculated. Given the contribution of each category of FSM to milk safety and quality is not the same, we compiled a food safety index (FSI) based on the weighted sum of the proportion of adopted FSM in each farm. The FSM were allocated weights based on their contribution to food safety and quality as suggested by Kumar et al. (2017a, b). The FSM weights of 0.25, 0.35, 0.20, and 0.20 were assigned to animal health, milking hygiene, hygienic milk storage and hygienic environment/surrounding measures, respectively. The weighted FSI ranged from 0 to 100% and could be used to compare FSM adoption across the surveyed farms.

The FSI was computed as explained by Kumar et al. (2017a, b). The FSI for the I^{th} farm was computed and represented as shown in Eq. (2):

$$\begin{aligned} FSI = {} & (proportion\ of\ adopted\ animal\ health * 0.25) \\ & + (proportion\ of\ adopted\ milking\ hygiene * 0.35) \\ & + (proportion\ of\ adopted\ hygienic\ storage * 0.20) \\ & + (proportion\ of\ adopted\ hygienic\ environment/surrounding\ practice\ groups * 0.20) \end{aligned} \quad (2)$$

The FSI scores were used to classify farmers into three groups based on their adoption of FSM (i.e., the percentile of the FSI). Farms with scores below the 30th percentile (i.e., below 30% in their FI score) were considered low adopters, those between 30 and 70th (i.e., 30–70% FSI score) percentile medium adopters, and those above the 70th percentile (over 70% FSI score) high adopters.

A regression analysis to assess the drivers of FSI adoption at the farm level was undertaken as outlined by Kumar et al. (2011) and (2017a, b) to identify factors that drive FI adoption at the farm level and that can be used to nudge farmers toward higher adoption of FSM. In the OLS regression model, FSI scores were used as the dependent variable following the procedure shown in Eq. 1.

All the OLS models were analysed using STATA statistical software version 17.0 (StataCorp, 2021).

2.5 Qualitative data collection

Qualitative data were collected across 18 farms (nine urban area farms and nine rural area farms) through participant observation undertaken by the first author across 18 farms (nine urban area farms and nine rural area farms). Data was collected and recorded as pictures with the prior consent of the farmers. The data obtained through observation were compared to the survey data and provided relevant additional contextual information which enabled data triangulation and ensured the reliability of the findings.

3 Results

3.1 Farmer characteristics

Table 1 provides a summary of farm characteristics in the study area. The majority of the participating households were smallholder dairy farmers in the urban and peri-urban areas around Addis Ababa and the surrounding areas of the Oromia administrative region.

3.2 Adoption of food safety measures

Table 2 presents the summary adoption of FSM in dairy farms. The intensity of FSM adoption determines the safety and quality level of the final milk product. In this study we considered 36 different components of FSM being adopted by dairy farmers in Ethiopia; nine were related to animal health measures, 11 to hygienic milking measures, seven to hygienic milk storage and nine to maintaining general hygiene of the farm premises and the surrounding environment.

Although farmers adopted animal health measures, there was low adoption (below 50%) of dry cow therapy (DCT) for the prevention of mastitis, daily observation of animal health, implementation of biosecurity plans and/or testing for cattle with aborted diseases. There was low adoption of milking hygiene measures such as lack of separate milking area, lack of fore stripping to check on mastitis, low disinfection of teats after milking, lack of hand sanitiser station in the cattle shed and the majority of farmers did not shave or trim cattle udder and tail hair to minimise potential milk contamination. Regarding the adoption of hygienic milk storage measures, there was widespread use of non-grade plastic containers for milking and storage and low adoption of insect or rodent control programmes in the milk storage area. There was low disinfection, cleaning and drying of the milking floor area, the presence of overgrown vegetation on the farm, the absence of a disinfection footbath and a lack of hand sanitation facility at the entrance of cattle sheds.

