An approach towards improving safety and hygiene control practices in emerging dairy chains

The case of Tanzania

James Ledo

Propositions

1. Differences in sub-standard safety and hygiene control practices do not translate into differences in milk safety.
   [This thesis].

2. Behaviour-based training intervention is an indispensable approach for better food safety outcomes in emerging dairy chains.
   [This thesis].

3. Success in multidisciplinary research depends more on collaboration skills than on individual competences.

4. Pooled funding is the only way to remove the suspicion around private sponsorship of scientific research.

5. Policy interventions for transforming emerging food chains must be radical to achieve any significant impact.

6. Success in distance marital relationship thrives only on emotional intelligence.

7. Running as a hobby, is more luxurious than any other form of luxury.

Propositions belonging to the thesis, entitled:

"An approach towards improving safety and hygiene control practices in emerging dairy chains: The case of Tanzania."

James Ledo
Wageningen, 23 November 2020

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James Ledo

Thesis

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Chapter 1

General introduction

1.1 Global demand for milk and dairy products and associated challenges

Globally, about 6 billion people consume milk and dairy products contributing essential minerals, vitamins and protein for human health and cognitive development of children (FAO, 2014). As a result, the demand for milk and dairy products continues to increase and expected to double by the end of the next decade. This increasing demand is triggered by population growth, urbanization and growing incomes in developing countries (FAO, 2019). As incomes improve and urbanization expands, the demand for high protein and micronutrient-rich diets will increase (Rae & Nayga, 2010; FAO, 2014;). Global milk production would have to expand beyond the current production of 864 million tons by 35% to meet these growing demands (IFCN, 2018). At the moment, 47% of global dairy production occurs in developing countries, especially in South-Asia and Africa (EU, 2018). However, expansion is needed in Africa to increase dairy production five-fold, as more than half of the world population growth by 2050 will occur in Africa (FAO, 2019).

The increasing demand and the expected expansion in production presents an opportunity for improved food security and nutrition, economic growth, and better livelihood in developing countries. For instance, milk production is labour-intensive and, hence, offers employment and regular income (Douphrate et al., 2013). However, challenges in dairy production, processing, and distribution system, particularly in developing countries hamper their ability to harness the full potential of these opportunities. For instance, in emerging dairy chains, small-scale farming dominates the primary production where inferior-quality feed resources, diseases, the low genetic potential of cows, unfavourable climates, underdeveloped technologies, and limited access to services limit cow and farm productivity (Douphrate et al., 2013; Kapaj & Deci, 2017; Hernández-Castellano et al., 2019). Likewise, challenges are not only present at the farming level, but also exist along the dairy chain, such as low milk volumes, seasonal variation in production, unreliable milk collection systems, and low processing capacity (Douphrate et al., 2013; Makoni et al., 2014).

The underlying constraints, coupled with the fragmented nature of the dairy production system in developing countries, create a domestic production deficit which is currently filled by imports. However, some have argued that improvement in basic production practices along the chain, particularly at the farm, can minimize milk losses caused by inferior quality and safety, and thereby reduce the reliance on imports (Kurwijila & Bennett, 2011; Taglioni & Winkler, 2016; Kapaj & Deci, 2017). Besides, urgent action is needed to tackle the food quality and safety risks associated with dairy products, as raw milk is a well-known potential source of foodborne illnesses (Oliver et al., 2009), with the highest burden of foodborne illnesses in developing countries (WHO, 2015). Thus, identifying approaches to improve basic practices of actors along the chain, with an emphasis on the dairy farm, is vital to realize the inherent production potential and reduce the risk of foodborne illnesses.

1.2 Scope of research

1.2.1 Emerging dairy chains

Emerging dairy chains in this thesis describe dairy chains in developing countries where underdeveloped production and distribution systems are still dominant with potential to expand production at the farm level and to improve chain efficiency. Typical of these chains is their diverse and fragmented nature with limited structural organization, many small-scale dairy actors, and a limited formalization of relationships. The informal organisation implies that many actors are unlicensed and difficult to monitor, while traditional production, processing and retailing are common (Roesel & Grace, 2014; Hoffmann et al., 2019). Moreover, underlying structural challenges are aggravated by the overall low capacity to consistently enforce regulations in the context of the broader food system (Grace, 2015; Hoffmann et al., 2019; Unnevehr, 2015). Consequently, for the consumer, the informal nature of the chain means that fresh milk and dairy products are available at their doorstep without quality and safety checks, implying public health risks.

Repeatedly recommended is the need to upgrade farm and chain operations to levels that safeguard the consumer. So far, improvement efforts have centred on increasing productivity and formalizing the chain (Roesel & Grace, 2014; Unnevehr, 2015). However, the growing risk of food safety and the burden of foodborne diseases in developing countries need a shift in focus to making food quality and safety the core of improvement strategies. Moreover, Unnevehr (2015) asserts that repositioning improvement efforts towards food safety would have a huge impact on food security, public health, nutrient availability, and ultimately on labour productivity and livelihoods. Therefore, there is a need for identification of bottlenecks that hinder good quality and safety outcomes and for tailored improvement approaches, particularly at the farm level, as it is the starting point of improving milk quality and safety.

1.2.2 LIQUID program

In 2013, the *Local and International business collaboration for productivity and Quality Improvement in Dairy chains in South-East Asia and East Africa (LIQUID*) program was designed to make emerging dairy chains perform better. The LIQUID program sought to contribute to the better livelihood and improved food and nutrition security in both South-East Asia and East Africa. Through research, capacity building and knowledge sharing, the LIQUID program aimed overall to find proper ways that intervention programs can create growth opportunities for smallholders and other chain actors to enhance the production of quality and safe dairy products. Over the years, dairy companies and development organizations have applied different intervention approaches to enhance the effectiveness of emerging dairy chains. However, it is not clear how these different approaches have been inclusive of women and youth, how beneficiaries perceive them, and how they can help to deliver improved quality and safety to the consumer. Thus, the LIQUID program aimed at filling those knowledge gaps. Five projects were formulated with specific research aims, as shown in Figure 1.1. This PhD thesis project carried out to fulfil research aim four.

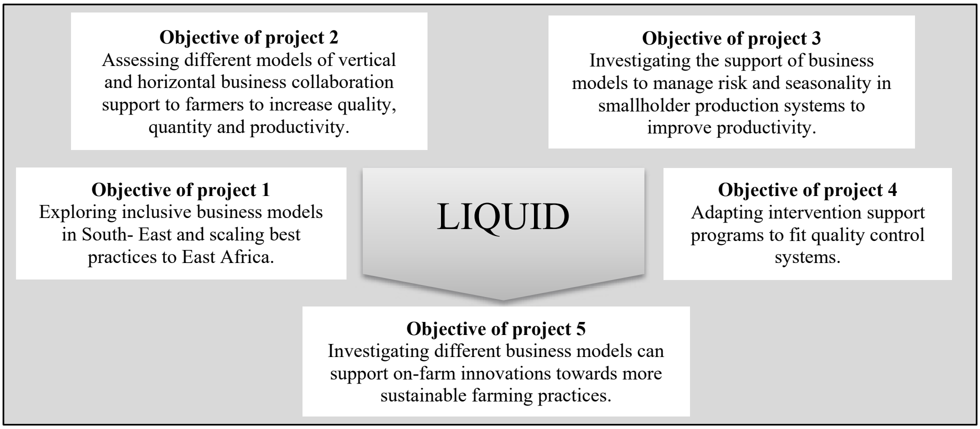

Figure 1.1 Overview of the LIQUID program

1.2.3 Dairy quality and safety issues associated with milk production

Generally, food quality refers to the expectation consumers or customers have regarding a certain product (Noordhuizen & Metz, 2005; Luning & Marcelis, 2009). Food quality can also be described as the intrinsic and extrinsic attributes associated with a product. Whereas the intrinsic attributes refer to the characteristics of the product such as safety, health, sensory, shelf life and convenience, the extrinsic attributes refer to the production systems employed and the marketing associated with the product quality (Espejel et al., 2007; Luning & Marcelis, 2020). A crucial aspect of food quality is food safety, which specifically refers to the assurance that food will not cause harm to the consumer when prepared or eaten according to its intended use (CAC, 2003). It includes all potential hazards, either chronic or acute, that may be harmful to the health of the consumer. Food quality, and specifically food safety, constitute an important part of the consumers' perception of a food product and can thereby affect the reputation of its producers.

Milk and dairy product quality begins from the secretion of milk from the mammary glands of mammals. Milk is a complex product composed of carbohydrates mainly as lactose, proteins, fats, vitamins, and minerals (Tamime, 2009), which determine its nutritional quality (Figure 1.2) and make it a good base for a variety of dairy products. Worldwide, cows alone produce 83% of all milk (Park et al., 2013). The nutritional quality of milk can vary depending on factors related directly to the cow such as the stage of lactation, genetic variability, type of breed, and health status (Kelsey et al., 2003; Tamime, 2009), as well as factors related to the production conditions such as season and quality of feed (Lanyasunya et al., 2006; Burke et al., 2010). Differences in cows and production conditions can have implications for quality of milk and dairy products and are therefore commonly used as parameters to judge nutritional composition and milk market price (Botaro et al., 2013; Murphy et al., 2016).

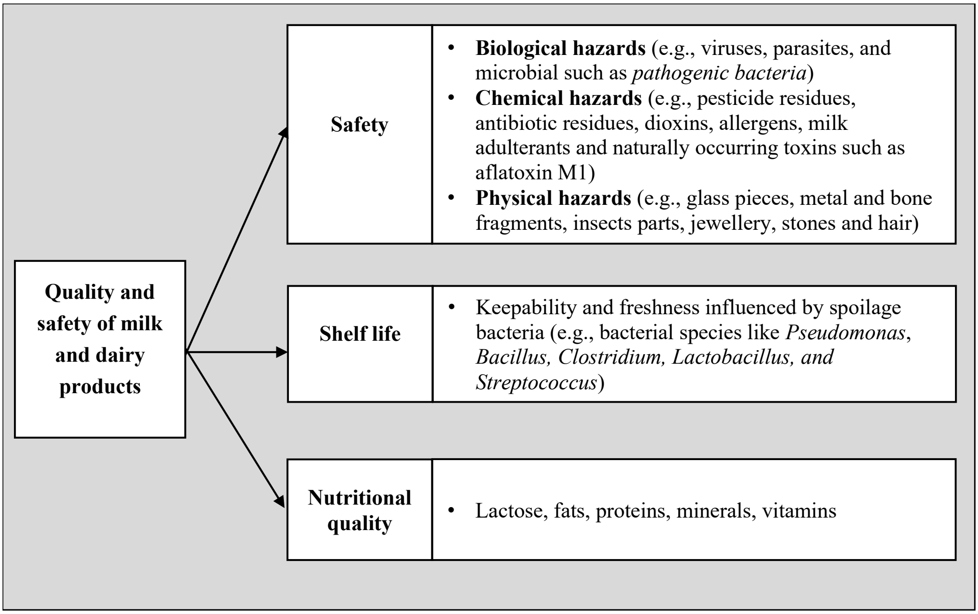

Figure 1.2. Quality and safety of milk and dairy products

Another major quality attribute of milk and dairy product is its safety. Milk safety refers to biological (e.g., bacterial, viruses, parasites), chemical (e.g., pesticide residues, naturally occurring toxins, antibiotic residues, dioxins, allergens, milk adulterants), and physical hazards (e.g., glass pieces, metal and bone fragments, insect parts, jewellery, stones and hair) associated with milk and dairy products, which can be detrimental to the health of the consumer (Muehlhoff et al., 2013). Milk and dairy products are characterized by nutritional components, neutral pH and high water-activity, which create an enabling medium for microbial hazards to proliferate. Whereas milk produced in the udder is assumed to be sterile, shedding of microbial hazards into the milk can occur inside the udder of unhealthy animals (Wallace, 2009). Also, contamination can occur outside the udder through the skin of milking-producing animals, unhygienic milking practices, unclean equipment, contaminated water sources, and inappropriate manual handling practices (Vissers & Driehuis, 2009; Papademas & Bintsis, 2010; Dufour et al., 2011). Microbial hazards associated with milk can be categorized into spoilage and pathogenic bacteria (Tamime, 2009), with some bacteria playing both roles. Growth of spoilage bacteria (e.g., bacterial species like *Pseudomonas, Bacillus, Clostridium, Lactobacillus,* and *Streptococcus*) following from contamination during milking, can cause remarkable changes to milk and dairy product quality. These changes can occur through microbial metabolic processes such as acidification, proteolysis, and lipolysis. For instance, spoilage bacteria can result in low yield and quality, shorter shelf life and changes in organoleptic properties of dairy products such as cheeses and yoghurt (Park et al., 2013). Similarly, contamination and growth of pathogenic bacteria can result in foodborne diseases, particularly when there is no heat-treatment before consumption. The common pathogenic bacteria associated with milk and dairy products include *Salmonella* and *Listeria monocytogenes* (Gould et al., 2014)*, Campylobacter jejuni* (Langer et al., 2012)*, E. coli 0157:H7* (Oliver et al., 2005)*,* Norovirus, *Staphylococcus aureus* and *Shigella* spp. (Zagrebneviene et al., 2005; Ostyn et al., 2010).

Also, chemical hazards such as pesticides, antibiotic residues, and aflatoxins, can contaminate milk posing public health risks and processing challenges. These hazards can occur through contamination from the environment, feed, and animal health management practices. For instance, inappropriate use of antibiotics for the treatment of animal infections and as feed additives can lead to antibiotic resistance in the cow affecting mastitis management (Getahun et al., 2008; Saini et al., 2012). Also, the consumption of tainted milk with antibiotic residues (Oliver et al., 2011; Girma et al., 2014) can result in antibiotic resistance in consumers over time. Technologically, antibiotic residues in the milk can also impede fermentation during dairy processing, resulting in inferior dairy product quality. Another important type of chemical hazard is aflatoxin M1 (AFM1), which is the main hydroxylated aflatoxin metabolite secreted in milk by dairy cows that have consumed feed contaminated with aflatoxin B1 (AFB1) produced by moulds (Flores-Flores et al., 2015). AFM1 remains a major safety concern for the dairy chain since processing and storage conditions are ineffective in reducing the concentration of AFM1 once in milk (Flores-Flores et al., 2015; Campagnollo et al., 2016). In developed countries, the risks of antibiotic residues and AFM1 may be low for consumers due to compliance with good dairy farming practices. Yet, in developing countries, these risks are still a concern in addition to microbial risks caused by the tropical climate and the dominance of informal production practices.

Foodborne disease outbreaks associated with the consumption of unpasteurized milk remains a major public health concern worldwide. However, in developing countries, this concern is exacerbated due to the extensive sales of fresh milk with improper pasteurization (Grace, 2015). On the other hand, well-performing production practices are lacking to guarantee consistent availability of safe milk products. A focus towards effective production systems is necessary at the farm and further in the chain to realise microbial and AFM1 safety of milk products in the emerging dairy chain.

1.2.4 Quality and safety management along dairy chains

Food quality management aims at realising product quality and safety in food production, which involves five food quality management functions identified as design, improvement, control, assurance, and policy and strategy (Luning & Marcelis, 2007). The production of milk and dairy products requires the implementation of control and assurance activities to achieve quality and safety along dairy chains. This thesis distinguishes quality assurance from quality control. Quality assurance involves setting system requirements, evaluating performance and organising necessary changes on production processes, whereas quality control aims at keeping product properties, production, and human processes within tolerable limits along a food chain (Luning & Marcelis, 2007; Park et al., 2013). Quality control involves thus the continuous action of gathering information and evaluating the performance of both technological and people-related processes to take corrective actions when needed (Luning & Marcelis, 2007; Luning et al., 2009).

The responsibility of quality assurance and control lies with actors at various stages of the food production chain. Generally, governments formulate public laws on food quality and safety, which are enforced through inspections, sanctions, and training (Trienekens & Zuurbier, 2008; Unnevehr & Hoffmann, 2015). At the manufacturing and retail stages, quality management systems (QMS) and food safety management systems (FSMS) are implemented based on prerequisite programs, hazard analysis critical control point (HACCP) principles and quality management requirements. Manufacturing and retail companies translate public and private quality and safety assurance requirements (e.g., ISO22000:2005, BRC) to set up their company-specific FSMS covering control and assurance practices

(Luning et al., 2008; Luning et al., 2009; Mensah & Julien, 2011). The private standards are formulated by scheme owners and enforced by certification bodies through third-party audits (Mensah & Julien, 2011). In the specific context of dairy chains, these systems are implemented to minimize deterioration of milk quality and safety through the use of proper storage facilities, compliance to personal, equipment and environmental hygiene procedures, and monitoring to ascertain compliance to technological and people related requirements (Burke et al., 2018; Baars, 2019). Likewise, during the transportation of products from manufacturing to retail shops, public and private requirements are formulated, such as good distribution practices (GDP) to assure and control quality and safety. Because milk and dairy products are highly perishable, good distribution practices are vital to prevent deterioration of quality and safety. At the farm, good agricultural practices (GAP) and good hygiene practices (GHP) are implemented to prevent and monitor quality and safety issues (Henson & Reardon, 2005; FAO & IDF, 2011). Good dairy farming practices (GDFP) are applied at the farm level. These detail socio-economic management, sustainable dairy farming, animal nutrition and welfare, animal health management, and hygienic milking practices (FAO & IDF, 2011).

Furthermore, because the farm is the starting point to realise quality and safety for the whole chain, farm practices are essential for mitigating microbial, chemical, and physical hazards. For instance, milk from healthy animals, hygienic milking and handling practices, proper use of equipment, adequate storage and transportation measures, and a hygienic farm environment prevent microbial contamination and growth. Also, animal health management practices, such as antibiotic withdrawal periods, prevent antibiotic residues in milk (Papademas & Bintsis, 2010). A well-ventilated storage facility controls temperature and humidity for proper feed storage to prevent mould growth and thereby, the occurrence of AFM1 in milk (Golob, 2007; Gizachew et al., 2016).

However, implementation and performance of quality assurance and control practices are not adequate throughout emerging dairy chains (Kussaga et al., 2014). Whereas dairy manufacturing companies are progressing in the implementation of these requirements and actual performance of these practices (Kussaga et al., 2015), non-compliance to hygienic practices still occurs (Millogo et al., 2010; Kamana et al., 2017). Furthermore, due to the fragmented nature of the chain and limited capacity to enforce requirements, traditional practices still characterize the informal milk chain (Millogo et al., 2010; Makoni et al., 2014; Kamana et al., 2017). Usual practices include traditional milking and handling equipment coupled with inadequate technical skills of farmers. Manual handling, non-compliance with hygienic procedures, limited quality and safety tests, and limited cold storage facilities thus typify practices along the chain (Swai & Schoonman, 2011; Yilma, 2012; Opiyo et al., 2013).

This thesis explores the realisation of quality and safety of fresh milk from the perspective of safety and hygiene control practices based on the assumption that improvements are necessary to prevent and monitor hazards. Moreover, insights are needed to differentiate the performance of safety and hygiene control practices more accurately, beginning at the farm and further in the chain, to develop specific and appropriate improvement interventions that can minimize existing bottlenecks.

1.2.5 Opportunities for tailored interventions in emerging dairy chains

Belcher and Palenberg (2018) defined an intervention as a deliberate action taken in a process or system to improve it or prevent it from getting worse. It may involve a single activity or sets of activities organised as part of a project or program. Interventions can occur at the level of government, sector, company, and retail (Kussaga et al., 2014). Furthermore, non-governmental organizations (NGOs), private enterprises, developmental agencies, and producer organizations can play the role of intermediaries through starting and sustaining interventions.

In emerging dairy chains, interventions have been implemented to ultimately achieve higher productivity, chain efficiency and improve food security to meet the growing demands for milk and dairy products (Ogutu et al., 2014). Different intervention approaches create opportunities for local actors in the dairy chain, such as commercial and non-commercial interventions. A dairy processing company with a business interest to engage individual or groups of dairy farmers to regularly supply good quality fresh milk for its processing activities, can start a commercial intervention. For example, as part of such an intervention, a dairy company provides a cooling tank for milk collection and bulking, milking equipment, artificial insemination services and sometimes provides training to its supplying farmers (Nada et al., 2012). In contrast, a non-commercial intervention involves non-governmental organizations (NGOs), development agencies, and governments, without a commercial interest, purposely initiated for a specific period, to support local farmers to benefit from their participation in the dairy chain. Broadly, these interventions take the form of capacity building, technical assistance, infrastructure development, strengthening farmer groups, and linking farmers with buyers (Staal et al., 2008; Uddin et al., 2011; Kilelu et al., 2013). Also, collaborative interventions between dairy companies, NGO/development agencies and governments, have proven beneficial to strengthen relationships along the chain (Kilelu et al., 2013). However, the perception of beneficiaries regarding these interventions and whether their participation have translated into milk quality and safety improvement (VanLeeuwen et al., 2012; Kilelu et al., 2017), remains to be researched. Moreover, most interventions are not primarily focused on quality and safety (Ogutu et al., 2014; Kamana et al., 2017), and the extent to which these generic approaches have improved dairy product quality and safety needs to be explored. Since inferior quality and safety continue to recur, which seems to be linked strongly to inadequate control practices, opportunities exist for research into more specific interventions that can significantly contribute to improved performance of safety and hygiene control practices along the chain.

1.2.6 Why the Tanzanian dairy chain as a case study?

In Tanzania, the dairy sector contributes about 2% to the gross domestic product (GDP) and is growing steadily with an anticipated prospect for employment, improved economic livelihood and food security (Swai & Karimuribo, 2011; Makoni et al., 2014). In 2014, the annual milk production averages 2 billion litres (Makoni et al., 2014), of which the majority is produced by indigenous breeds, involving many small-scale and a few large-scale dairy farms (Katjiuongua & Nelgen, 2014). Furthermore, formal and informal production and marketing channels exist in parallel. The formal chain is often long, organized around dairy processors, with intermediary milk bulking and collecting centres at the upstream end, and retail outlets at the downstream end of the chain. On the other hand, the informal chain is short, depicted by direct consumption on the farm and/or immediate delivery to neighbours, local restaurants, and milk traders, without any form of formal processing.

Meanwhile, interventions involving breed and feed improvement, provision of animal health services, and multi-stakeholder processes are implemented in the Tanzania dairy chain to mitigate the underlying challenges to realize the inherent production potential, achieve better livelihood and improve nutrition security. Examples of these interventions include Heifer International Project in Tanzania (HIT), Southern Highlands Dairy Development Programme (SHDDP), AustroProjekt Association (APA), Smallholder Dairy Support Programme (SDSP), Tanga Smallholder Dairy Development Programme, International Scheme for the Coordination of Dairy Development (ISCDD), Rural Livelihoods Development Company (RLDC), East Africa Dairy Development Phase 2 (EADD2) and MoreMilkit Project (Kilelu et al., 2017; Ogutu et al., 2014). Despite these efforts, opportunities still exist to empower farmers to produce safe and quality milk at the farm level of the dairy chain. Thus, Tanzania was chosen as an example of an emerging dairy chain to examine its organization, evaluate safety and hygiene control practices that may be related to milk quality and safety, and explore proper interventional approaches to improve on the performance of safety and hygiene practices.

1.3 Concepts, theories, and approaches

This section describes the different concepts (e.g., value chain), underlying theories (e.g., behaviour change theory), approaches (e.g., value chain analysis, techno-managerial approach, principles of diagnostic tool development, method of triangulation, and food safety and hygiene training approach) that are used in this thesis.

1.3.1 Value chain analysis

A value chain describes the sequence of activities and actors (e.g., farmers, traders, processors, retailers) required to bring a product (e.g., milk and dairy products) through the different phases of production to delivery to final consumers (Kaplinsky & Morris, 2000). Relationships are formed between different actors (i.e., vertical) or among similar actors (i.e., horizontal) in the chain (Trienekens, 2011).

Governance structures evolve for coordinating the different transactions between actors in the chain. A value chain analysis, therefore, is an analytical approach which involves systematically identifying the actors and their activities, distribution of benefits among actors upgrading opportunities, and the governance structures that exist within the chain (Kaplinsky & Morris, 2000; Van den Berg, 2004; Rich et al., 2011). However, Marshall (2015) argues that food value chains are embedded in the broader food system, which extends beyond chain activities to include the human and environmental dimensions within which food production to consumption occurs. In the context of food quality and safety management, the food system is viewed as a multi-layered system involving micro, meso and macro-level actors (Luning & Marcelis, 2020). The micro-level actors consist of chain operators such as farmers, firms, and consumers, directly involved in the production, processing, distribution, consumption, and disposal after use of a food product. The meso-level includes support service providers (e.g., civil society organisations, NGOs, research institutes), who provide advisory, research, development services, extension, marketing, and advocacy services. The macro-level refers to the government agencies and regulatory institutions, which provide an enabling environment and oversee the interactions between actors in the dairy food system (Jespersen et al., 2014). These interactions altogether influence the efficiency and effectiveness of the activities in the dairy system. This thesis uses value chain analysis as a basis to identify actors at various levels, analyse relationships, responsibilities, and information flows related to the quality and safety of milk and dairy products. Ultimately, a better understanding of the challenges and opportunities for the upgrading of the dairy chain would be achieved in this research.

1.3.2 Techno-managerial approach

The dairy chain is a complex system including multiple elements related to the dairy production system and people behaviour interacting to realise dairy quality and safety. To achieve consistent product quality, technological and administrative conditions are implemented to reduce variability in the production system and uncertainty in decision making of people along the chain, respectively (Luning & Marcelis, 2006; Luning & Marcelis, 2020). For instance, effective hand washing requires the availability of facilities, procedures, and the motivation of the individual engaged in it (Curtis et al., 2009; Todd, 2014). Understanding the causes of variability in the production system and uncertainties in people behaviour is a major step towards better performance of safety and hygiene control and the realisation of product quality (Luning & Marcelis, 2006). The techno-managerial approach proposed by Luning and Marcelis (2006) advocates a concurrent analysis of food and human systems by the integrative use of technological and managerial theories to explain food and people-related behaviour that constantly interact to achieve food quality. Consistent use of this approach to analyse food quality and safety issues have enabled a more comprehensive understanding of production systems and people behaviour as the basis for improvement strategies (Sampers et al., 2010; Luning et al., 2011; Kussaga et al., 2015; Nanyunja et al., 2015). Therefore, by applying the techno-managerial research approach, crucial technological and people-related aspects contributing to dairy quality and safety variations can be recognised and quantified to forecast better performance strategies along emerging dairy chains.

1.3.3 Principles of diagnostic tool development

Steps to improve dairy product quality and safety in emerging dairy chains need diagnosis of existing food quality and safety management to give evidence of their status as a basis for the development of proper interventions. A diagnostic tool provides a framework to perform a concurrent analysis of core control and assurance practices which together contribute to quality and safety in food production (Luning et al., 2008; Luning et al., 2009). Developing a diagnostic tool is based on principles which entail identification of core practices, their systematic analysis using indicators and assessment grids, which describe different levels of these practices (Luning et al., 2008; Luning et al., 2009). The grids enable a differentiated assessment of core practices as relating to the system output (e.g., quality, safe and hygienic milk product). Multiple studies have applied the principles of a diagnostic tool for differentiated assessment of core control and assurance activities of food safety management systems (FSMS) (Kussaga et al., 2014; Kirezieva et al., 2015; Kussaga et al., 2015; Luning et al., 2015; Nanyunja et al., 2015). These studies provided comprehensive insights into actual performance towards upgrading the system. For instance, Kirezieva et al. (2015) were able to propose stratified measures and policies for fresh produce companies in the design and operation of their FSMS. In emerging dairy chains, where informal production is dominant and control practices are still basic, present an opportunity to analyse the actual performance of core control practices along the chain. Accordingly, the analysis will serve as the basis to offer proper steps towards the production of high quality and safe dairy products. This research, therefore, applied the principles of diagnostic tool development to design a customised assessment tool for emerging dairy chains related to dairy quality and safety. In the end, adequate differentiation of actual core preventive and monitoring control practices (i.e., technological and people-related) to guide the design and implementation of tailored improvement strategies would be realised.

1.3.4 Increasing validity in data by using method triangulation

The application of the techno-managerial approach in food quality and safety research entails the gathering of both qualitative and quantitative data to explain technological and people-related aspects of a complex food system. The application of the techno-managerial approach therefore involves the use of multiple data sources to gain an in-depth understanding of a phenomenon. Method triangulation is, therefore, a useful approach to achieve this goal, as it offers the application of different research methods to study a phenomenon from more than one dimension using various data sources (Denzin, 2007; Carter et al., 2014). Generally, method triangulation is based on the underlying assumption that the findings of a study are more valid when different methods of data collection and analysis converge on the same conclusion (Carugi, 2016). It involves data gathering using both qualitative and quantitative methods, such as interviews, observations, questionnaires, focus groups and document analysis to examine a single phenomenon thereby increasing the reliability of data (Kopinak, 1999; Carugi, 2016). Besides, it provides a broader and multi-dimensional perspective of a phenomenon as the weakness in a single method is mitigated for by the counterbalancing strength of another thereby increasing validity and confidence in findings (Kopinak, 1999). The complex nature of emerging dairy chains and the interrelated influence of technological and people-related aspects to realise the dairy quality and safety informed the use of method triangulation to facilitate cross-checking, detail analysis and enrichment of findings from different perspectives (Kopinak, 1999; Thurmond, 2001; Ball et al., 2010). Altogether, applying method triangulation in this research will give a better conceptualization of safety and hygiene control practices in emerging dairy chains to guide proper improvement interventions.

1.3.5 Food safety and hygiene training approach

An important intervention approach to influence knowledge and behaviour towards food safety and hygiene is training (Milton & Mullan, 2010). An organized training facilities learning and skills development which can improve decision making related to safety and hygiene control in food production (Egan et al., 2007; Miri et al., 2014). Effective training approaches involve processes that include identification of training needs, choice of the training programme, the relevance of the training course to work activities, knowledge test and skill assessment, language considerations, and overall performance measures (Jacob et al., 2010; Seaman, 2010; Salas et al., 2012). Besides, it also involves appropriate teaching and learning methods such as interactive media, audio-visual material, videos, lectures and hands-on activities used to deliver the training (Medeiros et al., 2011). In developing countries, agricultural extension and participatory approaches dominate training efforts focused on knowledge sharing, skills development and improvement in the decision making of farmers towards better farm practices (Davis et al., 2012; Lukuyu et al., 2012; Lindahl et al., 2018). However, there is indication that increasing knowledge alone may not be adequate to change specific food safety behaviour as other underlying drivers may contribute to actual behaviours (Clayton & Griffith, 2008; Michie et al., 2008). Increasingly, training interventions using behaviour change theories to target underlying drivers of food safety and hygiene behaviour in farm settings are gaining attention (Nieto-Montenegro et al., 2008; Soon & Baines, 2012). Behaviour change theory-based training interventions integrates underlying behaviour drivers such as attitudes, social norm and motivation that can influence food safety and hygiene behaviour as it provides a shift from the usual training interventions focused on information sharing (Taylor et al., 2005; Steinmetz et al., 2016). This approach in the design and implementation of training interventions has helped to identify key barriers and motivators for the performance of food safety and hygiene practices and provided clarity on how knowledge mediates actual behaviour (Mullan & Wong, 2010; Soon & Baines, 2012; da Cunha et al., 2014). However, in emerging dairy chains, there is limited evidence of this approach in food safety and hygiene training interventions for farmers. Moreover, effective interventions to change behaviour towards food hygiene in developing countries are still needed (Curtis et al., 2011; Grace, 2017). Hence, this research applied the use of a behaviour change theory to develop, implement and assess the effectiveness of a tailored training intervention targeting underlying drivers of specific control practices to realize dairy quality and safety. Figure 1.3 shows the conceptual framework for the analysis of quality, safety and hygiene control practices in emerging dairy chains created from the synthesis of the background information, concepts, and approaches.

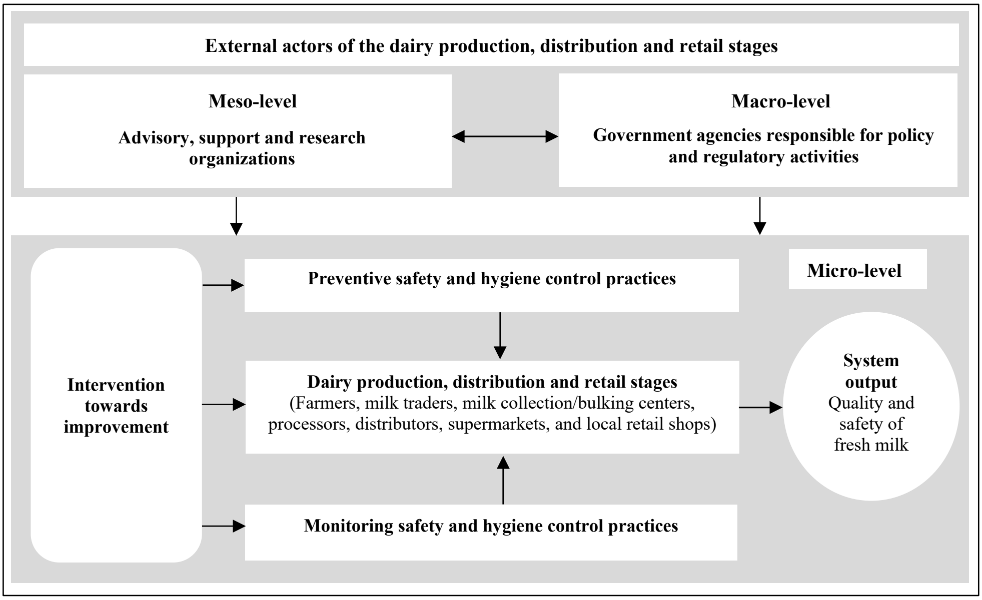

Figure 1.3 The conceptual framework for the analysis of safety and hygiene control practices in emerging dairy chains

1.4 Objectives, study location and thesis outline

1.4.1 Objectives

This thesis aims to gain insight into the underdeveloped state of safety and hygiene control practices in an emerging dairy chain and identify how to improve through a behavioural-based training intervention. To fulfil this purpose, a diagnostic tool customised for emerging dairy chains was developed to accurately differentiate practices to inform a tailored intervention, particularly for the dairy farm as it is the starting point for control along the chain. To realize this aim, four research questions were formulated:

1. What is the scientific state-of-the-art of safety and hygiene control practices, and interventions in a typical emerging dairy chain?
2. Which quality, safety and hygiene control practices influence microbial and chemical milk safety, and how to assess them in an emerging dairy chain?
3. What is the implication of differences in the performance of safety and hygiene control practices on milk safety measured along the dairy chain?
4. How to tailor a training intervention using behaviour change theory to improve safety and hygiene control practices of dairy farmers in an emerging dairy chain?

1.4.2 Study location

The study was conducted in Tanzania, in the Mvomero and Lushoto districts in Morogoro and Tanga regions, respectively. These locations were chosen to represent a spectrum of different small and large scale dairy farms, different activities of production, distribution and retailing, and involvement in several dairy-related interventions (Ogutu et al., 2014). Both Mvomero and Lushoto Districts are situated in the northern part of their respective regions. Also, Mvomero district is about 278 km, 5hrs 30 mins by car while Lushoto district is about 370km, 7hrs by car from Dar es Salaam, the commercial capital of Tanzania. Manyinga and Wami Dakawa villages were selected in Mvomero district, while Mwangoi and Ngulwi were selected in Lushoto district.

