frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 27 January 2025
DOI 10.3389/fsufs.2024.1539559

Impact of hygienic milk production training on knowledge, attitudes and practices of women farmers in the central highlands of Ethiopia

Abdi Keba[1]*, Alganesh Tola[2], Kerry E. Kaylegian[3], Muluken Kebede[4] and Ashagrie Zewdu[5]*

[1]Health Program, International Livestock Research Institute, Addis Ababa, Ethiopia, [2]Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, Holeta, Ethiopia, [3]Deparment of Food Science, The Pennsylvania State University, University Park, PA, United States, [4]Department of Chemical Engineering, Hawassa University, Institute of Technology, Hawassa, Ethiopia, [5]Center for Food Science and Nutrition, Addis Ababa University, Addis Ababa, Ethiopia

Check for updates

OPEN ACCESS

EDITED BY
Fatima Zahra Jawhari,
Higher Institute of Nursing and Health Techniques, Morocco

REVIEWED BY
Massik Abdelhamid,
Centre Hospitalier Universitaire Hassan II, Morocco
Ibtissam Bouabadi,
Higher Institutes of Nursing and Health Technology Professions (ISPITS), Morocco

*CORRESPONDENCE
Abdi Keba
A.Keba@cgiar.org
Ashagrie Zewdu
ashagrie.zewdu@aau.edu.et

RECEIVED 04 December 2024
ACCEPTED 24 December 2024
PUBLISHED 27 January 2025

CITATION
Keba A, Tola A, Kaylegian KE, Kebede M and Zewdu A (2025) Impact of hygienic milk production training on knowledge, attitudes and practices of women farmers in the central highlands of Ethiopia. *Front. Sustain. Food Syst.* 8:1539559. doi: 10.3389/fsufs.2024.1539559

Introduction: Food safety remains a challenge in developing nations, including Ethiopia, where dairy products are known to be contaminated with foodborne pathogens. Limited food safety interventions studies for improving food safety along the food supply chain have been conducted. The objective of this intervention study was to improve the knowledge, attitudes, and practices (KAPs) of women dairy farmers in the central highlands of Ethiopia by developing and delivering training customized to their education level.

Methods: A total of 120 dairy women farmers were recruited from local milk cooperatives and milk collection centers at four study sites. Training materials on clean milk production and hygienic milking practices were developed for an audience that may not be able to read or write. The 3-day curriculum was delivered using theoretical lecturing, video presentation, practical activities, and handouts, and learning was assessed with a questionnaire and checklist.

Results: The study indicated that women dairy farmers improved their knowledge, attitude, and practices relating to quality milk production. However, milk shade assessments of individual farmers identified many important risk factors for clean milk production that were due to infrastructure issues.

Discussion: The effectiveness of the training materials and approach was supported by the increase in KAPs assessment scores from pre-training to post-training for all study sites. Comparisons of the training outcomes and evaluation results of milk shades were found counterintuitive, which revealed the complexity of food safety interventions. Customized food safety training is effective but should be combined with dairy farming infrastructure improvements to achieve the goal of clean milk production at farm level.

KEYWORDS

dairy women farmers, dairy intervention, training evaluations, KAPs, milk shade assessment, central highlands, Ethiopia

1 Introduction

Foodborne illness remains a challenge in least developed countries due to the increased consumption of perishable crop and animal products, and the complex nature of the food value chain (Grace, 2015). It affects over 90% of the populations in low-and middle-income countries (LMICs), and around 40% of this burden affects children under the age of five. In 2010, dairy products and animal-sourced food consumption contributed 4 and 12% of global foodborne disease burdens, respectively (Havelaar et al., 2015; Grace et al., 2020; Grace, 2023).

Ethiopia has the potential for cattle production due to its ideal climate, however, milk production in terms of quantity and quality is low (Gebreselassie, 2019). In developing countries, lack of knowledge, technology, social barriers, and infrastructure are major constraints for high quality milk production (Ledo et al., 2019). As a result, dairy products serve as a significant medium for the spread of foodborne and spoilage organisms (Ntuli et al., 2023; Fereja et al., 2023), and consumption of dairy products without proper heat treatment may pose health risks to humans (EFSA Panel on Biological Hazards (BIOHAZ), 2015).

Previous studies reported that dairy products in Ethiopia, such as milk, yogurt, and cottage cheese, are contaminated with foodborne pathogens such as *Salmonella* spp., *Listeria* spp. and *Listeria monocytogenes*, *E. coli O157:H7*, and *Campylobacter* spp. (Keba et al., 2020; Bedassa et al., 2023; Mengstu et al., 2023; Asfaw et al., 2023; Hawaz et al., 2023; Hunduma et al., 2023). Studies indicated that potential risk factors of foodborne pathogens and associated public health risks were very high in the country, which can cause human diseases ranging from gastrointestinal disturbances characterized by diarrhea and vomiting to life-threatening illnesses (Bintsis, 2017).

Major factors of safe milk production at the farmer level are poor hygienic practices, lack of food-grade milk equipment, clean water sources, milk cooling, and animal health, including the teat and udder health of milking cows (Amenu et al., 2013; Abunna et al., 2018; Bereda et al., 2018; Gwandu et al., 2018; Kebede et al., 2019).