Table 1 Demographic and farm characteristics ($n = 159$)

Variable	Description	Frequency (percentage)
Farm location	Addis Ababa city	50 (31.4%)
	Oromo federal region	109 (68.6%)
Farm owner's level of education	No education	10 (6.3%)
	Primary school education	49 (30.8%)
	Secondary school education	61 (38.4%)
	Tertiary school education	39 (24.5%)
Milk marketing value chain	Subsistence	38 (23.9%)
	Informal value chain	86 (54.1%)
	Formal value chain	16 (10.1%)
	Both informal and formal value chain	19 (11.9%)
Dairy farming is the main source of income		118 (74.2%)
Farmer has another source of income		59 (37.1%)
Additional male labour employed	$\bar{x}$ (SD)	3 (6)
Additional female labour employed	$\bar{x}$ (SD)	1 (3)
Average number of cattle (herd size)	$\bar{x}$ (SD)	17 (18)
The average number of lactating cows	$\bar{x}$ (SD)	8 (8)
The average number of calves	$\bar{x}$ (SD)	4 (5)
Mode of milking	Manual/hand	100%
	Machine	0.0%
Cattle breed kept	Exotic breeds	41 (25.8%)
	Crosses of exotic breeds	108 (67.9%)
	Local breeds	10 (6.3%)
Average milk produced (in litres)	$\bar{x}$ (SD)	79 (118)
Average milk sold (in litres)		121 (335)
Average milk price (in Birr)	$\bar{x}$ (SD)	27 (7)
Farmer kept other livestock		64 (40.3%)
The farmer is a member of a farmer organisation /groups		36 (22.6%)

$\bar{x}$- mean, SD-standard deviation, 1 Birr = 0.019 United States dollars (accessed on 9th August 2022)

Table 3 summarises the results of participant observations. We observed widespread use of plastic containers for milking and storage, poor housing conditions, lack of milk cooling equipment, and poor animal health practices contrary to GAPs.

Table 4 presents the status of the adoption of safety practices and their components. There was a wide variation in the adoption of FSM ranging from 0 to 97%. The average adoption rate in the sample was 60.5%, with no major differences between Addis Ababa and Oromia, at 60.0% and 60.8% respectively. Based on the FSI results (Table 3), the majority of farmers (67.9%) can be classified as medium FSM adopters (those with FSI between 30–70%). A minority (1.3%) were low FSM adopters (FSI below 30%) while a considerable percentage (30.8%) were high FSM adopters (FSI over 70%).

3.3 Drivers of FSM Compliance

This study used OLS regression to explore the drivers of FSM compliance. The descriptive statistics of variables used in the OLS regression analysis are presented in Table 5. The dependent variables in the OLS models were the individual categories of the FSM adopted and the FSI (based on the weighted adoption of FSM categories). The OLS regression results showing the estimated coefficients and standard errors are presented in Table 5. The results of the empirical analysis provide information about the relationship between farm-level adoption of FSM and the characteristics of smallholder dairy farmers.

Table 6 presents the results of OLS regression. The estimated coefficients show the quantitative effect of the

Table 2 Farmers' adoption of food safety measures in smallholder dairy farms (in percentage, $n=159$)