1.4.3 Thesis outline

Figure 1.4 presents the thesis outline covering six chapters overall, with four chapters, each focused on answering one of the research questions. The current chapter (**Chapter 1**) presents the general introduction to the thesis, providing a background perspective to the research, the underlying concepts, theories and approaches applied, and the overall research aim and research questions. **Chapter 2** presents the causes of persistent challenges in safety and hygiene control practices. The goal was to use

Tanzania as an example of an emerging dairy chain to understand the organization of the chain and to provide a basis for the other chapters. Besides, an evaluation of current intervention support programs was presented. **Chapter 3** describes the development of a diagnostic tool customised for emerging dairy chains. A pilot study to demonstrate how the tool can be applied and its usefulness are presented. **Chapter 4** describes a follow-up study which was aimed at investigating the implication of differences in safety and hygiene control practices on microbial and chemical safety of fresh milk along the chain. It also involves the application of method triangulation to gain different perspectives on practices and milk safety. **Chapter 5** applies the knowledge gained from all previous research chapters to design and implement a tailored training intervention for dairy farmers in Tanzania. Furthermore, the chapter describes how a behaviour change theory is used in designing and implementing tailored training. Finally, **chapter 6** presents the general discussion, the recommendations, suggestions for future research, and the conclusions.

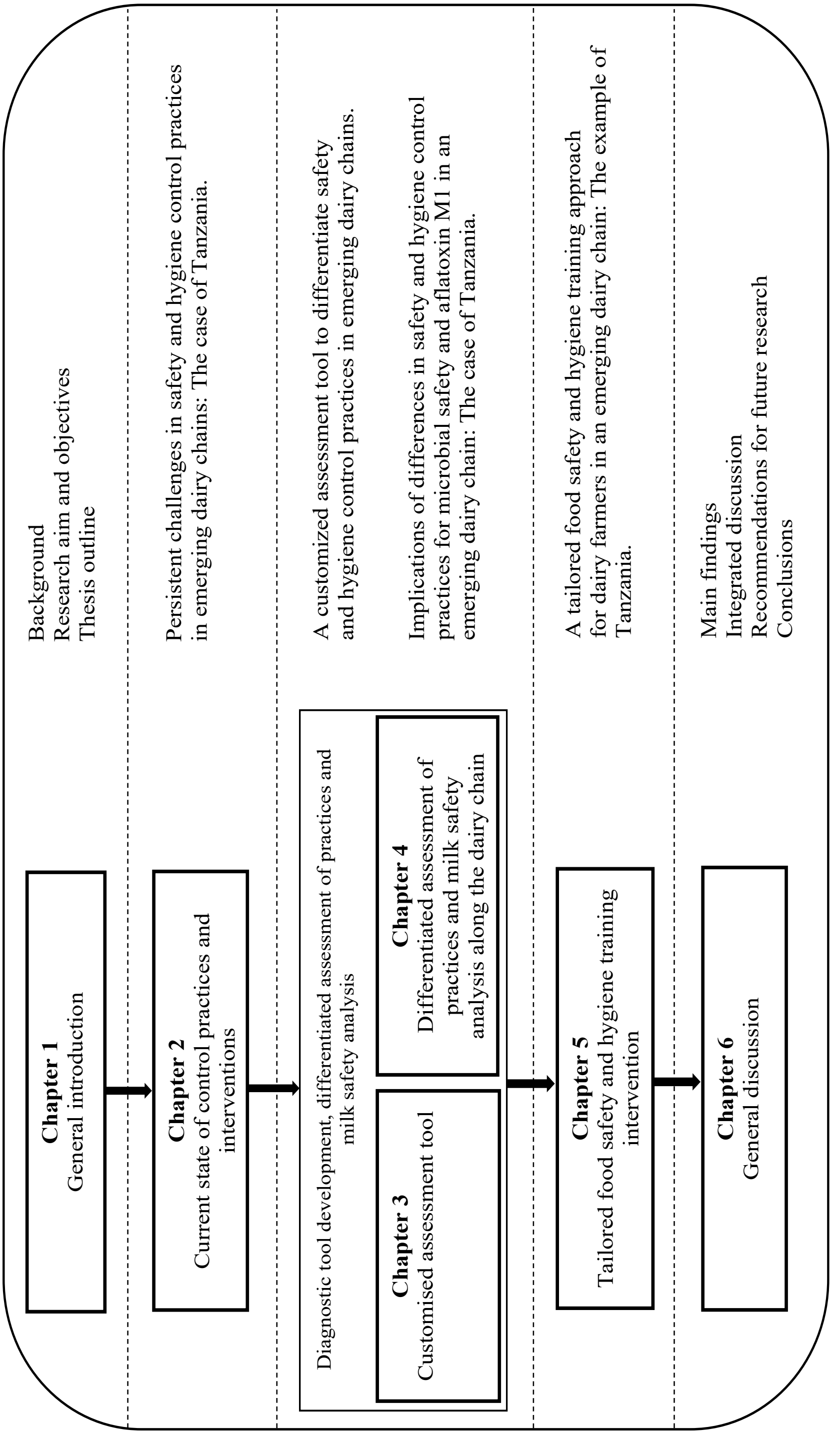

Figure 1.4 Thesis outline

Chapter 2

Persistent challenges in safety and hygiene control practices in emerging dairy chains: The case of Tanzania

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Abstract

In emerging economies, the demand for milk and milk products is growing speedily, leading to rapidly evolving dairy chains. However, milk quality and safety are not yet up to standard, despite substantial efforts to support actors in these emerging dairy chains. The aim of this study was, therefore, to get insight into possible causes of persisting poor milk safety and hygiene practices. The Tanzanian dairy chain was taken as a case for an emerging dairy chain because of its evolving nature and potential for growth. Depicting the organization of the dairy system involved a value chain analysis using focus group discussions and interviews with chain actors (in total 71). Face-to-face in-depth interviews and systematic on-site observations at actor locations in two different regions provided insights into current safety and hygiene control practices from the farm to the processor. Furthermore, 22 farmers were interviewed to examine how they perceived existing interventions in assisting their safety and hygiene control practices. Data showed that the organization of control activities and enforcement of requirements on dairy quality is not uniform across the dairy chain. Overall, safety and hygiene practices were basic or rudimentary. Preventive practices related to animal health care, hygiene, and feed storage control were mostly lacking. Milk cooling is not a common practice along the dairy chain, monitoring of milk safety and quality parameters is limited, particularly for pathogenic bacteria, indicating a risk for milk safety. Farmers perceived the support of the non-commercial intervention as more supportive to their on-farm safety and hygiene control practices than the commercial intervention. To avert public health risks of the increasing milk consumption, multiple safety and hygiene control practices require significant improvement. Support from interventions could more explicitly enhance awareness and competences on these safety and hygiene practices.

2.1 Introduction

In emerging economies, the demand for milk and milk products is growing (Gerosa & Skoet, 2013). This demand is growing averagely at 6% annually in East Africa and chain actors are under pressure to produce more to meet consumer needs (Bingi & Tondel, 2015). Optimal safety and hygiene control activities are crucial to deliver safe milk, especially when demand is growing fast. In spite of the increasing demand across East Africa, the developments of the dairy sector in the region is not uniform. For example in Kenya, the dairy sector is more advanced in terms of milk production and chain organization than in Uganda, Rwanda, and Tanzania (Makoni et al., 2014). In Tanzania, the milk production, processing and chain organization is evolving with potential for increased productivity and chain effectiveness to meet consumer demands (Kurwijila & Bennett, 2011). Nevertheless, the realization of this potential is hampered by a predominantly small-scale production system and little formalization along the dairy chain.

Characteristics of informal dairy chains are loose relationships and low levels of milking technology (Katjiuongua & Nelgen, 2014). Poor milk safety and inconsistent quality of fresh milk and milk products have been frequently reported in such informal dairy chains (Schooman & Swai, 2011; Dagmar Schoder et al., 2013; Kussaga et al., 2015). Moreover, even advanced processing factories with established hazard analysis critical control point (HACCP)-based food safety management systems (FSMS) seem to face challenges. In fact, a microbial assessment study of environment, hand samples, and products of dairy establishments in Tanzania indicated that the majority still operated at poor to moderate level (Kussaga et al., 2015).

In East Africa, multiple intervention programs have been developed such as the East Africa Dairy Development (EADD) program in Kenya and Uganda (Kilelu et al., 2013), Smallholder Dairy Support Program (SDSP) in Tanzania (Ogutu et al., 2014) and Rwanda Dairy Competitiveness Program (RDCP) (Grewer et al., 2016) to enhance dairy chains. These interventions have focused on increasing milk production, improving nutrition security, and reducing poverty (Kurwijila & Bennett, 2011; Ogutu et al., 2014). Most interventions mainly involve non-governmental organizations (NGO's) and development agencies, without a commercial interest. Common initiatives of these non-commercial interventions include creating access to farm inputs, facilitation to acquire milking equipment, training, and extension services to dairy farmers (Ogutu et al., 2014; Cadilhon et al., 2016). Other interventions are initiated by milk processing companies with a commercial interest to facilitate a regular supply of quality milk for processing (Vorley et al., 2009). However, the extent to which applied interventions are perceived by beneficiary farmers to assist their on-farm safety and hygiene control practices is still unexplored.

The aim of this study was to get insight in possible causes of persistent poor quality and safety in emerging dairy chains. We selected Tanzania as an example of an emerging dairy chain, because of its evolving nature, dominant small-scale production systems and potential for growth. Firstly, a value chain analysis was applied to understand the organization of the dairy system. Interviews, on-site visits, and observations with dairy actors in different regions was done to examine current hygiene and safety control practices from the farm to the local retail shops. Also, farmers were interviewed to understand how they perceived support from existing interventions in helping their on-farm safety and hygiene control practices.

2.2 Materials and methods

2.2.1 Field study design

The study design covered three key parts using a techno-managerial research approach as previously described by (Luning & Marcelis, 2006; Luning & Marcelis 2007). It implies an integrated analysis of technological conditions and people-related practices in a food chain context to obtain a more comprehensive understanding of possible causes of poor quality. The first part included the analysis of the dairy system organization using focus group discussion and interviews. The analysis aimed at understanding the roles and responsibilities of actors toward safety and hygiene control in the chain. The second part covered face-to-face, in-depth interviews and on-site visits to analyze safety and hygiene control practices implemented by dairy chain actors from the farm to the point of processing. The third part involved farmer interviews in examining the extent to which existing interventions helped their performance of on-farm safety and hygiene control practices. The study was conducted in two regions of Tanzania, and in total, 71 dairy chain actors participated in the study.

2.2.2 Characteristics of selected study areas and respondents

Fifty-six farmers (Table 2.1) in Tanzania participated in eight focus group discussions (FGDs) in Mvomero and Lushoto districts in Morogoro and Tanga regions, respectively. The regions and districts were selected because they cover all dairy chain activities such as production, collection, processing, and marketing, and because they have been the target of multiple dairy chain programs. The farmers were selected based on a minimum dairy farming experience of more than one year, having at least one milking cow, and showing a willingness to participate in the research. Two study sites were selected from each district. The study sites were selected using a categorization data obtained from the International Livestock Research Institute-Tanzania (ILRI, 2016) on the organizational strength and level of advancement of farmer associations in the two regions. From the data, farmer associations in Manyinga, Wamidakawa and Ngulwi were categorized as slow-growing. In contrast, the association in Mwangoi, was categorized as fast-growing in terms of financial health, effective leadership, relationship with the external environment, and membership loyalty. Also, four milk traders, three milk collection centre (MCC) supervisors, four local retail shop operators, two dairy company managers and two district livestock officers (DLO) were contacted for face-to-face in-depth interviews to depict the organization of the dairy system regarding quality and safety control activities. Approval to conduct scientific research was obtained from Sokoine University of Agriculture, Tanzania. Respondents were contacted, the purpose of the study was explained, and individual consent was obtained as a commitment to the study.

Table 2.1 Characteristics of respondents in focus group discussions and face-to-face in-depth interviews [a]

Characteristics of respondents	F (n=56)	MT (n=4)	MCC Supervisors (n=3)	LRSO (n=4)	DCM (n=2)	DLO (n=2)
Age (years)						
Average age	43	44	27	41	43	56
Gender (%)						
Male	48	75	33	25	100	100
Female	52	25	67	75		
Years in dairy activity (%)						
5month to 10years	60	75	100	75		100
11 years to 20years	36	25			100	
>20years	4			25		
Level of education (%)						
Primary level	64	75	33	50		
Secondary level	16	25	67	25		
Tertiary level					100	100
Others	2					
None	19			25		

[a]All values are percentages except average age in years. F=farmers; MT=milk trader; MCC=milk collection center; LRSO=local retail shop operator; DCM=dairy company manager; DLO=district livestock officer

2.2.3 Characteristics of evaluated dairy chain interventions

The perceived support was evaluated for commercial and non-commercial interventions. These were selected based on their differences in orientation and direct involvement with dairy farmers in the last five years. The commercial intervention was initiated by TangaFresh, a dairy company with a processing capacity of about 50,000 liters per day, and produces a range of dairy products including fresh milk, plain and flavoured yoghurt, cheese, butter and ghee. The primary goal of this intervention is to increase the efficiency of milk collection. TangaFresh owns several milk collection centres (MCCs) and supports some privately owned MCCs with cooling tanks. The company determines the milk price, collects the milk every 2 to 3 days and trains some farmers to improve their ability to supply milk that meets the company requirements.

The non-commercial intervention was led by the International Livestock Research Institute (ILRI) and implemented together with Sokoine University of Agriculture (SUA), Tanzania Dairy Board (TDB), Heifer Project International, farmer organizations, Faida Market Linkages, with a financial contribution from Irish

Aid. This intervention aimed to achieve inclusive growth to reduce poverty and vulnerability among farmers and traders in selected rural areas of Tanzania (ILRI, 2014). The intervention consisted mainly of capacity building activities, but also other support such as linking farmers to veterinary services and helping them to acquire milk containers to improve quality milk production and transportation.

2.2.4 Data collection methods

Focus group discussions

The FGDs were conducted to collect qualitative data from dairy farmers following the recommendations of Richard and Casey (2000) in selecting participants, moderators, and in preparing open-ended questions. The guideline of "Making value chains work better for the poor; a toolbox for practitioners of value chain analysis" (Van den Berg, 2004) was used to systematically determine three crucial sections for guiding questions in milk value chain analysis. The first section involved questions related to milk quality requirements, the flow of milk and specific roles of each actor in the chain. The second section involved questions on agreements used in selling milk, information flow on milk quality requirements, and influence of each actor on setting quality requirements and enforcement. The third section involved questions on constraints and opportunities to produce and supply safe milk. We conducted two separate FGDs in each chosen study site, one with farmers supplying milk in the formal and one with farmers supplying in the informal dairy chain. Each group consisted of seven individual farmers selected to achieve gender balance. The group discussions were led by a moderator using the guiding questions and an assistant for notetaking, who were native language speakers. By probing on the guiding questions, the moderator helped to stimulate the discussion and gain in-depth clarity. For consistency, the same moderator and note-taker were present in all the FGDs. Each discussion lasted about two hours, were audiotaped, transcribed and translated into English with the support of the note-taker for analysis.

Face-to-face in-depth interviews and structured on-site observations

Face-to-face in-depth interviews with key actors (Table 2.1) were structured in two parts. The first part involved collecting qualitative data to examine the dairy system from the perspective of different actors along the chain. The format of questions followed the same structure as used for the farmers' FGDs. Face-to-face in-depth interviews were chosen over focus group discussions to avoid confrontation between actors who could be competitors (Boyce & Neale, 2006). One milk trader (MT) and one local retail shop operator (LRSO) from each study site were interviewed. Three MCC supervisors were interviewed in three study sites except in Manyinga where there was no MCC. Two managers of two different dairy companies from two separate regions were also interviewed, as well as the district livestock officers (DLO) of Mvomero and Lushoto districts. All respondents were identified through a local livestock officer, contacted by telephone and interviewed.

In the second part, safety and hygiene control practices of chain actors were investigated. Questionnaires with open-ended questions to represent preventive and monitoring aspects of safety and hygiene control practices were developed based on acceptable international and regional standards (CAC, 2004; Tamime, 2009; FAO & IDF, 2011; Park et al., 2013). Overall, 22 farmers, four milk traders (MTs), four local retail shop operators (LRSOs), three MCC supervisors and two dairy company managers (DCMs) were interviewed. Furthermore, on-site observation was conducted at actor locations using a checklist of closed-ended questions to verify practices of actors, presence of milking equipment and facilities. Out of the 22 farmers, eight and eleven were interviewed using closed-ended questions on their perceived support received toward on-farm safety and hygiene control practices from the commercial and non-commercial interventions, respectively. The farmers scored their perceived level of support received with a three-point scale of strong, moderate and no support. Strong support (score 3) meant intervention activities helped safety and hygiene control practices beyond the expectations of the farmer. Moderate support (score 2) meant intervention activities helped safety and hygiene control practices somewhat, but did not exceed expectations of the farmer. No support (score 1) meant intervention activities did not help safety and hygiene control practices and the expectations of the farmer were not met.

2.2.5 Data analysis

Analyzing focus group discussions and face-to-face in-depth interview responses

The micro-interlocutor analysis approach by Onwuegbuzie et al. (2009) was adapted to analyze the responses from the FGDs. In this approach, individual responses to a guiding question were evaluated for the level of consensus and disagreement among other participants. A matrix of guiding questions against each participant number was kept by the note-taker to assess the level of agreement, dissent and nonresponse for each response. This helped to quantify particular responses to enrich the qualitative data gathered during the discussions. Each FGD and face-to-face in-depth interviews were analyzed first as a unit and then collectively. The independent analyses were systematically compared collectively by two researchers manually for consistency in common trends, themes and differences. Based on analyzed responses of group discussions and face-to-face in-depth interviews, we drew a chain map (Figure 2.1) to depict the multi-layered organizational nature of the dairy system.

Evaluation of safety and hygiene control practices

Individual responses of each category of actors on implemented safety and hygiene practices were analyzed independently for farmers, milk traders, milk collection centres and dairy companies by two researchers for reliability. We grouped similar responses to questions on safety and hygiene control practices for each category of actors and their collective frequencies determined. Our initial comparison of frequencies of farmers' practices supplying through the formal and informal dairy chains revealed no notable differences. Therefore, we combined both groups of farmers as a single dataset and their frequencies determined. This approach helped to translate responses into quantifiable numbers (Table 2.2 to 2.5).

Analyzing farmers' perceived support of identified support programs

The corresponding assigned scores of perceived support of farmers from identified interventions for each safety and hygiene control practice was entered into Microsoft Excel. We clustered similar scores for each practice, and the frequency of pooled scores were visualized as bar graphs.

2.3 Results and discussion

2.3.1 Organization of the dairy system in Tanzania

Figure 1.1 shows the multi-level nature of the dairy system with micro, meso and macro-level actors, the product, and information flow on milk quality and safety requirements. At the micro-level, farmers, MTs, local retail shops, MCCs, dairy companies, distribution agents, retailers and consumers are involved in milk production, collection, processing, marketing, and consumption activities. Written agreements are common in the formalized dairy chain where dairy companies source milk from MCCs. However, these written agreements are with farmer associations, commercial farms or private owners of MCCs rather than with individual small farmers. This type of arrangement is often common, where farmer cooperatives and commercial farms are strongly present (Eaton et al., 2008; Ulicky et al., 2013). Some private owners of MCCs have written agreements with MTs. Individual farmers are informed about milk quality, safety and hygiene requirements through MCCs operated by the cooperative or through MTs. In the informal dairy chain, oral agreements and informal communication channels are dominant in transactions. Customers rely on organoleptic perception of milk quality to accept milk from farmers, which can vary from one customer to the other. Our findings are consistent with the study of Abdulai and Birachi (2009) who identified spot markets, verbal contracts and written contracts as transactional arrangements in dairy chains in Kenya.

The meso-level actors involve associations, business organizations, development partners, NGOs, academic and research institutions, which provide support services in the dairy chain. Tanzania Milk Producers Association (TAMPRODA) and Tanzania Milk Processors Association (TAMPA) are groups that represent the interest of the producers and processors, respectively. These type of associations are common across East Africa in representing the dairy farmer interest in the dairy chain (Bingi & Tondel, 2015).

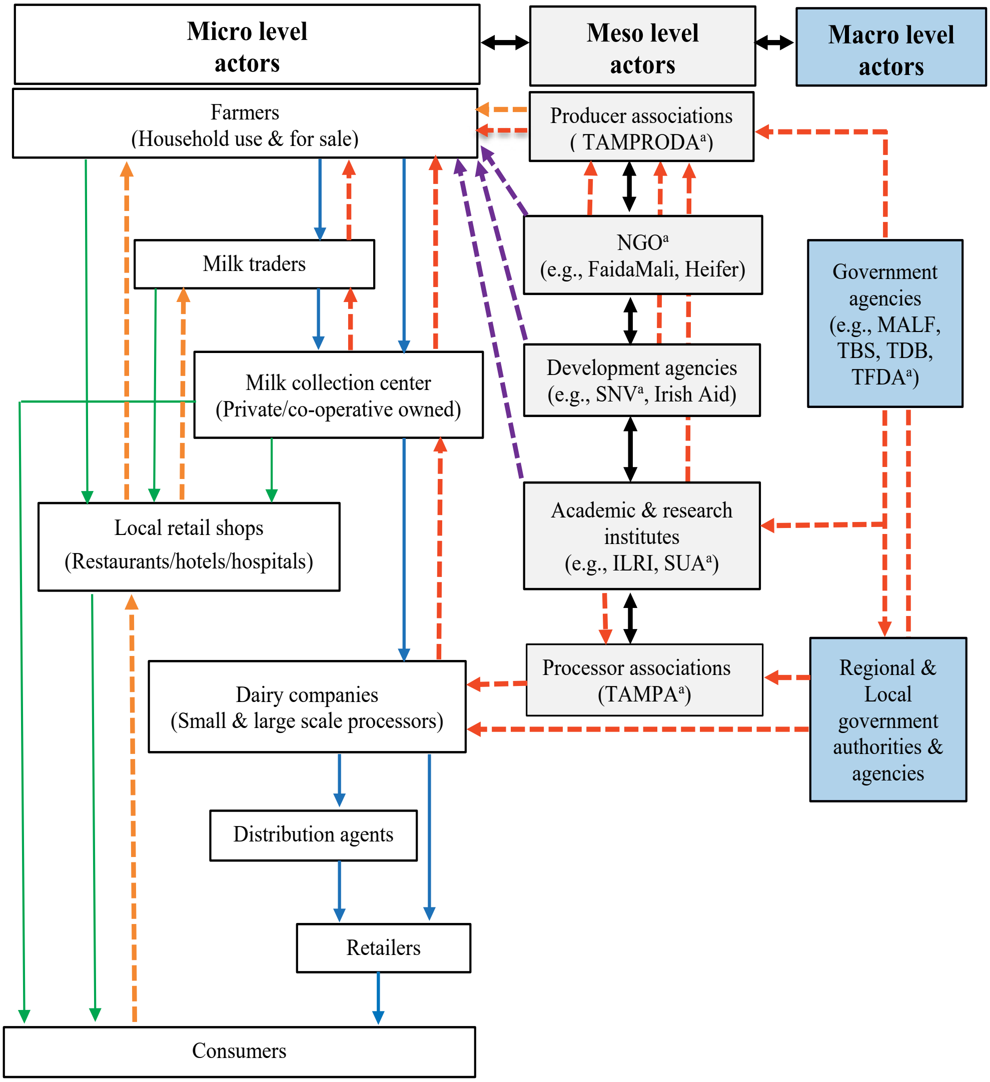
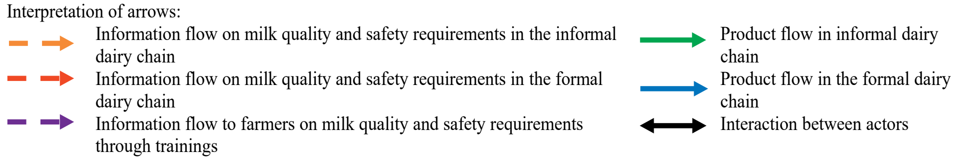


Figure 1.1 Dairy chain map showing interaction between actors, product and information flow in the Tanzania dairy system

[a] MALF=Ministry of Agriculture, Livestock and fisheries; SNV=Netherlands Development Organisation; TBS=Tanzania Bureau of Standards; TFDA=Tanzania Food & Drugs Authority; NGO=non-governmental organisations; TAMPRODA=Tanzania Milk Producers Association; TAMPA=Tanzania Milk Processors Association; SUA=Sokoine University of Agriculture; ILRI=International Livestock Research Institute

Interpretation of arrows:



The associations offer a common platform for development partners (e.g., Irish Aid, ILRI), NGO's (e.g., Land O'lakes, Heifer international), business organizations (e.g., Faida Mali) and other external service providers to support chain effectiveness through these associations instead of individual farmers (Shiferaw et al., 2011). Furthermore, producer and processor associations advocate and negotiate member interests during national consultations on standards for the milk chain (Larsen et al., 2009; Urassa, 2014; Nanyunja, 2015).

The macro-level actors (Figure 2.1) provide enabling conditions for the overall operation of the milk sector through setting milk standards (TBS) and enforcement (TFDA) whereas developing, regulating and promoting dairy industry activities is facilitated by TDB (Urassa, 2014), which is similar to Kenya and Uganda (Makoni et al., 2014). However, setting and enforcing milk quality and safety standards is mainly targeted at the formal dairy chain, with no enforcement in the informal dairy chain, although only a small fraction of the total milk supply is accounted for by the formal chain. Overall, the organization of control activities and enforcement of requirements on dairy quality is not uniform across the chains.

2.3.2 On-farm safety and hygiene control practices

On-farm animal health care and hygiene practices

Table 2.2 shows the different categories of on-farm disease prevention, monitoring and treatment practices to ensure animal health care and hygiene. Elementary disease prevention practices such as vaccination and deworming (59%), spraying of the milk shed with insecticides (50%), and keeping hygiene in the shed (41%) were common practices among farmers. Various studies on dairy cattle health management in Kenya (Maingi & Njoroge, 2010; Odhong et al., 2015) and Ethiopia (Wesonga et al., 2010) found similar elementary farmer practices. Their use was attributed to farmers' accessibility to vaccination and deworming drugs, and insecticides. However, these practices may not be adequate against important dairy cow diseases such as mastitis. Although Biffa et al. (2005) and Karimuribo et al. (2006) have pointed out that animal and environmental hygiene are crucial preventive practices against dairy cattle diseases, only 41% of the farmers are performing these practices (Table 2.2). Veterinarian services focus on prescribing drugs, treating sick cows and vaccination (91%), and on educating farmers on disease-preventing practices (86%). However, frequent education of farmers on disease prevention and follow-ups (5%) on treated sick cows are limited. This can be attributed to the limited number of professionals available to meet the needs of each farmer, because veterinary officers serve more than one community, which are often far apart.

Pre- and post-milking practices (Table 2.2) lack alignment with good milking practices among all the farmers. Most farmers (82%) cleaned the udder and teats pre-milking with warm water, soap and dried with a piece of cloth, whereas about 36% of farmers do not clean the udder and teats post-milking at all. Studies in Kenya (Sraïri et al., 2009) and Ethiopia (Welearegay et al., 2012), found similar non-alignment among farmers in pre- and post-milking practices. Pre-dipping of teats with a disinfectant after cleaning the udder was generally lacking in farmer's pre-milking practices. Elmoslemany et al. (2010) found that pre-dipping with an effective disinfectant followed by cleaning with a single-use towel significantly reduced bacterial count in milk compared to other teat care practices. Current on-farm pre- and post-milking practices thus expose the milk to bacterial contamination from incomplete udder and teat hygienic care, and thereby increase the chance of mastitis.

According to the FAO and IDF (2011) guide on good dairy farming practices, regular checks of animal behaviour and body condition are useful ways to detect diseases on dairy farms. In the current study, the majority of farmers relied on behavioural (96%) and observable physical changes (91%), while 32% relied on a drop in milk yield to monitor disease occurrence. The use of confirmatory tests such as using rectal thermometers and laboratory tests to make an accurate diagnosis of diseases was completely absent among all the farmers. A recent study by Alonso et al. (2015), which compared farmer's ability to use observable changes and confirmatory laboratory tests in Tanzania, revealed a lack of alignment in the detection of specific diseases. This discrepancy highlights the vital role of confirmatory tests, because a lack of animal disease detection can lead to many conditions not being detected in time, increasing the risk of milk contamination from diseased animals.

Table 2.2 Characteristics of on-farm animal health care and hygiene preventive and monitoring practices [a]

On-farm practices on animal health care & hygienic practices

Animal disease preventive practices	n=22
Prevention of disease	
Preventive medication (i.e., vaccinate & deworm)	59
Sprays the shed with paranex	50
Hygiene in shed	41
Washes cow with soap & sprays shed	14
Applying zero-grazing system	9
Milks cow regularly to reduce mastitis	5
Dipping teats	5
Veterinarian services	
Prescription of drugs, treatment & vaccination	91
Educates farmers on farming practices to prevent diseases	86
Implementing national health programs	41
Advises on healthy treatment of cows	32
Follow up on treated cows	5
Support to dehorn	5
Pre-milking practices	
Clean udder and teats with warm water & dry with a piece of cloth	46
Udder and teats cleaned with warm water, soap &dried with a clean piece of cloth	36
Allows calf to suck on teats before milking	14
Udder and teats cleaned with cold water, soap & dried with a clean piece of cloth	5
Uses only warm water to clean udder and teats	5
Cleans udder and teats with warm water, soap, dried with a clean piece of cloth & lubricates with oil	5
Post-milking practices	
Udder was cleaned with warm water & dried with a clean piece of cloth	46
Udder not cleaned	36
Allows calf to suck	18
Animal disease monitoring and treatment practices	n=22
Detection of disease	
Behavioural changes (e.g., laziness, loss of appetite & irregular breaths)	96
Physical observable changes (e.g., changes in dung, eyes, feet, swollen udder, erect skin hair & dryness of nuzzle)	91
Drop in milk production	32
Action taken when disease is detected	
Consults the veterinarian	86
No consultation with veterinarian but separates disease cows and treats them	14
Storage of veterinary drugs	
No storage of drugs, brought in by veterinarian	73
Uncontrolled storage (e.g., in a box or polythene bag at room temperature)	23
Controlled storage (e.g., in a refrigerator)	4

[a] All values represent percentages and n represent the number of farmers

On-farm feed and feed storage practices

Table 2.3 shows the different categories of on-farm feed and feed storage preventive and monitoring practices. The majority of farmers used roughages (100%) and concentrates (77%) as feed, which are the two common types of feed in dairy farming. The current study showed that 36% of the farmers stored roughages outside the house, and 41% stored roughages in a semi-controlled manner at room temperature, whereas 32% stored concentrates under semi-controlled conditions in plastic or jute bags. Current feed storage practices by farmers for both concentrates and roughages lack alignment with acceptable feed storage practices (FAO & IDF, 2011). The inadequate feed storage practices combined with high environmental temperatures and humidity can cause bacterial and fungal growth, as demonstrated in recent studies in Tanzania (Salum Mohammed et al., 2016) and Kenya (Kang'ethe & Lang'a, 2009). These studies found over 60% of feed samples to be contaminated with aflatoxin B1 beyond national and international maximum residue levels. Monitoring for moulds in stored feed by the farmers is largely based on colour and smell (75%). This practice is not very accurate and increases the chance of feeding dairy cattle with mould-infested feed. Therefore, current feed storage practices do not prevent feed contamination routes for mycotoxins, due to the lack of implementation of internationally acceptable feed storage and monitoring practices, which causes a high public health risk from consuming aflatoxin M1 in raw milk.

Table 2.3 Characteristics of on-farm feed and feed storage preventive and monitoring practices [a]

On-farm feeding and feed storage practices	
Feed and feed preventive storage practices	n=22
Feed type	
Roughages	100
Concentrates & Supplements	77
Feed storage facilities for roughages	
Semi-controlled (e.g., kept in-house)	41
Uncontrolled (e.g., outside the house)	36
No storage (e.g., cut when needed)	23
Feed storage facilities for concentrates	
No storage of concentrates	45
Semi-controlled (e.g., in jute/plastic bags)	32
No use of concentrates	23
Feed stored monitoring practices	n=22
Feed inspection for mould	
Regular physical observation by checking colour and smell	73
No inspection and action taken	23
Manually feel temperature & moisture	23
Regularly spreads feed and turns it	18
Hand removal of mould in feed	5

[a] All values represent percentages and n represent the number of farmers

2.3.3 Sanitation practices and hygienic design of facilities for milk handling

Table 2.4 shows the characteristics of preventive sanitation and milk handling practices, and Figure 2.2 shows the sanitation practices and hygienic design of facilities for milk handling. The results in Table 4 show that having, and following, a written sanitation plan was lacking across the milk supply chain, except in dairy companies. Regulation and inspection by government authorities is limited to dairy company activities in Tanzania (Katjiuongua & Nelgen, 2014), and this may account for their adherence to written sanitation plans. This is consistent with other studies in East Africa where micro-level chain actors are not regulated or inspected by government authorities (Grace et al., 2007; Kamana et al., 2016). Consequently, variable sanitation practices are applied by micro-level actors, which are all avenues for milk contamination.

The cleaning of milking and facility floors varied across milk supply chain actors depending on type of floors. The majority of MCCs and local retail shops use soapy water and long brushes/brooms to sweep concrete floors. Few farmers (14%) with concrete floors only use running water. The dairy companies, one MCC (33%) and one milk bar (25%) add mopping to dry the concrete floors after sweeping with brushes and soapy water. Concrete floors are easier to clean and maintain than sandy or wooden floors (Goopy & Gakige, 2016). The majority of farmers with sandy and wooden floors clean them by sweeping and collecting dung with a hoe (Figure 2.2). These practices limit the proper cleaning of watery waste, and udders and teats can easily become dirty with mud and dung in such a situation. Poor floor hygiene has been found to increase the chances of milk contamination from pathogenic bacteria (Oliver et al., 2005; Vissers & Driehuis, 2009).

Cold storage tanks were only available at MCCs and dairy companies (Figure 2.2). Farmers, milk traders and local retail shops had different milk containers to store milk. Generally, stainless steel containers are recommended, but only some farmers (32%) and one milk trader used them. All the local retail shops used thermos flasks, and very few farmers (9%) had specially designed plastic containers called Mazzican, which are largely available than only in Tanzania. They have wide neck openings, are easier to clean, and therefore more useful than non-Mazzican plastic containers (Goopy & Gakige, 2016). However, Mazzicans still can't be cleaned as well as stainless steel containers. Overall, non-Mazzican plastic containers were common among the majority of farmers (68%) and milk traders (75%). Some of the non-Mazzican plastic containers used by farmers and milk traders were observed to have scratches which hamper their adequate cleaning, similar to previous studies in Tanzania (Kivaria et al., 2006), Kenya (Ndungu et al., 2016) and Uganda (Grimaud et al., 2007). The dominant use of plastic containers by dairy chain actors can be attributed to their availability and low price, but increases the risk of milk contamination because of the inability to clean and disinfect them well.