Women perform most of the dairy farming activities and, therefore, contribute to the major risk factors in producing good quality milk (Getachew and Tadele, 2015; Kinati and Mulema, 2018). However, women farmers have less access to education, dairy farm management and animal husbandry, and training opportunities (Tassew and Seifu, 2009; Yuya, 2018; Didanna et al., 2019). In 2022, Garsow et al. published a paper that described the importance of gender-sensitive food safety initiatives in reducing foodborne illness and improving family health.

Capacity building and creating food safety awareness for women farmers could improve knowledge of individuals and communities and long-term food safety system partnerships in the food supply chain (Gallina, 2016; Lindahl et al., 2018). The objective of this intervention study was to improve the knowledge, attitudes, and practices (KAPs) of women dairy farmers in the central highlands of Ethiopia by developing and delivering training customized to their education level. Changes in KAPs indicators were measured by pre-and post-training self-assessments and an evaluation of milk shade environments by the trainees. The study showed the training improved KAPs indicators of the women farmers, but there were infrastructure issues that provided challenges with improving milk quality at the farm level.

2 Materials and methods

2.1 Study area

The study was conducted in the Oromia region, in the central highlands of Ethiopia. Four training areas were selected based on the potential of milk flow to the capital city, Addis Ababa: Wolmera, Bishoftu, Asella, and Selale (Figure 1). The study areas were within a radius of 175 km from the capital city and at altitudes of 1850 to 4,130 m above sea level. The mean annual rainfall varies from 866 to 1800 mm, and the annual average temperature ranges from 18.7 to 22.5°C (CSA, 2019).

2.2 Inclusion and exclusion criteria

Dairy farmers, within the study area identified above, who were female, over 18 years old, held lactating cows and sold raw milk to milk cooperatives and/or direct-to-consumers were eligible to participate in the study. Farmers who were outside of Wolmera, Bishoftu, Asella and Selale areas or commercial and organized farms were excluded from participating in the study.

2.3 Sample size and selection process

The number of the participants needed was calculated to achieve 80% of the power to detect a change ($\alpha = 0.05$), which was determined to be 80 dairy women farmers. To protect against dropouts, loss of follow-up, and other sources of missing data, a total of 120 women dairy farmers were purposefully selected in equal proportions from the Wolmera, Bishoftu, Asella, and Selale areas to ensure sufficient power for analysis.

Lists of dairy producers were collected from milk cooperatives and milk collection centers in the four study sites. A total of 280 dairy farmers were screened from the original lists of 530 producers based on dairy women farmers and delivering milk to the milk collection centers or cooperatives. Then, 120 dairy women farmers were randomly selected from the four sites, and 30 dairy women represented each site (Figure 2). Farmers were invited to the training with the help of developmental agent workers by informing training objectives and incentives.

2.4 Training materials and curriculum

A training guide, teaching video, and handouts on improving milk quality and safety were developed in English by scholars from the Pennsylvania State University, the Ethiopian Institute of Agricultural Research, Addis Ababa University, and Hammer Video Production PLC. The materials were adapted to local contexts and translated to the *'Afan oromo and Amharic'* local languages.

The contents of the guide, video, pictures, and handouts were developed for some trainees who might not be able to read or write, and there would be a range of literacy levels at all training sessions. Each visual image contained one or two key concepts that were presented with simple words and pictures or a graphic image. Complex concepts were broken down into several slides or images, rather than presented as a text-heavy list. Key concepts in sanitation were reinforced with repetition during lectures, by inclusion of

FIGURE 1
Study areas. Credit: ENSURE Project/AAU.

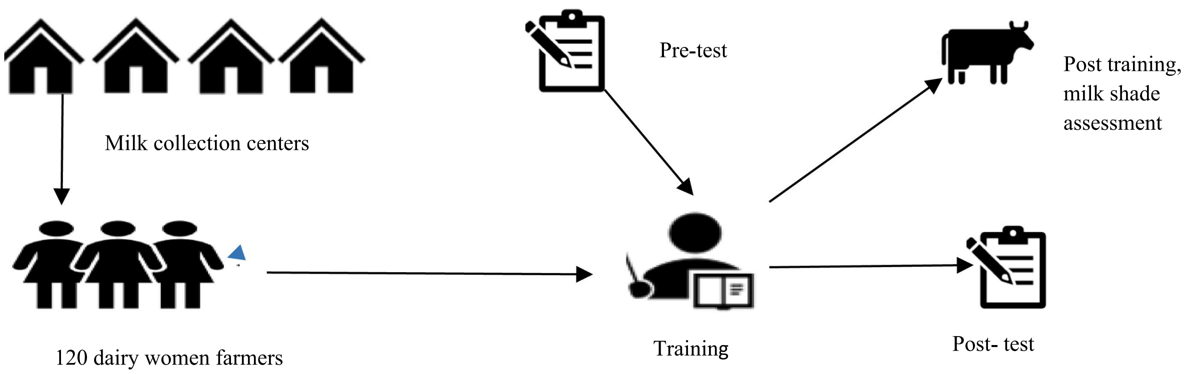

FIGURE 2
Dairy women farmers interventions design. Credit: TARTARE Project.

real-life examples, demonstrations, hands-on activities such as hand washing in the classroom and udder preparation on the farm, and in the take home handouts.

The curriculum included three consecutive days at each site to cover the theoretical lectures, practical sessions, teaching videos, and assessments. The training started at 10:00 am and ended by 4:00 pm to allow the women to attend to their daily farm and family responsibilities. We have provided breakfast, lunch, transportation facilities, and time compensation costs for the effectiveness of the training and covering their time, respectively.