Adopted animal health measures	(%)
Cattles vaccinated	94.3
Farmer performed dry cow therapy (DCT)	15.7
Animal health monitored/ observed daily	54.1
Cows are cleaned to remove dung on their body	95.0
Endoparasites (deworms) in cattle controlled	94.3
Ectoparasites (ticks) in cattle controlled	76.1
The farm has a biosecurity plan	44.0
Aborting cattle tested for diseases (such as brucellosis or Q-fever)	13.8
Sick cattle isolated when diseased	67.9
Mean and Std dev of adopted animal health measures	6 (2)
Adopted milking hygiene measures	
There is a separate milking area	30.2
Milker washes their hands before milking	99.4
Milker dries their hands after washing them before milking	88.1
Cattle udder and teats cleaned before milking	94.9
Cattle udder and teats dried after washing and before milking	92.5
Milker undertook fore-stripping to check on mastitis	32.1
Milker disinfected teats after milking	19.7
Cattle udder and tail shaved to reduce hairs (contaminants)	30.2
Hand sanitiser station present in the cattle shed	40.9
Milker trimmed hand nails to ensure hygiene	76.7
Milker covered cuts and wounds with a waterproof dressing	62.3
Mean and Std dev of adopted milking hygiene measures	7 (2)
Adopted hygienic milk storage measures	
Milk is stored in a separate area from the cattle shed	73.6
The milk storage area floor is kept clean always	76.4
Milk-bulking containers are washed, dried and kept in a sanitary environment	91.1
Milk from sick cattle under treatment is discarded	86.8
Food-grade plastic or aluminium containers used for milk storage	17.0
Insect control measures present in the milk storage area	35.2
Rodent control measures present in the milk storage area	32.7
Mean and Std dev of adopted hygienic milk storage measures	4(2)
Adopted hygienic premises and surrounding environment measures	
The cattle shed is cleaned regularly (daily or every two days in zero grazing housing)	90.6
Disinfectant used to clean the milking area floor	49.1
Vegetation growth around the cattle shed controlled	46.5
Footbath present at the entrance of the cattle shed	28.3
Employees and visitors are required to wash their hands before entering the cattle shed	61.0
The cattle shed has hand washing or sanitiser at the entrance	40.9
Milking areas floor cleaned and dried before milking	53.5
The milking area floor was kept well-drained and free of cattle urine and dung	93.7
No chemicals i.e., pesticides are used around the milking area	82.9
Mean and Std dev of adopted hygienic premises and surrounding environment measures	5(2)

independent variables and the direction of change. These empirical results provide information about the relationship between FSM adoption intensity and dairy farmers' characteristics. Dairy farmers whom a veterinarian contacted regarding vaccination programs were more likely to adopt animal health while farmers who kept crossbred cattle were likely to adopt fewer animal health measures compared with those who kept local breeds. Farmers with other animals on the farm, those contacted by a veterinarian regarding vaccination programs, and those practising semi-zero grazing practices were likelier to adopt milking hygiene FSM. However, farmers' trust in government

Table 3 Results of participant observations about FSM adoption in dairy farms ($n=18$)

Description	Number of participants
Farm used plastic non-food grade containers	14
Farm had an unhygienic milking environment	11
Farm used the recommended milk containers, such as "Mazzican" or aluminium containers for milking and milk storage	7
Farm had good cattle housing hygiene	7
Farm had good milking hygiene and storage	8
Milk was sieved to remove contaminants	10
Farmer or milker performed teat dipping before and/or after milking	5
Cattle udders and teats were cleaned before milking	17
Milker and farm workers used PPE	2
Farm had good manure disposal and management	5
Farm had good feed storage	8
Farm controlled for flies and other vectors	2
Milk was cooled immediately after milking (within 15 min of milking)	4
Milk is sold immediately after milking (within an hour after milking)	16

interventions, keeping of crossbreed cows and farmers with only primary education were likely to adopt fewer milking hygiene FSM.

An increase in the number of lactating cattle, the presence of other livestock on the farm, trust in government-provided information, contact from a veterinarian regarding vaccination programs and practising semi-zero grazing led to increased adoption of hygienic milk storage FSM. However, farmers who trust government interventions, those who depend on public health services, farmers with crossbred cattle, farmers who sold their milk in the formal value chain, farms that have experienced disease problems in the last two years and knowledge of historical cattle disease outbreaks were likely to adopt fewer hygienic milk storage FSM. Farmers' trust in government-provided information positively influenced their adoption of maintaining general hygiene of the premises and the surrounding environment FSM. The farmers who trust government interventions, those with knowledge of historical cattle disease outbreaks, those who trust government interventions, and those keeping crossbred cattle were likely to adopt fewer measures for maintaining general hygiene of the premises and the surrounding environment.