Table 2.4 Characteristics of preventive sanitation and milk handling practices of dairy chain actors [a]

Preventive sanitation and milking handling practices	F	MT	MCC	LRS	DC
Available and follow sanitation plan					
Available and follows written plan					100
No available written plan and follows personal instinct	100	100	100	100	
Cleaning of milking/facility floor					
Sweeps floor with long brush/broom and soapy water			67	50	
Sweeps floor with long brush/broom and soapy water and mopping to dry after sweeping			33	25	100
Sweeps with broom and removes dung with a hoe	50				
Sweeps floor with broom only	36			25	
Sweeps floor with broom and after with running water	14				
No cleaning because has no specific area for milking	14				
Cleaning of milk storage cooling tanks					
Manually cleans with warm water, brush, liquid soap & rinsing with clean water			67		
Manually cleans with warm water, brush, liquid soap & drying with towel after rinsing with clean water			33		
Uses caustic soda and nitric acid for cleaning-in-place					50
Uses only caustic soda for cleaning-in-place					50
Cleaning of milk containers					
Hot water, brush, bar soap & rinse with cold water	64			100	
Hot water, brush, bar soap, rinsed with cold water & sun-dried	4	75		75	
Hot water, brush, bar soap, rinsed with cold water & dried with piece of cloth/towel	4	25		50	
Coldwater, brush, bar soap & rinse with cold water	27				
Pest control practices					
Fitted window nets to keep flies and birds out					100
Fitted automatic door closers to keep doors closed					100
Sprays environment with insecticides occasionally	96		67	50	
Sprays environment with insecticides twice in a day				25	
Sprays environment with insecticides three times week				25	
Fumigates environment every three months					50
Maintains cleanliness	14		33		
Temporary storage of milk					
Stores inside the house (30 °C)	91				
Stores inside the house in a thermos flask				100	
Stores outside the house (35 °C)	9	100			
Stores in a cooling tank (lower than 4°C)			100		100
Handwashing before milking & handling milk					
Washes hand with water & soap	96	100	100	100	100
Washes hand with only water	4				

[a]All values represent percentages. F=farmer (n=22), MT=milk trader (n=4), MCC=milk collection center (n=3), LRS=local retail shop (n=4) and DC= dairy company (n=2)

Cleaning practices of cold storage tanks varied within and between dairy companies and MCCs. The dairy companies cleaned tanks with cleaning-in-place (CIP) using alkaline and acid solutions or only alkaline solutions (Figure 2.2). MCCs, on the other hand, cleaned cold storage tanks manually and sometimes dried them with a towel after rinsing. Some farmers (4%), milk traders (25%) and local retail shops (50%) also cleaned their milk containers manually. They dried the containers with a piece of cloth instead of draining under dry conditions as recommended by Pandey and Voskuil (2011). The use of towels to dry cooling tanks and containers can lead to poor microbiological quality, as dirty towels can result in recontamination with bacteria (Elmoslemany et al., 2010; Tamime, 2009b). With regard to insect control practices, the use of insecticide spray was common on farms (96%), MCCs (67%) and local retail shops (50%), and fumigation in one of the dairy companies (50%). The dominant use of aerosol sprays on farms can be attributed to persistent insects such as ticks and tsetse flies as observed by Odhong et al. (2015), their ready availability and low price across East Africa. However, these aerosols can easily contaminate the milk when not applied properly (Fagnani et al., 2011; Desoky et al., 2015).

Storage of milk below 7ºC was limited to MCCs and dairy companies (Table 2.4). Farmers, milk traders and local retail shops often stored milk at 30ºC to 35ºC before consumption or marketing. This range of temperatures favours a wide spectrum of pathogenic and spoilage bacteria to grow, and potentially compromises the microbiological quality of fresh milk. Our finding is consistent with studies in Mali by Bonfoh et al. (2003) and in Kenya by (Ndungu et al., 2016), where most farmers, milk traders and bars held milk at ambient temperatures. The limited milk cooling early in the chain, can be attributed to overreliance on MCCs for cold storage. This neglects the fast growth of bacteria at increased temperatures, which may cause problems before the milk arriving at the MCC. The long distances to MCCs and their inability to maintain the required cold storage temperatures may further decrease the microbiological quality of milk. Overall, major shortfalls in practices related to the cleaning of floors and milk storage facilities, type of milk storage facilities and temperature of cooling the milk.

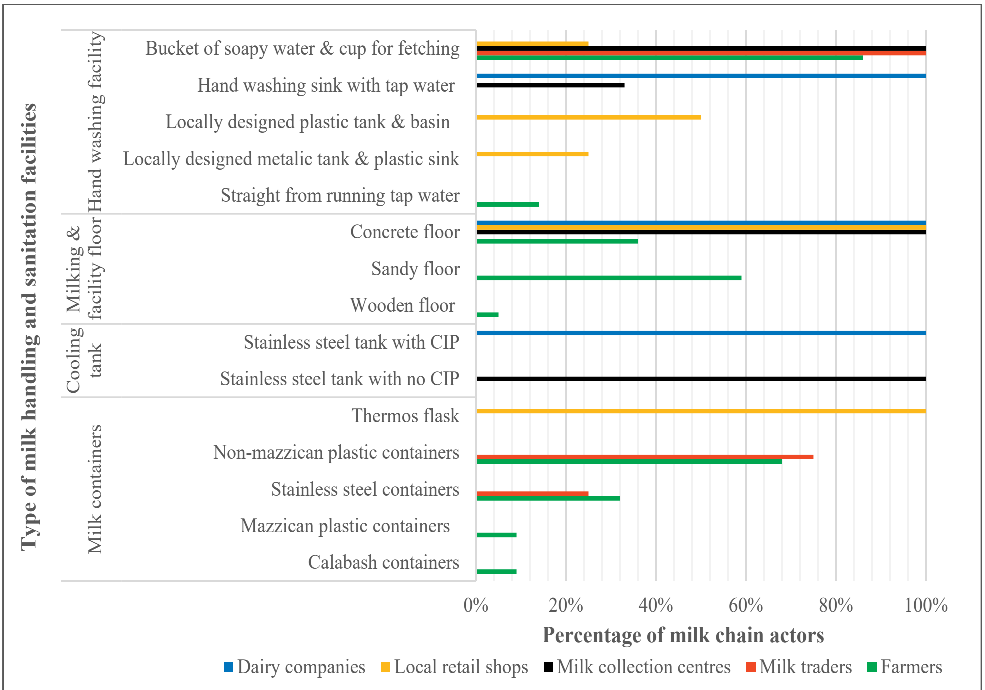


Figure 2.2 Sanitation practices and hygienic design of facilities for milk handling by dairy chain actors

2.3.4 Monitoring of milk quality and safety requirements

Table 2.5 shows monitoring practices of dairy chain actors to assure milk quality and safety. The milk quality and safety requirements lack coherence across the dairy chain (Table 2.5). Overall, physical and observable quality requirements such as density, temperature, colour, cleanness of milk, and no-off odors were predominantly checked by the majority of actors. These are consistent with rapid milk quality checks recommended by Draaiyer et al. (2009) and, Goopy and Gakige (2016) for quality assurance in tropical developing countries. Most farmers (55%) and all local retail shops relied predominantly on organoleptic checks such as milk colour and smell due to lack of standard instruments for quality checks. Very rudimentary methods were observed among some farmers (23%), one milk trader (25%) and half of local retail shops who pour milk in the sand to observe how quickly the milk is absorbed to check for density. Investment into quality monitoring per unit volume of milk may be too high for farmers, traders and local retail shops (Vorley et al., 2009), which may account for the sole reliance on rudimentary methods and on MCCs.

Table 2.5 Characteristics of milk quality and safety requirements monitoring practices by dairy chain actors [a]

Milk quality and safety requirements monitoring practices	F	MT	MCC	LRS	DC
Milk quality and safety requirements monitored					
Cleanness of the milk	100	50	67	50	100
Creamy white colour	55	50	33	50	100
No-off odours	55	75	33	50	100
Density	36	10	100	50	100
Temperature		0	100		100
Milk acidity		75	100		100
Total bacteria presence			67		100
Presence of antibiotics					50
Total solids					50
Fat content					50
Protein levels					50
Pathogenic bacteria presence (e.g., *Staphylococcus aureus)*					
Methods for checking milk quality and safety in the dairy chain					
Observes cleanness of the milk	100	50	67	50	100
Observes colour and smells milk for off-odours	55	75	33	50	100
Checks density with lactometer		50	100		100
Conducts alcohol test for milk acidity			100		100
Conducts Resazurin test for total bacteria presence			100		100
Conducts lab analysis of total solids, protein & fat					50
Dips match stick in milk & lighted stick means density is acceptable				50	
Pours milk in soil to observe absorption rate to check density	23	25		50	
Relies only on MCC without further checks	23			50	
Relies on instinct to check taste & density		50			
Touches milk can to check temperature		25			
Heats milk to observe if the milk cuddles		25			
Pours milk into a transparent bottle to check density	14				
Relies only on milk trader	5				

[a] All values represent percentages. F=farmer (n=22), MT=milk trader (n=4), MCC=milk collection center (n=3), LRS=local retail shop (n=4) and DC= dairy company

Specific milk quality checks such as absence of antibiotics, and levels of milk fat and protein, and total solids were lacking at farmer, milk trader, MCC and milk bar levels. Checks for total bacteria and milk acidity using e.g., Resazurin and alcohol tests, respectively, were limited to MCCs and dairy companies. High milk acidity may hamper further processing (Tamime, 2009b). The Resazurin test acts as a first line indication of bacterial presence (Pandey & Voskuil, 2011) and enables MCCs and dairy companies to reject bacteria-infested milk that could contaminate bulk milk. This is vital since immediate haulage of milk by dairy processing companies is often lacking. On top of that, when it comes to pathogens public health risks exist due to absence of monitoring for any pathogen.

2.3.5 Farmers perceived support towards safety and hygiene control practices

In this section, we present an analysis of two dairy chain interventions by examining how beneficiary farmers perceive the assistance received towards on-farm safety and hygiene control practices. Figure 2.3 shows that overall, farmers receiving assistance from the non-commercial intervention perceived stronger support than those receiving assistance from the commercial intervention. Support exceeding expectations (score 3) predominated farmers' perceived support for the non-commercial intervention regarding on-farm practices. For the commercial intervention, no support (score 1) predominated.

Analysis of both interventions revealed differences in implementation approach which may have accounted for the pattern observed in the perception of support. While the non-commercial intervention provided both training and containers for storing and transporting milk, the commercial intervention only provided training on demand. Farmers assisted under the non-commercial intervention could acquire Mazzican milk containers on credit, whereas in the commercial intervention, this was not possible. The risk of losing supported farmers to competing milk buyers may account for the lack of investment in infrastructure and tools by the dairy company-run intervention. Although support was perceived to be stronger for the non-commercial intervention towards on-farm practices, this has not translated into actual practices. We still observed basic and rudimentary control practices from our study, independent of type of support given.

Accordingly, our analysis triggered the consideration whether results of the non-commercial intervention are able to generate a lasting change in farmer practices. Davies (2011) argued that only interventions directly embedded in the core business strategy of a private company are sustainable as they are aligned with the long term business operation of the company. A dairy company which operates a commercial intervention creates a business relationship that guarantees a consistent milk supply for the company and offers farmers a buyer (Cadilhon et al., 2016). On the other hand, the non-commercial intervention is not-for-profit, not linked with the core operation of any dairy company and therefore, does not give farmers a reliable milk buyer.

The long term sustainability of the non-commercial intervention may be at risk due to inconsistent buyers and the demand for individual farmers to self-finance their own trainings. This may affect refresher training and ultimately impact performance of practices. Consequently, for emerging dairy chains we propose an integrative program which incorporates aspects of both the commercial and the non-commercial intervention. In such a program, intervention goals are aligned with the core business operation of a dairy company, like the commercial intervention, while beneficiary farmers are supported with regular trainings and technical tools, like the non-commercial intervention. The long-term commitment of a dairy company can avert the risk of inconsistent buyers and reduce the long term sustainability concerns of existing non-commercial interventions.

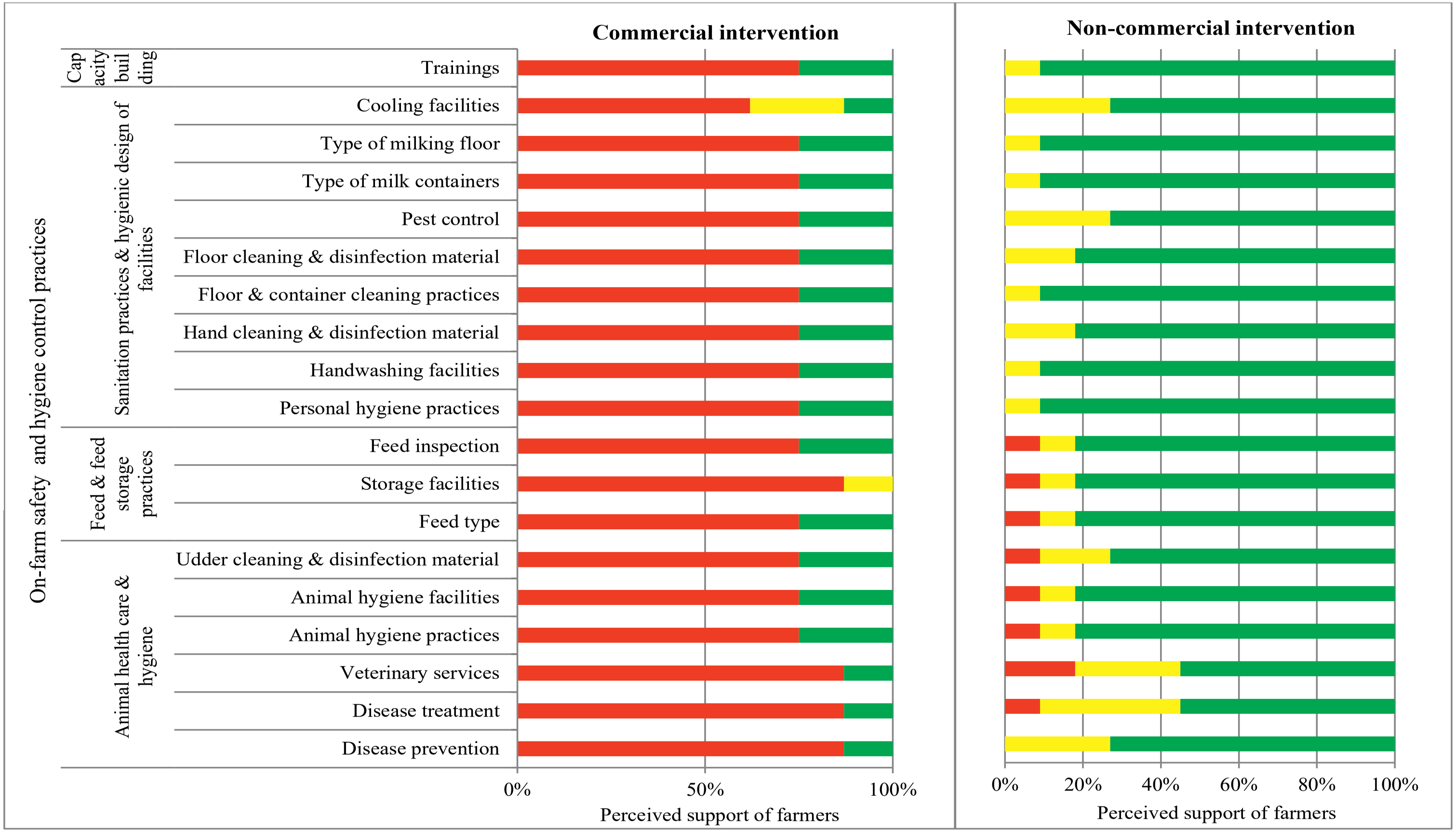


Figure 2.3 Farmers' perceived support of dairy chain support programs toward on-farm safety and hygiene control practices

Interpretation of scores; Score 1 Score 2 Score 3

2.4 Conclusions

This study investigated causes of persisting poor quality and safety, and analyzed farmer's perceived support of identified support programs toward these practices in an emerging dairy chain. Our analysis of the multi-layered nature of the dairy system identified that safety and hygiene control activities are inconsistent across the dairy chain. Furthermore, preventive and monitoring safety and hygiene control practices were predominantly basic and rudimentary at the farm, milk trader, and milk bar levels, increasing milk safety risks for consumers. Marginal improvement in safety and hygiene control practices were observed at milk collection centers and dairy processing. Overall, there is thus a need for significant improvements in practices along the chain. Future research could aim at more precisely establishing the level at which practices are performed, to determine the steps needed to achieve improvement.

The study also revealed that the non-commercial intervention, which combined training and provision of milk storage containers, was perceived by farmers to be more supportive of on-farm safety and hygiene control practices than the commercial intervention that only offered training on demand. However, in spite of the favourably perceived support by the farmers of the non-commercial intervention, both supports did not directly achieve safety and hygiene control improvements. Intervention support could more explicitly enhance awareness and competences on safety and hygiene control practices, to avert public health risks associated with milk consumption, aiming at significantly improving multiple of these practices.

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Chapter 3

A customised assessment tool to differentiate safety and hygiene control practices in emerging dairy chains

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Abstract

In emerging dairy chains, inconsistent product quality and safety are recurring issues. The need for improvement in hygiene and safety control practices to meet rapidly growing demands for dairy products quality and safety is imperative. However, existing assessment tools do not consider specific situations in emerging dairy chains, where practices are often performed below standard requirements, which presents an inaccurate picture when these tools would be used. This study presents the development of a customised tool to assess and differentiate levels of safety and hygiene control practices in emerging dairy chains. The tool consists of indicators to analyse control practices and four corresponding grids to assess and differentiate the levels of the safety and hygiene control practices at the farm, during transportation, milk collection, and at local retail points crucial for microbial and chemical (i.e., aflatoxin) safety. The customised tool was piloted in Tanzania to assess on-farm practices, as an example of an emerging dairy chain, using interviews, farm visits and audio-visual assisted observations. Thirty-eight small and three large-scale farmers were interviewed, and their control practices observed. The responses were scored based on the grids and the scores were used for data analysis to identify patterns among the farmers. The customised assessment tool was able to accurately differentiate safety and hygiene practices of the farmers into three distinct clusters. The majority of the small-scale dairy farms were performing practices at poor to basic level with very few practices at an intermediate level. The large-scale farms were operating mainly at intermediate to standard level but with basic level performance on milk safety monitoring method, udder and teat care, and personal hygiene practices. Incremental changes are required for on-farm practices to adequately mitigate microbial and aflatoxin contamination of fresh milk. The obtained profiles on farm safety and hygiene control practices provide input for the development of training programs tailored to the knowledge and skills needs of groups of farmers with similar performance levels. Further research is needed to provide insight into the relationship between the level of control practices and milk safety outcomes.

3.1 Introduction

Food safety remains a major global public health concern. A recent study estimates that 8% of the world's population suffers from foodborne diseases (FBD) annually (Havelaar et al., 2015). The highest burdens are reported in emerging economies, particularly in Africa, where increased consumption of fresh, perishable foods such as milk, have been implicated (Uyttendaele et al., 2015). Typical of dairy chains in emerging economies, which we describe as emerging dairy chains, is the dominant informal production and distribution systems, characterized by basic handling practices, limited cold chain, and pasteurization restricted to only processing of fresh milk (Grace, 2015; Wanjala et al., 2018). Consequently, there is a high risk of fresh milk contamination and proliferation of foodborne disease pathogens due to its nutritional components, neutral pH and high water activity (Oliver et al., 2005; Touch & Deeth, 2009). In addition, the risk of chemical hazards such as aflatoxins linked with feed handling practices remains a concern (Iqbal et al., 2015). Inevitably, multiple cases of fresh milk contamination with microbial and chemical hazards continue to be reported in emerging dairy chains (Kouamé-Sina et al., 2012; Kamana et al., 2014; Gizachew et al., 2016).

Several studies pointed to inadequacies in the performance of safety and hygiene control practices in emerging dairy chains (Swai & Schoonman, 2011; Dagmar Schoder et al., 2013; Kamana et al., 2017). Other studies showed persisting rudimentary practices related to milk safety monitoring and use of improper equipment (Ledo et al., 2019; Washabaugh et al., 2019), and feed handling practices leading to prevalence of aflatoxin M1 in marketed fresh milk (Gonçalves et al., 2018; Lindahl et al., 2018). These studies demonstrated a lack of progress in safety and hygiene control practices in emerging dairy chains and thereby stressed the need for improvement. However, to tailor improvement strategies for the particular context of emerging dairy chains, a systematic and differentiated assessment of the current practices is necessary (Kussaga et al., 2015). Various tools have been developed to assess food safety management systems (FSMS); particularly tools for animal-based food manufacturing industries (Luning et al., 2008; Luning et al., 2011; Luning et al., 2015) and fresh produce chains (Kirezieva et al., 2013; Macheka et al., 2017). These tools can differentiate the actual performance of FSMS activities based on the assumption of implemented public and private requirements as minimum standard

(Jacxsens et al., 2011; Luning et al., 2011). However, these tools do not consider the specific situations in emerging dairy chains, where practices are often performed below the minimum requirements, which may lead to limited differentiation of the situation when these tools would be used.

The aim of this study was to develop a customised tool to assess and differentiate performance levels of safety and hygiene practices crucial for control of microbial and chemical (i.e., aflatoxin) safety of fresh milk along emerging dairy chains. The development of the tool followed the principles for the development of diagnostic tools as previously described (Luning et al., 2008; Jacxsens et al., 2011; Kirezieva et al., 2013). Finally, we validated the customised tool in a pilot study in the Tanzanian dairy chain, as an example of an emerging dairy chain where persisting challenges in safety and hygiene control is prominent and opportunities exist to upgrade to meet growing consumer demands (Ledo et al., 2019).

3.2 Materials and methods

3.2.1 Design principles of the customised tool

The customised tool aims at enabling detailed analysis and differentiated assessment of crucial safety and hygiene control practices along emerging dairy chains from farm to retail points. The design principles of previous diagnostic tools (Luning et al., 2008; Jacxsens et al., 2010; Luning et al., 2011; Kirezieva et al., 2013; Macheka et al., 2017) were used to guide the development of the customised tool. Fundamentally, these include the identification of crucial safety and hygiene control practices and establishment of practice performance indicators, the development of grids to differentiate the performance levels of practices and the identification of dairy safety performance output indicators.

The first design principle concerns the identification of crucial safety and hygiene control practices along the emerging dairy chain. We conceptualize the dairy chain as a system with different interrelated elements connected in channelling fresh milk from farm to consumers. From a system perspective, different technological (i.e., facilities, equipment and tools) and people-related (i.e., behaviour requirements) factors influence the performance of crucial preventive and monitoring safety and hygiene control activities (Luning & Marcelis, 2006). We define as crucial those control practices for which there is empirical evidence suggesting their use can mitigate the occurrence of safety-related bacterial and chemical hazards in fresh milk along the chain from the farm to the retail point without going through pasteurization.

The second design principle involves the development of grids to assess and differentiate safety and hygiene control practices. The assessment grids represent for each indicator characteristic descriptions of different levels of performance of the control practices. The descriptions of the levels are formulated using criteria and empirical data (Ledo et al., 2019). The last design principle relates to the identification of dairy safety system performance output indicators. This step in the design involves the selection of specific microbial and chemical safety parameters as indicators to give a judgement of the system output. For the customised tool, the system performance output refers to safe and hygienic fresh milk where microbial and chemical indicators assessed are within the acceptable margin of safety requirements (Jacxsens et al., 2010; Kang'ethe & Lang'a, 2009). Assessed indicators exceeding the acceptable margin of safety indicate inadequacies in the performance of crucial safety and hygiene control practices.

Identification of crucial safety and hygiene control practices and its indicators

A structured literature search was conducted to identify preventive and monitoring safety and hygiene practices crucial for control of microbial and chemical contamination of fresh milk at primary production, trading, collection and local retailing stages of the chain. Preventive control practices were selected when their performance mitigate fresh milk contamination while monitoring control activities provide information on the effectiveness of the production processes and fresh milk safety (Luning et al., 2008). Adequate performance of crucial control practices should substantially mitigate poor milk safety output at any stage of the chain. The literature search covered the Scopus database, Web of Science, and Google Scholar using keywords “milk quality”, “milk safety”, “safety control”, “hygiene practices”, “developing countries” and “dairy chain”. A further literature search was conducted to establish specific practices that give adequate information about the actual performance of practices as indicators (Luning et al., 2011). Documents for review were selected based on the criteria, that the document is peer-reviewed, or a scientific report or standards associated with dairy and food hygiene in general, that the document was relevant to dairy chains from emerging economies (Ruiz-Nuñez & Wei, 2015), and that the document or part of the document relates to specific safety and hygiene practices in the dairy chain. The identified crucial control practices were synthesized into a conceptual framework (Figure 3.1) which was the basis of the customised assessment tool development.

Development of grids to assess and differentiate safety and hygiene practices

For each identified practice performance indicator, an assessment grid was developed reflecting four performance levels, i.e., poor, basic, intermediate, and standard. The criteria for differentiation of each performance level included 1) the type of equipment used, 2) the degree of performance of actual practices, and 3) the extent of documentation of procedures and data recording applied. The *poor level* is depicted by improvised equipment not specific to dairy, inadequate handling practices based on wrong understanding, with no documentation and no data reporting. The *basic level* is characterized by basic equipment, irregular or sometimes inappropriate practices with oral instructions or no formal procedure for performing practices, no documentation and ad hoc or irrelevant data collection. The *intermediate level* is typified by simple food-grade equipment, the systematic performance of practices but not always done well with some form of formal description for practices, with basic data collection and reporting not always well preserved. The *standard level* is typified by compliance to common standard requirements for equipment and practices where practices are all performed systematically in a precise and regular manner with well-described procedures for practices, relevant data collection and proper reporting.

Identification of dairy safety system performance output indicators

Assessing the system output involves establishing microbiological and chemical parameters that can give an indication of the performance of the control practices. The selected system output indicators were based on the assumption that a better system performance should be reflected in low and less variable contamination loads (Jacxsens et al., 2009). Multiple microbial parameters can be assessed to give specific indications of the actual performance of implemented mitigation measures. Total bacteria count (TBC) can be selected as an indicator to quantify aerobic mesophile bacteria (Robinson, 2005), which are the most abundant bacteria in fresh milk and provides indication of the overall bacterial contamination. To assess the effectiveness of environmental hygiene control practices, coliforms can be assessed, as they give an indication of faecal and environmental contamination of fresh milk along the dairy chain (Martin et al., 2016; Wanjala et al., 2018). On the other hand, more specific bacteria, e.g. *Staphylococcus aureus*, can be evaluated to provide an indication of how well specific control practices are performed, e.g., appropriate personal and hand hygiene practices (Jacxsens et al., 2009; Viguier et al., 2009). The chemical safety output in the customised assessment tool was targeted at aflatoxin M1 (AFM1) in fresh milk, which may arise when feeds containing mycotoxins are ingested by the cow. Appropriate feed handling practices on the farm mitigate aflatoxins in the feed and subsequent contamination of the milk, which can be verified by measuring AFM1 levels (Kang'ethe & Lang'a, 2009).

3.2.2 Design of the pilot study

A pilot study was conducted to test the usefulness and robustness of the tool to differentiate on-farm safety and hygiene practices in the emerging Tanzanian dairy chain. Two categories of dairy farms were targeted; smallholder farms with a minimum of one milking cow and large-scale farms with more than 20 milking cows. Overall, farmers of 38 small-scale and three large-scale farms from Mvomero and Lushoto Districts of Tanzania, were contacted and signed up for the study (Table 3.1).

Face-to-face interviews and on-site observation

An open-ended questionnaire was developed to systematically collect data on safety and hygiene control practices on the farm. The questionnaire was structured into two sections. The first section covered background information of the respondent and the characteristics of the farm. The second section covered questions which are connected to the indicators on crucial safety and hygiene control practices related to animal health management, hygienic milking, milk cooling and storage, feed and feed storage, environmental hygiene and milk safety monitoring. In addition, a structured on-site and audio-visual assisted observation was conducted using a checklist to verify the availability of equipment, farm facilities and tools associated with the indicators identified for on-farm practices. On average, the interviews and on-site observations took an hour and a half.

Table 3.1 Characteristics of respondents and farms of the pilot study

Characteristics of farmers	Small-scale farmers (n=38) N (%)	Large-scale farmers(n=3) N (%)
Gender		
Male	25 (66)	2 (67)
Female	13 (34)	1 (33)
Age		
< 20 years.		
21-30 years.	6 (16)	1 (33)
31-40 years.	4 (10)	1 (33)
41-50 years.	9 (24)	
> 50 years.	19 (50)	1 (33)
Education level		
No school attendance	5 (13)	
Primary school level	26 (68)	
Secondary school level	6 (16)	
Higher education level	1(3)	3 (100)
Ability to read and write		
Yes	34 (89)	3 (100)
No	4 (11)	
Years in dairy farming		
< 5 years	5 (13)	3 (100)
5 – 10 years	9 (24)	
>10 years	24 (63)	
Number of milking cows		
< 3 cows	16 (42)	
3 – 6 cows	15 (40)	
7 -10 cows	7 (18)	
>10 cows		3 (100)
System of dairy farming		
Intensive (Zero grazing)	22 (58)	
Semi-intensive	5 (13)	3 (100)
Extensive (Free grazing)	11 (29)	

Data processing and analysis

Individual responses of farmers on implemented safety and hygiene control practices were judged using the scores 1, 2, 3 and 4, corresponding to grid descriptions for the poor, basic, intermediate and standard levels, respectively. A higher score thus reflects situations where practices are performed at a more advanced level. To ensure the scores are valid and consistent, two researchers independently allocated scores for each farmer's response on the indicators and then compared the scores to arrive at a consistently assigned score for the indicators. All scores were entered in Excel and IBM SPSS statistics version 25 for windows was used to analyse descriptive statistics of the dataset. Hierarchical and K-means cluster analyses were performed with the ward linkage method, using R 3.5.0 version. After obtaining the clusters, the mode values for each practice indicator were calculated for each cluster and used to construct the spiderwebs. The Cronbach's Alpha for the 11 safety and hygiene control practices was found to be 0.883, which suggest a relatively high internal consistency between the indicators. Further, principal component analysis (PCA) was performed to investigate the practices which were responsible for the variation between the farmers and for the differences between the clusters, for details see supplementary materials. PCA was used to confirm differentiation of the farmers on the basis of practice performance observed in the cluster analysis (Figure S1).

3.3 Results and discussion

3.3.1 Customised assessment tool

Conceptual framework of identified crucial safety and hygiene control practices

Figure 3.1 shows the conceptual framework, which synthesizes the identified crucial safety and hygiene control practices (Tables 3.2-3.4), and their relationship to safe and hygienic fresh milk along the dairy chain. Safe and hygienic milk production involves the implementation of multiple practices to mitigate microbial and chemical (i.e., aflatoxin) contamination of milk along the dairy chain to safeguard consumer health. Most of these practices occur at the farm, whereas a limited number is applied further in the dairy chain. Practices such as animal health management, hygienic udder and teat care, and feed and feed storage practices are exclusive to on-farm operations and constitute crucial avenues for microbial and aflatoxin contamination of milk if not properly applied (Oliver et al., 2005; Vissers & Driehuis, 2009) (Table 3.2). On the other hand, personal hygiene, hygienic handling, cooling and storage, environmental and equipment hygiene, and milk safety monitoring practices are consistent along the dairy chain and inadequate practices form additional avenues for fresh milk contamination and bacteria proliferation. Yet, on-farm control practices during and after milking form the crucial starting point for the initial milk safety along the dairy chain, as fresh milk from the alveoli of the udder is almost uncontaminated (Vissers & Driehuis, 2009).

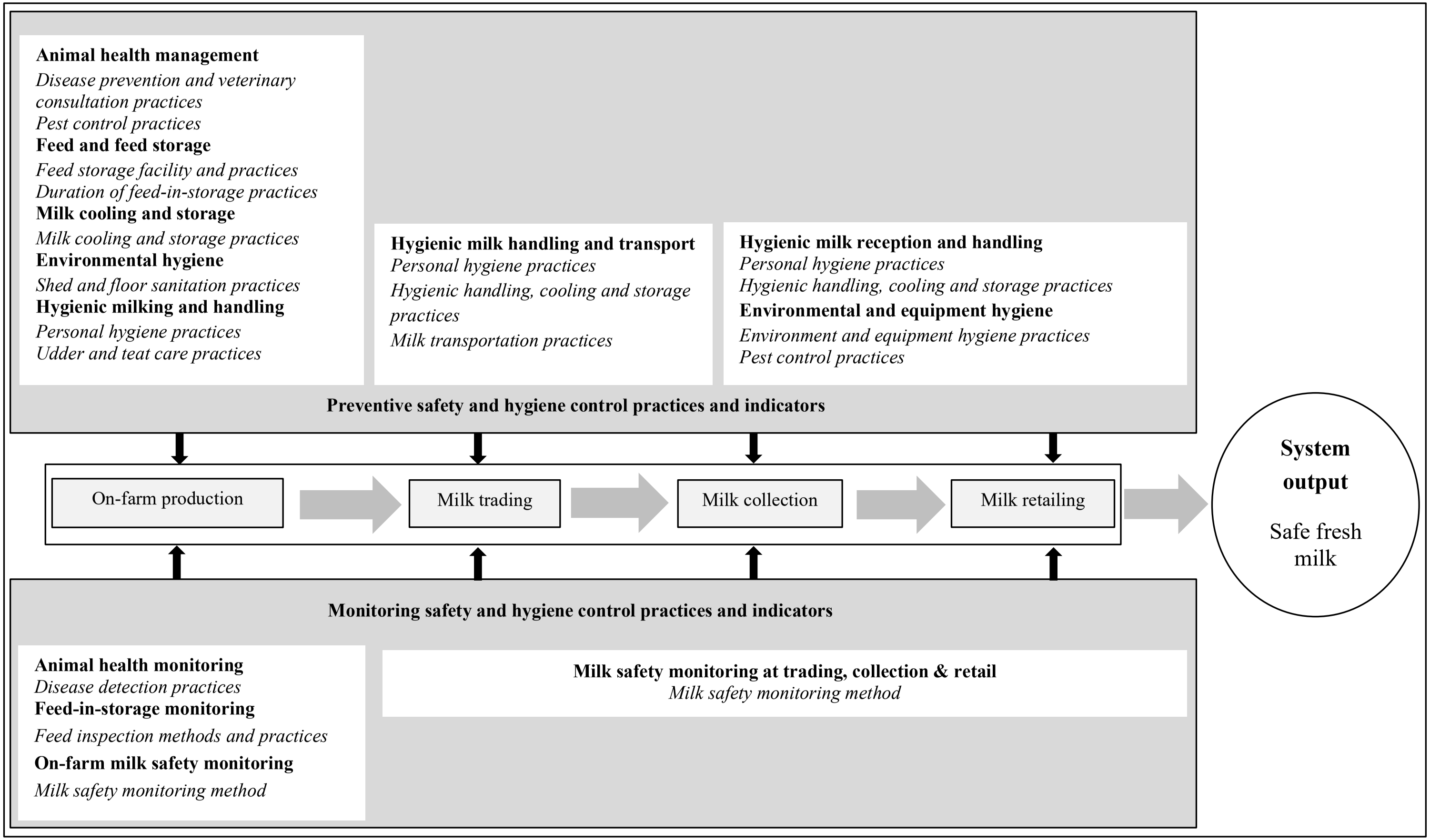

Figure 3.1 Conceptual framework showing the synthesis of crucial practices contributing to safe and hygienic fresh milk along the dairy chain

However, once contamination of the milk occurs on the farm, inadequate cooling can lead to spoilage effects such as rancid odour or the rapid production of toxins, which cannot be eliminated by pasteurization further in the chain (Tamime, 2009). In emerging dairy chains, the milk trading stage provides a bridge between the farm and collection centers, and direct consumers (Kamana et al., 2017; Ledo et al., 2019), where inadequate safety and hygiene control practices can lead to microbiological recontamination and rapid growth except for presence of aflatoxin, which is attributed to on-farm practices (Prandini et al., 2009). Appropriate safety and hygiene control practices are required, as there is no inactivation step implemented to limit bacterial contamination and growth from on-farm or trading operations. Consequently, appropriate hand hygiene, adequate storage equipment during transportation, proper cooling and milk safety monitoring practices are crucial to maintaining fresh milk safety along the chain (Table 3.3).