Classroom sessions were conducted using a laptop computer connected to a projector, and with the aid of flip charts and markers. Question and answer sessions were included to encourage participation and comprehension, and two to three participants were asked to give a recap of the prior day's activities before the commencement of second and third training days.

Topics included the importance of clean milk production, factors affecting clean milk production, the basic principles of cleaning and disinfecting, methods to produce clean water, proper procedures for hand washing, and proper hygienic milking steps.

10.3389/fsufs.2024.1539559

Practical activities were conducted in the classroom and at selected dairy farms near the training sites to demonstrate procedures and to assess the knowledge, attitudes, and practices of the women farmers. Proper hand washing practices were demonstrated by the instructors, and then the cleaning efficiency of participants that washed hands with and without soap was evaluated using Glo-Germ™ gel and a UV lamp.[1] Proper steps in cleaning and disinfection of milk equipment were demonstrated by instructors, and then the cleaning efficiency of individual and group participants that washed milk equipment only using cold water or cold water followed by hot water was evaluated with Glo-Germ™ powder and a UV lamp (see text footnote 1, respectively).

Appropriate milking procedures were demonstrated by the instructors at the dairy farm and included cleaning udders, pre-dipping of the teats, mastitis checking, full-hand milking, post-dipping of the teats, and milk filtering. The women farmers were given an opportunity to practice these techniques during the session.

2.5 Intervention training and farmer assessments

Two training sessions, with 15 women farmers each, were conducted at each of the four study sites (Figure 1). Hand and equipment washing skills of trainees were assessed during the practical sessions using Glo-Germ ™, as described above.

The knowledge, attitude and practices (KAPs) on hygienic milk practices of women dairy farmers were assessed using semi-structured questionnaires before and after the intervention training program. The questionnaires contained approximately 10 questions covering clean milk characteristics, risk factors for contamination, cleaning and disinfecting theory and practice, and hygienic milk practices (Supplementary material; Appendix 1).

Milk shade assessment of individual farmers was done at the end of the training using prepared standard checklists (Supplementary material; Appendix 2). The milk shade was evaluated on basic dairy environment factors and hygienic practices. The dairy environment was evaluated in terms of the personal hygiene of the milker, availability of clean water sources, cleanliness of milking areas, and appropriateness of milking and milk handling equipment. Dairy farmers were evaluated based on standard training provided for them on milk filtering and cooling, teat dipping and mastitis checking practices, availability of clean towels, and sanitizing detergents. Then, instructors scored each element of dairy environments using an evaluation method rated as 0 = absent, 1 = insufficient, 2 = fair, 3 = good, 4 = very good, and 5 = excellent.

All questionnaires and checklists were translated to *'Afan oromo and Amharic'* local languages. Instructors and assistants were available to help trainees that were unable to read and/or write complete the questionnaires and checklists.

2.6 Data analysis

Statistical analysis was done using statistical software SPSS version 22 (SPSS, Inc., Chigago, United States). Basic descriptive analysis was conducted of the socio-demographic profiles of the participants, and pre-and post-test data were compared using a paired T-test. Milk shades observation data was analyzed by using a nonparametric chi-square test at $p \leq 0.05$.

3 Results

3.1 Intervention training

The intervention training sessions were delivered in collaboration with Holeta Agricultural Research Center, Ethiopian Meat and Milk Development Institute, Kulumsa Agricultural Research Center, and Selale University from 1 February to 30 March 2022.

The socio-demographic profiles of dairy women farmers that participated in the hygienic milk production intervention training sessions are shown in Table 1. More than half (59%) of the trainees were between the ages of 31 and 50, and the other trainees were approximately equally proportioned (20%) between the age groups of 18 and 30 and above 50 years of age. Most of the trainees completed secondary school (34%) or primary school (33%), while 15% of the attendees who had no formal education. Approximately 12% of the trainees a had basic adult education, but very few trainees (less than 6%) completed college or had any higher education. The largest populations of trainees were from rural areas (44%), but a sizeable amount was from urban (37%) and peri-urban areas (19%). The majority of trainees obtained their primary source of income of from dairy farming (48%), followed by mixed crops and livestock farming (17%) and crop farming (12%).

The practical sessions with demonstrations of proper washing techniques and a novel assessment method like Glo-Germ ™ was an engaging learning experience for the trainees. Figure 3A shows dairy

TABLE 1 Socio-demographic profiles of the dairy women farmers participating in the intervention training in all four sites (total *N*[1]= 120).

Characteristic		*N*	Percent (%)
Age	18–30 years	25	20.83
	31–50 years	71	59.17
	50 years and above	24	20.00
Education	No formal education	18	15.00
	Basic adult education	14	11.67
	Primary	40	33.33
	Secondary	41	34.17
	College and higher	7	5.83
Type of farming system	Urban	44	36.67
	Peri-urban	23	19.17
	Rural	53	44.17
Source of income	Dairy farming	58	48.33
	Crops farming	12	10.00
	Earned wages	1	0.83
	Mixed crops and livestock farming	17	14.17
	Other	4	3.33

[1]N = number of the participants.