Overall, the farm FSM adoption intensity increased in cases where there was a presence of other livestock on the farm, trust in government-provided information, contact from a veterinarian regarding vaccination programs and practising semi-grazing production system. Farmers who had experienced disease problems in the last two years, those with knowledge of historical cattle disease outbreaks, farmers who trusted in government interventions, those who kept crossbreed cattle and farmers with only primary education were likely to have adopted fewer FSM.

4 Discussion

This study investigated the adoption of food safety measures (FSM) by smallholder farmers in Ethiopia. It also explored the drivers of the adoption of FSM in smallholder farms. FSM compliance by dairy farms showed that a lot of effort is needed to increase the implementation of FSM. Although there was high adoption of some FSM measures such as cattle vaccination, control of ectoparasites and endoparasites, hand washing, among others, there was also low adoption of other critical FSM measures such as low uptake of dry cow

Table 4 Proportion of FSM adopted in smallholder dairy farms, ($N=159$)

Food safety measures	Addis Ababa $n=50$ $\bar{X}$ (S. D)	Oromia $n=109$ $\bar{X}$ (S. D)	Average $n=159$ $\bar{X}$ (S. D)
Animal health measures	15.17 (4.13)	15.55 (4.25)	15.43 (4.20)
Milk handling hygiene	10.72 (3.33)	11.01 (3.65)	10.92 (3.54)
Milk storage measures	11.91 (3.70)	12.23 (4.05)	12.13 (3.94)
Environmental measures	21.06 (5.82)	21.25 (7.10)	21.19 (6.71)
Food safety index	58.86 (13.80)	60.04 (16.62)	59.67 (15.75)
Range (minimum-maximum)	36.10 – 91.64	24.18 -93.78	24.18 -93.78

Table 5 Statistics of the descriptive variables used in the OLS models

Variable	Mean	Std. dev	Min	Max
Log of Food Safety Index	4.065	0.278	3.174	4.554
Animal health measures	4.082	0.292	3.101	4.605
Storage	3.985	0.501	2.660	4.605
Environment	4.046	0.361	2.408	4.605
Hygiene	4.037	0.407	2.207	4.605
Herd size	13.887	9.880	4	34
Lactating cows	7.566	5.661	2	20
Proportion of milk sold	1.054	0.541	0.067	5.500
Other livestock present	0.403	0.492	0	1
Heard disease	0.553	0.499	0	1
Knowledge of historical outbreaks	0.352	0.479	0	1
Trust government agencies Information	0.937	0.244	0	1
Trust government interventions	0.912	0.284	0	1
Veterinarians contacted farmers about vaccination programs	0.761	0.428	0	1
Farmer keeps cross-breeds	0.742	0.439	0	1
Formal Marketing Value chain	0.220	0.416	0	1
Semi zero grazing	0.799	0.402	0	1
Primary education	0.371	0.485	0	1
Public vet usage	0.264	0.442	0	1

therapy, testing of aborting cattle, lack of mastitis testing, lack of insect and pest control strategies that could compromise milk quality and safety. Moreover, this study revealed that factors such as historical knowledge of cattle disease outbreaks, trusting information provided by government agencies, trust in government disease control interventions, and regular contact with a veterinarian regarding vaccination programs were important drivers of FSM adoption.

Dairy farmers play an important role in implementing disease prevention and control practices on farms, leading to improved food safety (Suit-B et al., 2020). Farm-level efforts are important for controlling most hazards, including animal feed, milking, and milk storage as they determine milk safety and quality (Abebe et al., 2020; Kumar et al., 2017a, b; Lemma et al., 2018). Adoption of FSM and good farming practices can contribute to food safety at the farm level (Kebebe et al., 2017; Lemma et al., 2018). Some FSM, however, such as testing of aborting cattle and mastitis and dry cow therapy can be expensive which can discourage farmers leading to low adoption (Pritchard et al., 2015; Suit-B et al., 2020). Some FSM require high recurrent and/or non-recurrent costs which may be beyond the capital resources available to smallholder dairy farmers (Handschuch et al., 2013; Kebebe et al., 2017).