Milk collection centres are intermediate facilities for bulking fresh milk from dairy farmers and traders for onward distribution to processors and consumers. These centers are equipped with milk monitoring tools to rapidly verify milk quality and safety, and with the cooling tanks to slow down bacteria growth. For example, O'Connell et al. (2016) found that total bacteria count (TBC) of bulk raw milk increased significantly at 6ºC compared to 2ºC and 4ºC under natural conditions within the same time duration. In addition, Malacarne et al. (2013) found that under control laboratory conditions of temperature and storage duration, TBC increased significantly at higher temperatures of 8-10ºC after 24 hours of storage. Both studies demonstrated the importance of marginal differences in cooling temperature and storage duration on the proliferation of bacteria. Hygienic milk reception and handling, environmental and equipment hygiene, and milk safety monitoring activities are crucial for milk safety at milk collection centers to mitigate further contamination and bacterial growth (Table 3.4). At local retailing points, handling and storage activities are performed to preserve fresh milk safety. Most practices at local retail points are like those at milk collection centres in emerging dairy chains although the extent of technology and type of equipment used vary. For instance, cooling tanks with fitted thermometers and refrigeration system are used for milk cooling at milk collection centers, whereas less advanced means or limited cooling of the milk is performed at local retail points (Ledo et al., 2019).

Table 3.2 Identified crucial safety and hygiene control practices on the farm

Indicators	Assumed relation with milk safety	Required practices	Empirical evidence from the literature
		Animal health management preventive and monitoring practices	
Pest control practices	Pest control that is specific and inclusive of all possible pests for the geographical location eliminates disease-causing pests which will positively contribute to milk safety.	• The farm environment is kept clean to prevent pest breeding. • An integrated pest control system considering different on-farm pests to prevent their breeding and transfer of diseases. • Pest control systems are regularly monitored for effectiveness to prevent pests on the farm.	• Spraying with insecticides/pesticides is common among dairy farmers for pest control (Rutz et al., 2000; Oliveira et al., 2011; De Meneghi et al., 2016; Vudriko et al., 2018). • A study in Zambia revealed that using acaricides in dip tanks at repeated 1-week intervals was able to reduce tick causing theileriosis and reduce cow mortality (De Meneghi et al., 2016).
Disease prevention and veterinary consultation practices	Adoption of appropriate farming systems, structured vaccination and regular consultation with veterinary officers will prevent diseases occurrence which will positively contribute to milk safety.	• Vaccinates animals according to regional and national requirements to increase immunity against specific pathogens. • Animals are kept under a well-monitored farming system to prevent communicable and parasitic infections • New animals are thoroughly checked for signs of disease and continuously checked for clinical and subclinical disease signs.	• An evaluation study in Tanzania revealed that an Infection and Treatment Immunization program against East Coast Fever was able to protect cows up to 98% against the disease (Di Giulio et al., 2009). • A major shift in dairy health has been a focus on disease prevention and inclusion of subclinical conditions i.e. subclinical mastitis, ketosis and rumen acidosis as part of the disease (LeBlanc et al., 2006).
Disease detection practices	Daily observation of animals for specific diseases to identify early signs of sickness, carefully isolating and marking treated sick animals will prevent the spread of diseases resulting in reduced pathogenic contamination of milk	• A regular check of cows for clinical and subclinical signs of mastitis using strip cup or California Mastitis Tests (CMT). • Sick animals are isolated from the herd and treated promptly with the right method, and records kept on disease detection and treatment. Proper separation of milk from sick and treated cows under treatment.	• Abebe et al. (2016) screened 529 lactating cows in Hawassa, Ethiopia for subclinical mastitis. By using CMT and clinical examination, 75% and 63% prevalence of mastitis was detected at the herd and cow level respectively. • Cows with contagious mastitis bacteria can readily be transmitted to the teats of a non-infected cow through hand milking or teat cleaning cloths. Isolation of the infected cow prevents the spread to healthy cows (De Vliegher et al., 2018).
		Milk cooling and storage preventive practices	
Milk cooling and storage practices	More reliable cooling facilities that lower and maintain the temperature of milk after milking coupled with hygienically designed milk storage containers will limit the rapid growth of microorganisms and decrease the chance of (cross-) contamination leading to safe milk	• Stainless steel/aluminium cooling tanks and storage cans or food-grade plastic containers with wide-open heads for easy cleaning. • Cleaning of storage containers by separate physical (turbulent flushing, heat or scrubbing) and chemical (detergents, acids or alkaline) or combined methods. • Rapid cooling and storage to 4-6°C will prevent microbial growth within 24hrs. Quick delivery to customers is most preferred.	• A study by Kivaria et al. (2006) found that frequency of cleaning, type of milk containers, and milk storage time was significantly associated with the mean total bacteria count of fresh milk. • The effect of storage temperature on microbial quality was assessed at 2, 4 and 6^{O}C after a 96 hr storage period. Total bacteria count increased during storage at 6^{o}C but no increase was noticed at 2 ^{o}C or 4^{o}C (O'Connell et al., 2016).

Table 3.2 (continued)

Indicators	Assumed relation with milk safety	Required practices	Empirical evidence from the literature
		Feed and feed storage preventive and monitoring practices	
Feed storage facility and practices	Feed storage facilities with the capability to maintain temperature and/or atmosphere conditions will prevent the growth of bacteria and fungus which will contribute to fresh milk within an acceptable level of aflatoxin M1.	• Clean, dry, well ventilated and roofed/ceiled storage facility controls temperature and moisture to prevent bacteria and fungus growth in stored feed. • Feeds stored in bags are clean, well labelled and stacked on pallets to prevent contact with floor and pests.	• A study of 300 farmers in Benin revealed that storing feed under or on top of the roof of the house was directly linked with higher aflatoxin development in the feed (Hell et al, 2000). • Kang'ethe and Lang'a (2009) found that many dairy farmers in Kenya stored feed under poor conditions. Feed samples under humid, in a dry place or on the floor were all positive for aflatoxin B1.
Duration of feed-in-storage practices	Appropriate feed storage duration in the tropical region (short duration) with the practice of first-in-first-out prevents growth and multiplication of microorganisms positively contributing to milk safety.	• Clear demarcation of feeds separating new feed from old feed (first-in, first-out) • Short term storage (3 to 6 months) of well-dried feed prevents mould growth. Prolonged storage practices without temperature and humidity control increases mould growth • Record keeping on feed first-in and first-out.	• The influence of three storage time was studied (i.e., 2-6 months, >6 months and 1 year) and reveal that the aflatoxin level increased with increasing storage period (Kaaya & Kyamuhangire, 2006). • Ledo et al. (2019) found that feed storage practices of dairy farmers in Tanzania did not align with acceptable standards increasing the risk for contamination.
Feed-in-storage inspection method and practices	Repeated and specific inspection of feed for moulds helps to manually sort and discard contaminated feeds will contribute to the reduction in aflatoxin levels.	• A weekly inspection of the feed for mould growth, temperature changes, identification of wet spots of feed for further drying, insect and rodent activity • Sorting and discarding of mouldy feeds from the lot prevent contamination of the whole feedlot.	• A review by Kabak et al. (2006) found that proper periodic monitoring for moisture content of feed during storage is crucial to restrict mycotoxin contamination. • Analysis of poor and good quality sorted maize grains showed that good quality grain had lower mycotoxin levels than poor-quality grain (Afolabi et al. 2006)
		Environmental hygiene preventive practices	
Shed and floor sanitation practices	Shed made of easy to clean floor (e.g. concrete) and well-fitted drains reduce chances of dirt on cows which reduces opportunities for growth and transmission of pathogenic bacteria resulting in positive milk safety outcomes	• Shed and milking floors are designed with materials for easy cleaning (e.g. concrete). • A high standard of shed and milking floor sanitation involving dry and wet cleaning to remove the accumulation of manure, mud and feed debris and decreases soiling of cows and udder. • Regularly maintained and replaced dry bedding materials. Well-constructed and maintained drainage to facilitate easy disposal of liquid waste.	• Elmoslemany et al. (2010) found that both the total aerobic counts and the preliminary incubation counts correlate positively with the amount of cow soiling before udder preparation. • Moist bedding materials were positively associated with high total bacteria count in milk when bedding features and risk of mastitis was studied. Dry, loose bedding materials will result in cleaner animals and reduced mastitis risk (Fávero et al., 2015).

Table 3.2 (continued)

Indicators	Assumed relation with milk safety	Required practices	Empirical evidence from the literature
		On-farm milk safety monitoring practices	
Milk safety monitoring method	More accurate methods and responsive standards to monitor fresh milk produced will result in adequate monitoring which will contribute to fresh milk safety	• Performs standard tests which give an indication of bacteria present in fresh milk for appropriate corrective action before delivery to the customer. • Keeps records on fresh milk safety for verification.	• Grimaud et al. (2007) assessed the quality of fresh milk in Uganda using preliminary (clots on boiling, alcohol tests, temperature and density) and specific tests (Total bacteria count, Coliforms and *E.coli*). They found that the coliform count was attributed to faecal coliforms including *E.coli.* • Burke et al. (2018) recommend the measuring of somatic cell count (SCC) as an early detection test for mastitis. They also recommend Resazurin test as a control for microbial contamination levels in raw milk. Other specific tests are also recommended for specific bacteria such as *S. aureus, E.coli.*
		Hygienic milking and handling practices	
Personal hygiene practices	Dedicated handwashing facilities coupled with accurate adherence to handwashing practices will ensure hand hygiene during milking which reduces (cross) contamination and positively contribute to microbial safety of milk.	• Handwashing of milker or milk handlers is performed from the dedicated facility before and after milking and during moments of the high risk of microbial contamination (i.e. after using the toilet, handling raw food or contaminated materials). • Hand washing steps followed with emphasis on washing hands with clean water and detergent, rubbing hands together for 10-15 seconds, rubbing between fingers and under nails, rinsing and drying with a cloth or paper towel, and with a disinfectant. • Milker or milk handlers maintain a high degree of personal cleanliness by wearing clean protective clothing and boots and seeks immediate medical care when communicable signs of illness emerge.	• Abdalla and Elhagaz (2011) studied the impact of three hygienic treatments on total bacterial load. Treatment 1: no hygienic practice, treatment 2: milker cleans udder, teats and hands with a clean wet towel and treatment 3: milker washed hands with soap and water, wore coats, covered hair and cleaned udder and teat with a wet towel. The results show a significant reduction in bacterial load with treatment 2 and 3. • A study on the relationship between somatic cell count (SCC) and milking personnel in 68 dairy herds revealed that 28% of the variation in SCC among herds was explained by milking personnel well-being (Esguerra et al., 2018).
Udder and teat care practices	Appropriate udder/teat care which involves udder being clipped and checked for mastitis kept clean and properly disinfected will reduce chances of bacterial contamination of milk contributing to milk safety.	• Hygienic milking begins with clean cows. A clean cow means clean teats, udder, abdomens of the animal, flanks, and groins. • Pre-milking udder and teat care practices involving fore-stripping, pre-dip, and the use of dedicated moist washable towels or single-use paper towels are crucial for udder and teat health. • Post-dipping teats with appropriate disinfectant. Both pre-and post-dip are essential mastitis control measures.	• Elmoslemany et al. (2010) studied the association between several factors with microbial quality of fresh milk on the dairy farm. They found that various pre-milking udder preparations are important and pre-dip coupled with drying was significant in reducing bacteria counts than others. • Both pre- and post-milking udder and teat preparation contribute significantly to reducing mastitis-causing bacteria in dairy cows (Oliveira et al., 2011; Baumberger et al., 2016).

Table 3.3 Identified crucial safety and hygiene control practices during milk trading

Indicators	Assumed relation with milk safety	Required practices	Empirical evidence from the literature
		Hygienic milk handling practices	
Personal hygiene practices	Appropriate personal hygiene practices which ensure clean hand hygiene and proper clothing during milk reception and transportation will help to prevent contamination of the milk thereby contributing to milk safety.	• Compliance with hand hygiene requirements before and after handling milk prevents further contamination. • Milk trader/transporter maintains overall personal cleanness by wearing clean protective clothing and short nails during milk handling. • Milk trader/transporter is not suffering from a communicable disease or has no open sores on the arms, hands, head or neck.	• Hand washing after activities that soil hands and before handling food products is crucial for preventing microbial contamination. Non-compliance to hand hygiene results in faecal contamination of fingers and hands (Todd et al., 2010; Girma et al., 2014) • There were no available formal procedures for personal hygiene practices by milk traders. Procedures were mainly verbal (Ledo et al., 2019).
Hygienic milk handling, cooling and storage practices	More accurate milk handling, precooling and storage practices at reception which ensures appropriate hygiene, and control of temperature will reduce bacteria multiplication which will contribute to milk safety.	• Hygienic handling involving the use of easy to clean, well-insulated containers and fitted covers during transportation. • Precooling practices ensure that fresh milk is kept cooled by avoiding exposure to high temperatures using insulated containers or kept on ice. Storage containers are well preserved and prevented from being used to store other goods.	• The study by Ledo et al. (2019) revealed that the majority of milk traders in emerging dairy chains use non-Mazzican containers while a few use stainless steel containers. Also, the cooling of milk by traders was often absent. • Milk is often contaminated after milking but poor handling practices during milk channelling worsens the quality before it gets to consumers (Millogo et al., 2010).
Milk transportation practices	Appropriate milk collection and transportation, which limits environmental contamination and allows a short lag time of transportation, will reduce bacterial growth resulting in safe milk.	• Well cleaned transport vehicle for delivering fresh milk to customers. • Rapid transportation of milk to the next point of sale at least within 3 hours. • Milk under transportation is insulated from exposure to direct sunlight and dust.	• Kurwijila (2006) proposed that milk transporters in emerging dairy chains are a major link and must ensure a high standard of hygiene, speedy delivery and proper handling as their actions minimize the proliferation of bacteria, spoilage and milk safety risk. • Schoder et al. (2013) conducted a study in Tanzania to investigate milk quality and safety at various steps throughout the milk production chain and found that all milk traders used bicycles when collecting milk and milk was not cooled when transported.
		Milk safety monitoring practices	
Milk safety monitoring method	Accurate and reliable methods for assessing milk safety will help milk traders to evaluate milk safety	• Carry out standard organoleptic, temperature, density and alcohol tests and test for milk safety on receiving milk. • Milk trader is aware of milk safety demands and uses proper tools for quality and safety checks	• Platform checks are important measures for verifying the milk quality and safety (Kurwijila, 2006; Burke et al., 2018) • A study across the dairy chain in Tanzania showed that the majority of milk traders rely on rudimentary means for checking milk quality and safety (Ledo et al., 2019).

Table 3.4 Identified safety and hygiene control practices at milk collection and retailing

Indicators	Assumed relation with milk safety	Required practices	Empirical evidence from the literature
		Hygienic milk receiving and handling preventive practices	
Personal hygiene practices	Appropriate personal hygiene practices which ensure clean hand hygiene and proper clothing during milk reception and handling will prevent contamination contributing to milk safety.	• Compliance to hand hygiene, protective clothing and personal health requirements. • Dedicated facility for hand washing and drying hands before and after handling milk • Available guide/picture reminders for hand washing steps.	• Todd et al. (2010) recommend that regular laundering of garments or overalls is necessary to prevent clothing from becoming an easy avenue to contaminate food. • Hand washing facility at milk collection centers (MCC) are mainly buckets of soap water supported with a container for fetching water. Very few MCC's have installed sinks. At retail shops, locally manufactured facilities are used (Ledo et al., 2019).
Milk cooling & storage practices	More adequate cooling facility and storage containers which better maintains strict temperature conditions to preserve fresh milk for onward transportation to processing facilities will positively contribute to milk safety.	• Hygienically designed cooling tanks with a fitted calibrated thermometer or external hand thermometers for monitoring temperature variation. • Records on the temperature of the cooling tank at reception, during storage and before transportation to processing plants.	• A study by Nato et al. (2018) to assess predisposing factors on microbial loads in milk, found that along with the value chain microbial counts increased as milk was held at 28 to 33°C before cooling. • Vilar et al. (2012) identified milk cooling capacity and functioning as a critical controlling point in the implementation of HACCP along the dairy chain.
		Environment and equipment hygiene preventive practices	
Environment and equipment hygiene practices	Full scale environmental and equipment hygiene practices with appropriate floor type, cleaning agents and dedicated cleaning equipment better prevents contamination, positively contributing to milk safety.	• A well-ventilated facility with smooth-rendered concrete and drains for easy cleaning. • Well-designed stainless steel or aluminium cooling tank & equipment for easy cleaning and disinfection. • Cleaning tools are well labelled for floor and equipment cleaning. Consistent floor sanitation using appropriate detergents.	• Kamana et al. (2017) and Ledo et al. (2019) found that milk collection centers and retail facilities in Rwanda and Tanzania have concrete floors for easy cleaning. • Kamana et al. (2017) found that all eight collection centers had appropriate cooling tanks and the premises was designed to reduce chances of microbial contamination and growth. • Ledo et al. (2019) revealed that most local retail bars use thermos flask in Tanzania, which is not appropriate for milk storage as cleaning becomes difficult with the small open necks.
Pest control practices	Pest control that is specific and inclusive of all possible pests for the geographical location eliminates disease-causing pests which will positively contribute to milk safety.	• Well established and regularly monitored pest control system to prevent flies and rodents. • Windows and doors are fitted adequately to kept pest away.	• Frye and Kilara (2016) recommend dairy handling facility should have solid doors and windows to limit access for insects and rodents • Ledo et al. (2019) found that the majority of MCC's and retail bars rely on insect spraying and maintaining a clean environment as a pest control measure
		Milk safety monitoring practices	
Milk safety monitoring method	Accurate and reliable methods for assessing milk safety during milk reception at MCC or retail point will help to evaluate safety parameters.	• Accurate and reliable platform tests for milk safety such Resazurin test to receive or reject fresh milk. • Proper record-keeping on fresh milk safety for guiding corrective action.	• MCC's apply Resazurin test to check the microbial quality of milk at reception but lack regular checks for specific pathogen bacteria. At the retail bars, no checks for bacteria are carried out. There is a reliance on organoleptic checks (Burke et al., 2018; Ledo et al., 2019).

Grids for differentiation of safety and hygiene control practices

Figure 3.2 presents examples of the crucial indicators and grids differentiating preventive and monitoring practices on the farm, during trading, milk collection and retail; the complete set of grids can be found in the supplementary information (Table S1-S4). The basic assumption underpinning the differentiation grids is that safety and hygiene control practices performed at higher levels will reduce variability and thereby ensure consistent performance to achieve the desired system output at each stage of the chain. The description of the standard level is in line with the internationally established dairy production requirements (FAO & IDF, 2011); when adequately performed they will mitigate contamination avenues and safeguard the consumer from food safety risks. A typical example of the standard level related to the on-farm udder and teat care practice involves complete adherence to pre-milking measures such as fore-stripping, drying with a single-use towel or dedicated clean towels with regular clipping of udder hair followed by consistent post-dipping as a post milking measure, with well documented and retrievable protocols.

The intermediate level depicts situations where the type of equipment, the actual performance of practices, and the extent of documentation of protocols are not entirely meeting these minimum requirements, creating some avenues for fresh milk contamination. For instance, incomplete adherence to pre- and post-milking udder and teat care preparations such that there is fore stripping to check for mastitis, cleaning with a dedicated towel but no post-dipping or hair clipping when needed. The complete lack of post-dipping will expose the mammary glands to mastitis-causing pathogens through the teat canal (Klostermann et al., 2010) which increases chances of mastitis infection and microbial contamination of fresh milk. The negative impact of incomplete pre- and post-milking udder and teat care to cow health, have been demonstrated by several studies (Elmoslemany et al., 2010; Baumberger et al., 2016) and therefore a key requirement for hygienic milking. The basic level reflects situations where several opportunities for milk contamination exist due to prominent use of basic equipment, inconsistent and over-reliance on own understanding of practices with no structured documentation of procedures and data recording.

	Poor	Basic	Intermediate	Standard
On-farm Udder and teat care practices	• Completely lacking hygienic milking practices. Major hygiene milking steps are absent. • No adherence to pre- and post-milking routines. Allows calf to suck on teats without any cleaning. • No written protocols on udder/teat care. Wrong experiences are maintained.	• Ad hoc hygienic milking practices. Multiple hygienic practices are inappropriately done. • Inconsistent adherence to pre- and post-milking routines (inconsistent pre-teat dipping and no post-teat dipping). • Protocol on udder/teat care practices are verbal, rely on recollection from memory and not documented.	• Incomplete hygienic milking practices. Focuses on only udder and teats. Restricted cleanness of cows and udder clipping. • Incomplete adherence to pre- (fore-stripping, teat cleaning and pre-teat dipping) and post-milking (no post-teat dipping) routines at all times. • Documented protocols on loose material not easily retrievable.	• Comprehensive hygienic milking practices involving clean udder and teats, regular clipping of udder hair and overall cow cleanness. • Complete adherence to pre- (fore-stripping, pre-dipping, drying with dedicated towels) and post-milking routines (post-dipping) at all times. • Well documented and retrievable protocols for udder/teat care practices.
Milk trading Milk transportation practices	• Mode of transport has no capability to condition temperature. • No specific time limit for milk delivery. Milk is delivered in any type of container and not in cleaned transport vehicles.	• Mode of transport vechicle (e.g., motocycles) used has no capabilities to condition temperature, milk is stored in non-milk food grade containers and never protected. • Never regular milk delivery within time and mode of transport not always clean.	• Dedicated mode of transport for fresh milk (e.g., open trucks) with limited capability to condition temperature. • Delivers milk within agreed time in milk food grade containers protected from sun and dust (tarpaulins) in clean transport vehicle.	• Dedicated mode of transport for fresh milk with capabilities to condition temperature. • Milk delivery within shortest time in well insulated containers and in clean transport vehicle with protection from sun and dust.
Milk collection Hygienic handling, cooling and storage practices	• Improvised cooling facilty not hygienically designed and has no thermometers for checking milk temperature. • Initial milk temperature is checked with bare hands, and no conditioning and monitoring of temperature until transported. • No described work protocols for cooling and cleaning activities. No data is kept.	• Cooling facility not hygiencially designed and no functional fitted thermometer. • Initial temperature of milk is checked with uncalibrated hand thermometers. No proper conditioning and monitoring until transported. • No documented work protocols for cooling and cleaning activities. Verbal instructions are common for performing practices. Data recording is limited only when demanded.	• Hygienically designed cooling tank for easy cleaning with fitted thermometers not regularly calibrated. • Initial temperature of milk is checked with uncalibrated thermometers, conditioned to acceptable temperature within 1hr but not always monitored until transported. • Work protocols for cooling and cleaning incompletely described & not well preserved. Data on temperature variation & milk quality not regularly kept.	• Hygienically designed cooling facility for easy cleaning with well fitted calibarated thermometers to maintain milk at acceptable temperature. • Initial temperature of milk is checked, conditioned to acceptable temperature in less than 1hr, maintained and monitored until transported with calibrated thermometers. • Work protocols for cooling and cleaning are comprehensively described & well preserved. Data on temperature variation and milk quality is kept.
Milk retailing Milk safety monitoring method	• No standard tests to check for milk quality or safety. Relies on own instincts. • No written protocol or data recording for milk quality and safety.	• Non-standardized tests (very rudimentary) are performed to check fresh milk quality and no test for milk safety. • No written protocols for checking milk quality and safety. Relies on verbal instruction.	• Standardized tests performed regularly and immediately to check fresh milk quality but not for milk safety. • Written protocols for conducting quality checks. Data on quality not always kept	• Standardized tests performed regularly and immediately to check fresh milk quality (i.e., organoleptic, alcohol and lactometer) and safety (i.e., Resazurin). • Documented and preserved protocols for conducting quality and safety tests. Data on quality/safety kept.

Figure 3.2 Examples of grids for differentiating indicators of safety and hygiene control practices at the farm, during trading, collection and retail

In the case of udder and teat care practices, it implies ad hoc hygienic milking where multiple hygienic practices are done wrongly such as using only bare hands to clean udder and teats with no post-teat dipping. In contrast, the poor level situation is characterized by countless avenues for fresh milk contamination because of complete neglect in applying dairy production requirements for equipment, practices and documentation. A typical example of poor practice is the absence of fore stripping to check for mastitis coupled with allowing the calf to suck on the teats before and after milking without any further cleaning with a dedicated or single-use towel, increasing risk of mastitis and microbial contamination of the milk. Ledo et al. (2019) recently provided evidence of the persisting rudimentary execution of practices, particularly on the farm, on multiple practices with only small differences among the farmers, which is a risk for fresh milk safety. This highlights the vital need to include grid descriptions which can distinguish differences among farmers, even at lower performance levels.

3.3.2 Pilot study in Tanzania

Cluster analysis of safety and hygiene control practices of dairy farmers

Figure 3.3 shows the hierarchical cluster analysis conducted to classify the in total 41 (small and large-scale) farms based on their control practice performance levels using the scores assigned based on the interviews and observations. Three major clusters were identified using ward linkage. Cluster I consist of one large and 22 small-scale farms, and clusters II and III consist respectively of small-scale farms (16), and large-scale farms (2). The clusters show a clear distinction among farmers in the performance of safety and hygiene control practices. However, there was no clear pattern observed in differentiating the clusters according to practice performance of the farmers and the type of farming system.

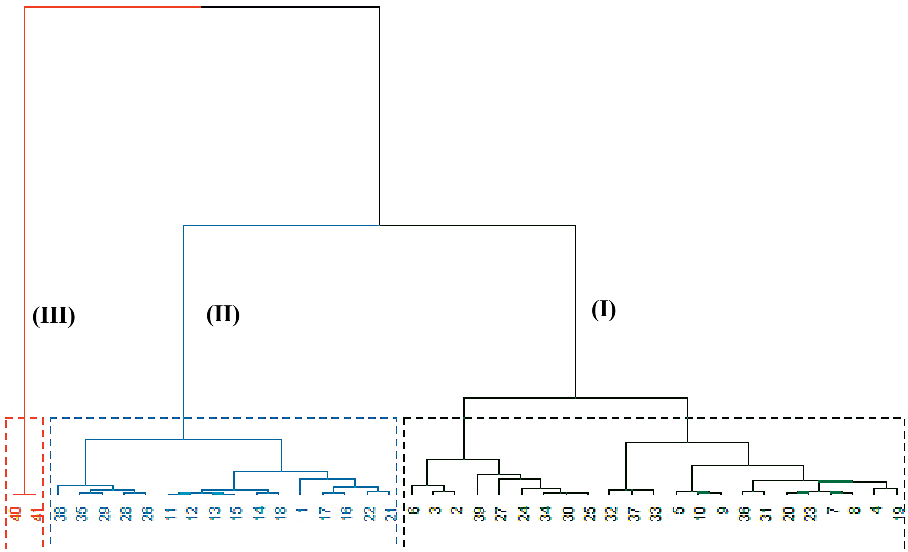

Figure 3.3 Dendrogram showing clustering of small and large-scale dairy farms on safety and hygiene control practices

Differentiation of on-farm safety and hygiene control practices

Figure 3.4 shows the spiderweb of mode scores obtained for the practices in each cluster of dairy farmers (Table 3.5). The spiderwebs indicate that the farmers of the large-scale farms (Cluster III) performed several practices such as disease detection, pest control, shed and floor sanitation, and feed storage facility and practices at the intermediate level (score 3) while disease prevention and veterinary consultation, feed inspection method, duration of feed-in-storage and, milk cooling and storage practices were performed at the standard level (score 4). However, crucial practices such as udder and teat care, personal hygiene and milk safety monitoring were performed at the basic level (score 2). The score of 4 for disease prevention and veterinary consultation indicate that for these farmers of the large-scale farms, there is a comprehensive identification system for the cows coupled with detailed screening by a veterinary officer for subclinical signs of diseases. The limited use of the California Mastitis Test (CMT), incomplete implementation of isolation and milking of diseased cows last, resulted in score 3 for disease detection practices. The same level of effort in disease prevention and veterinary consultation does not seem to be invested in monitoring disease presence although evidence exists that early disease detection restricts the spread of contagious mastitis bacteria and prevalence of the disease (Abebe et al., 2016; De Vliegher et al., 2018). Furthermore, a score 3 on the feed storage facility and practices indicate that temperature and humidity are not completely controlled allowing opportunities for mould growth. However, the shortfall in the feed storage facility and practices seem to be compensated for by a score 4 for feed inspection method and duration of feed-in-storage practices. This implies that a structured method exists to observe and physically check stored feed multiple times a week for signs of mould infestation. Moreover, because the feeds are stored shortly, properly labelled and demarcated according to old feed and fresh feed, it is much easier to identify and discard mould-infested feed. However, the element of variation in physical inspection and the effectiveness to accurately discard mouldy feed still creates avenues for aflatoxin contamination.

The large-scale farms had hygienically designed cooling tanks with refrigeration capacity to lower milk temperature down to 4°C within one hour accompanied by well-described protocols for cleaning the tank contributed to score 4 for milk cooling and storage practices. This is consistent with the findings of Kamana et al. (2017) who showed that modern farms in Rwanda were better resourced with cooling infrastructure than other types of farms. The fact that these farmers supply most of their milk to well-established dairy processors that demand, and check for, quality and safety, and collect the milk after 24hrs, may account for the implementation of well-established cooling facilities. However, the observed basic performance level (score 2) related to the udder and teat care, personal hygiene and milk safety monitoring method, indicate that ad hoc hygienic milking practices, irregular adherence to hand washing and personal health care and rudimentary checks for milk quality and safety are still prevalent among the large-scale farms. These inconsistent patterns in the adherence to crucial practices by the large-scale farmers create a loophole for microbial and aflatoxin contamination to occur.

The majority of the farmers in cluster I were performing multiple safety and hygiene control practices at the basic level (score 2), while only disease detection, feed inspection method and practices were performed at the intermediate level (score 3). A basic level score on udder and teat care implies that practices are rudimentary and crucial steps such as dedicated or single-use towels for teat cleaning and post-teat dipping are not consistently adhered to.

Table 3.5 Frequency of individual scores and mode scores for on-farm safety and hygiene control practices

Practice indicators		Cluster 1 (n=23)					Cluster 2 (n=16)					Cluster 3 (n=2)				
		1[a]	2	3	4	Mode	1	2	3	4	Mode	1	2	3	4	Mode
Animal health management	*Disease prevention and veterinary consultation practices*	0	**14**	9	0	**2**[b]	5	**11**	0	0	**2**	0	0	0	**2**	**4**
	Pest control practices	2	**20**	1	0	**2**	7	**9**	0	0	**2**	0	0	**2**	0	**3**
Animal health monitoring	*Disease detection practices*	2	5	**16**	0	**3**	**14**	1	1	0	**1**	0	0	**1**	**1**	**3***
Hygienic milking and handling	*Personal hygiene practices*	0	**16**	7	0	**2**	**15**	1	0	0	**1**	0	**2**	0	0	**2**
	Udder and teat care practices	5	**9**	**9**	0	**2***	**13**	3	0	0	**1**	0	**2**	0	0	**2**
Milk cooling and storage practices	*Milk cooling and storage practices*	0	**17**	6	0	**2**	2	**13**	1	0	**2**	0	0	0	**2**	**4**
Milk safety monitoring method	*Milk safety monitoring method*	1	**19**	3	0	**2**	1	**15**	0	0	**2**	0	**1**	**1**	0	**2***
Environmental hygiene	*Shed and floor sanitation practices*	5	**11**	7	0	**2**	**10**	5	1	0	**1**	0	0	**1**	**1**	**3***
Feed and feed storage practices	*Feed storage facility and practices*	2	**10**	**10**	1	**2***	**12**	4	0	0	**1**	0	0	**1**	**1**	**3***
	Duration of feed-in-storage practices	1	**17**	4	1	**2**	**11**	5	0	0	**1**	0	0	0	**2**	**4**
Feed-in-storage monitoring	*Feed inspection method and practices*	5	5	**13**	0	**3**	**11**	4	1	0	**1**	0	0	0	**2**	**4**

[a] Scores representing; 1 – Poor level, 2 – Basic level, 3 – Intermediate level, 4 – Standard level
[b] The mode represents the most frequent score among the farmers in each cluster
*Bimodal distribution and we used the lower score for the spiderweb

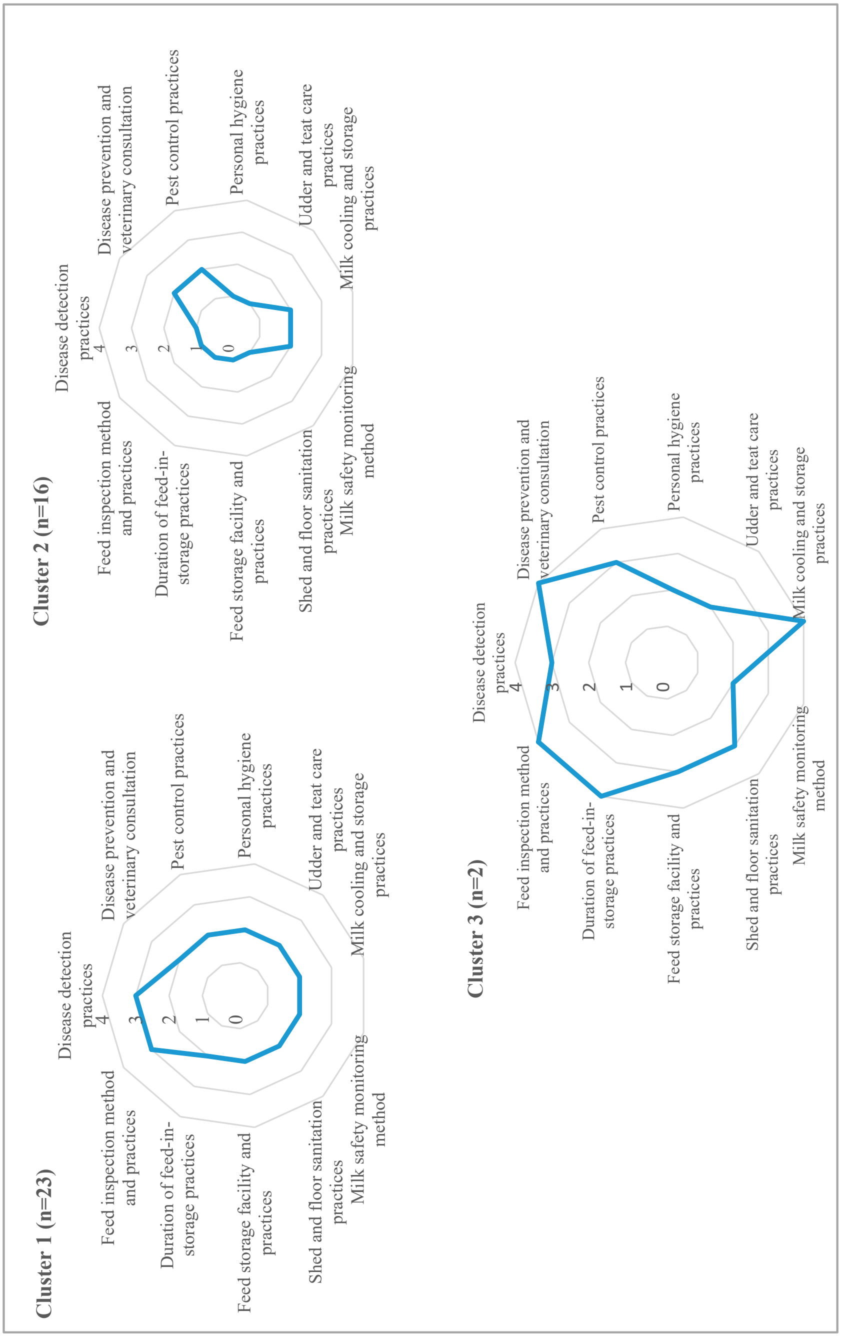

Figure 3.4 Spiderwebs showing the mode scores for safety and hygiene control practices for the three clusters of dairy farmers in Tanzania

Also, personal hygiene practices such as compliance to hand washing, personal care and health status routines are also consistently not performed appropriately. A basic level score for shed and floor sanitation practices implies limited hygienic consideration in the design where drains are absent making wet cleaning impossible. Furthermore, protocols for the performance of practices are mainly verbal with no documentation resulting in variable actual practices (Pacholewicz et al., 2016). Full adherence to udder and teat care, personal hygiene and environmental sanitation practices are crucial for animal health and bulk milk safety as highlighted by multiple studies (Elmoslemany et al., 2010; Esguerra et al., 2018; Oliveira et al., 2011), as they constitute a major mitigation measure against mastitis-causing bacteria and foodborne pathogens. Consequently, the mitigation measures among these farmers are inadequate to guarantee consumer health. Also, feed storage facilities and practices at a basic level (score 2) represent uncontrolled storage facilities which exposes feed to varying temperature and humidity, creating a conducive condition for mould growth (Armando et al., 2012; Lahouar et al., 2016), and subsequent aflatoxin contamination of fresh milk. The lack of awareness of the risk of aflatoxin contamination as noticed from inadequate feed handling practices probably accounts for the substandard measures implemented.