1 www.glogerm.com

FIGURE 3
The hand washing practical session: **(A)** Dairy women farmers practicing the proper hand washing steps; **(B)** instructor evaluating the women on efficiency of proper hand washing using UV lamp; **(C)** trainees evaluating efficiency of proper hand washing using UV lamp without instructor. Credit: ENSURE Project/AAU.

farmers practicing proper hand washing steps by applying enough soap to their hands, and Figure 3B shows hand washing efficiency being evaluated by instructor. The farmers were so motivated by the method and its simplicity that they started to evaluate themselves on their hand washing skills, even in absence of the instructor (Figure 3C), thus demonstrating a significant change of attitudes in proper hand washing practices among the participants during the training sessions.

The hygienic milking practical sessions illustrated new concepts for the trainees. Again, the instructors demonstrated the proper procedures, and the trainees were given time to practice. Figure 4A shows trainees practicing teat dipping, including cleaning and disinfecting teats with iodine solution. Figures 4B,C are the instructor demonstrating mastitis checking and full hand milking, respectively. During the practical sessions, we observed the absence of teat dipping with anti-microbial agents, checking for mastitis, and proper full hand milking practices by the trainees. We learned during the milk shade assessment (below), that very few farmers had experience with hygienic milking practices.

3.2 Trainee assessments

Trainees were assessed on their knowledge, attitudes, and practices of hygienic milking concepts through observations during practical sessions as reported above and using a milk shade checklist and a pre-and post-training questionnaire.

We observed in the practical sessions that trainees had little experience with hygienic milking practices, and this was supported by the milk shade risk factor assessment that showed 98.3% of farmers had no experience with teat dipping or mastitis checking practices (Table 2). Cleaning of the milking area also scored low, with 39% rated fair and 26% rated insufficient. Scores for cleaning equipment and using towels were higher, with 26 to 35% of the ranked as good or very good, and 23 to 38% of the scores for cooling milk, using detergents, and filtering milk were ranked as very good or excellent.

The assessment of risk factors in the milk shed environment showed that approximately 25 to 48% were ranked insufficient on personal hygiene, water source, milking area, dairy house, and milking equipment (Table 3). The milk storage areas were rated highest; with 55% scoring very good and 26% had a score of good. Other areas with high ratings included milk equipment (35% very good, 23% good), and milking area (30% good). Water source was scored insufficient at 39.5%% of the milk sheds.

The pre-and post-training questionnaire on the KAPs of hygiene milking practices and factors affecting quality milk production are presented as a mean score by training site in Table 4. The pre-training score means ranged from 5.6 to 7.5 at all training sites, which increased to 9.1 to 9.6 for the post-training assessment. The mean score of the pre-training KAPs results increased from 6.7 to 9.4 for the post-training assessment, which indicated a significant difference before and after training ($\chi^2 = 167$, $p < 0.05$).

4 Discussion

In this study, customized training was found to improve knowledge, attitudes, and practices on hygienic milking and quality milk production of women dairy farmers in the central highlands of Ethiopia. Tola et al. (2016) published a research article that described women dairy farmers as primarily responsible for milk production, and Garsow et al. (2022) pointed out that they are exposed to food safety problems. Improving food safety knowledge at the farm level might not only achieve clean milk production but also play a vital role in improving the wellness and health of the family (Lindahl et al., 2018; Ahuja et al., 2019; Amenu et al., 2020; De Vries et al., 2020; Ledo et al., 2021). This study paid particular attention to developing content that was relevant to these specific farmers using targeted, simple messages and culturally relevant graphics, for example ones that showed Ethiopian women's hands and typical milking equipment found in Ethiopian milk shades. The daily agenda was set to allow the women to attend to their family and farm responsibilities and still complete the training.

Food safety training targeted at women could contribute to multiple positive outcomes and socioeconomic impacts (Alonso et al., 2018). The incorporation of engaging practical sessions like

FIGURE 4
The hygienic milking practical session: **(A)** Teats dipping practice before and after milking; **(B)** instructor demonstrating mastitis checking practice prior to milking; **(C)** instructor showing proper full hand milking practice. Credit: ENSURE Project/AAU.

TABLE 2 Assessment of major hygienic milking risk factors in milk shades at small holder farmers level (*N*[1] = 120).

Hygienic practice	Rate of hygienic milking risk factors in milk shades (%)						Factor score[2]	
	Absent	Insufficient	Fair	Good	Very good	Excellent	Mean rank[3]	Median
Teat dipping	98.3	0.8	0.8				1.57[a]	0
Mastitis checking	98.3	0.8	0.8				1.57[a]	0
Cleaning milking area		26.3	39.0	23.7	10.2	0.8	4.07[b]	2
Cleaning equipment		10.1	24.4	34.5	28.6	2.5	5.04[c]	3
Using towels		14.3	14.3	33.6	26.1	11.8	5.12[c]	3
Cooling milk		5.0	5.0	28.6	37.8	23.5	6.12[d]	4
Using detergents		2.5	10.1	19.3	37.8	28.6	6.19[d]	4
Filtering milk	1.7	0.8	5.9	24.4	38.7	28.6	6.31[d]	4

[1]*N* = number of the participants. [2]Factor score: 0 = absent, 1 = insufficient, 2 = fair, 3 = good, 4 = very good, 5 = excellent. [3]Mean rank values in columns with different letters and superscripts are significantly different ($p < 0.05$).

TABLE 3 Assessments of major risk factors in milk shed environments at small holder farmers level (*N*[1]=120).