Table 6 Results of OLS Models for the drivers of Food Safety Index, adoption of animal health, milk hygiene, milk storage, and environmental hygiene measures

	Animal health	Milking hygiene	Hygienic milk storage	Hygienic environment measures	Food Safety Index
	b/se	b/se	b/se	b/se	b/se
Herd size	0.000 (-0.005)	0.012 (-0.007)	-0.006 (-0.008)	-0.001 (-0.006)	0.003 (-0.004)
Number of lactating cows	0.015 (-0.009)	-0.015 (-0.012)	0.033 (-0.014) *	0.017 (-0.011)	0.008 (-0.007)
Proportion of milk sold	-0.015 (-0.038)	-0.031 (-0.052)	0.009 (-0.06)	0.01 (-0.044)	-0.019 (-0.03)
Other livestock present	0.007 (-0.045)	0.129 (-0.062) *	0.177 (-0.073) *	0.021 (-0.053)	0.082 (-0.036) *
Farm has had a case of cattle disease (last two years)	-0.075 (-0.047)	-0.06 (-0.064)	-0.165 (-0.075) *	-0.111 (-0.054) *	-0.085 (-0.037) *
Farmer knows historical cattle disease outbreaks	-0.026 (-0.049)	-0.069 (-0.068)	-0.186 (-0.079) *	-0.188 (-0.057) **	-0.095 (-0.039) *
Farmer trusts government agencies information	0.155 (-0.088)	0.184 (-0.121)	0.386 (-0.14) **	0.251 (-0.102) *	0.196 (-0.07) **
Farmer trusts government interventions	-0.003 (-0.076)	-0.227 (-0.105) *	-0.451 (-0.122) ***	-0.387 (-0.089) ***	-0.237 (-0.061) ***
Farmer contacted by veterinarian regarding Vaccination programs	0.231 (-0.05) ***	0.284 (-0.069) ***	0.422 (-0.081) ***	0.105 (-0.058)	0.242 (-0.04) ***
Farmer keeps cross-breeds	-0.112 (-0.05) *	-0.156 (-0.069) *	-0.114 (-0.081)	-0.234 (-0.059) ***	-0.146 (-0.04) ***
Farmer sells milk to formal value chain	0.053 (-0.051)	-0.115 (-0.071)	-0.149 (-0.082)	0.04 (-0.06)	-0.03 (-0.041)
Farmer practices semi-zero grazing	-0.017 (-0.050)	0.159 (-0.069) *	0.169 (-0.082) *	0.077 (-0.058)	0.093 (-0.04) *
Farmer has primary education	-0.067 (-0.045)	-0.184 (-0.062) **	0.027 (-0.073)	-0.089 (-0.053)	-0.077 (-0.036) *
Farmer uses public veterinarian	-0.015 (-0.046)	-0.045 (-0.064)	-0.132 (-0.074)	-0.011 (-0.054)	-0.033 (-0.037)
Constant	3.828 (-0.134) ***	3.932 (-0.184) ***	3.631 (-0.215) ***	4.225 (-0.156) ***	3.966 (-0.107) ***

$*p<0.05$; $**p<0.01$; $***p<0.001$

4.1 Adoption of FSM

The results of this study show gaps in the adoption of animal health FSM measures which could expose cattle to diseases including zoonoses of public health concern. The results also reveal that the majority of farms lacked a biosecurity plan, did not perform fore-stripping to check on mastitis, had low use of disinfectant for teat cleaning and lacked teat dipping after milking. Milk microbial contamination including zoonotic pathogens in Ethiopia has led to calls for better disease control and prevention in dairy farming systems (Amenu et al., 2019a). The absence of external and internal biosecurity measures exposes the farm to introducing cattle diseases and spreading within the herd (Richens et al., 2015; Suit-B et al., 2020). Poor udder health practices such as low adoption of dry cow therapy (DCT) and teat dipping can lead to mastitis, which affects milk quality (Bauman et al., 2018). The practice of not testing aborting cows for diseases could expose farmers and consumers to zoonoses such as brucellosis and bovine tuberculosis (Deneke et al., 2022; Terefe et al., 2017). There is a need to improve animal health practices, including adopting biosecurity measures that can reduce animal diseases and improve milk quality and safety.