For cluster II, all the farmers of the small-scale farms were performing milk cooling and storage, disease prevention and veterinary consultation, milk safety monitoring method, and pest control practices at the basic level (score 2) while most of the other safety and hygiene control practices were performed at the poor level (score 1). Characteristic of the poor level udder and teat care performance is the complete lack of hygienic milking measures where the calves can suckle on the teats before milking without any further cleaning. This is consistent with the study of Schoder et al. (2013) who reported similar practices among small-scale farmers in Tanzania, who seem not to know the risk of transferring mastitis bacteria when the teats are not cleaned after the calves suckle. Additionally, there is no adherence to hand washing, personal care and health status routines. Typical of a poor level of feed and feed handling practices is the complete lack of consideration for temperature and humidity control for feed during storage, no limit for feed storage, and no demarcation for fresh and old feed, while also no inspection of feed for moulds is performed. As a result, countless avenues arise for mould to grow freely which increases aflatoxin contamination of the milk. Overall, a dominant poor level performance on practices is characteristic of small-scale dairy farmers (Millogo et al., 2012; Kamana et al., 2017; Tegegne & Tesfaye, 2017) and dairies (Njage, et al., 2018) in emerging dairy chains where the implementation of food safety measures are restricted, and heightens the public health risk for consumers of fresh milk without any form of heat treatment. This is particularly important for Tanzania, as over 70% of the estimated 2 billion litres of milk produced per year is consumed on the farm or sold through informal channels (Makoni et al., 2014).

Altogether, the small and large scale farms differ in terms of farm size, educational level of the farmer (Table 3.1) and the number of farm support staff available. Kumar et al. (2011) found that high educational level influences farmers awareness of required practices, which often translates into actual appropriate performance. This is the case for the large-scale farmers as they all had high educational levels with professional training in dairy farm management compared to the small-scale farmers, where the majority only had elementary-level education. This advantage of the large-scale farmers may have accounted for the better performance of more technical practices such animal health management, feed-in-storage monitoring, and shed and floor sanitation (in cluster III) compared to the low-level practices in clusters I and II, dominated by farmers of the small-scale farms. Additionally, the size of the large-scale farms explains the multiple farm support staff observed, which helped the division of safety and hygiene task compared to the small-scale farms, where only one person performed multiple tasks. However, similar lower scores were obtained by the farmers of the large-scale as well as the small-scale farms for hygienic milking and handling practices, despite the advantage of high educational level and more support staff. Typical of both groups of farmers is the use of single towel for cleaning teats of multiple cows, the lack of cleaning after allowing the calves to suckle on the teats, and the inconsistency in the performance of hand washing routines before milking. Consequently, the inadequate practice performance for crucial mitigation measures such as udder and teat care, and personal hygiene can erode the impact of the high-performance scores obtained for other technical practices leading to milk safety risks (Vissers & Driehuis, 2009). This suggests the lack of knowledge on the importance of good hygienic milking and handling practices. Regular training for both the large and small-scale farmers can reinforce knowledge, which can translate into better performance of practices (Lindahl et al., 2018; Rovai et al., 2016) in spite of the limited inspection to enforce compliance to legislations on good dairy farming and hygiene practices, typical of emerging dairy chains.

3.4 The usefulness of the customised assessment tool

The customised assessment tool provides a comprehensive analysis of dairy actor practices using a systematic approach to identify crucial practices linked with recurrent milk safety challenges along the dairy chain. The variation in scores in the assessment of on-farm safety and hygiene control practices in Tanzania demonstrated the ability of the tool to accurately distinguish the level of performance of safety and hygiene control practices of farmers by using the grid descriptions. The grid descriptions are consistent with the recommendations of Kilelu et al. (2013) and Kussaga et al. (2015) for stepwise strategies in dairy development programs for emerging dairy chains. The developed grids show the structural, technical inputs involved, and the level of investment required to achieve a transition towards more advanced levels of practice performance and the specific technical equipment (i.e., teat cup, single-use towel) support to be provided to achieve that level. A comprehensive analysis of on-farm practices for a small group of farmers, as done in the case of Tanzania, can serve as a basis for more precise advice towards specific incremental changes to farmers performing at a similar low level. Additionally, the tool can be extended to large groups of farmers and different actors across the chain to develop dedicated national dairy development policies for removing structural barriers such as high cost of dairy farm inputs, lack of integrated disease control, and limited cooling facilities hindering practice performance to guarantee milk safety. Finally, the tool can be used by researchers and non-governmental agencies to determine the specific needs and define the inputs for dedicated training programs to address specific inadequacies in practices.

3.5 Conclusions

Our study presented the development of a customised tool which enables differentiated assessment of safety and hygiene practices for the control of microbial and chemical safety (i.e., aflatoxin) in fresh milk by actors along emerging dairy chains. Uniquely, the tool incorporated the peculiar minimum level of practice performance in emerging dairy chains and demonstrated the capacity to distinguish differences in the performance of crucial on-farm safety and hygiene control practices. The pilot study conducted in Tanzania differentiated dairy farmers into three distinct clusters that differed in their control practices. Clusters dominated by farmers of the small-scale dairy farms were performing practices at poor to basic level with very few practices at an intermediate level. On the other hand, farmers of the large-scale farms were performing mainly at intermediate to standard level but with basic level performance on some crucial practices which point to specific risks for contamination also on these farms. Dedicated improvement in practices is still needed to adequately mitigate microbial and aflatoxin contamination of fresh milk. Further research is needed to be able to conclude whether the different levels of safety and hygiene control practices will be reflected in actual differences in fresh milk safety along the dairy chain.

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Supporting information

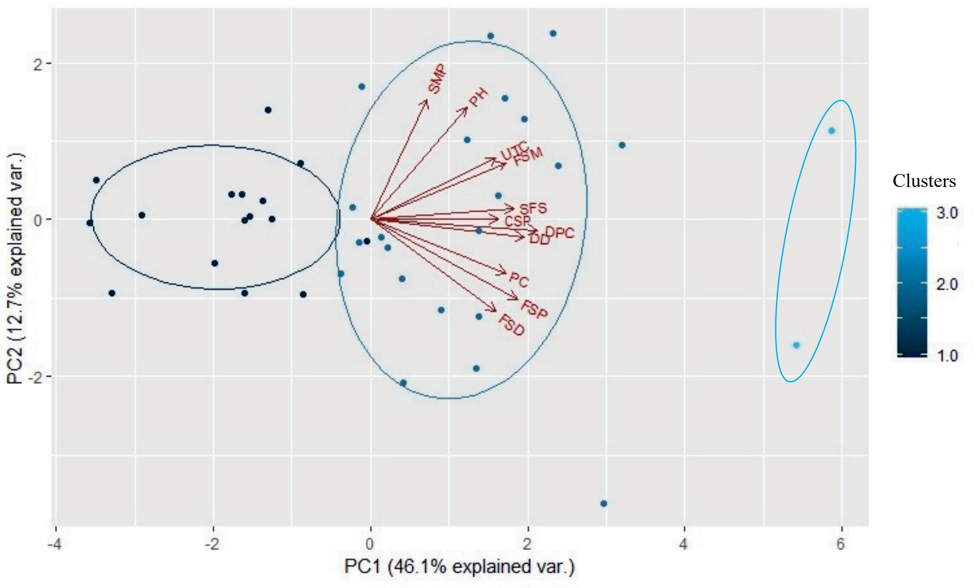

Figure S1 PCA plot of the crucial practices discriminating the three clusters of dairy farmers
PC=Pest control practices, **PH**-Personal hygiene practices, **UTC**-Udder and teat care practices, **SFS**-Shed and floor sanitation practices, **CSP**-Milk cooling and storage practices, **DD**-Disease detection practices, **DPC**-Disease prevention and veterinary consultation practices, **FSM**-Feed inspection method and practices, **FSP**-Feed storage facility and practices, **FSD**-Duration of feed in storage practices

Table S1 Identified indicators with grids to assess on-farm safety and hygiene preventive and monitoring activities

	On-farm safety and hygiene preventive practices			
Indicators	Poor level	Basic level	Intermediate level	Standard level
Animal health management practices				
Pest control practices	• No established pest control system, and no use of insecticides and no consistency in environment cleanliness. • Only responds to insect control initiated as result of national programs. • No protocols for monitoring insect and rodent control system.	• No established pest control system, insecticide use is demand driven and tries to keep a clean environment. • Insecticide use is driven by overwhelming insects or pests or when cautioned by extension officers. • No written protocol for insecticide use mainly verbal, derived from product labels and experience.	• Incomplete pest control system, systematic use of insecticides and maintains a clean environment to control on-farm pests. • Regularly sprays farm with insecticides once a week and has biological means to control rodents but no cow dipping. • Protocol for use of insecticides are incompletely described	• Complete pest control system and uses specific insecticides to control specific insects and maintains a clean environment on the farm. • Regularly sprays the farm, performs cow dipping and monitors rodent traps more than once a week. • Well described protocols for insect and rodent control.
Disease prevention and veterinary consultation practices	• No identification tags for dairy cows. Dairy cows move freely under uncontrolled system and exposed to health hazards. • No observation of cows, no structured vaccination program and no structured medical screening before introduction on the farm. • No records on health status or vaccination are kept. No data on vaccine type and dosages exist.	• No identification tags for dairy cows but kept in a shed and allowed to graze under semi-control system. • Observation of dairy cows is irregular and unstructured, vaccination is irregular and no subclinical screening for diseases before introduction on the farm. • Unstructured records on health status and vaccination. Records are often from memory and not written.	• Incomplete identification of cows but dairy cows are kept in well controlled system which limits exposure to hazards. • Regular and semi-structured observation of cows for clinical signs of disease, regular vaccination according to national programs but limited subclinical screening before introduction on the farm. • Specific records on vaccination time, type of drugs use and dry off time are kept with other information difficult to retrieve	• Comprehensive identification of cows with tags under well controlled system limiting completely exposure to disease hazards. • Regular observation for clinical and subclinical signs of disease, regular vaccination based on national and own programs. Comprehensive screening with help of veterinary officer for subclinical signs before introduction on the farm. • Specific logbook for specific records of animal health status, time of vaccination, time of next vaccination, type of drug used. Records easy to retrieve.
Milk cooling and storage practices				
Milk cooling and storage practices	• No structured mechanism to lower fresh milk temperature and milk is stored in unhygienically designed containers (plastic gallons) not easy to clean. • Fresh milk is collected, not cooled and transported in unhygienically designed containers (plastic gallons) to customers without regard for time. Inappropriate cleaning routines with multiple key steps absent (no disinfection). • No described protocols for cooling or cleaning.	• Unstructured mechanism to lower temperature of fresh milk (left in the open inside the house) and stored in containers not specifically designed for fresh milk (Plastic buckets from other products). • Fresh milk is collected, cooled and transported in containers not designed for milk to customers not always aware of time. Cleaning routines for containers irregular and not always complete. • No described protocols for cooling and cleaning containers. Relies on memory recollection.	• Incompletely structured mechanism to lower fresh milk temperature and store in food grade containers (Mazzican) immediately after milking. • Fresh milk is collected, cooled and transported in food grade containers (Mazzican) within one hour after milking. Incomplete cleaning routines of food grade containers before and after milk handling. • Protocols for cooling milk and cleaning storage containers somewhat described but not well preserved	• Structured mechanism to lower fresh milk temperature and stored in hygienically designed storage containers immediately after milking. • Fresh milk is collected, cooled and transported to customer in hygienically designed containers (stainless steel) within one hour of milking. Complete cleaning routines of hygienically designed containers before and after milk handling. • Protocols for cooling milk and cleaning storage containers after milking are comprehensively described, well preserved and easy to retrieve.

Table S1 (continued)

Indicators	Poor level	Basic level	Intermediate level	Standard level
Environmental hygiene practices				
Appropriate shed and floor sanitation	• No hygienic design consideration of shed and milk floors. No drainage and floors often wet. • No structured floor sanitation. Very reactive and bedding materials are removed on when completely damaged. • No documented protocols.	• Hygienic consideration very limited in shed and floor design. Shed close to dirt and foul smell without drains or trenches. • Ad hoc floor sanitation mainly dry cleaning. Bedding materials are changed when damaged. • No documented description of sanitation protocols. Mainly verbal and instinctive.	• Incomplete hygienic design of shed and milking floors. Shed located away from dirt and foul smell with broken cement floors and sandy trenches as drains. • Incomplete floor sanitation with no wet cleaning. Inconsistent maintenance and replacement of bedding materials. • Incomplete description and not well preserved sanitation protocols	• Hygienic designed shed and milking floors (concrete/cement) with concrete drains for easy cleaning. Shed located away from dirt and foul smell. • Complete floor sanitation involving dry and wet cleaning. Regular maintenance and replacement of bedding materials. • Detailed description and well-preserved floor sanitation protocols
Hygienic milking and handling practices				
Personal hygiene	• No dedicated facility for handwashing. Handwashing is done from any available facility. • No adherence to hand washing before and after milking, personal care and health. No idea of the dangers of ill health to milking. • No available reminders of any form on personal hygiene practices.	• Hand washing facility is not completely dedicated but manually filled with water. Used for other household activities. • Irregular adherence to hand washing before and after milking, personal care and health. Seeks medical care only when sick incapable to milk. • No available work protocols on personal hygiene practices. Relies mainly on verbal instructions.	• Not completely specific but dedicated bucket for only handwashing which is filled manually with water. • Regular handwashing before and after milking is adhered. Incomplete adherence to steps, personal care and health. Seeks medical care on when communicable symptoms persist. • Work protocols are described on loose material without visual reminders.	• Specific and dedicated handwashing facility (available sinks) connected with clean flowing tap water. • Complete adherence to handwashing before and after milking, personal care (clean clothing, shot nails) and health. Seeking medical care when communicable symptoms emerge. • Available work protocols and with visual reminders on personal hygiene practices (handwashing steps).
Appropriate udder/teat care	• Completely lacking hygienic milking practices. Major hygiene milking steps are absent. • No adherence to pre- and post-milking routines. Allows calf to suck on teats without any cleaning. • No written down protocols on udder/teat care. Wrong experiences are maintained	• Ad hoc hygienic milking practices. Multiple hygienic practices are inappropriately done. • Inconsistent adherence to pre- and post-milking routines. • Protocol on udder/teat care practices are very verbal, relies on recollection from memory and not documented.	• Partial hygienic milking practices. Focus on udder and teats. Restricted cleanness of cows and udder clipping. • Incomplete adherence to pre- (fore-stripping, teat cleaning but no pre-dipping) and post-milking (no post-dipping) routines at all times. • Documented protocols on loose material not easily retrievable.	• Comprehensive hygienic milking practices involving clean udder and teats, regular clipping of udder hair and overall cow cleanness. • Complete adherence to pre- (fore-stripping, pre-dipping and drying with dedicated towels) and post-milking routines (post-dipping) at all times. • Well documented and retrievable protocols for udder/ teat care practices.
Feed and feed storage practices				
Feed storage facility and practices	• No consideration for temperature and moisture control. Feeds are stored anyhow and exposed to all weather conditions. • No first-in-first-out approach. New feed and old feed kept together under all weather conditions.	• Uncontrolled feed storage facility exposed to fluctuating temperature and moisture. Ventilation uncontrolled. • Feed placed on raised platforms in the open sometimes covered with plastic. All feeds are kept together with no demarcations.	• Semi-controlled and ventilated feed storage facility (feed kept in ceiled bags) on wooden platforms but no control for temperature and moisture. • Storage of feed on raised platforms in ceiled bags with labels of feed first-in-first-out.	• Specifically, well designed and controlled ventilation of feed storage facility with capability to control temperature and moisture. • Feed is kept in an enclosed facility on raised platforms with clear labels of feed first-in and feed first-out.

Table S1(continued)

Indicators	Poor level	Basic level	Intermediate level	Standard level
Duration of feed-in-storage practices	• No limit to feed storage and feed exposed to all weather. Feed is stored in the open air all year (12months) without labels for new and old feed. • No record on feed first-in-first-out.	• Unstructured feed storage in the open air under uncontrolled conditions. Feed is sometimes covered with plastic bags/tarpaulin in the open for over 6months. • No detailed record on feed first-in - first-out. Record is instinctive.	• Semi-structured storage duration under semi-controlled conditions. Feed is stored for up to 6months with labels for new and old feed. • Identifies and records feed first-in-first-out. Information not easily retrievable.	• Well-structured storage duration (short term of 3months) under controlled condition. New feeds are clearly separated from old ones. • Detailed record keeping on feed first-in-first-out. Information easily retrievable.
On-farm safety and hygiene monitoring practices				
Animal health monitoring practices				
Disease detection practices	• No disease detection practices. Diseases are only detected when clinical signs are obvious. • Diseased cows are not properly identified and not isolated. Disease cows are treated with healthy cows and milked anytime during milking. • No records are kept on disease treatment of cows. Information on disease treatment very difficult to retrieve.	• Disease detection practices are mainly based on observable clinical signs. Subclinical checks are absent. • Seriously disease cows are identified, isolated and treated. Veterinary officers are rarely consulted for treatment help. • Irrelevant record keeping and information is difficult to retrieve.	• Disease detection practices are semi-structured covering clinical and limited aspects of subclinical signs of disease. Limited use of specific methods such as California Mastitis Test. • Disease cows are identified, isolated and treated. Sometimes consults a veterinary officer and cows are milked last. • Incomplete records on disease detection and treatment. Antibiotic withholding time absent.	• Structured disease detection practices covering clinical and subclinical aspects using specific methods like strip-cup and California Mastitis Test daily on milking cows. • Structured way to identify, isolate and treat diseased cows. Regularly consults veterinary officers for help and disease cows are milked last. • Complete and specific animal treatment records covering disease detection date, drug used and antibiotic withholding time.
Feed in storage monitoring practices				
Feed inspection method and practices	• No inspection of feed for moulds. Feeds are fed to cows without any inspection for moulds and no step to remove contaminated feeds.	• Unstructured and irregular inspection of stored feeds (triggered by concerns of a problem). No standard guides are used and feeds often used without checking for moulds.	• Semi-structured and regular inspection (once in a week) of stored feed. Observation of stored feeds for moulds not guided by standard aids. Incomplete removal of mouldy feeds and cows are sometimes fed with mouldy feeds.	• Structured and regular inspection of stored feeds (multiples times in a week). Detailed observation of feed to identify mouldy feed. Mouldy feeds are completely removed using standards aids and protocols. Contaminated feeds are not fed to cows.
On-farm milk safety monitoring practices				
Milk safety monitoring method	• No standard tests to check for milk quality or microbial load. Often relies on customer to confirm quality. • No written protocol or data for milk quality and microbial load.	• Non-standardized tests (very rudimentary) are performed to check fresh milk quality but no test for milk load. • No written protocols for checking milk quality and microbial load. Relies on recollection from memory.	• Standardized tests performed regularly and immediately to check fresh milk quality but not for microbial load in milk. • Written protocols for conducting quality checks but not for microbial load. Data on quality not always kept	• Standardized tests performed regularly and immediately to check fresh milk quality (i.e. organoleptic, alcohol and lactometer) and microbial load (i.e., Resazurin). • Documented and preserved protocols (logbook) for conducting quality and microbial load tests. Data on quality/microbial load kept.

Table S2 Identified indicators with grids to assess safety and hygiene preventive and monitoring activities during milk trading

Indicators	Poor level	Basic level	Intermediate level	Standard level
Hygienic milk handling preventive practices				
Personal hygiene practices	• No dedicated facility for handwashing. Handwashing is done from any available facility. • No adherence to hand washing before and after milking, personal care and health. No idea of the dangers of ill health to milking. • No available reminders on personal hygiene practices.	• Hand washing facility is not completely dedicated but manually filled with water. Used for other household activities • Irregular adherence to hand washing before and after milking, personal care and health. Seeks medical care only when sick incapable to milk. • No available work protocols on personal hygiene practices. Relies mainly on verbal instructions.	• Dedicated bucket for only handwashing which is filled manually with water • Regular handwashing before and after milking is adhered. Incomplete adherence to steps, personal care and health. Seeks medical care on when communicable symptoms persist. • Work protocols are described on loose material without visual aids.	• Dedicated handwashing facility (available sinks) connected with clean flowing tap water. • Complete adherence to handwashing before and after milking, personal care (clean clothing, shot nails) and health. Seeking medical care when communicable symptoms emerge. • Available work protocols and with visual aids on personal hygiene practices (handwashing steps).
Hygienic handling, cooling and storage practices	• No structured mechanism to lower fresh milk temperature and milk is stored in unhygienically designed containers (plastic gallons) not easy to clean. • Fresh milk is collected, not cooled and transported in unhygienically designed containers (plastic gallons) to customers without regard for time. Inappropriate cleaning routines with multiple key steps absent (no disinfection). • No described protocols for cooling or cleaning.	• Unstructured mechanism to lower temperature of fresh milk (left in the open inside the house) and stored in containers not specifically designed for fresh milk (plastic buckets from other products) • Fresh milk is collected, cooled and transported in containers not designed for milk to customers not always aware of time. Cleaning routines for containers irregular and not always complete. • No described protocols for cooling and cleaning containers. Relies on memory recollection.	• Structured mechanism to lower fresh milk temperature and store in food grade containers (Mazzican) immediately after milking. • Fresh milk is collected, cooled and transported in food grade containers (Mazzican) within one hour after milking. Incomplete cleaning routines of food grade containers before and after milk handling. • Protocols for cooling milk and cleaning storage containers somewhat described but not well preserved	• Structured mechanism to lower fresh milk temperature and stored in hygienically designed storage containers immediately after milking • Fresh milk is collected, cooled and transported to customer in hygienically designed containers (stainless steel) within one hour of milking. Complete cleaning routines of hygienically designed containers before and after milk handling. • Protocols for cooling milk and cleaning storage containers after milking are comprehensively described, well preserved and easy to retrieve.
Milk transportation practices	• Mode of transport has no capability to condition temperature. • No specific time limit for milk delivery. Milk is delivered in any type of container and not in cleaned transport vehicles.	• Mode of transport vechicle (e.g., motocycles) used has no capabilities to condition temperature, milk is stored in non-milk food grade containers and never protected. • Never regular milk delivery within time and mode of transport not always clean.	• Dedicated mode of transport for fresh milk (e.g. open trucks) with limited capability to condition temperature. • Delivers milk within agreed time in milk food grade containers protected from sun and dust (tarpaulins) in clean transport.	• Dedicated mode of transport for fresh milk with capabilities to condition temperature. • Milk delivery within shortest time in well insulated containers and in clean transport with protection from sun and dust.
Milk safety monitoring practices				
Milk safety monitoring method	• No standard tests to check for milk quality or microbial load. Often relies on customer to confirm quality. • No written protocol or data for milk quality and microbial load.	• Non-standardized tests (very rudimentary) are performed to check fresh milk quality but no test for milk load. • No written protocols for checking milk quality and microbial load. Relies on recollection from memory.	• Standardized tests performed regularly and immediately to check fresh milk quality but not for microbial load in milk. • Written protocols for conducting quality checks but not for microbial load. Data on quality not always kept	• Standardized tests performed regularly and immediately to check fresh milk quality (i.e., organoleptic, alcohol and lactometer) and microbial load (i.e., Resazurin). • Documented and preserved protocols (logbook) for conducting quality and microbial load tests. Data on quality/microbial load kept.

Table S3 Identified indicators with grids to assess safety and hygiene preventive and monitoring activities at milk collection centres

Indicators	Poor level	Basic level	Intermediate level	Standard level
Hygienic milk reception and handling preventive practices				
Appropriate personal hygiene practices	• No dedicated facility for handwashing. Handwashing is done from any available facility. • No adherence to hand washing before and after milking, personal care and health. No idea of the dangers of ill health to milking. • No available work protocols and reminders of any form on personal hygiene practices.	• Hand washing facility is not completely dedicated but manually filled with water. Used for other household activities. • Irregular adherence to hand washing before and after milking, personal care and health. Seeks medical care only when sick incapable to milk. • No available work protocols on personal hygiene practices. Relies mainly on verbal instructions.	• Dedicated bucket for only handwashing which is filled manually with water. • Regular handwashing before and after milking is adhered. Incomplete adherence to steps, personal care and health. Seeks medical care only when communicable symptoms persist. • Work protocols are described on loose material without visual aids.	• Dedicated handwashing facility (available sinks) connected with clean flowing tap water. • Complete adherence to handwashing before and after milking, personal care (clean clothing, shot nails) and health. Seeking medical care when communicable symptoms emerge. • Available and well -preserved work protocols with visual aids on personal hygiene practices.
Hygienic handling, cooling and storage practices	• Improvised cooling facilty not hygienically designed and has no thermometers for checking milk temperature. • Initial Milk temperature is checked with bare hands, and no conditioning and monitoring of temperature until transported. • No described work protocols for cooling and cleaning activities. No data is kept.	• Cooling facility not hygiencially designed and no functional fitted thermometer. • Initial temperature of milk is checked with uncalibrated hand thermometers. No proper conditioning and monitoring until transported. • No documented work protocols for cooling and cleaning activities. Verbal instructions are common for performing practices. Data recording is limited only when demanded.	• Hygienically designed cooling tank for easy cleaning with fitted thermometeers not regularly calibrated. • Initial temperature of milk is checked with uncalibrated thermometers, conditioned to acceptable temperature within 1hr but not always monitored until transported. • Work protocols for cooling and cleaning, incompletely described & not well preserved. Data on temperature variation & milk quality not regularly kept.	• Hygienically designed cooling facility for easy cleaning with well fitted calibrated thermometers to maintain milk at acceptable temperature. • Initial temperature of milk is checked, conditioned to acceptable temperature in less than 1hr, maintained and monitored until transported with calibrated thermometers. • Work protocols for cooling and cleaning are comprehensively described & well preserved. Data on temperature variation and milk quality is kept.
Environment and equipment hygiene preventive practices				
Environmental and equipment hygiene practices	• Equipment and facility not hygienically designed. General cleaning agents and equipment are not specific and dedicated. • Facility floors and equipment are cleaned manually using general cleaning agents and equipments. • No procedures for cleaning equipment and facility environment	• Some facility and equipment show deficiency in hygienic design. Facility floors and equipment showing obvious signs of craks and breakdown. Cleaning agents and equipment are general and used for all purpose. • Facility floors and equipment are manually cleaned. • No available work protocols on cleaning equipment and facility environment. Relies mainly on verbal instructions.	• Incomplete hygienic designed facility (i.e., made of concrete, well slanted & drains) and equipment to facilitate cleaning are easy. • Limited automated cleaning of cooling facility with dominant manual cleaning. Facility floor and equipment regularly cleaned with cleaning and cleaning equipments not always specific. • Work protocols for cleaning equipment and facility environment not well described and preserved.	• Complete hygienic design of facility/floor (i.e., concrete, well slanted & drains) and equipment to facilitate easy cleaning. • Automated cleaning of cooling facility (i.e., CIP) with limited manual cleaning. Facility floor and equipement regularly cleaned with specific cleaning agents and dedicated specific cleaning equipments. • Work protocols for environement and equipment well described and preserved.

Table S3 (continued)

Indicators	Poor level	Basic level	Intermediate level	Standard level
Pest control practices	• No established pest control system, and no use of insecticides and no consistency in environment cleanliness. • Only responds to insect control initiated as result of national programs. • No written protocols for monitoring pest control system. No records are kept on efficiency of pest control system.	• No complete pest control system, insecticide use is demand driven and tries to keep a clean environment. • Insecticide use is driven by overwhelming insects and pests or when cautioned. • No written protocol for insecticide use, derived from product labels and experience. No specific documented records. Largely from memory.	• Incomplete pest control system, systematic use of insecticides and maintains a clean environment to control pests. • Regularly sprays MCC with insecticides once a week and but no rodent traps. • Protocol for use of insecticides are incompletely described (i.e., not for rodent traps). Some specific records are kept on efficiency of insecticides with other information.	• Complete pest control system and uses specific insecticides to control specific insects and maintains a clean environment at the MCC. • Regularly sprays the MCC, performs and monitors rodent traps more than once a week. • Well described protocols for insect and rodent traps. Has a specific log book for keeping records on efficiency of pest control system.
Milk safety monitoring practices				
Milk safety monitoring method	• No standard tests to check for milk quality or microbial load. Often relies on customer to confirm quality. • No written protocol or data for milk quality and microbial load.	• Non-standardized tests (very rudimentary) are performed to check fresh milk quality but no test for milk load. • No written protocols for checking milk quality and microbial load. Relies on recollection from memory.	• Standardized tests performed regularly and immediately to check fresh milk quality but not for microbial load in milk. • Written protocols for conducting quality checks but not for microbial load. Data on quality not always kept	• Standardized tests performed regularly and immediately to check fresh milk quality (i.e. organoleptic, alcohol and lactometer) and microbial load (i.e., Resazurin). • Documented and preserved protocols (logbook) for conducting quality and microbial load tests. Data on quality/microbial load kept.

Table S4 Identified indicators with grids to assess safety and hygiene preventive and monitoring activities at local retail

Indicators	Poor level	Basic level	Intermediate level	Standard level
Hygienic milk reception and handling preventive practices				
Personal hygiene practices	• No dedicated facility for handwashing. Handwashing is done from any available facility. • No adherence to hand washing before and after milking, personal care and health. No idea of the dangers of ill health to milking. • No available work protocols and reminders for practices.	• Hand washing facility is not completely dedicated but manually filled with water. Used for other household activities. • Irregular adherence to hand washing before and after milking, personal care and health. Seeks medical care only when sick incapable to milk. • No available work protocols on personal hygiene practices. Relies mainly on verbal instructions.	• Dedicated bucket for only handwashing which is filled manually with water. • Regular handwashing before and after milking is adhered. Incomplete adherence to steps, personal care and health. Seeks medical care only when communicable symptoms persist. • Work protocols are described on loose material without visual aids.	• Dedicated handwashing facility (available sinks) connected with clean flowing tap water. • Complete adherence to handwashing before and after milking, personal care (clean clothing, shot nails) and health. Seeking medical care when communicable symptoms emerge. • Available and well-preserved work protocols with visual aids on personal hygiene practices.
Hygienic handling, cooling and storage practices	• No structured mechanism to lower fresh milk temperature and milk is stored in unhygienically designed containers (plastic gallons) not easy to clean. • Fresh milk is received and not cooled. Inappropriate cleaning routines with multiple key steps absent (no disinfection). • No described protocols for cooling or cleaning.	• Unstructured mechanism to lower temperature of fresh milk (left in the open inside the house) and stored in containers not specifically designed for fresh milk (plastic buckets from other products). • Fresh milk is received and not always cooled. Cleaning routines for containers irregular and not always complete. • No described protocols for cooling and cleaning containers. Relies on verbal instructions and own experience.	• Structured mechanism to lower fresh milk temperature and store in food grade containers (Mazzican) immediately after receiving. • Fresh milk is collected, cooled and transported in food grade containers (Mazzican) within one hour after milking. Incomplete cleaning routines of food grade containers before and after milk handling. • Protocols for cooling and cleaning storage containers somewhat described but not well preserved	• Structured mechanism to lower fresh milk temperature and stored in hygienically designed storage containers immediately after receiving. • Fresh milk is received and cooled within one hour. Complete cleaning routines of hygienically designed containers before and after receiving milk. • Protocols for cooling and cleaning storage containers are well-described, well preserved and easy to retrieve.
Environmental & equipment hygiene preventive activities				
Environmental and equipment hygiene practices	• Equipment and facility not hygienically designed. General cleaning agents and equipment are not specific and dedicated. • Facility floors and equipment are cleaned without soaps. • No procedures for cleaning equipment and facility environment	• Some facility and equipment show deficiency in hygienic design. Facility floors and equipment showing obvious signs of craks and breakdown. • Cleaning agents and equipment are general and used for all purpose. Facility floors and equipment sometimes cleaned without soap. • No available work protocols on cleaning equipment and facility environment. Relies mainly on verbal instructions.	• Incomplete hygienic designed facility (i.e., made of concrete, well slanted & drains) and equipment to facilitate cleaning are easy. • Facility floor and equipment regularly cleaned with cleaning and cleaning equipments not always specific. • Work protocols for cleaning equipment and facility environment not well described and preserved.	• Complete hygienic design of facility/floor (i.e. made of concrete, well slanted & drains) and equipment to facilitate easy cleaning. • Facility floor and equipement regularly cleaned with specific cleaning agents and dedicated specific cleaning equipments. • Work protocols for environement and equipment well described and preserved.

Table S4 (continued)

Indicators	Poor level	Basic level	Intermediate level	Standard level
Pest control practices	• No established pest control system, and no use of insecticides and no consistency in environment cleanliness. • Only responds to insect control initiated as result of national programs. • No written protocols for monitoring pest control system.	• No complete pest control system, insecticide use is demand driven and tries to keep a clean environment. • Insecticide use is driven by overwhelming insects and pests or when cautioned. • No written protocol for insecticide use mainly verbal, derived from product labels and experience.	• Incomplete pest control system, systematic use of insecticides and maintains a clean environment to control pests. • Regular spraying with insecticides once a week and but no rodent traps. • Protocol for use of insecticides are incompletely described (not for rodent traps).	• Complete pest control system and uses specific insecticides to control specific insects and maintains a clean environment. • Regularly sprays and monitors rodent traps more than once a week. • Well described protocols for insect and rodent traps.
Milk safety monitoring practices				
Milk safety monitoring method	• No standard tests to check for milk quality or microbial load. Often relies on customer to confirm quality. • No written protocol or data for milk quality and microbial load.	• Non-standardized tests (very rudimentary) are performed to check fresh milk quality but no test for milk load. • No written protocols for checking milk quality and microbial load. Relies on recollection from memory.	• Standardized tests performed regularly and immediately to check fresh milk quality but not for microbial load in milk. • Written protocols for conducting quality checks but not for microbial load. Data on quality not always kept	• Standardized tests performed regularly and immediately to check fresh milk quality (i.e. organoleptic, alcohol and lactometer) and microbial load (i.e., Resazurin). • Documented and preserved protocols (logbook) for conducting quality and microbial load tests. Data on quality/microbial load kept.