Factors	Rate of environmental risk factors in milk shades (%)						Factor score[2]	
	Absent	Insufficient	Fair	Good	Very good	Excellent	Mean rank	Median
Personal hygiene		47.9	37	10.9	3.4	0.8	2.26[a]	2
Water source		39.5	27.7	19.3	13.4		2.97[a]	2
Milking area		25.1	36.1	30.3	5.6	2.2	3.14[b]	2
Dairy house		47.9	37	10.9	3.4	0.8	3.32[b]	2
Milk equipment		27	11.8	23.5	35.3	1.7	4.02[c]	3
Milk storage		0.8	8.4	26.1	54.6	10.1	5.30[d]	4

[1]N = number of the participants. [2]Factor score: 0 = absent, 1 = insufficient, 2 = fair, 3 = good, 4 = very good, 5 = excellent. [3]Mean rank values in columns with different letters and superscripts are significantly different ($p < 0.05$).

hand washing with Glo-Germ ™ helped reinforce concepts and provided additional opportunities for learning, particularly for adult learners that prefer to "do" rather than "read" or "watch." The effectiveness of the training materials and approach was supported by the increase in KAPs assessment scores from pre-training to post-training for all study sites. Improving knowledge, attitudes, and practices among women farmers could have positive impacts on animal health, dairy productivity, and connecting the food to the nutrition of households and communities (Jadav et al., 2014; Stewart et al., 2015; Lenjiso et al., 2015; Amenu et al., 2019).

TABLE 4 Pre- and post-training assessments result of knowledge, attitudes and practices (KAPs) on hygienic milking practices and quality milk production of trainees.

Location	Pre-training KAPs[1] results			Post-training KAPs results			
	N^2	Mean ±SD[3]	Percentage (%)	N	Mean ± SD	Percentage (%)	χ^{2}[4]
Wolmera	30	7.5 ± 1.8[a]	46.3	30	9.4 ± 0.8[b]	53.7	52
Bishoftu	30	6.9 ± 1.7[a]	42.4	30	9.4 ± 0.9[b]	57.6	35
Asella	30	5.6 ± 2.7[a]	42.1	30	9.1 ± 0.9[b]	57.9	51
Selale	30	5.7 ± 1.8[a]	39.2	30	9.6 ± 0.5[b]	60.8	36
Total	120	6.7 ± 2.0[a]	42.1	120	9.4 ± 0.8[b]	57.9	167

[1]KAPs = knowledge, attitude, and practices. [2]N = number of participants. [3]SD = Standard deviation. The mean values in rows with different letters and superscripts are significantly different ($p < 0.05$). [4]χ^2, Chi-square.

Comparisons of the training outcomes and evaluation results of milk shades were found counterintuitive, which revealed the complexity of food safety interventions. We observed substandard dairy infrastructure resulting in a lack of a well-organized dairy houses and milking areas, which affected the use of hygienic practices for cleaning dairy equipment and selecting clean areas for milking. The basic requirements of dairy farming and hygienic practices emerged as critical barriers to improving milk quality at the production level.

Personal hygiene problems might be related to limited and unclean water sources and access to personal facilities such as milking gowns, gumboots, and hair protective materials.

Clean water sources play crucial roles in the cleaning of the dairy equipment as well as for drinking purposes of milking cows. These findings support other studies that reported that poor personal hygienic conditions and unclean water sources could be potential sources of microbiological hazards, which can affect the microbial quality of dairy products as well as animal and human health (Ransom et al., 2017; Kurniawan et al., 2018; Ledo et al., 2020. Giri et al., 2020; Jensen and Vestergaard, 2021).

Bacteria have the ability to adhere to milk containers to form biofilm, which contain spoilage and pathogenic bacteria (Marchand et al., 2012). Staining stainless dairy equipment is important in reducing biofilm formation (Dewangan et al., 2015), and maintaining the sensory properties of the dairy products (Radu and Toma, 2024). On the question of milk containers used by the dairy farmers, this study found that almost half of the farmers used the food-grade materials for milking and handling purposes, which indicated this risk factor was less important compared to others for producing high quality milk.

Other risk factors observed in the milk shades were related to the farm designs and layouts that indicated poor drainage, insufficient light in the dairy farm, and uncomfortable bedding materials designed for the milking cows. These practices can be a potential source of microorganisms that easily enter the food supply chain and contaminate the dairy products.

Appropriate dairy housing should provide adequate light and natural expressions for the dairy cows, while also maintaining cleanliness of the cows and their surroundings, thereby improving the health of both animals and dairy workers (Bewley et al., 2017).

It has been reported that unhygienic dairy environments and milking areas and poor bedding are major contributor factors to teat mastitis infections in milking cows, and, hence, farmers should use teat dipping practices to minimize the infections (Girma and Tamir, 2022). Mastitis control was observed as a major risk factor for quality milk production in this study.

The current study provides further support of holistic approaches to the nexus of animal, human, and environmental health (Rock et al., 2009; Mwangi et al., 2016; Destoumieux-Garzón et al., 2018), through improving dairy environments and management practices (Noordhuizen and Metz, 2005), clean water for dairy cows, and safe milk productions (Fawell and Nieuwenhuijsen, 2003; Garcia et al., 2019).

5 Conclusion

This study showed that food safety training customized for women dairy farmers provides an opportunity to improve milk quality production at the farm. However, the current level of dairy farming infrastructure and farming practices poses major challenges to improving dairy product quality in the central highlands of Ethiopia. Our study has gone some way toward enhancing our understanding of a path forward to improving the dairy production system, transforming the sector from small-scale production to intermediate, clustering, or cooperatives, and encouraging commercial dairy farming for improving food system and scale up of the training.