The widespread use of non-food grade containers for milking and storage can contaminate milk. Findings from this study show that farmers are not using the appropriate milking containers and are largely using plastic containers which could contaminate the milk. This is similar to the findings of previous studies conducted in Ethiopia (Amenu et al., 2019b; Lemma et al., 2018). It is important to assist farmers in accessing the recommended containers and equipment, such as the adoption of "mazzican" (improved food-grade plastic containers) and aluminium containers and equipment which can contribute to improved milk quality as they are easy to clean and have low bacteria load after cleaning (Kebebe et al., 2017; Kurwijila et al., 2016; Ledo et al., 2019; Nyokabi et al., 2021).

There was low adoption of some crucial milking hygiene measures, such as the lack of a separate milking area and failure to shave the cattle udder and tail hairs to reduce potential milk contaminants. Milking cattle in the main shed can lead to milk contamination as animal excreta can be a contaminant. The lack of spaces to build a separate milking shed due to the small land sizes, particularly in urban and peri-urban areas constrains farmers and hinders FSM adoption (Kebebe et al., 2017).

The majority of farms had overgrown vegetation and lacked pest control programmes for insects and rodents in the milk storage area and cattle sheds. Pests can contaminate milk and can act as disease vectors. Additionally, farms can contaminate the environment and create a habitat for pests if waste is not well managed as has been reported by Groot and van't Hooft (2016).

Our results reveal that the majority of farmers failed to regularly clean and disinfect the milking floor area and cattle shed. Furthermore, farms lacked a handwashing station and a footbath at the cattle shed's entrance, contrary to biosecurity recommendations. The majority of farms lack hand sanitisation in the cattle shed, making it difficult for the milker and farmer to maintain good hygiene.

4.2 FSM adoption intensity

The overall farm FSM adoption intensity (Table 4) was average (around 50%) which shows a gap in FSM adoption. FSM adoption intensity is important as it influences animal health, milk quality and safety. The FSM adoption intensity reported in this study is similar to studies in India (FSI of 62—66%) (Kumar et al., 2017b) but below the FSM adoption intensity reported for Nepal (FSI of 66.3—77.4%) (Dongol et al., 2017). Farms with high FSM are likely to have good animal health practices, adopt biosecurity measures and produce quality and safe milk (Dongol et al., 2017; Kumar et al., 2017b; Ledo et al., 2020). Dongol et al. (2017) documented that farms with high FSI had milk that passed quality tests compared to those with low FSI. Bauman et al. (2018) and Lemma et al. (2018) have documented that a farm with good FSM is likely to have good animal health and good milk quality, i.e., low somatic cell count (SCC), low total bacteria and coliform count. In this study, however, the association between FSI and milk quality was not assessed.

4.3 Drivers of FSM adoption

The results of OLS regression (Table 6) revealed that some farm and farmer characteristics determined the adoption of FSM. Farmer education is an important driver of FSM adoption. Farmers with only primary education were more likely to adopt fewer FSM including milking hygiene, hygienic milk storage and maintaining general hygiene of the premises and the surrounding environment. Previous studies in India have reported low education is associated with low FSM adoption which could also be a driver for the low implementation of FSM in smallholder dairy farms in Ethiopia (Groot & van't Hooft, 2016; Kumar et al., 2011). Farmers with low education are less likely to have a secondary source of income which can limit their FSM adoption. Additionally, these farmers may not be able to access and process information compared to their more educated peers (Kebebe et al., 2017; Suit-B et al., 2020).