Chapter 4

Implications of differences in safety and hygiene control practices for microbial safety and aflatoxin M1 in an emerging dairy chain: The case of Tanzania

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Abstract

The varying performance of safety and hygiene control practices by chain actors can influence the consistent production of milk of good quality and safety in dairy chains. Therefore, the study aimed to investigate if differences in safety and hygiene control practices translate into distinctions in milk quality and safety at the farm, and to analyze the implications for actors further in the Tanzanian dairy chain. A previously developed diagnostic tool, customised for emerging dairy chains, was applied to assess and differentiate the performance of safety and hygiene control practices of actors from the farm to local retail shops. Based on interviews and on-site visits, each safety and hygiene control practice were differentiated into a poor, basic, intermediate or standard level. Milk samples were collected with a 7-day interval over three-time points to determine total bacterial counts (TBC), coliforms and *Staphylococcus aureus*. Besides, aflatoxin M1 (AFM1) occurrence was determined in farm milk as an indication of feed storage and monitoring practices. Data showed that none of the chain actors attained the standard level on any of the safety and hygiene control practices. Cluster analysis of on-farm safety and hygiene control practices generated two clusters, which differed mainly on the scores for udder and teat care, and disease detection practices. Differences in safety and hygiene control practices observed among farmers did not translate into differences in milk quality and safety. The analysis for AFM1 showed that 22% exceeded the maximum limit of the United States Food and Drug Authority Standard. Also, the microbial data showed that the farm milk already exceeded maximum limits of the East Africa Community (EAC) standard to the extent that no continued growth was observed further in the chain. The study demonstrates that improvements in milk quality and safety would require multiple practices to be upgraded to the standard level. Research is needed to advance the performance of control practices towards compliance with international standard requirements.

4.1 Introduction

Global milk production has increased by more than 50% over the last three decades (FAO, 2018). This growing trend would continue in emerging economies due to rapid population growth and improve income (Gerosa & Skoet, 2013; Kapaj & Deci, 2017). Simultaneously, reports of food safety scares associated with the consumption of fresh milk, and related products continue in developed and emerging dairy chains (Cheng et al., 2016; Johler et al., 2015; Van Asselt et al., 2017). Loopholes in the performance of safety and hygiene control practices, which create avenues for microbial and chemical contamination, have been implicated in several of these food scares (Powell et al., 2011; Todd, Michaels, Greig, et al., 2010; Van Asselt et al., 2017). In emerging dairy chains, the concern for food scares is magnified by the lack of uniformity in the implementation of food control systems (Kamana et al., 2017; Ledo et al., 2019). More so, when there is the direct sale of a large proportion of fresh milk to consumers (Grace, 2015) without any form of adequate milk cooling and pasteurization.

At the same time, only a limited number of dairy processing industries in emerging dairy chains, have implemented the Hazard Analysis and Critical Control Point (HACCP) principles into their food safety management systems (FSMS) (Kussaga et al., 2014). Moreover, non-compliance with hygienic practices typifies the performance of these implemented systems (Kussaga et al., 2015; Opiyo et al., 2013). On the farm, safety and hygiene control practices are still being performed at levels that demonstrate a lack of progress to standard requirements (Islam et al., 2018; Ledo et al., 2019). Concerns about the adequate performance of safety and hygiene control practices by other actors such as milk traders, milk collection centers (MCCs) and local retail shops in the chain, continue to recur (Islam et al., 2018; Kamana et al., 2014). The underlying limitations in the performance of practices have implications for microbial and chemical milk safety risks. Bacteria and aflatoxin M1 (AFM1) contamination are common representatives of these type of risks (Vissers & Driehuis, 2009a), as they are linked to multiple on-farm safety and hygiene control practices. Consequently, poor microbial quality and safety (Belli et al., 2013; Kunadu et al., 2018; Swai & Schoonman, 2011) and occurrence of AFM1 (Ahlberg et al., 2018; Iqbal et al., 2015) above maximum limits in milk, continue to persist. The need to focus on AFM1 is necessary due to its common occurrence in emerging dairy chains in tropical countries, more so, when dairy farmers in these chains are often not aware of this specific risk. Hence, strategies to enhance the performance of safety and hygiene control practices and mitigate the recurring milk safety risks in emerging dairy chains are still necessary, as consumer demands for milk and milk products continue to increase.

Recently, we developed a customised assessment tool to support a systematic and differentiated analysis of safety and hygiene control practices and milk safety performance along the chain (Ledo et al., 2020a). The tool describes crucial practices necessary to mitigate microbial and AFM1 contamination. It includes four different levels (i.e., poor, basic, intermediate and standard) to position the performance level of the practices accurately. A pilot study with the new tool in Tanzania demonstrated that many dairy farmers were performing the practices below the minimum standard level. Actual milk safety performance was, however, not assessed. Expanding the application of the tool to assess practices and milk safety performance during milk trading, collection/bulking, and retailing is essential, as this will give a better indication of the overall chain effectiveness to safeguard food quality and safety.

This study aimed to investigate if differences in safety and hygiene control practices translate into distinctions in milk quality and safety at the farm, and to analyze the implication for actors further in the chain, using the Tanzanian dairy chain as an example. The customised assessment tool for emerging dairy chains was applied to systematically distinguish practices of dairy chain actors from the farm to local retail shops. The practice assessment was followed by fresh milk sampling and laboratory analysis of microbial and aflatoxin M1 levels to investigate the possible relations between the level of practices along the chain with milk quality and safety.

4.2. Materials and methods

4.2.1 Study design

The study was designed based on the techno-managerial research approach previously outlined by Luning and Marcelis (2006, 2007) for food chains, to unravel the interrelatedness of technological and people-related conditions impacting milk safety in emerging dairy chains. The study covered two major parts. The first part comprised the application of a customised assessment tool previously developed by

Ledo et al. (2020a) to evaluate the level of practice performance of farmers, milk traders, milk collection centers (MCCs), and local retail shops, using interviews and structured on-site observations. The second part involved the sampling of fresh milk from the actors along the chain to investigate the presence and levels of bacteria and aflatoxin M1, as an indication of milk quality and safety. The study was conducted in two selected milk-producing districts of Tanzania: Mvomero and Lushoto, located in the Morogoro and Tanga regions, respectively. The regions and districts were selected because they have been part of multiple dairy intervention programs with prominent dairy production and marketing activities, and representative of the Tanzanian dairy chain (Njehu & Omore, 2014). In each district, two study locations were selected, linked to our previous study (Ledo et al., 2019).

Selection of study participants

The dairy farmers were contacted through livestock officers of the study locations from a register of farmers used in a previous study Ledo et al. (2019). Those willing to participate were followed up for interviews, on-site observations and milk sampling for laboratory analysis. The milk traders, milk collection centers and milk retail points were identified through the snowball sampling technique (Biernacki & Waldorf, 1981), where the dairy farmers referred their customers of the fresh milk and were contacted to plan the interviews and on-site observations. All the dairy farmers were operating at a small-scale with at least one milking cow at the time of the study and over a year experience in dairy farming. All the milk traders and retailers were private local businesses. Two of the MCCs were individually owned while the other two were owned by farmer co-operative groups. Overall, 24 dairy farmers, three milk traders, four MCCs and four retail shops were included in the study (Table 4.1).

Table 4.1 Characteristics of study respondents along the Tanzania dairy chain

Characteristics of respondents	Farmers (n=24) n (%)	Milk traders (n=3) n (%)	MCC (n=4) n (%)	Local retail shops (n=4) n (%)
Respondents from study sites				
Manyinga	6 (25)			1 (25)
Wamidakawa	6 (25)	2 (66.7)	2 (50)	1 (25)
Mwangoi	6 (25)		1 (25)	1 (25)
Ngulwi	6 (25)	1 (33.3)	1 (25)	1 (25)
Age				
< 20 years				
21 - 30 years	2 (8)			
31 - 40 years	2 (8)	1 (33.3)	3 (75)	2 (50)
41 - 50 years	8 (34)	1 (33.3)	1 (25)	1 (25)
> 50 years	12 (50)	1 (33.3)		1 (25)
Sex				
Male	18 (75)	3 (100)	3 (75)	1 (25)
Female	6 (25)		1 (25)	3 (75)
Education level				
Attended no school	3 (12)			
Primary school level	17(71)	3 (100)	1 (25)	3 (75)
Secondary school level	4(17)		3 (75)	1 (25)
Post-secondary certificate training				
Tertiary/higher education level				
Ability to read and write				
Yes	21 (88)	3 (100)	4 (100)	4(100)
No	3 (12)			
Water source used for hygiene activities				
Tap water	4 (17)	1 (33.3)	4 (100)	3 (75)
Borehole water	10 (42)	1 (33.3)		
Streams/rivers/dams	4 (17)	1 (33.3)		
Tap water & borehole water	1 (4)			1 (25)
Borehole & streams/rivers/dams	2 (8)			
Tap water & stored rainwater	3 (12)			
Who buys most of your milk?				
Milk traders	5 (21)			
MCC	7 (29)	3 (100)		
Neighbours/individuals	10 (42)			4(100)
Milk retail shops	1 (4)			
Neighbours and retail shops	1 (4%)			
Processing company			4 (100)	
Type of farming system				
Intensive (zero-grazing)	14 (58)			
Semi-intensive (Zero + free)	6 (25)			
Extensive (Free range)	4 (17)			
No. of milking cows				
1 - 3 cows	13 (54)			
4 - 6 cows	8 (34)			
> 7 cows	3 (12)			

Customised assessment tool

The tool consists of indicators that reflect the crucial practices, from farm to retail shops (Figure 4.1), that may influence milk safety. For each indicator, four situational descriptions with a score were established (i.e., grids) describing a poor (score 1), basic (score 2), intermediate (score 3), and standard level (score 4) to differentiate the practice performance, as described in detail in (Ledo et al., 2020a).

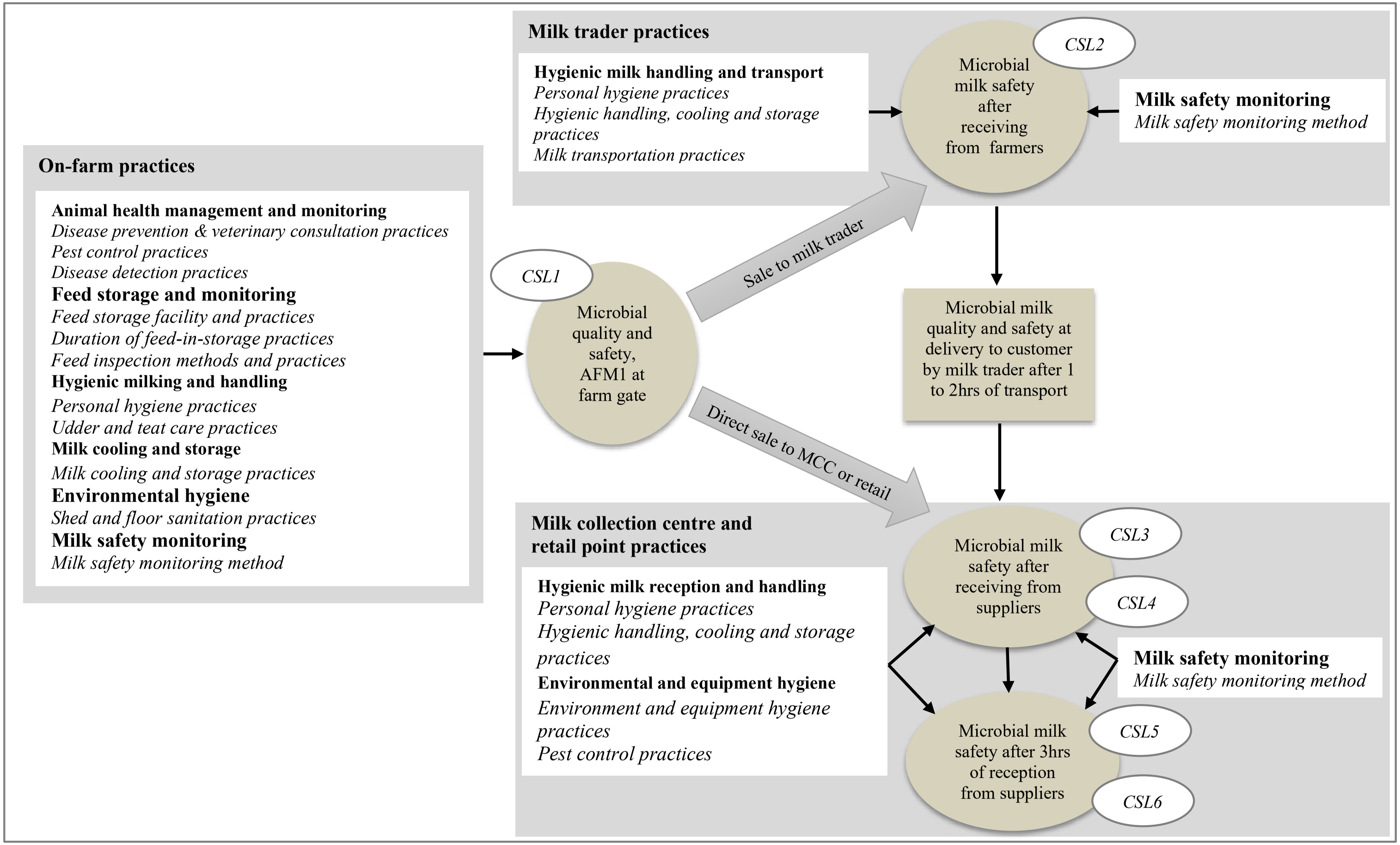

Figure 4.1 Analytical framework showing the crucial safety and hygiene control practice indicators and the critical sampling locations (CSL) along the chain.

4.2.2 Data collection approach

Questionnaire and observation checklist design

For each indicator, a set of open-ended questions were formulated to assess the performance level (and corresponding score) of the safety and hygiene control practice. The format of the open-ended question was chosen to allow respondents to detail how they perform their practices freely. Besides, an observation checklist was developed to verify the presence of cleaning and personal hygiene tools, milk handling and storage equipment, facility floor design, and extent of documentation unique to the performance of practices.

Face-to-face interviews and structured on-site observation

The face-to-face interviews and structured on-site observations were conducted for all identified respondents at the farm or the dairy business location. The scientific research approval was obtained from the Sokoine University of Agriculture, Tanzania, and written informed consent of each respondent was obtained. The questions for the face-to-face interviews were read out to respondents in their local language; their responses were written out and audio-taped at the same time. The structured on-site observation followed immediately after the interviews. On average, the visits took 1½ hours.

Milk sample collection

The fresh milk samples were collected under aseptic conditions into sterile falcon screw-capped vials of 50 ml. The samples were stored and transported to the laboratory in isolation boxes on blue ice packs at less than 4°C, consistent with the sampling technique described by Chye et al. (2004). The milk samples were transported immediately to the laboratory, stored at 0°C and further analyzed within 24 hours. Overall, 72 milk samples were collected from the dairy farmers, nine samples from milk traders, 12 samples each from the MCCs and retail points. Altogether, the sampling and analysis were done over three months covering all the study locations. Sampling details and explanation are described below.

Microbial analysis of the fresh milk

The microbial analysis was performed based on a modification of the principles underpinning microbial assessment scheme (MAS) described by Jacxsens et al. (2009). Firstly, we identified critical sampling locations (*CSL*) along the chain (Figure 4.1), which refers to points at each stage of the chain where microbial sampling provides an indication of practices performance (Jacxsens et al., 2009), as detailed in the customised tool. CSLs were identified to assess on-farm microbial quality and safety (*CSL1*), during milk trading (*CSL2*), at the MCC (*CSL3* and *CSL5*), and at the retail shops (*CSL4* and *CSL6*). Secondly, we defined microbiological parameters, to enable judgement of the level of contamination in terms of the number of bacteria present (Jacxsens et al., 2009). We assumed that low bacterial counts with small variations are evidence of well-performed practices at that stage of the chain (Jacxsens et al., 2009; Ledo et al., 2020a). Total bacteria count (TBC) was selected as an indicator of the presence of aerobic mesophile bacteria (Robinson, 2005), which are the most abundant in raw milk, thus providing insights in overall contamination.

We also selected coliforms as an indicator of environmental and hygienic handling performance (Wanjala et al., 2018), and *Staphylococcus aureus* as an indicator of udder health, hand hygiene and food safety performance (Jacxsens et al., 2009; Perin et al., 2019). All microbial parameters were analyzed at each CSL. Thirdly, a three-time sampling frequency was adopted at an interval of 7-days between samplings, to provide an insight into the microbial load profile overtime at each CSL. Finally, the sampling method and method of analysis were based on ISO standards and all the analyses were performed in the microbiology laboratory of Tanzania Official Seed Certification Institute (TOSCI). The details of the sampling method and method of analysis are described for each selected microbial parameter. Colony counts between 30 and 300 were used for calculating the number of colony-forming units (CFU) per mL of milk according to the formula, colony count = $n \times \frac{1}{V} \times \frac{1}{d}$ (ISO, 1996). Where n is the number of colonies counted per plate, V is the volume of inoculum in each plate (mL), and d is the dilution factor used to determine the colony count. The average number of the countable colonies after the incubation time of the duplicate plates was used for the calculations

Total bacterial count analysis

Total bacterial count (TBC) was enumerated, as stated by ISO 4833-1:2013 (ISO, 2013), using Plate Count Agar (PCA) prepared according to the manufacturer's direction (HIMEDIA M091, Mumbai, India). Serial dilutions of the fresh milk were made in peptone water (HIMEDIA MO28, Mumbai, India) prepared according to the manufacturer's specifications. Based on the suspected level of contamination, exactly 1 mL of 10^{-5}, 10^{-7} and 10^{-9} dilutions were pour plated with 15 mL of PCA in duplicate, allowed to set and incubated in inverted positions at 30°C for 72 hours.

Coliform analysis

The total coliform was enumerated based on the procedure described by (Wehr & Frank, 2004) using MacConkey agar consisting of 0.15% bile salts, crystal violet (CV) and sodium chloride (NaCl) (HIMEDIA M081, Mumbai, India). The MacConkey agar is a selective and differential medium to detect gram-negative bacteria. Serial dilutions of 10^{-2}, 10^{-4} and 10^{-6} were prepared based on the suspected level of contamination, 0.1 mL of each dilution was surface plated in duplicate and incubated in inverted positions at 37°C for 48 hours.

Staphylococcus aureus analysis

Staphylococcus aureus was identified and enumerated using Baird-Parker Agar (BPA) (HIMEDIA M043, Mumbai, India), as outlined by ISO 6888-1 and 2 (ISO, 1999a, 1999b). Serial dilutions of 10^{-3} and 10^{-5} of the fresh milk were spread plated and incubated at 37°C for 48 hours. Typical black colonies surrounded by clear zones and atypical colonies were picked, inoculated into 5ml Brain Heart Infusion (BHI) (HIMEDIA M210, Mumbai, India) broth prepared according to the manufacturer's specification and incubated at 37°C. After 24 hours, 0.1 ml of the enriched broth was transferred into 0.3 mL of coagulase plasma (from Rabbit) (HIMEDIA FD 248, Mumbai, India) and incubated at 37°C for another 24 hours. Clotted tubes were identified, and the presence of coagulase-positive *Staphylococcus aureus* was confirmed. Confirmed typical and atypical colonies were used to determine the count of *Staphylococcus aureus.*

Aflatoxin M1 analysis of fresh milk

The level of contamination of fresh milk samples with aflatoxin (AFM1) was determined using Aflasensor Quanti 0.5ppb-KIT078 (Unisensor, 2016). This is a rapid assay in dipstick format to visualize and quantify AFM1 without elaborate sample preparation. The kit consists of 96 dipsticks and microwells, a heat sensor DUO-APP032 for incubation and a read sensor-APP038 (Unisensor, 2016). Exactly 200 µL of fresh milk was added to one reagent microwell using a specific micropipette of 200 µL, mixed thoroughly to homogenize, placed in the heating block in the heat sensor and incubated at 25°C for 10 mins. The dipstick drops down automatically into the microwell after the first incubation time and incubates for another 10 mins at 25°C. The dipstick was observed to detect the presence or absence of AFM1 after the incubation. Positive and negative controls were used to confirm the colour changes of the dipsticks to verify presence or absence of AFM1 in the milk samples. The quantitative value was then determined by inserting the dipstick into the dipstick reader which was programmed for AFM1. The dipsticks were tailored to read actual values from the lower limit of 0.2 µg/L up to the maximum limit of 0.75 µg/L regarding the United States Food and Drug Administration (USFDA) standard. The USFDA standard of 0.5 µg/L (Iqbal et al., 2015) was preferred over the European Union (EU) standard to provide a wider spectrum for quantification of AFM1. Analyses were done in duplicate for each fresh milk sample, and the average AFM1 value was calculated.

4.2.3 Data processing and interpretation

Interview responses depicting poor, basic, intermediate and standard practice performance were assigned scores 1, 2, 3 and 4 as described in detail in Ledo et al. (2020a). The assigned scores were entered in Microsoft Excel and imported into IBM SPSS statistics version 25 for windows for descriptive statistical analysis. To determine the frequency of occurrence of AFM1 in the farm milk, the number of milk samples tested (144) with their corresponding AFM1 values were compared with the detection range of the dipstick method (0.2 µg/L to 0.75 µg/L) and with the USFDA maximum limit of 0.5µg/L. Also, to gain insight into the overall microbial quality and safety regarding TBC, coliforms and *Staphylococcus aureus* for farmers (72 samples), milk traders (9 samples), MCCs (12 samples) and local retail shops (12 samples), the log CFU/mL were calculated. These were compared with the microbiological criteria (Table 2) of the East Africa Community (EAC, 2006) and the European Union (EC, 2004; EC, 2005), and the corresponding frequencies for each parameter were determined. Hierarchical and K-means cluster analyses were performed with R version 3.5.0 using Ward's method and Euclidean distance (Kassambara, 2017) to determine the cluster number and pattern that best fitted the dairy farmers data set using the assigned scores of the safety and hygiene control practices. The mode scores for each practice was determined for both clusters and these were used to construct the spiderwebs. For each cluster, the average $\log_{10}$ CFU/mL were determined for each farmer regarding TBC, coliforms and *Staphylococcus aureus* of the three-time points. For the AFM1, the average of the three-time points was computed for each farmer of the two clusters for interpretation.

Table 4.2 Microbiological criteria for classifying fresh milk quality and safety

Microorganisms	East Africa Community (EAC) standards (EAS 67:2006)	European Union (EU) standards (Regulation (EC) No 853/2004)
	$\log_{10}$ CFU/mL	$\log_{10}$ CFU/mL
Total bacteria count (TBC)		
Grade 1	<5.3	5.0
Grade 2	5.3 - 6.0	5.6
Grade 3	6.0 - 6.3	
Beyond grade 3	>6.3	
Coliforms		
Very good	<3.0	
Good	3.0 - 4.7	
Below good	>4.7	
Staphylococcus aureus*		
Within range		4 - 5
Outside range		> 5

*We used the EU criteria for raw milk intended for cheese making (Regulation (EC) No 2073/2005).

4.3 Results and discussion

4.3.1 Occurrence of Aflatoxin M1 in farm milk

Figure 4.2 shows the occurrence of AFM1 in farm milk sampled from dairy farmers as an indication of the level of performance of feed storage and monitoring practices, and the extent of risk for the chain. Overall, the majority (63%) of the farm milk samples (91/144) were below the lower detection limit (0.2 μg/L) of the dipstick method, while 14% were between the lower detection limit and the maximum limit of the USFDA legal standard (0.5 μg/L). About 22% of the farm milk samples (32/144) exceeded the USFDA maximum limit. A previous study by Mohammed et al. (2016) in Tanzania, and Gizachew et al. (2016) in Ethiopia, also found that 16% (6/37) and 26% (29/110) respectively, of all milk samples, exceeded the USFDA maximum limit for AFM1. The majority of the milk samples were below the USFDA maximum limit of AFM1. Still, even at lower levels, AFM1 poses a risk to consumers given that processing does not remove or reduce AFM1 in milk (Roze et al., 2013). More so, long-term exposure to aflatoxins can lead to chronic health effects such as liver damage for both cows and humans (Liu et al., 2012; Wu et al., 2014). In the Tanzanian context, this is crucial as for example, Magoha, et al. (2014) found that infant growth could be impaired through the exposure of AFM1 in the breast milk of their mothers. Appropriate steps are needed to mitigate the risk AFM1 to safeguard public health.

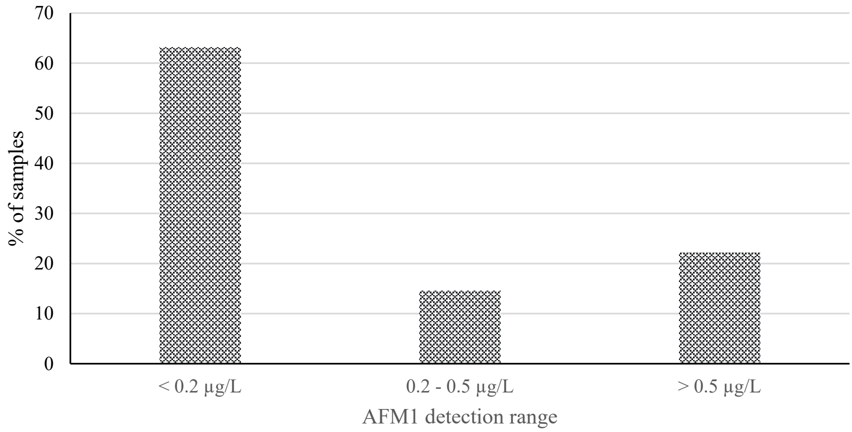

Figure 4.2 Occurrence of aflatoxin M1 in all tested farm milk samples of dairy farmers.
Milk samples (n = 72) were analysed in duplicate; Dipstick lower detection limit = 0.2 µg/L, USFDA maximum limit = 0.5 µg/L.

4.3.2 Feed storage and monitoring related practices about Aflatoxin M1 in farm milk

The performance of dairy farmers on feed storage and monitoring practices was analyzed to relate it to the occurrence of AFM1 in the farm milk samples. Cluster analysis using the scores for the feed storage facilities, feed inspection method and duration of feed-in-storage practices (Figure S1), yielded two clusters of dairy farmers. Figure 4.3 shows the spiderwebs of mode scores for these feed storage and monitoring practices (Table 4.3) and the occurrence of AFM1 of farmers in these clusters. Overall, none of the farmers performed at the standard level (score 4) for any of the practices. Nevertheless, farmers in cluster 1 performed better on feed storage and monitoring practices than farmers in cluster 2. Most of the farmers in cluster 1 performed at the intermediate level (score 3) for feed inspection method and practices, whereas for feed storage facility and duration of feed-in-storage practices, they performed at the basic level (score 2). A basic level corresponds overall with the use of basic facilities, irregular practices with oral instructions, no documentation and ad hoc data collection. In contrast, most of the farmers in cluster 2 performed at the poor level (score 1) on all feed storage and monitoring practices. A poor level overall indicates that farmers exposed feed to all weather conditions, did not separate new feed from the old feed, did not monitor storage time, did not inspect for or remove mold, and did not keep records. Underlying this low score was that most of these farmers did not have a dedicated feed storage facility, which limits temperature and moisture control when feed would be stored. The resulting exposure of feed to the temperature range of 10-40ºC and the relative humidity of about 70% (Lanyasunya et al., 2005), typical of tropical countries like Tanzania, would easily favor mold growth. Interestingly, figure 4.3 reveals that for most of the milk samples from farmers in cluster 2, the AFM1 levels were below the USFDA maximum limit (0.5 µg/L). The poor level of practices was expected to reflect in a higher occurrence of AFM1 in the farm milk. The absence of this relationship is likely because the on-site observations showed that most of these farmers took their cows to graze on the open fields and rarely used concentrates as feed. Flores-Flores et al. (2015) showed in their review that cows fed by grazing had lower AFM1 levels than those fed on concentrates. Thus, our data indicate that the mode of feeding may be more important in explaining AFM1 in milk than the performance level of feed storage and monitoring practices.

For farmers in cluster 1, intensive and semi-intensive dairy farming was the dominant systems and storing feed for the dry seasons was common, which explains their basic level performance (score 2). A basic level means that feeds are kept on raised platforms covered with plastic bags, temperature and moisture fluctuates, feeds are stored for more than six months, and without a structured system to separate new from an old feed. An intermediate level (score 3) on feed inspection method and practices may compensate for this shortfall. The farmers in cluster 1, perform weekly visual observations of the stored feed and physically remove moldy feed based on their experience. Although manually inspecting and discarding contaminated feed is a useful measure to control mold growth (Kabak et al., 2006; Golob, 2007), it can be time-consuming and not always thorough. The latter is substantiated by our finding that the AFM1 levels in several milk samples from farmers in cluster 1 exceeded the maximum USFDA limit of 0.5 µg/L with some samples being higher than 0.7 µg/L. Moreover, the variation between the three-time points was relatively large (Figure 4.3), indicating that the inconsistent performance of the practices leads to variable AFM1 levels in milk

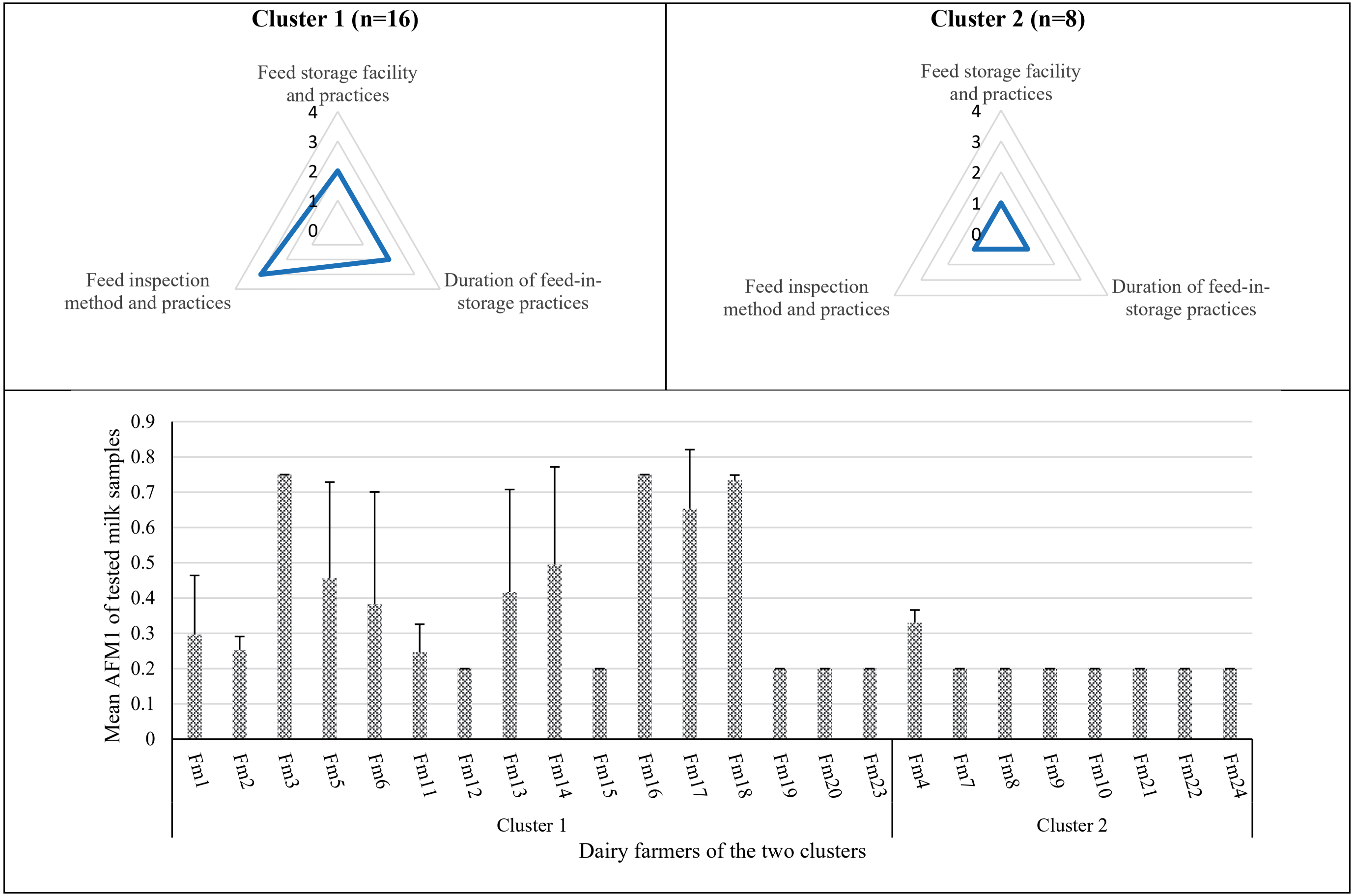

Figure 4.3 Spiderwebs depicting mode scores of feed storage and monitoring related practices of dairy farmer clusters and corresponding AFM1 concentrations detected

Table 4.3 Frequency of individual scores and mode scores for on-farm feed storage and monitoring practices

Practice indicators		Cluster 1 (n=16)					Cluster 2 (n=8)				
		1[a]	2	3	4	Mode [b]	1[a]	2	3	4	Mode [b]
Feed and feed storage practices	*Feed storage facility and practices*	4	**8**	4	0	**2**	**5**	3	**0**	0	**1**
	Duration of feed-in-storage practices	3	**11**	2	0	**2**	**4**	**4**	0	0	**1***
Feed-in-storage monitoring	*Feed inspection method and practices*	**1**	5	**10**	0	**3**	8	0	**0**	0	**1**

[a] Scores representing; 1 – Poor level, 2 – Basic level, 3 – Intermediate level, 4 – Standard level
[b] The mode represents the most frequent score among the farmers in each cluster
*Bimodal situation and we used the lower score for the spiderweb

Nevertheless, the AFM1 concentrations in milk samples of some farmers in this cluster were at the lower detection limit (0.2 µg/L), suggesting that additional factors such as the amount of AFB1 ingested from the contaminated feed and the carryover of AFM1 into the milk could have contributed to the pattern seen. Several studies (Battacone et al., 2009; Xiong et al., 2015; Gonçalves et al., 2017) have demonstrated the direct relationship between the amount of AFB1 intake in naturally contaminated concentrate feed and the occurrence of AFM1 in dairy farm milk. While our study could not be conclusive on the actual intake of contaminated feed concerning the occurrence of AFM1 in milk, the variability in AFM1 levels does demonstrate the complexity of AFM1 contamination in farm milk. Thus, awareness of these underlying factors and progression on all feed storage and monitoring practices to the 'standard level' is necessary for farmers that store feed.

4.3.3 Microbial load of fresh milk samples along the chain

Figure 4.4 shows the classification of microbial load of the milk samples over the three-time points for TBC, coliforms and *Staphylococcus aureus* as an indication of milk quality and safety along the chain. Overall, most of the milk samples exceeded the maximum microbial limit (grade 3) for TBC and over 70% were over the maximum limit for coliforms according to the East Africa Community (EAC) standard for all the chain actors (Figure 4.4). This is consistent with the study of Ngasala et al. (2015) in Tanzania, who reported that 91% of fresh milk samples analyzed across the milk chain, exceeded the maximum limit for TBC. Likewise, other studies reported that up to 60% of fresh milk samples exceeded the maximum limit for TBC at the farm (Nonga et al., 2015; Gwandu et al., 2018). Also, a study by Swai and Schoonman (2011) reported that 83% of fresh milk samples were over the maximum limit for coliforms along the milk chain in Tanzania, which is comparable with the findings of our study. The high microbial load of milk samples over the maximum limit at all stages of the chain compares closely with other emerging dairy chains, like in Bangladesh (Islam et al., 2018) and Rwanda (Kamana et al., 2014). Collectively, the high TBC and coliforms load indicates poor production, handling and environmental hygiene practices (Perin et al., 2019). For *Staphylococcus aureus*, more than half of the tested samples from milk traders, MCCs and local retail shops were above the limit of the E.U. standard, whereas this was slightly below half for the farmers (Figure 4.4). This corresponds to 33% of milk samples that were found to be contaminated with *Staphylococcus aureus* over the maximum E.U. limit in a study by Ngasala et al. (2015) in Tanzania. These results imply that the risk for consumers is persistently high, as direct sale of raw milk is prevalent in the Tanzanian dairy chain. Moreover, poor microbial quality can significantly alter the composition, quality and yield of processed dairy products, such as cheese (Murphy et al., 2016; Velázquez-Ordoñez et al., 2019), thus leading to losses if milk would be further processed in a formal production chain.