As part of a joint activity, the changes in microbial results and knowledge, attitude, and practices (KAPs) long time duration of the training were conducted by the TARTARE project.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found at https://data.mendeley.com/datasets/gc34gbjfkd/1 and are also included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review

& editing. AT: Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. KK: Conceptualization, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. MK: Project administration, Resources, Writing – review & editing. AZ: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The Bill and Melinda Gates Foundation and the United Kingdom Foreign, Commonwealth, and Development Office jointly sponsored this study under the grant INV-008459.

Acknowledgments

This work was done in collaboration between the projects entitled "The Assessment and Management of Risk from Non-Typhoidal Salmonella, Diarrheagenic Escherichia Coli, and Campylobacter in Raw Beef and Dairy in Ethiopia (TARTARE, The Ohio State University, OPP1195643) and Ensuring the Safety and Quality of Milk and Dairy Products Across the Dairy Value Chain in Ethiopia (ENSURE, Addis Ababa University, INV-008459)." We would like to express our gratitude to TARTARE project members who contributed to the training design and successful completion of the dairy women farmer's study. We would like also to express our gratitude to Holeta Agricultural Research Center, Kulumsa Agricultural Research Center, Ethiopian Meat and Milk Development Institute, and Selale University for providing the training environment and dairy farms.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1539559/full#supplementary-material

References

Abunna, F., Worku, H., Gizaw, F., Ragassa, F., Ayana, D., and Amenu, K. (2018). Assessment of post-harvest handling practices, quality and safety of milk and antimicrobial susceptibility profiles of Escherichia coli O157: h7Isolated from milk in and around Asella town, Oromia, Ethiopia. *Ann. Public Health Res.* 5:1072. doi: 10.47739/2378-9328/1072

Ahuja, S., Bhanot, V., and Mandal, B. S. (2019). Impact in knowledge gain of rural women through dairy trainings. Pharm. Innov, 8, 351–353.

Alonso, S., Muunda, E., Ahlberg, S., Blackmore, E., and Grace, D. (2018). Beyond food safety: socio-economic effects of training informal dairy vendors in Kenya. *Glob. Food Sec.* 18, 86–92. doi: 10.1016/j.gfs.2018.08.006

Amenu, K., Agga, G. E., Kumbe, A., Shibiru, A., Desta, H., Tiki, W., et al. (2020). MILK symposium review: community-tailored training to improve the knowledge, attitudes, and practices of women regarding hygienic milk production and handling in Borana pastoral area of southern Ethiopia. *J. Dairy Sci.* 103, 9748–9757. doi: 10.3168/jds.2020-18292

Amenu, K., Markemann, A., and Valle Zárate, A. (2013). Water for human and livestock consumption in rural settings of Ethiopia: assessments of quality and health aspects. *Environ. Monit. Assess.* 185, 9571–9586. doi: 10.1007/s10661-013-3275-3

Amenu, K., Wieland, B., Szonyi, B., and Grace, D. (2019). Milk handling practices and consumption behavior among Borana pastoralists in southern Ethiopia. *J. Health Popul. Nutr.* 38, 1–12. doi: 10.1186/s41043-019-0163-7

Asfaw, T., Genetu, D., Shenkute, D., Shenkutie, T. T., Amare, Y. E., Habteweld, H. A., et al. (2023). Pathogenic bacteria and their antibiotic resistance patterns in milk, yoghurt and milk contact surfaces in Debre Berhan town, Ethiopia. *Infect. Drug Resist.* 16, 4297–4309. doi: 10.2147/IDR.S418793

Bedassa, A., Nahusenay, H., Asefa, Z., Sisay, T., Girmay, G., Kovac, J., et al. (2023). Prevalence and associated risk factors for *Salmonella* enterica contamination of cow milk and cottage cheese in Ethiopia. *Food Saf. Risk* 10:2. doi: 10.1186/s40550-023-00101-3

Bereda, A., Yilma, Z., Eshetu, M., and Yousuf, M. (2018). Hygienic practices, microbial quality and safety of raw cow's milk and traditional fermented milk (Irgo) in selected areas of Ethiopian central highlands. *East Afr. J. Vet. Anim. Sci.* 2, 17–26.

Bewley, J. M., Robertson, L. M., and Eckelkamp, E. A. (2017). A 100-year review: lactating dairy cattle housing management. *J. Dairy Sci.* 100, 10418–10431. doi: 10.3168/jds.2017-13251

Bintsis, T. (2017). Foodborne pathogens. *AIMS Microbiol.* 3, 529–563. doi: 10.3934/microbiol.2017.3.529

CSA. (2019). *Federal Democratic Republic of Ethiopia Central Statistical Agency Agricultural Sample Survey 2020/21*. [2013 E. C] VOLUME II REPORT ON: Vol. II (Issue). CSA.