The findings of the OLS model revealed that herd size was an important driver of FSM adoption. For example, an increase in the number of lactating cattle increased the adoption of hygienic milk storage FSM. This could be because a large herd will produce more milk, hence the need for better storage. Milk storage equipment and the storage temperature determine microbial contamination (Dongol et al., 2017; Kumar et al., 2017b; Ledo et al., 2020). There is, therefore, a need to incentivise and motivate milk producers to provide better storage conditions for their milk (Lemma et al., 2018).

The results showed that regular contact with a veterinarian about vaccination programs could influence farmers' adoption of practices that improve animal health in smallholder dairy farms. Previous studies have shown that using veterinary services is a risk-reduction strategy for cattle farmers in Ethiopia (Bishu et al., 2018). It has been documented that farmers are willing to pay for animal health services (Jemberu et al., 2020) and that veterinarians are an important source of information for farmers, particularly regarding the making of decisions about vaccination and disease control (Richens et al., 2015). They are also a crucial source of advice about biosecurity measures (Jemberu et al., 2020; Pritchard et al., 2015). Furthermore, in Ethiopia, veterinarians are the preferred and trusted suppliers of vaccines, animal health product vaccination interventions, deworming interventions, ectoparasite control and artificial insemination (Bishu et al., 2018; Solomon et al., 2019).

Our results also show that the farming system influenced FSM adoption. Practising semi-zero grazing increased the adoption of milking hygiene, hygienic milk storage and the overall farm adoption intensity of FSM. This could be related to the risk of grazing and livestock mixing in semi-grazing systems. Additionally, the results of this study show that farmers with local breed cattle were more likely to adopt more animal health measures which is contrary to the findings of Jemberu et al. (2020) who reported that farmers with exotic and crossbred cattle were likely to adopt more animal health measures.

Farmers keeping crossbred cattle were likely to adopt fewer FSM such as maintaining the general hygiene of the premises and the surrounding environment. One possible explanation for this result could be that farmers rely on traditional farming practices commonly used in keeping local cattle breeds under extensive grazing systems but that is not ideal for crossbred cattle (Jemberu et al., 2020; Terefe et al., 2017). In Ethiopia, cattle in the extensive production systems mix during grazing, watering, and sheltering, increasing the risk of disease exposure (Terefe et al., 2017).

The presence of other livestock on the farm positively influenced the adoption of practices that improve animal health, milking hygiene, hygienic milk storage and the overall farm FSM adoption intensity. Mixing of animal species increases the risk of cattle exposure to animal diseases, particularly zoonoses and hence it is crucial to ensure the adoption of biosecurity measures and GAP (Jemberu et al., 2020; Pritchard et al., 2015). An increase in the number of livestock species on a farm increases the risk of diseases and farmers are more likely to comply with GAP (Bishu et al., 2018). In Ethiopia, it has been documented that the mixing of livestock species, including small ruminants and camels, can increase the risk of disease exposure to cattle (Terefe et al., 2017).

The results show that farms with recent disease incidents and/or farms with historical knowledge of diseases were likely to adopt less hygienic milk storage measures and maintain general hygiene of their premises and the surrounding environment. Moreover, they were likely to have a low overall farm FSM adoption intensity. Farmers' knowledge and exposure to disease risks could reduce the farmers' perception of disease severity due to the knowledge gained for managing cattle disease or risk (Suit-B et al., 2020).

Farmers' trust in government-provided information led to increased adoption of hygienic milk storage, maintaining general hygiene of the premises and the surrounding environment and the overall farm FSM adoption intensity. Access to information and extension can help the diffusion of technology and empower farmers to make informed decisions on husbandry practices (Suit-B et al., 2020). Access to veterinary information is however a challenge in Ethiopia (Solomon et al., 2019).