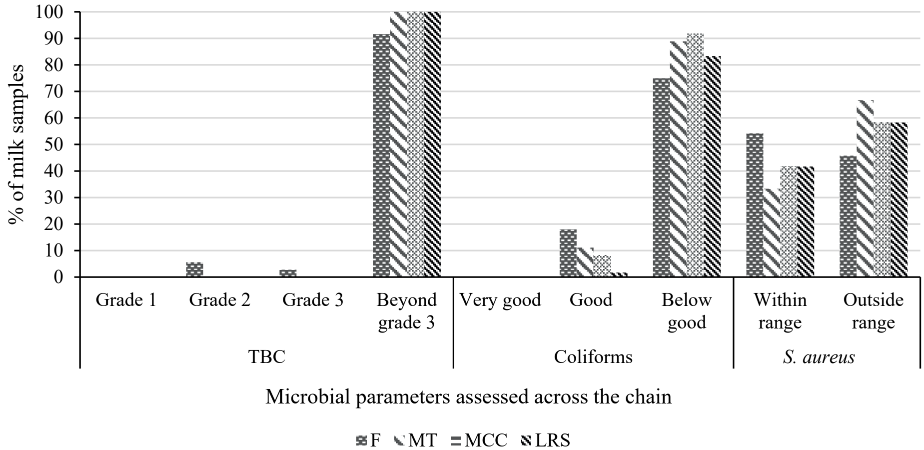

Figure 4.4 Classification of microbial contamination of milk samples taken over three-time points along the dairy chain
TBC (EAC): Grade 1: <5.3 $\log_{10}$ CFU/mL, Grade 2: 5.3 – 6.0 $\log_{10}$ CFU/mL, Grade 3: 6.0 – 6.3 $\log_{10}$ CFU/mL, Beyond grade 3: >6.3 $\log_{10}$ CFU/mL; **Coliforms (EAC)**: Very good: 0-3.0 $\log_{10}$ CFU/mL, Good: >3.0 – 4.7 $\log_{10}$ CFU/mL, Below good: >4.7 $\log_{10}$ CFU/mL; ***S. aureus* (EU):** Within range: 4 – 5 $\log_{10}$ CFU/mL, Outside range: >5 $\log_{10}$ CFU/mL; **F**: farmers (n = 72 samples), **MT**: milk traders (n = 9 samples), **MCC**: milk collection centers (n = 12 samples), **LRS**: local retail shops (n = 12 samples)

4.3.4 On-farm safety and hygiene control practices and microbial load of farm milk

A cluster analysis was performed with the scores for on-farm safety and hygiene control practices and the microbial data of farm milk to gain insight into possible relations between the level of practices and microbial load (Figure S2). The hierarchical cluster analysis yielded two distinct clusters of farmers. Figure 4.5 shows the spiderweb profiles made of the mode scores of farmers' control practices for the two clusters. Overall, the dominant low levels (scores 1 and 2) of dairy farmers' safety and hygiene practices in both clusters reflect that rudimentary practices commonly reported in previous studies related to developing countries (Kamana, et al., 2017; Islam, et al., 2018; Ledo, et al., 2019), still persevere.

However, obvious differences can be seen for the udder and teat care, and disease detection practices of the two clusters where farmers in cluster 1 performed mainly at the poor level (score 1) compared to the intermediate level (score 3) for farmers in cluster 2. Poor performance on the udder and teat care implied no adherence to pre-/post-milking routines where the calves suckle on the teats without cleaning before milking. Also, no fore-stripping, no California Mastitis Test (CMT), and no records for diseases identified or treated depicts disease detection practices of similarly poor performance (Ledo et al., 2020a). Good dairy production measures are lacking, which magnifies cow health and microbial risks. For farmers in cluster 2, the intermediate performance on the same practices indicates that the type of equipment used, the actual practices, documentation of protocols and data are much better but still not compliant with the 'standard level'. For instance, they apply fore-stripping and teat cleaning with a dedicated towel to clean the udder and teats; however, they do not apply post-dipping. Incomplete records on disease detection and treatment are kept, while the California Mastitis Test is sometimes, but not always, performed to identify subclinical signs of mastitis. Yet, the absence of post-dipping, particularly when shed and floor sanitation, and personal hygiene practices are performed at a poor level (score 1), can expose the cows to mastitis and microbial risks (Klostermann et al., 2010; Baumberger et al., 2016).

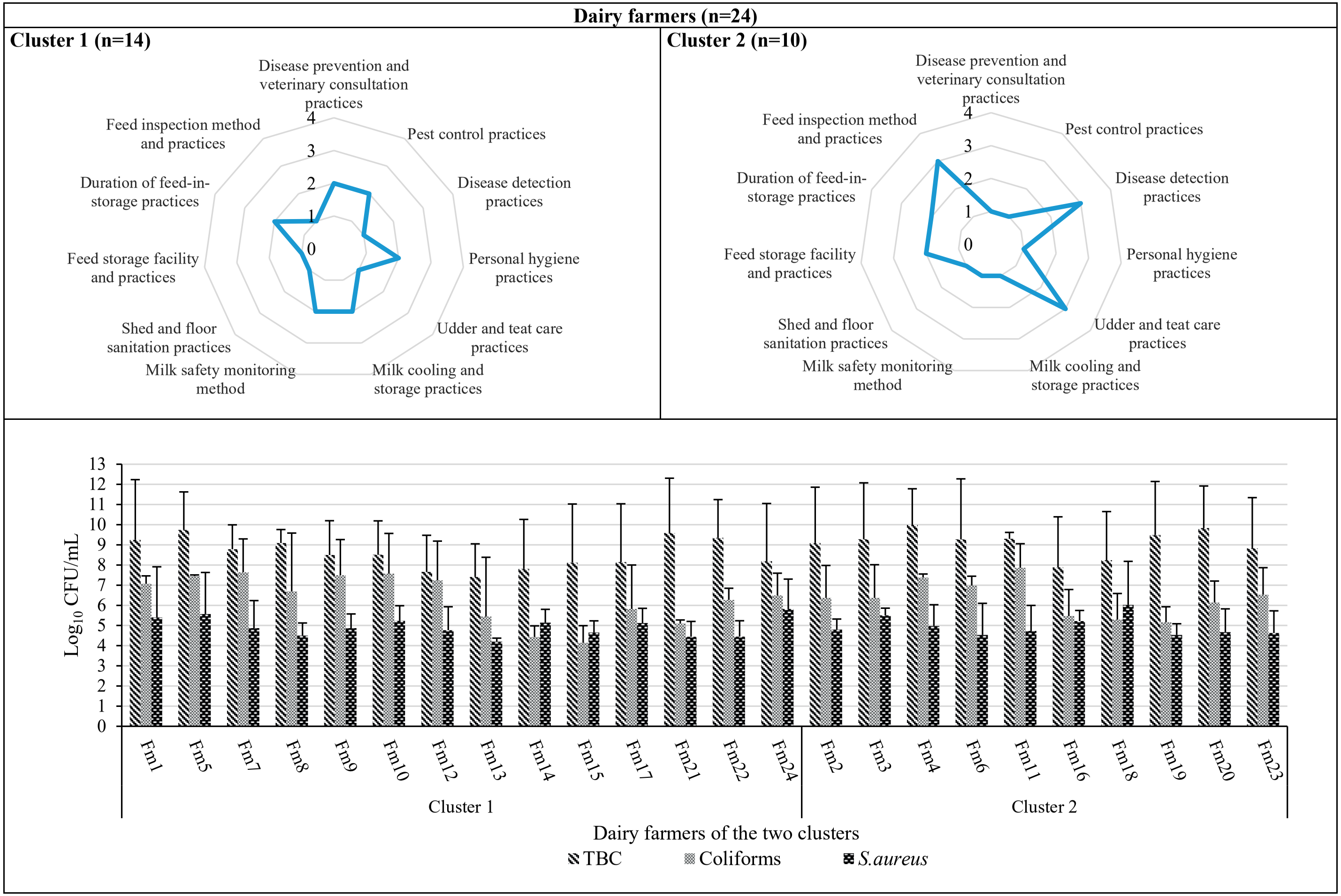

Figure 4.5 Spiderweb depicting mode scores of on-farm safety and hygiene control practices and the corresponding microbial load for the two clusters

The microbial data of both clusters indicate that the average counts were over the maximum limits for TBC (> 6.3 log_{10} CFU/mL) and coliforms (> 4.7 log_{10} CFU/mL) according to the EAC criteria (Figure 4.5). Furthermore, the average counts of *Staphylococcus aureus* were close to the maximum limit (5 log_{10} CFU/mL) according to the E.U. criteria, and these levels were equally high for both clusters. The high TBC (Cluster 1: 8.5 log_{10} CFU/mL; Cluster 2: 9.1 log_{10} CFU/mL), and high level of coliforms (Cluster 1 and 2: 6.3 log_{10} CFU/mL) and high counts for *Staphylococcus aureus* demonstrated that the poor dominating safety and hygiene practices created avenues for microbial contamination as demonstrated in several previous studies (Elmoslemany et al., 2009; Mhone et al., 2011; Tolosa et al., 2016). For instance, coliforms in farm milk have been associated with poor shed and floor sanitation practices that can lead to fecal contamination (Belbachir et al., 2015; Wanjala et al., 2018). Also, the prevalence of *Staphylococcus aureus* in the farm milk is indicative of its possible presence in the udders of the dairy cow (Viguier, et al., 2009; Abebe et al., 2016) and an indication of inadequate hygiene practices during milking (Perin et al., 2019). However, the observed differences in the performance of practices between farmers in cluster 1 and 2, were not reflected in clear differences in the microbial load. Small transitions from the low to basic to intermediate level are not sufficient to substantially improve the microbial safety of milk. Progress to the standard level should thus be the minimum level aimed for. Nevertheless, the farmers in cluster 2 that perform the udder and teat care, and disease detection practices at the intermediate level are at a better position to advance towards the standard level.

4.3.5 Safety and hygiene control practices and microbial load of fresh milk along the chain

Table 4.4 shows the mode scores of the safety and hygiene control practices of the actors and Figure 4.6 shows how the microbial load in the milk, directly from the farm, evolved along the dairy chain. Overall, the microbial load of all fresh milk samples exceeded the maximum limit for TBC and coliforms and *Staphylococcus aureus* levels were equally high. For all actors, the scores for safety and hygiene control practices were below 4, so none of them performed according to international requirements (i.e. the standard level). Most practices were dominated by a poor (score 1) to a basic level (score 2), except for milk safety monitoring method and personal hygiene practices at the milk collection centers (Table 4.3).

Table 4.4 Mode scores of safety and hygiene control practices along the dairy chain

Practice indicators	Farmers (n=24)[a]										Milk traders (n=3)[a]					MCC (n=4)[a]					Local retail shops (n=4)[a]				
	Cluster 1 (n=14)					Cluster 2 (n=10)																			
	1	2	3	4	Mode	1	2	3	4	Mode	1	2	3	4	Mode	1	2	3	4	Mode	1	2	3	4	Mode
Practices exclusive to the farm																									
Disease prevention and veterinary consultation practices	2	12	0	0	**2**	6	**4**	0	0	**1**															
Disease detection practices	**8**	3	3	0	**1**	**1**	3	**6**	0	**3**															
Feed storage facility and practices	**8**	6	0	0	**1**	1	**5**	4	0	**2**															
Duration of feed-in-storage practices	6	**8**	0	0	**2**	1	**7**	2	0	**2**															
Feed inspection method and practices	7	3	**4**	0	**1**	2	2	**6**	0	**3**															
Udder and teat care practices	10	4	0	0	**1**	4	0	**6**	0	**3**															
Practices performed by all actors in the chain																									
Personal hygiene practices	0	**13**	1	0	**2**	**5**	0	5	0	**1***	1	**2**	0	0	**2**	0	1	**3**	0	**3**	0	**2**	**2**	0	**2***
Milk safety monitoring method	1	**13**	0	0	**2**	**9**	0	1	0	**1**	**1**	**1**	**1**	0	**1***	0	2	**2**	0	**2**	**4**	0	0	0	**1**
Hygienic milk handling, cooling and storage practices	1	**11**	1	0	**2**	**6**	**0**	4	0	**1**	**2**	1	0	0	**1**	1	**2**	1	0	2	**2**	**2**	0	0	**1***
Practices exclusive to some actors in the chain																									
Pest control practices	6	**8**	0	0	**2**	9	**1**	0	0	**1**						**4**	0	0	0	1	**2**	**2**	0	0	**1***
Shed and floor sanitation/ Environmental and equipment hygiene practices	8	**3**	3	0	**1**	**6**	0	4	0	**1**						0	**3**	1	0	2	0	**2**	**2**	0	**2***
Milk transportation practices											**2**	1	0	0	**1**										

[a] MCC=milk collection centre; 1=Poor level, 2=Basic level, 3=Intermediate level 4=Standard level

*Bimodal distribution; we used the lower scores for the discussion.

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The intermediate level (score 3) for milk safety monitoring method, implies that standardized tests are performed whereas the Resazurin test for bacteria presence is limited. For personal hygiene, it indicates that a dedicated facility for hand hygiene exists, handwashing occurs before and after milk handling, but work protocols are not described completely. Because the MCCs are involved in bulking milk for onward transfer to dairy processors, these practices are performed at a higher level to meet their quality demands. However, these measures are not sufficiently comprehensive. For instance, we observed that some cooling tanks missed an available or calibrated thermometer at the MCCs. While containers used by traders and retail shops for storage of fresh milk lacked hygienic design with wide necks and stainless steel for proper cleaning. Also, a poor level (score 1) for milk transportation practices indicates that the transport vehicle used by milk traders is not clean and cannot maintain a specific low temperature during transportation. A rapid increase in microbial load is inevitable as there is no control of temperature. This limited proper transportation is characteristic of milk traders in Tanzania (Schoder et al., 2013; Gwandu et al., 2018) and in other emerging dairy chains, such as Gambia (Washabaugh et al., 2019) and Ethiopia (Tolosa et al., 2016).

Figure 4.6 shows that even though the microbial load of the farm milk was already high, it remained stable in the milk samples taken across the other actors in the chain. The observation in this study differs from other studies in Tanzania (Swai & Schoonman, 2011; Schoder et al., 2013; Nonga et al., 2015) and other emerging dairy chains (Millogo et al., 2010; Kamana et al., 2014; Islam et al., 2018), which showed amplification of microbial load beyond the farm. The high contamination level at the farm may have created a limiting effect for further rapid bacterial proliferation (Quigley et al., 2013; Li et al., 2018), which may explain why there is no further increase even though the safety and hygiene practices were performed below the 'standard level'.

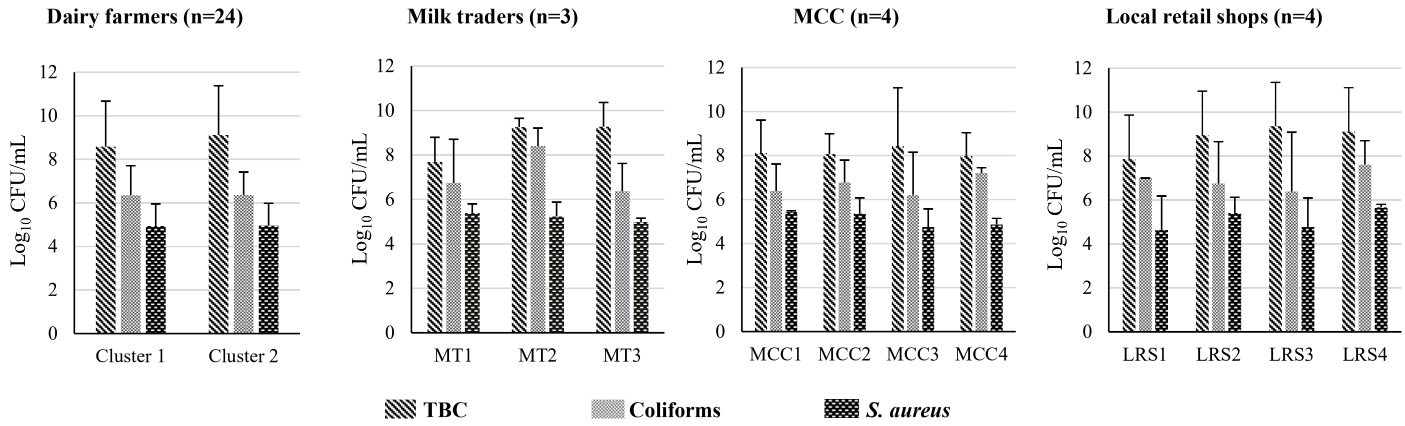

Figure 4.6 Microbial milk quality and safety along the dairy chain

MT = Milk traders, MCC = Milk collection centres, LRS = Local retail shops; TBC (EAC): Grade 1: <5.3log$_{10}$ CFU/mL, Grade 2: 5.3 – 6.0 log$_{10}$ CFU/mL, Grade 3: 6.0 – 6.3 log$_{10}$ CFU/mL, Beyond grade 3: >6.3 log$_{10}$ CFU/mL; Coliforms (EAC): Very good: 0 – 3.0 log$_{10}$ CFU/mL, Good: >3.0 – 4.7 log$_{10}$ CFU/mL, Below good: >4.7 log$_{10}$ CFU/mL; *S. aureus* (EU): Within range: 4-5 log$_{10}$ CFU/mL, Outside range: >5 log$_{10}$ CFU/mL

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4.4 Conclusions

In this study, we demonstrated that differences in low and basic levels of safety and hygiene control practices performed did not translate into clear distinctions in milk quality and safety along the chain. The microbial load in milk samples at the farm, as well as along the chain, remained stable even though their safety and hygiene practices were also below the standard level. The transition in multiple practices towards the standard level should be aimed for to achieve a significant reduction in the occurrence of AFM1 and microbial contamination in milk as improvement in isolated practices do not seem to translate into significant outcomes in milk quality and safety. Nevertheless, practices performed at the intermediate level are at a better position to advance towards the standard level. Further research into appropriate interventions to help farmers and chain actor's progress toward the standard level is necessary.

Acknowledgement

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Supporting information

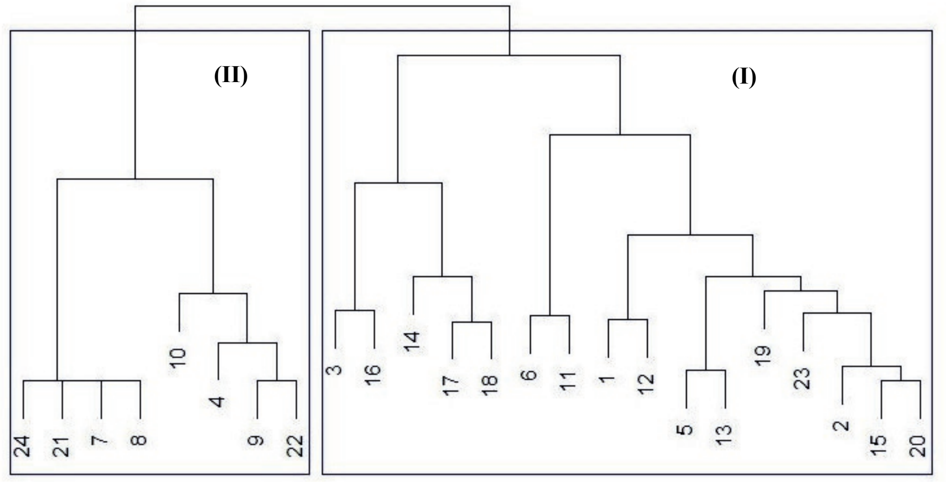

Figure S1 Hierarchical clusters for feed storage and monitoring practices, and AFM1 concentrations of farm milk. (I) Cluster 1 and (II) Cluster 2

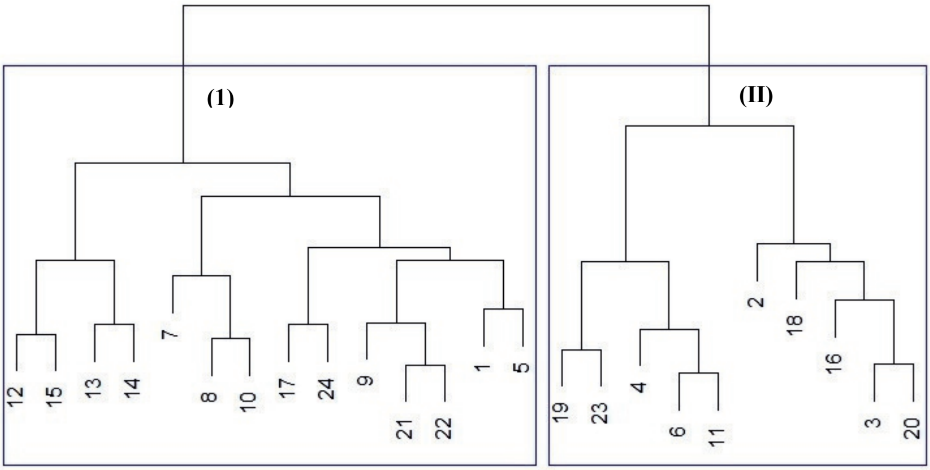

Figure S2 Hierarchical cluster analysis for all on-farm safety and hygiene control practices, and microbial load of farm milk. (I) Cluster 1 and (II) Cluster 2

Chapter 5

A tailored food safety and hygiene training approach for dairy farmers in an emerging dairy chain: The example of Tanzania

Submitted as: *Ledo, J., Hettinga, K. A., Bijman, J., Kussaga J.A., & Luning, P. A. A tailored food safety and hygiene training approach for dairy farmers in an emerging dairy chain: The example of Tanzania.*

Abstract

Improvement in the knowledge level of dairy farmers and the performance of on-farm safety and hygiene practices in emerging dairy chains is repeatedly recommended. However, appropriate training interventions to help farmers is not yet fully explored. Behaviour change theories to design training to improve knowledge and explore drivers of safety and hygiene control performance have been found useful in food service settings, but were not yet tested in dairy farming. This study aimed to develop a training intervention based on the theory of planned behaviour (TPB) and analyze its effectiveness in influencing drivers of dairy farmers' behaviour to perform safety and hygiene control practices. Three teaching and learning methods were adopted: 1) slides and group discussions, 2) videos, pictures and story analysis, and 3) practical demonstrations. A total of 107 dairy farmers participated in a three-day training programme. Measuring at pre-training and post-training, we found that the knowledge level of most farmers improved. The number of farmers with a positive intention to perform specific pre- and post-milking practices such as hand washing, teat dipping, cleaning the shed, and milk storage in clean containers was higher post-training. Multiple linear regression analysis of the TPB model explained 25% of the variance of the intention to perform personal hygiene, 18% of udder and teat care, 10% of the shed and floor sanitation, and 16% of milk cooling and storage practices. Also, the perceived pressure from others was a significant predictor of the intention to perform personal hygiene, udder and teat, and shed and floor sanitation practices.

5.1 Introduction

The implementation of food safety and hygiene measures throughout the dairy chain is a major priority to mitigate the risk of foodborne hazards in dairy products. However, persisting challenges in the performance of safety and hygiene control practices characterize emerging dairy chains (Kussaga et al., 2015; Kamana et al., 2017; Amenu et al., 2019; Ledo et al., 2019). Moreover, human resource and capacity constraints, loose relationships between chain actors, and underdeveloped technologies in the production and distribution system challenge the potential to enlarge dairy production (Makoni et al., 2014; Hoffmann et al., 2019). Consequently, dairy products are characterized by a risk of high bacterial load (Kamana et al., 2014; Islam et al., 2018; Washabaugh et al., 2019) and aflatoxin M1 occurrence (Flores-Flores et al., 2015; Iqbal et al., 2015). In a previous study, we applied a customised tool to precisely assess the practice performance of chain actors in Tanzania (Ledo et al., 2020a; Ledo et al., 2020b). We found gaps in farmer knowledge related to milk cooling, personal and environmental hygiene, as reflected in the sub-standard performance of the assessed hygiene practices. Moreover, we observed that differences in the level of safety and hygiene practices of groups of farmers did not translate into differences in milk safety and quality parameters, because the practices were universally performed below international standards. This emphasizes that dedicated training may be needed to improve farmers' knowledge and attitude towards their hygiene practices, which may subsequently lead to improved milk quality and safety.

In developing countries, different training approaches such as the training and visits (T&V), and farmer field schools (FFS) typify the transfer of knowledge and skills in agricultural food chains to farmers (Anderson & Feder, 2007). The T&V is a top-down approach, where extension staff transfers knowledge to a contact farmer, who then leads the dissemination of knowledge to other farmers (Anderson & Feder, 2007). On the other hand, FFS are a bottom-up, participatory, hands-on learning and collective decision-making approach by farmers to generate solutions to specific farming challenges, with support of a trained facilitator (Duveskog et al., 2011). Participatory activities of FFS have helped dairy farmers gain knowledge and skills on specific topics, such as milk production, animal health, and marketing (Vaarst, 2007). However, the usefulness of this FFS approach is contested, with some studies demonstrating improvement in farmers food security, adoption of new technology, and improvement in yield (Braun et al., 2006; Vaarst et al., 2007; Davis et al., 2012; Diab, 2015; Stewart et al., 2015), whereas others have expressed concerns about the lack of evidence of its long term impact (Van den Berg & Jiggins, 2007; Waddington et al., 2014).

There is growing evidence in foodservice operations that using behaviour change theories to underpin the design and implementation of training interventions is effective, as they help to target underlying behaviours (i.e., attitude, norm and self-efficacy) necessary to perform safety and hygiene practices (Prestwich et al., 2015; Young et al., 2018). But in farm settings, there is yet the limited application of such theories in developing training interventions, addressing drivers of behaviour towards the performance of specific farm practices. Nevertheless, a study by Soon and Baines (2012), which used the theory of planned behaviour to develop training materials and investigated handwashing intention of fresh produce farmworkers, demonstrated improvements in knowledge and provided clarity into underlying barriers to handwashing.

To our knowledge, applying a behaviour change theory as a basis to design and implement training interventions for dairy farmers tailored for safety and hygiene control practice improvement is still unexplored. Therefore, we aimed to develop a training intervention based on the theory of planned behaviour (TPB) and analyzed its effectiveness to influence drivers of behaviour of dairy farmers' safety and hygiene control practices. The structure of the paper is as follows. Firstly, we present behaviour change theories for food safety and hygiene training as a theoretical basis for the design and implementation of the training. Secondly, we present the choice of educational materials, the design of the tailored training, and the implementation of the actual training. Finally, we assess the effectiveness of the training.

5.2 Theoretical framework underlying training intervention

Figure 5.1 shows the theoretical framework developed for the design and implementation of a tailored training intervention for dairy farmers in an emerging dairy chain. The framework was developed based on the principles of the techno-managerial research approach, the food hygiene training model, and the theory of planned behaviour (Ajzen, 1991; Luning & Marcelis, 2006; Seaman, 2010; Ajzen et al., 2011). The techno-managerial research approach was used to enable a concurrent analysis of the interplay between technological and people-related factors that can influence food quality and safety (Luning & Marcelis, 2006). The approach better explains the variability arising from manual handling practices coupled with different levels of underdeveloped technologies which dominate on-farm milk production activities in emerging dairy chains (Makoni et al., 2014; Islam et al., 2018; Ledo et al., 2019).

The framework shows the integration of the teaching and learning process with the targeted behavioural drivers using the theory of planned behaviour. We underpinned the teaching and learning process with the definition of training by Salas et al. (2012), which is the planned and systematic activities designed to promote the acquisition of knowledge, skills and attitudes. We postulate, based on Salas and Cannon-Bowers (2001), that training would boost an individual's competence to perform a behaviour. We adapted the food hygiene training model of Seaman (2010) as a guide to identifying training needs, defining learning objectives, determining teaching and learning methods, designing the training programme, and assessing the training effectiveness.

According to Conner and Norman (2005), behaviour change theories provide a basis to explain the underlying intrinsic (i.e., sociodemographic, personality, self-efficacy) and extrinsic (i.e., social incentives and restrictions) factors, which influence an individual's behaviour. We adopted the theory of planned behaviour (TPB) because is it widely used in designing and implementing food safety and hygiene training interventions (Mullan & Wong, 2010; Young et al., 2018), and because of its reliability to predict the variation in behavioural intention and actual behaviour (Ajzen, 1991; Shapiro et al., 2011; Young et al., 2018). Moreover, it provides a clear structure to evaluate the effectiveness of interventions targeted at food safety and hygiene behaviour change (Mullan & Wong, 2010). Overall, TPB outlines that the intention to perform a behaviour, and the perceived behavioural control, i.e., the individual's perceived ease or difficulty to perform the behaviour, determines an individual's actual behaviour (Ajzen, 1991). Ajzen (1991) also asserts that the intention to perform a behaviour is a function of the attitude, i.e., the overall disposition to perform the behaviour, subjective norm, i.e., the perceived pressure from significant others to perform the behaviour, and the perceived behavioural control.

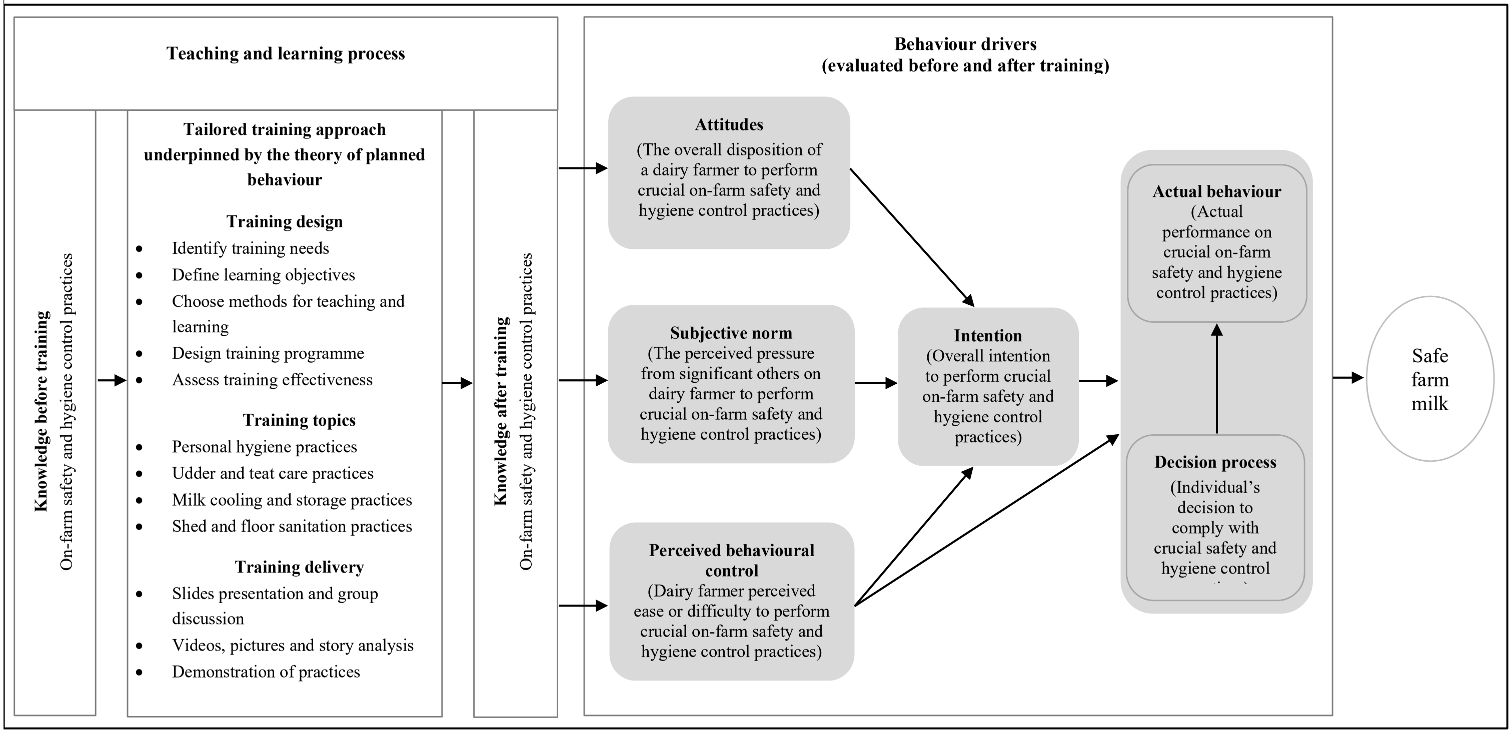

Figure 5.1 Theoretical framework of the tailored training intervention integrating the knowledge transfer process and the behaviour drivers of the theory of planned behaviour concerning on-farm safety and hygiene practices (adapted from Ajzen (1991) and Seaman (2010))

We used the underlying attitudes, subjective norm, perceived behavioural control and intention to perform safety and hygiene practices on the farm to formulate questions for assessing the knowledge of dairy farmers before, during and after the training. Furthermore, the learning objectives and mode of training delivery were formulated and developed, respectively, based on the underlying drivers of behaviour. Ultimately, the framework shows that appropriate knowledge received through effective teaching and learning processes will trigger positive attitudes, subjective norm and perceived behavioural control, which can all stimulate strong intentions to perform crucial on-farm safety and hygiene practices.

5.3 Materials and methods

5.3.1 Training design approach

Our approach in designing the training design involved identifying training needs, defining learning objectives, choosing methods of teaching and learning, designing the training programme, providing the actual training, and assessing the effectiveness of the training.

Identification of training needs

Identification of training needs was performed as a starting point for the design, according to provisions in the food hygiene training model by Seaman (2010), since it informs trainers about the important needs of trainees. For our study, we determined the training needs using previous studies, which differentiated dairy farmers in Tanzania according to the level eleven on-farm safety and hygiene control practices were performed (Ledo et al., 2020a; Ledo et al., 2020b). To determine the relevant practices to focus on for the training, we used the following criteria: 1) the selected safety and hygiene practices were within the control of the dairy farmers, 2) they reduce microbial sources, transmission and growth on the farm, and 3) the implementation does not involve additional personal cost to participating dairy farmers. Based on these criteria, personal hygiene, udder and teat care, milk cooling and storage, and shed and floor sanitation practices were selected. To determine whether the selected practices aligned with the needs of the participating farmers, statements were generated related to the selected practices. The farmers had to rank the importance of the practice as expressed in each statement on a 5-point Likert scale (i.e., 1=not important, 2=slightly important, 3=somewhat important, 4=important and 5=very important) (Figure S1).

Defining learning objectives

According to Stacy and Freeman (2016), defining training objectives clarifies the purpose of teaching and learning, and helps to evaluate the success of the training intervention after implementation. Seaman (2010) stressed that training objectives related to food safety and hygiene need to be given careful consideration, as participants are bound to devalue the teaching and learning process if the objectives do not align with their work. Therefore, we defined the following main learning objectives: 1) to enhance dairy farmer's knowledge on crucial on-farm safety and hygiene practices, 2) to provide knowledge that may trigger changes in attitude, subjective norm and perceived behavioural control, and 3) to enhance behavioural intention to perform on-farm practices according to international standards, which is not commonly reached in emerging dairy chains (Ledo et al., 2020b).