De Vries, A., Kaylegian, K. E., and Dahl, G. E. (2020). MILK symposium review: improving the productivity, quality, and safety of milk in Rwanda and Nepal. *J. Dairy Sci.* 103, 9758–9773. doi: 10.3168/jds.2020-18304

Destoumieux-Garzón, D., Mavingui, P., Boetsch, G., Boissier, J., Darriet, F., Duboz, P., et al. (2018). The one health concept: 10 years old and a long road ahead. *Front. Vet. Sci.* 5:14. doi: 10.3389/fvets.2018.00014

Dewangan, A. K., Patel, A. D., and Bhadania, A. G. (2015). Stainless steel for dairy and food industry: a review. *J. Mater. Sci. Eng.* 6, 66–71. doi: 10.15740/HAS/RJAHDS/6.1/66-71

Didanna, H., Shano, B., and Wossen, A. (2019). Future prospects and challenges of intensifying dairy production systems in Ethiopia. *Afr. J. Sci. Technol. Innov. Dev.* 11, 653–661. doi: 10.1080/20421338.2019.1571149

EFSA Panel on Biological Hazards (BIOHAZ) (2015). Scientific opinion on the public health risks related to the consumption of raw drinking milk. *EFSA J.* 13:3940. doi: 10.2903/j.efsa.2015.3940

Fawell, J., and Nieuwenhuijsen, M. J. (2003). Contaminants in drinking water: environmental pollution and health. *Br. Med. Bull.* 68, 199–208. doi: 10.1093/bmb/ldg027

Fereja, A. B., Aboretugn, N. F., and Bulti, N. Q. (2023). Determination of microbial hygiene indicators of raw cow Milk in Assosa District, Ethiopia. *J. Food Qual.* 2023, 1–6. doi: 10.1155/2023/6769108

Gallina, A. (2016). *Gender dynamics in dairy production in Kenya: A literature review*. CCAFS Working Paper.

Garcia, S. N., Osburn, B. I., and Cullor, J. S. (2019). A one health perspective on dairy production and dairy food safety. *One Health.* 7:100086.

Garsow, A. V., Biondi, M. R., Kowalcyk, B. B., Vipham, J. L., Kovac, J., Amenu, K., et al. (2022). Exploring the relationship between gender and food safety risks in the dairy value chain in Ethiopia. *Int. Dairy J.* 124:105173. doi: 10.1016/j.idairyj.2021.105173

Gebreselassie, L. (2019). Review on dairy production system, constraints and opportunities in Ethiopia. *J. Sci. Innov. Res.* 8, 108–111. doi: 10.31254/jsir.2019.8403

Getachew, M., and Tadele, Y. (2015). Dairy production, processing and marketing in Chencha and kutcha districts, southern Ethiopia. *J. Mark. Consum. Res.* 9, 2422–8451.

Giri, A., Bharti, V. K., Kalia, S., Arora, A., Balaje, S. S., and Chaurasia, O. P. (2020). A review on water quality and dairy cattle health: a special emphasis on high-altitude region. *Appl Water Sci* 10, 1–16. doi: 10.1007/s13201-020-1160-0

Girma, A., and Tamir, D. (2022). Prevalence of bovine mastitis and its associated risk factors among dairy cows in Ethiopia during 2005–2022: a systematic review and meta-analysis. *Vet. Med. Int.* 2022, 1–19. doi: 10.1155/2022/7775197

Grace, D. (2015). Food safety in low and middle income countries. *Int. J. Environ. Res. Public Health* 12, 10490–10507. doi: 10.3390/ijerph120910490

Grace, D. (2023). Burden of foodborne disease in low-income and middle-income countries and opportunities for scaling food safety interventions. *Food Secur.* 15, 1475–1488. doi: 10.1007/s12571-023-01391-3

Grace, D., Wu, F., and Havelaar, A. H. (2020). MILK symposium review: foodborne diseases from milk and milk products in developing countries—review of causes and health and economic implications. *J. Dairy Sci.* 103, 9715–9729. doi: 10.3168/jds.2020-18323

Gwandu, S. H., Nonga, H. E., Mdegela, R. H., Katakweba, A. S., Suleiman, T. S., and Ryoba, R. (2018). Assessment of raw cow milk quality in smallholder dairy farms in Pemba Island Zanzibar, Tanzania. *Vet. Med. Int.* 2018, 1–9. doi: 10.1155/2018/1031726

Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J., et al. (2015). World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med.* 12:e1001923. doi: 10.1371/journal.pmed.1001923

Hawaz, H., Taye, M., and Muleta, D. (2023). Characterization and antimicrobial susceptibility patterns of *Listeria monocytogenes* from raw cow Milk in the southern part of Ethiopia. *J. Food Qual.* 2023, 1–11. doi: 10.1155/2023/5590136

Hunduma, D., Amenu, K., Desta, H., Grace, D., Agga, G. E., and Kerro Dego, O. (2023). Prevalence and antimicrobial resistance of *Escherichia coli* O157: H7 and Salmonella, and the prevalence of *Staphylococcus aureus* in dairy cattle and camels under pastoral production system. *Antibiotics* 13:26. doi: 10.3390/antibiotics13010026

Jadav, S. J., Rani, V. D., Mudgal, S., and Dhamsaniya, H. B. (2014). Women empowerment through training in dairy farming. *Asian J. Dairy Food Res.* 33, 147–153. doi: 10.5958/0976-0563.2014.00592.2

Jensen, M. B., and Vestergaard, M. (2021). Invited review: freedom from thirst—do dairy cows and calves have sufficient access to drinking water? *J. Dairy Sci.* 104, 11368–11385. doi: 10.3168/jds.2021-20487

Keba, A., Rolon, M. L., Tamene, A., Dessie, K., Vipham, J., Kovac, J., et al. (2020). Review of the prevalence of foodborne pathogens in milk and dairy products in Ethiopia. *Int. Dairy J.* 109:104762. doi: 10.1016/j.idairyj.2020.104762

Kebede, M., Biondi, M., Keba, A., Kovac, J., Vipham, J., Zewdu, A., et al. (2019). Risk factors and possible strategies to mitigate microbiological hazards in Milk and dairy products in Ethiopia: a review. *Ethiop. J. Anim. Prod.* 20, 53–69.