Farmers' trust in government interventions reduced adoption of milking hygiene, hygienic milk storage, maintaining general hygiene of the premises and the surrounding environment and the overall farm FSM adoption intensity. This could be because poor farmers were likely to rely on free government services and interventions (Solomon et al., 2019). In Ethiopia, integrated herd health intervention packages are virtually absent even though they have a huge potential to improve productivity with highly favourable cost-benefit ratios (Solomon et al., 2019). In Ethiopia, animal health service provision is dominated by the public sector and more than 90% of veterinary staff work in government service (Berhanu, 2003).

4.4 Food safety and public health policy implications

Low adoption of FSM at the farm level, as revealed in this study, has food safety and public health implications for consumers of milk and dairy products. The results of this study reveal a gap in the adoption of good agricultural practices and low compliance with Ethiopian food safety regulations which can lead to milk contamination and expose consumers to foodborne zoonoses (Kumar et al., 2011; Kumar et al., 2017b; Nyokabi et al., 2021). There is therefore a need to enact policies and intervention strategies that promote farm-level FSM adoption. Farmers could be incentivised to adopt good agricultural practices and comply with food safety regulations by the provision of training related to livestock production; the creation of a milk quality-based payment system; and a food safety education campaign that leads to increased awareness of how FSM adoption at the farm level influences milk and dairy product quality and safety (Nyokabi et al., 2021). Increasing the adoption and compliance with FSM at the farm level could generate benefits for smallholder dairy farmers by increasing access to a formal market which has high milk quality requirements but offers higher milk prices (Kumar et al., 2017b). However, FSM adoption requires farmers to invest in technology and equipment which can increase farm production costs and reduce profit margins (Kumar et al., 2017b). The results of this study underscore that contamination risks originate at the farm level and cascade across a value chain; for this reason, it is important to assist farmers in accessing the capital, information and technology necessary to incorporate FSM into their production strategies (Kumar et al., 2011, 2017b).

4.5 Strengths and limitations of the study

The research approach we used provides a standardised way for comparing smallholder dairy farms' performance with regard to the adoption of FSM which has the potential to contribute to milk quality (Kumar et al., 2011, 2017a) The research approach provides indicators that can be used to improve milk quality in smallholder farms (Dongol et al., 2017; Kumar et al., 2017a). Moreover, the FSM are easy to understand and if adopted can lead to improved farm performance (Dongol et al., 2017). We propose that future studies explore the relationship between farm-level FSM and their contribution to milk quality in smallholder farms in Ethiopia.

One limitation of this study was that we did not investigate the relationship between FSM adoption and milk quality. Secondly, the sample of farmers surveyed in this study were mostly smallholder farmers practising zero grazing which may not apply to large farms and extensive pastoral systems.

5 Conclusion

The findings from this study provide an overview of the current status of compliance with FSM at the farm level in Ethiopia's smallholder dairy farming systems. The results reveal an FSM adoption gap and low compliance with food safety regulations and good agricultural practices in smallholder farms which needs to be urgently addressed. Moreover, this study identified the drivers of FSM adoption at the farm level. Overall farm FSM adoption is determined by factors linked to dairy farmers' characteristics. Specifically, the results have indicated that herd size, education level, expertise in dairying, and the integration and participation of dairy farmers in the modern milk supply chain positively influence the adoption intensity of FSM at the farm level. There is thus a need to increase farmers' knowledge of FSM through training and access to information. Furthermore, it is crucial for the government to invest in laboratory facilities that could enable veterinarians to diagnose cattle abortion, mastitis and other diseases which can lead to improved animal health in smallholder farms. Additionally, there is a need to enable farmers to access financing and technology that can lead to increased adoption of FSM given the potential to improve food safety and also improve farmers' livelihoods by increasing earnings and reducing postharvest losses in Ethiopia.

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Data Availability Data is available from the lead author on reasonable request.

Declarations

Conflict of interest The authors state that there was no conflict of interest resulting from funding or otherwise.

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