Kinati, W., and Mulema, A. A. (2018). *Gender issues in livestock production in Ethiopia: A review of literature to identify potential entry points for gender responsive research and development*, No. 10. p. 80.

Kurniawan, W., Suryani, D., and Wibowo, W. (2018). Relationship between Milker's personal hygiene and sanitation with contamination of *Escherichia coli* in the fresh goat Milk of Etawa in Boyong Hargobinangun Village, Pakem, Sleman. *Health Notions* 2, 1077–1082.

Ledo, J., Hettinga, K. A., Bijman, J., Kussaga, J., and Luning, P. A. (2021). A tailored food safety and hygiene training approach for dairy farmers in an emerging dairy chain. *Food Control* 124:107918. doi: 10.1016/j.foodcont.2021.107918

Ledo, J., Hettinga, K. A., Bijman, J., and Luning, P. A. (2019). Persistent challenges in safety and hygiene control practices in emerging dairy chains: the case of Tanzania. *Food Control* 105, 164–173. doi: 10.1016/j.foodcont.2019.05.011

Ledo, J., Hettinga, K. A., and Luning, P. A. (2020). A customized assessment tool to differentiate safety and hygiene control practices in emerging dairy chains. *Food Control* 111:107072. doi: 10.1016/j.foodcont.2019.107072

Lenjiso, B. M., Smits, J., and Ruben, R. (2015). *Transforming dairy production and marketing. In 2015 IEEE Canada international humanitarian technology conference, IHTC 2015.*

Lindahl, J. F., Deka, R. P., Asse, R., Lapar, L., and Grace, D. (2018). Hygiene knowledge, attitudes and practices among dairy value chain actors in Assam, north-East India and the impact of a training intervention. *Infect. Ecol. Epidemiol.* 8:1555444. doi: 10.1080/20008686.2018.1555444

Marchand, S., De Block, J., De Jonghe, V., Coorevits, A., Heyndrickx, M., and Herman, L. (2012). Biofilm formation in milk production and processing environments; influence on milk quality and safety. *Compr. Rev. Food Sci. Food Saf.* 11, 133–147. doi: 10.1111/j.1541-4337.2011.00183.x

Mengstu, B., Tola, A., Nahusenay, H., Sisay, T., Kovac, J., Vipham, J., et al. (2023). Evaluation of microbial hygiene indicators in raw milk, pasteurised milk and cottage cheese collected across the dairy value chain in Ethiopia. *Int. Dairy J.* 136:105487. doi: 10.1016/j.idairyj.2022.105487

Mwangi, W., de Figueiredo, P., and Criscitiello, M. F. (2016). One health: addressing global challenges at the nexus of human, animal, and environmental health. *PLoS Pathog.* 12:e1005731. doi: 10.1371/journal.ppat.1005731

Noordhuizen, J. P. T., and Metz, H. M. (2005). Quality control on dairy farms with emphasis on public health, food safety, animal health and welfare. *Stočarstvo* 59, 39–55.

Ntuli, V., Sibanda, T., Elegbeleye, J. A., Mugadza, D. T., Seifu, E., and Buys, E. M. (2023). "Dairy production: microbial safety of raw milk and processed milk products" in Present knowledge in food safety. ed. V. Ntuli (Cambridge, MA: Academic Press), 439–454.

Radu, S., and Toma, S. L. (2024). Stainless steel deposits on an aluminum support used in the construction of packaging and food transport containers. *Coatings* 14, 2079–6412. doi: 10.3390/coatings14111431

Ransom, E., Bain, C., Bal, H., and Shannon, N. (2017). Cattle as technological interventions: the gender effects of water demand in dairy production in Uganda. *Facets* 2, 715–732. doi: 10.1139/facets-2017-0031

Rock, M., Buntain, B. J., Hatfield, J. M., and Hallgrímsson, B. (2009). Animal–human connections,"one health," and the syndemic approach to prevention. *Social science and medicine*. 68, 991–995.

Stewart, R., Langer, L., Da Silva, N. R., Muchiri, E., Zaranyika, H., Erasmus, Y., et al. (2015). The effects of training, innovation and new technology on African smallholder farmers' economic outcomes and food security: a systematic review. *Campbell Syst. Rev.* 11, 1–224. doi: 10.4073/csr.2015.16

Tassew, A., and Seifu, E. (2009). Smallholder dairy production system and emergence of dairy cooperatives in Bahir Dar Zuria and Mecha Woredas, northwestern Ethiopia. *World J. Dairy Food Sci.* 4, 185–192.

Tola, A., Keba, A., Hailu, M., Asefa, Z., and Melesse, K. (2016). Role of female and male headed households in dairy production, processing and marketing in Walmera district of central high lands of Ethiopia. *J. Biol. Agric. Healthc* 6, 48–61.

Yuya, B. A. (2018). Valuation of gender differentiated dairy farming and household level food security status in eastern Oromia, Ethiopia. *Turk. J. Agric. Food Sci. Technol* 6, 719–728. doi: 10.24925/turjaf.v6i6.719-728.1772