Methods for teaching and learning

We adopted three methods for teaching and learning: 1) slides presentation and group discussions, 2) videos, pictures and story analysis, and 3) practical demonstrations. Our choice of methods was based on studies (Molenda, 2003; Hamilton & Tee, 2016) that had demonstrated that understanding of individuals improves when teaching involves a combination of methods with a transition from verbal towards visual and doing. The content of each method for teaching was formulated using a manual that was developed based on international and regional standards (CAC, 2004; Kurwijila, 2006; FAO & IDF, 2011; Goopy & Gakige, 2016) and covering the four selected safety and hygiene practices. The methods were implemented using a classroom-style interactive training, as it enables many participants to engage at the same time at a relatively limited cost (Dipietro, 2006) with the opportunity to learn at their own pace and through sharing experiences (Birkenholz, 1999; Johnson et al., 2008). The training was facilitated by an experienced instructor (Duveskog et al., 2011).

Slides presentation and group discussions

The slides covered the four-selected safety and hygiene practices (i.e., shed and floor sanitation, milk cooling and storage, udder and teat care, and personal hygiene). The slides were prepared in simple, non-technical English language (Jacob et al., 2010), translated into Swahili, the local language of participants, and validated by two experts familiar with the content and the local language. Each presentation session took a maximum of 15 minutes. Before each presentation, group discussions by four to five members enabled the dairy farmers to discuss among themselves the influence of the selected on-farm practices on milk quality and safety. Each group elected one person to present their findings to the whole group after 25 to 30 minutes of discussion. The group discussions were used to stimulate collective learning and promote positive intentions towards behavior change (Jackson-Davis et al., 2015).

Videos, pictures and story analysis

Videos, pictures and stories were prepared for the four selected practices. The videos were prepared in Swahili by the researchers using the manager of the Sokoine University of Agriculture dairy farm as the instructor. The videos covered general knowledge and requirements on the health status of the milker as an important step before milking, the importance of hand hygiene before and after milking, and appropriate hand washing steps. Other videos showed udder and teat care practices before and after milking, milk cooling, and proper handling of milk storage containers. YouTube videos, produced by the smallholder dairy commercialization programme (SDCP) and specific for dairy farming in developing countries, were used to demonstrate shed and floor sanitation practices (see references for link). These videos were meant to create awareness, on-farm safety and hygiene practices (Martin et al., 1999; Mathiasen et al., 2012).

Furthermore, pictures were used on specific aspects of personal hygiene, milk cooling and storage, udder and teat care, and shed and floor sanitation practices, to reinforce knowledge gained through the videos. These pictures were obtained from different sources such as Google pictures and the FrieslandCampina dairy development program. Two stories were written by the researchers to enhance understanding, trigger group learning and interaction (Adamson et al., 2006; Banks, 2012). The stories were read out by the facilitator and analyzed by the participants. After the interaction, the facilitator emphasized the key learning points from the stories, to reinforce expected behaviour.

Practical demonstrations

Practical demonstration sessions were included as an active learning experience to create a real-life experience for the farmers by doing (Nicol et al., 2009; Grossman et al., 2013). All farmers participated in practical sessions with demonstrations on appropriate hand washing steps using a handheld ultraviolet

(UV) light and Glogerm gel, the impact of different environmental temperatures on milk cooling, and strip cup test and teat dipping on the udder and teat care.

Training programme

Figure 5.2 shows an overview of the training programme. A three-day training programme was adopted using one of the teaching and learning methods for each day, and each method covered all the four-selected safety and hygiene practices. We based this approach on the premise that consistent communication of food safety messages is effective in inducing a change in behaviour (Jacob et al., 2010; Chapman et al., 2011). Overall, each day took five and a half hours with three 10 mins breaks and one lunch break of 50 mins. The first day began with a pre-assessment of knowledge and all drivers of behaviour. As part of the first day, we presented the outcome of the previous studies conducted by the researchers in the same area of the training. On subsequent days, we performed an assessment of knowledge and a recap of key learning points of the previous day to start the day, while a summary of key learning points was provided at the end of each training day. At the end of the third day, a "bring it all together session" was conducted as self-reflection for participants to identify collective improvement steps towards on-farm safety and hygiene practices. After that, we performed a post-training assessment on knowledge and all the behaviour drivers.

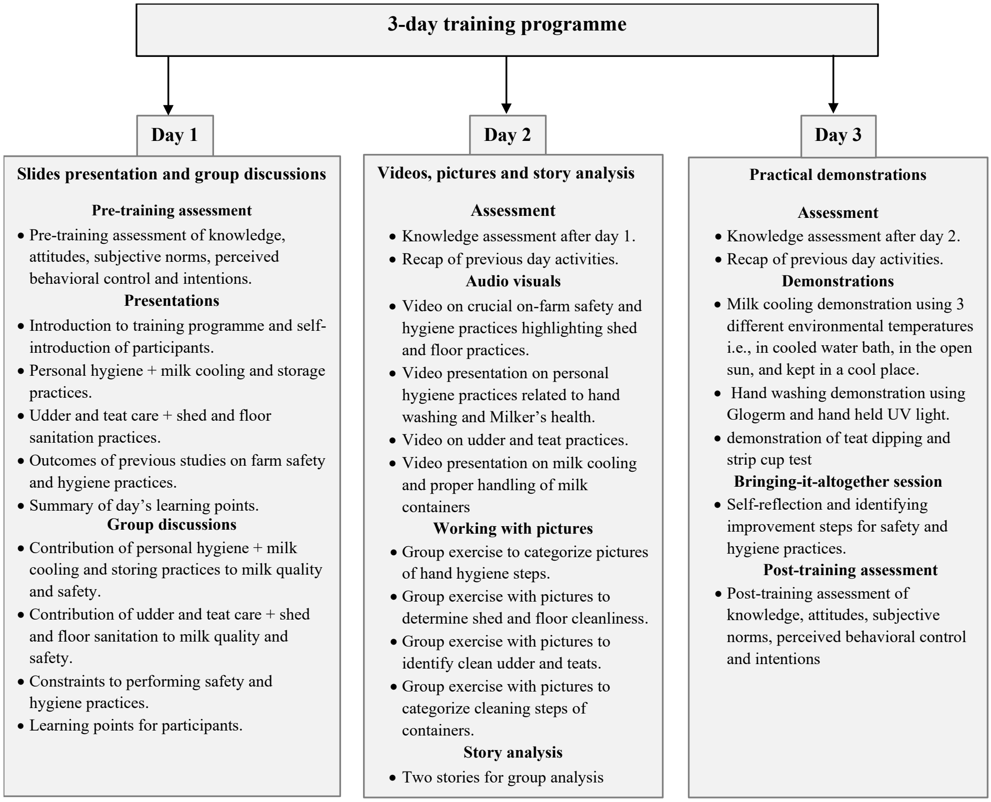

Figure 5.2 Overview of the training programme

The actual training

Selection and characteristics of participants

The training was implemented in Mvomero and Lushoto districts of Tanzania, which have been the sites of previous studies conducted by the researchers (Ledo et al., 2019; Ledo et al., 2020a). Farmers were contacted through the village livestock officers of Manyinga and Wamidakawa in the Mvomero district and those of Mwangoi and Ngulwi in the Lushoto district. Priority was given to farmers who participated in the previous studies, while other farmers were also contacted and accepted to participate once they demonstrated interest. Overall, 107 dairy farmers participated in the training, 35 from Manyinga, 36 from Wamidakawa, 18 from Mwangoi, and 18 from Ngulwi. Most of the farmers were over 40 years, had up to primary level education, were able to read and write, and had never participated in any training (Table 5.1).

Table 5.1 Background information of training participants

Characteristics of respondents	Farmers (n=107) n (%)
Participants at training sites	
Manyinga	
Group 1	18 (16.8)
Group 2	17 (15.9)
Wamidakawa	
Group 3	17 (15.9)
Group 4	19 (17.8)
Mwangoi	
Group 5	18 (16.8)
Ngulwi	
Group 6	18 (16.8)
Age	
Less than 20 years	2 (1.9)
21 to 30 years	18 (16.8)
31 to 40 years	23 (21.5)
41 to 50 years	21 (19.6)
More than 50 years	43 (40.2)
Sex	
Male	61 (57.0)
Female	46 (43.0)
Level of education	
Attended no school	21 (19.6)
Primary school level	63 (58.9)
Secondary school level	16 (15.0)
Post-secondary certificate training	4 (3.7)
Tertiary/higher education level	3 (2.8)
Reading and writing ability	
Yes	84 (78.5)
No	23 (21.5)
Last time trained	
3 months ago	9 (8.4)
6 months ago	6 (5.6)
1 year ago	21 (19.6)
2 years ago	11 (10.3)
3 years ago	6 (5.6)
4 years ago	8 (7.5)
Never had any training	46 (43.0)

Organization of the training

We organized the training to accommodate 17 to 19 participants for each three-day training programme, resulting in six training sessions overall. Appropriate venues were identified and booked in advance based on the consideration that the location was easily accessible for all participants, the size of the venue was adequate for group interactions, the venue was free from noise, there was back-up electrical power, and there was a place for having lunch as a group. These conditions have been advised in multiple studies (Sanjeevkumar & Yanan, 2011; EL Hajjar & Alkhanaizi, 2018) that have demonstrated that a conducive training environment positively correlates with training effectiveness. Transport incentives were provided to each participant to facilitate their prompt access to the training venue. Additionally, we provided lunch to promote group interaction and reduce disruption in the training programme. To encourage ownership of the training, two leaders from among the participants were selected and assigned the responsibility to generate ground rules for participants and trainers. These ‘owners’ also communicated important updates to all participants.

Assessing training effectiveness

Salas et al. (2012) stressed that evaluation of training effectiveness is important, as it verifies whether learning objectives have been attained. We developed pre- and post-training questionnaires consistent with previous studies (Medeiros et al., 2011; Soon & Baines, 2012; Lindahl et al., 2018). We asked questions on the background of each participant (reported in Table 1), knowledge, attitudes, subjective norms, perceived behavioural control and intentions, all tailored to the selected safety and hygiene practices. Altogether, we formulated 21 knowledge questions to assess knowledge covering all selected safety and hygiene practices. Three answer options of “true”, “false” and “don’t know” were provided. The option of “don’t know” was included to limit the probability of guessing, as suggested by Soon and Baines (2012). The same questionnaire was used to assess farmer knowledge before, during and after the training. TPB components were assessed, pre- and post-training, with statements reflecting positive and negative situations related to personal hygiene, udder and teat care, milk cooling and storage, and shed and floor sanitation practices. Attitude, subjective norm and perceived behavioral control were assessed on a 5-point Likert scale (i.e., 1 = strongly disagree to 5 = strongly agree) except for intention to perform safety and hygiene practices, which was assessed using a scale of 1 = very unlikely to happen to 5 = very likely to happen. Details of the questionnaires are provided in the supplementary material.

5.3.2 Data analysis and interpretation

Analysis of safety and hygiene knowledge

Responses were entered in Microsoft Excel and imported into IBM SPSS statistics version 25 for further analysis. Each correct answer on the knowledge questionnaire was assigned a one, and an incorrect answer was assigned a zero. For each participant, the correct scores were aggregated for the pre-, peri, and post-training knowledge assessments. The frequencies of similar aggregated scores and the mean scores for the different knowledge assessments were determined. We performed paired t-test analyses ($p<0.05$) to evaluate the influence of each teaching and learning method on pre-training knowledge, in comparison to the knowledge gained after day 1 and 2, and post-training.

Analysis of TPB components

We determined the frequencies of responses to TPB components for the safety and hygiene practices. These frequencies were used to demonstrate the changes in behaviour as they transition from the first to last day of training. To test the predictive ability of attitudes, subjective norm and perceived behavioural control on the intention to perform the selected safety and hygiene control practices, we conducted a multiple linear regression analysis after converting all the negative statements into positive ones according to the procedure followed by Mullan and Wong (2009). We applied the simultaneous regression since we did not want to assume which variables could be a better predictor (Leech et al., 2014).

5.4 Results

5.4.1 Safety and hygiene knowledge level

We assessed a total of 107 dairy farmers on their knowledge level regarding on-farm safety and hygiene control practices pre-training; after day 1; after day 2; and post-training. Figure 5.3 shows the total knowledge scores obtained by the dairy farmers. Many of the farmers improved their total knowledge score from pre- to post-training. The mean total knowledge score of the pre-training knowledge test (13.8±4.0) was significantly different ($p<0.05$) from the mean total score of all the other subsequent training days.

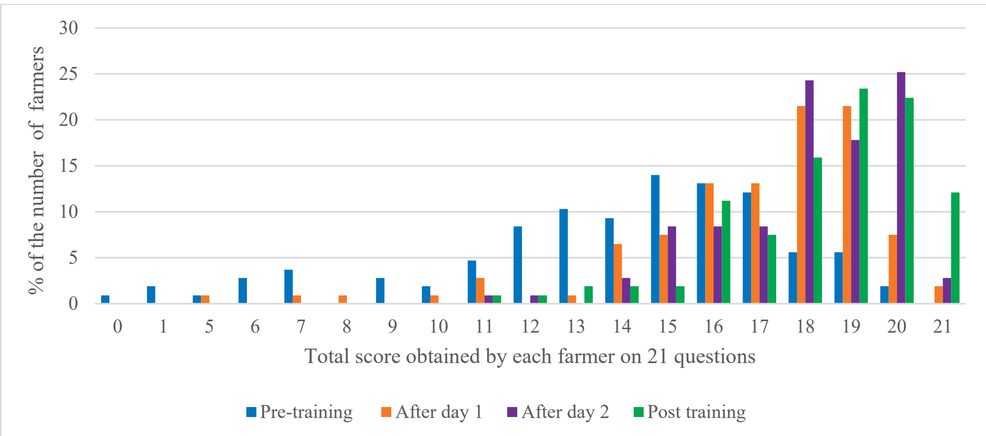

Figure 5.3 Total knowledge scores of dairy farmers before, during and after training

The total knowledge scores of the dairy farmers, pre-, after day 1 and 2, and post-training, were significantly different (Table 5.2). Only between day two and post-training, there was no significant difference between the mean total knowledge scores (p<0.083).

Table 5.2 Analysis of the mean of total knowledge scores of dairy farmers using paired t-test

		Pre-training		After day 1		After day 2		Post-training	
Assessments	Mean score ± SD	*T value*	*Sig.*	*T value*	*Sig.*	*T value*	*Sig.*	*T value*	*Sig.*
Pre-training	13.8 ± 4.0			-6.8	**0.001**	-10.6	**0.001**	-11.2	**0.001**
After day 1	16.9 ± 2.1					-3.9	**0.001**	-5.2	**0.001**
After day 2	18.0 ± 1.9							-1.8	0.083
Post-training	18.4 ± 2.1								

5.4.2 Components of the Theory of Planned Behavior

Tables 5.3 shows the proportion of dairy farmers' response to statements measuring TPB components related to personal hygiene practices pre- and post-training. The proportions of farmers indicating strongly disagree (1) and strongly agree (5), negative and positive statements, respectively, increased post-training. At the same time, the proportions of farmers decreased for disagree (2) and agree (4) for the majority of the TPB components. For instance, the proportion of farmers who strongly agree with the attitude statement: "*For me to wash my hands before and after milking, I consider it very important for milk safety*" increased from pre-training (60.7%|) to post-training (66.3%), while the proportion of farmers who agree decreased from pre-training (35.5%) to post-training (31.8%), indicating that scores move from agree to strongly agree.

Table 5.3 Proportion of dairy farmers' response to statements related to personal hygiene control practices pre- and post-training

Statements		Scale [a, b] n (%)				
		1	2	3	4	5
Attitudes						
For me to wash my hands before and after milking, I consider it very important for milk safety.	Pre	1 (0.9)	2 (1.9)	1 (0.9)	38 (35.5)	65 (60.7)
	Post	2 (1.9)			*34 (31.8)*	**71 (66.3)**
For me, following the proper handwashing steps is not important to milk safety.	Pre	38 (35.5)	27 (25.2)	6 (5.6)	17 (15.9)	19 (17.7)
	Post	**52 (48.2)**	*27 (25.2)*	1 (0.9)	13 (12.1)	14 (13.1)
For me washing my hands always in a particular container/facility is not important.	Pre	51 (47.7)	31 (29.0)	8 (7.5)	7 (6.5)	10 (9.3)
	Post	**64 (59.8)**	*32 (29.9)*		6 (5.6)	5 (4.7)
When I fall ill of any sickness, it is not important to seek immediate medical help.	Pre		2 (1.9)	2 (1.9)	52 (48.5)	51 (47.7)
	Post	2 (1.9)	1 (0.9)	1 (0.9)	*42 (39.2)*	**61 (57.0)**
Milking wearing clean clothes all the time is very important for milk safety.	Pre	3 (2.8)	1 (0.9)	6 (5.6)	40 (37.4)	57 (53.2)
	Post	3 (2.8)		1 (0.9)	*30 (28.0)*	**73 (68.2)**
Subjective norm						
My customers whom I value will disapprove if I don't wash my hands properly	Pre	5 (4.7)	6 (6)	2 (1.9)	43 (40.1)	51 (47.6)
	Post	4 (3.7)	3 (3)	2 (1.9)	43 (40.1)	**55 (51.4)**
It is required of me to wash my hands before milking	Pre	1 (0.9)	2 (1.9)		37 (34.5)	67 (62.6)
	Post	4 (3.7)			*38 (35.5)*	**65 (60.7)**
People whom I respect (i.e., customers) will disapprove if I do not stay away from milking when I am sick	Pre	2 (1.9)	9 (8.4)	11 (10.2)	51 (47.6)	34 (31.7)
	Post	7 (6.5)	8 (7.5)	1 (0.9)	*36 (33.6)*	**55 (51.4)**
I am expected of me to stay away from milking when I am sick	Pre	5 (4.7)	7 (6.5)	5 (4.7)	49 (45.7)	41 (38.3)
	Post	5 (4.7)	2 (1.9)		*43 (40.1)*	**57 (53.2)**
The people I supply milk will disapprove if I don't wear clean clothes before handling milk.	Pre	4 (3.7)	10 (9.3)	4 (3.7)	50 (46.7)	39 (36.4)
	Post	5 (4.7)	4 (3.7)	1 (0.9)	*45 (42.1)*	**52 (48.5)**
Perceived behavioural control						
Washing my hands before and after milking is completely up to me.	Pre	2 (1.9)	1 (0.9)		46 (42.9)	58 (54.2)
	Post	1 (0.9)			*45 (42.1)*	***61 (57.0)***
Not having support from others would make it more difficult for me to wash my hands properly.	Pre	46 (43.0)	34 (31.7)	4 (3.7)	12 (11.1)	11 (10.2)
	Post	**58 (54.2)**	*27 (25.2)*		15 (14.0)	7 (6.5)
It is entirely up to me to wash my hands from dedicated handwashing containers.	Pre	2 (1.9)	3 (2.8)	2 (1.9)	52 (48.5)	48 (44.8)
	Post	2 (1.9)	1 (0.9)		*42 (39.2)*	**62 (57.9)**
It is completely up to me to stay away from milking when I fall sick of diarrhoea, cholera or sneezing.	Pre	7 (6.5)	4 (3.7)	2 (1.9)	54 (50.4)	40 (37.4)
	Post	3 (2.8)	5 (4.7)		*41 (38.3)*	**58 (54.2)**
Not having support when sick would make it difficult for me to stay away from milking.	Pre	16 (15)	27 (25.2)	7 (6.5)	35 (32.7)	22 (20.5)
	Post	**27 (25)**	*24 (22.4)*	3 (2.8)	32 (29.9)	21 (19.6)
It is entirely up to me to wear clean clothes all the time when milking.	Pre	1 (0.9)	1 (0.9)	4 (3.7)	53 (49.5)	48 (44.8)
	Post	1 (0.9)	1 (0.9)		*48 (44.8)*	**57 (53.2)**
Not having support from government to acquire protective clothes would make it difficult for me to wear clean protective clothes when milking.	Pre	41 (38.3)	36 (33.6)	12 (11.2)	9 (8.4)	9 (8.4)
	Post	**56 (52.3)**	*31 (28.9)*	3 (2.8)	9 (8.4)	8 (7.5)
Intentions [c]						
I will always wash my hands before and after milking.	Pre	7 (6.5)	6 (5.6)	6 (5.6)	31 (28.9)	57 (53.2)
	Post	11 (10.2)	3 (2.8)		*27 (25.2)*	**66 (61.6)**
I will always apply soap, rub my well, rinse my hands and dry them before and after milking.	Pre	3 (2.8)	5 (4.7)	7 (6.5)	38 (35.5)	54 (50.5)
	Post	6 (5.6)		1 (0.9)	*31 (28.9)*	**69 (64.4)**
I will always wash my hands from any handwashing facility.	Pre	4 (3.7)	4 (3.7)	12 (11.2)	42 (39.2)	45 (42.1)
	Post	1 (0.9)	1 (0.9)	4 (3.7)	*40 (37.3)*	**61 (57.0)**
I will always continue milking when I fall sick of diarrhoea, cholera or I when I am sneezing.	Pre	60 (56.1)	30 (28.0)	9 (8.4)	5 (4.7)	3 (2.8)
	Post	58 (54.2)	35 (32.7)	5 (4.7)	6 (5.6)	3 (2.8)
I will always wear clean clothes when milking.	Pre	5 (4.7)	3 (2.8)	8 (7.5)	45 (42.1)	46 (42.9)
	Post	1 (0.9)		2 (1.9)	*40 (37.3)*	**64 (59.8)**

[a] Bold colour of numbers indicates an increase and italics indicates a decrease in the proportion of farmers

[b] Likert scale for assessing attitudes, subjective norm and perceived behavioural control; 1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree

[c] Likert scale for assessing intentions; 1 = very unlikely to happen; 2 = unlikely to happen; 3 = moderately likely to happen; 4 = likely to happen; 5 = very likely to happen

Table 5.4 shows the proportion of farmers' response to statements measuring TPB components related to udder and teat care practices pre- and post-training. Similar to personal hygiene practices, there was a remarkable increase in the proportion of farmers who strongly disagree (1) and strongly agree (5) on negative and positive statements, respectively.

Table 5.4 Proportion of dairy farmers' response to statements related to udder and teat care control practices pre- and post-training

Statements		Scale [a, b] n (%)				
		1	2	3	4	5
Attitudes						
I consider that regularly changing udder and teat cleaning cloth is not very important for milk safety.	Pre	50 (46.7)	26 (24.3)	9 (8.4)	9 (8.4)	13 (12.1)
	Post	**66 (61.6)**	*25 (23.3)*	1 (0.9)	5 (4.7)	10 (9.3)
For me I don't consider teat dipping before and after milking important.	Pre	46 (42.9)	30 (28.0)	15 (14.0)	7 (6.5)	9 (8.4)
	Post	**61 (57.0)**	*22 (20.5)*	1 (0.9)	12 (11.2)	11 (10.2)
For me, I consider milking from a clean cow always important for the quality of the milk.	Pre	5 (4.7)	4 (3.7)	5 (4.7)	37 (34.5)	56 (52.3)
	Post	3 (2.8)	1 (0.9)		*32 (29.9)*	**71 (66.3)**
I consider a well-maintained udder not very important.	Pre	46 (42.9)	26 (24.3)	8 (7.5)	15 (14.0)	12 (11.2)
	Post	**60 (56.1)**	*18 (16.8)*	1 (0.9)	13 (12.1)	15 (14.0)
I need to milk from a healthy udder and teat all the time.	Pre	3 (2.8)	5 (4.7)	6 (5.6)	44 (41.1)	49 (45.7)
	Post	3 (2.8)	1 (0.9)	1 (0.9)	*39 (36.4)*	**63 (58.8)**
Subjective norm						
It is required of me to milk from clean cows and udders.	Pre			3 (2.8)	39 (36.4)	65 (60.7)
	Post	2 (1.9)	1 (0.9)	1 (0.9)	*32 (29.9)*	**71 (66.3)**
My customers will disapprove if I don't milk from clean cows and udders.	Pre	5 (4.7)	4 (3.7)	8 (7.5)	47 (43.9)	43 (40.1)
	Post	5 (4.7)	2 (1.9)	1 (0.9)	49 (45.7)	**50 (46.7)**
It is required of me to clean the teats before milking.	Pre	5 (4.7)	6 (5.6)	4 (3.7)	35 (32.7)	57 (53.2)
	Post	1 (0.9)		1 (0.9)	*34 (31.7)*	**71 (66.3)**
Perceived behavioural control						
It is entirely up to me to milk from clean cows and udders all the time.	Pre	1 (0.9)	3 (2.8)	2 (1.9)	46 (42.9)	55 (51.4)
	Post	1 (0.9)			*44 (41.1)*	**62 (57.9)**
Not having support from village livestock officers would make it difficult for me to milk from clean cows and udders all the time.	Pre	25 (23.3)	31 (28.9)	8 (7.5)	22 (20.5)	21 (19.6)
	Post	**45 (42.1)**	*34 (31.7)*	1 (0.9)	11 (10.2)	16 (14.9)
It is entirely up to me to always clean the teats before and after milking.	Pre	1 (0.9)	2 (1.9)	5 (4.7)	50 (46.7)	49 (45.7)
	Post	1 (0.9)	1 (0.9)		*42 (39.2)*	**63 (58.8)**
Not having enough time would make it difficult for me always to clean the teats.	Pre	38 (35.5)	40 (37.3)	7 (6.5)	15 (14.0)	7 (6.5)
	Post	**49 (45.7)**	*38 (35.5)*		15 (14.0)	5 (4.7)
It is entirely up to me to change the teat cleaning cloth/towel regularly.	Pre	3 (2.8)	1 (0.9)	6 (5.6)	52 (48.5)	45 (42.1)
	Post		1 (0.9)		*51 (47.6)*	**55 (51.4)**
Not having enough support to buy new cloth would make it difficult for me to change teat cleaning cloth/towel regularly.	Pre	43 (40.1)	42 (39.2)	7 (6.5)	9 (8.4)	6 (5.6)
	Post	**53 (49.5)**	*34 (31.7)*		17 (15.8)	3 (2.8)
Intentions [c]						
I will always change udder and teat cleaning cloth every month.	Pre	4 (3.7)	4 (3.7)	12 (11.2)	43 (40.1)	44 (41.1)
	Post	1 (0.9)	3 (2.8)	3 (2.8)	*38 (35.5)*	**62 (57.9)**
I will always milk from a clean cow and udder all the time.	Pre	5 (4.7)	6 (5.6)	6 (5.6)	30 (28.0)	36 (33.6)
	Post	2 (1.9)		2 (1.9)	37 (34.5)	**66 (61.6)**
I will always dip the teats before and after milking.	Pre	11 (10.2)	12 (11.2)	18 (16.8)	30 (28.0)	36 (33.6)
	Post	2 (1.9)	4 (3.7)	6 (5.6)	41 (38.3)	**54 (50.4)**
I will always clean the cow teats before and after milking.	Pre	6 (5.6)	3 (2.8)	7 (6.5)	36 (33.6)	55 (51.4)
	Post	3 (2.8)		2 (1.9)	36 (33.6)	**66 (61.6)**
I will always follow the proper steps to clean the teats.	Pre	3 (2.8)	3 (2.8)	11 (10.2)	32 (29.9)	58 (54.2)
	Post	2 (1.9)		2 (1.9)	32 (29.9)	**71 (66.3)**

[a] Bold colour of numbers indicates an increase and italics indicates a decrease in the proportion of farmers
[b] Likert scale for assessing attitudes, subjective norm and perceived behavioural control; 1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree
[c] Likert scale for assessing intentions; 1 = very unlikely to happen; 2 = unlikely to happen; 3 = moderately likely to happen; 4 = likely to happen; 5 = very likely to happen

Farmers' responses to statements measuring TPB components related to shed and floor sanitation, and milk cooling and storage practices pre- and post-training, respectively showed again a change in the proportion of farmers who strongly disagreed (1) and strongly agreed (5) on negative and positive statements, respectively, concerning attitudes, subjective norm and perceived behavioural control (Tables 5.5 and 5.6). For example, the proportion of farmers who strongly agree with the intention statement related to shed and floor sanitation practices: "*I will always maintain a clean shed before and after milking,"* increased from pre-training (51.4%) to post-training (69.1%). At the same time, the proportion of agree decreased from pre-training (34.5%) to post-training (27.1%) (Table 5.5).

Table 5.5 Proportion of dairy farmers' response to statements related to shed and floor sanitation practices pre- and post-training

Statements		Scale [a, b] n (%)				
		1	2	3	4	5
Attitudes						
For me, a clean floor is always important for quality milk.	Pre	4 (3.7)	4 (3.7)	5 (4.7)	47 (43.9)	47 (43.9)
	Post	3 (2.8)			*34 (31.7)*	**70 (65.4)**
I consider that when I keep the milking floor and shed clean always is important for the quality of the milk.	Pre	5 (4.7)	4 (3.7)	6 (5.6)	36 (33.6)	56 (52.3)
	Post	3 (2.8)	1 (0.9)		*34 (31.7)*	**69 (64.4)**
For me cleaning the milking floor with a particular cleaning equipments all the time is not important for the quality of the milk.	Pre	44 (41.1)	31 (28.9)	7 (6.5)	10 (9.3)	15 (14.0)
	Post	**48 (44.8)**	*28 (26.1)*		10 (9.3)	21 (19.6)
I find it very important always to keep the cowshed and milking floors clean from dung.	Pre	12 (11.2)	10 (9.3)	5 (4.7)	43 (40.1)	37 (34.5)
	Post	14 (13.0)	4 (3.7)		*37 (34.5)*	**52 (48.5)**
For me, a dry milking floor is not important for milk quality.	Pre	51 (47.6)	34 (31.7)	7 (6.5)	5 (4.7)	10 (9.3)
	Post	**65 (60.7)**	*25 (23.3)*		5 (4.7)	12 (11.2)
Subjective norm						
It is required of me to produce milk from clean sheds and milking floors	Pre	1 (0.9)	4 (3.7)	6 (5.6)	42 (39.2)	54 (50.4)
	Post	1 (0.9)			*37 (34.5)*	**69 (64.4)**
People I supply milk to will disapprove of me if I don't milk from a clean shed and milking floors	Pre	6 (5.6)	7 (6.5)	9 (8.4)	46 (42.9)	39 (36.4)
	Post	5 (4.7)	4 (3.7)	1 (0.9)	*39 (36.4)*	**58 (54.2)**
Perceived behavioural control						
Milking from a clean shed and clean milking floors is entirely up to me all the time.	Pre	2 (1.9)	4 (3.7)	6 (5.6)	43 (40.1)	52 (48.5)
	Post	1 (0.9)			*39 (36.4)*	**67 (62.6)**
Not having enough time would make it difficult for me to keep a clean shed and clean milking floors all the time	Pre	27 (25.2)	51 (47.6)	6 (5.6)	12 (11.2)	11 (10.2)
	Post	**47 (43.9)**	*34 (31.7)*	1 (0.9)	16 (14.9)	9 (8.4)
Intentions [c]						
I will always clean the milking floors before and after milking.	Pre	7 (6.5)	2 (1.9)	12 (11.2)	33 (30.8)	53 (49.5)
	Post			6 (5.6)	*32 (29.9)*	**69 (64.4)**
I will always clean the milking floors with the same kind of cleaning equipment every time	Pre	18 (16.8)	22 (20.5)	19 (17.7)	25 (23.3)	23 (21.4)
	Post	24 (22.4)	18 (16.8)	15 (14.0)	*21 (19.6)*	**29 (27.1)**
I will always milk from a dry, milking floor.	Pre	6 (5.6)	6 (5.6)	12 (11.2)	36 (33.6)	47 (43.9)
	Post		3 (2.8)	5 (4.7)	*31 (28.9)*	**68 (63.5)**
I will always maintain a clean shed before and after milking.	Pre	5 (4.7)	4 (3.7)	6 (5.6)	37 (34.5)	55 (51.4)
	Post		1 (0.9)	3 (2.8)	*29 (27.1)*	**74 (69.1)**

[a] Bold colour of numbers indicates an increase and italics indicates a decrease in the proportion of farmers
[b] Likert scale for assessing attitudes, subjective norm and perceived behavioural control; 1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree
[c] Likert scale for assessing intentions; 1 = very unlikely to happen; 2 = unlikely to happen; 3 = moderately likely to happen; 4 = likely to happen; 5 = very likely to happen

Table 5.6 Proportion of dairy farmers' response to statements related to milk cooling and storage practices pre- and post-training

Statements		Scale [a, b] n (%)				
		1	2	3	4	5
Attitudes						
For me cooling the milk immediately after milking is very important to prevent bacteria growth.	Pre	12 (11.2)	12 (11.2)	11 (10.2)	42 (39.2)	30 (28.0)
	Post	1 (0.9)	1 (0.9)	1 (0.9)	*42 (39.2)*	**62 (57.9)**
I consider that it is not important always to store milk in clean containers.	Pre	51 (47.6)	32 (29.9)	2 (1.9)	11 (10.2)	11 (10.2)
	Post	**61 (57.0)**	*21 (19.6)*	1 (0.9)	15 (14.0)	9 (8.4)
Using warm water to wash the milking equipment and milk storing containers is very important to prevent bacteria growth.	Pre	2 (1.9)	4 (3.7)	1 (0.9)	46 (42.9)	54 (50.4)
	Post	5 (4.7)		1 (0.9)	*38 (35.5)*	**63 (58.8)**
For me, I must deliver the milk to my customers in the best form of quality.	Pre	2 (1.9)	1 (0.9)	3 (2.8)	35 (32.7)	66 (61.6)
	Post	3 (2.8)		1 (0.9)	*34 (31.7)*	**69 (64.4)**
Subjective norm						
It is expected of me to cool the milk immediately after milking	Pre	8 (7.5)	10 (9.3)	17 (15.8)	47 (43.9)	25 (23.3)
	Post	*3 (2.8)*	*1 (0.9)*		48 (44.8)	**55 (51.4)**
My customers will disapprove of me if I don't cool the milk immediately after milking	Pre	13 (12.1)	30 (28.0)	15 (14.0)	25 (23.3)	24 (22.4)
	Post	*12 (11.2)*	*6 (5.6)*	7 (6.5)	*46 (42.9)*	**36 (33.6)**
It is expected of me to milk and store milk in clean containers	Pre	3 (2.8)	2 (1.9)		40 (37.3)	62 (57.9)
	Post	2 (1.9)			*36 (33.6)*	**69 (64.4)**
My customers will disapprove of me if I don't supply milk in clean containers	Pre		8 (7.5)	1 (0.9)	45 (42.0)	53 (49.5)
	Post	5 (4.7)	4 (3.7)	1 (0.9)	*39 (36.4)*	**58 (54.2)**
Perceived behavioural control						
It is entirely up to me to cool the milk immediately after milking.	Pre	8 (7.5)	11 (10.2)	12 (11.2)	46 (42.9)	30 (28.0)
	Post	5 (4.7)	2 (1.9)		46 (42.9)	**54 (50.4)**
Not having enough time after milking would make it difficult for me to cool the milk after milking.	Pre	29 (27.1)	38 (35.5)	15 (14.0)	17 (15.8)	8 (7.5)
	Post	**45 (42.0)**	*37 (34.5)*	2 (1.9)	19 (17.7)	4 (3.7)
Storing milk in clean and appropriate containers is entirely up to me	Pre	4 (3.7)	4 (3.7)	2 (1.9)	52 (48.5)	45 (42.0)
	Post	5 (4.7)	*2 (1.9)*		*39 (36.4)*	**61 (57.0)**
Not having enough support to clean milk containers would make it difficult for me to store milk in clean containers.	Pre	29 (27.1)	49 (45.7)	6 (5.6)	11 (10.2)	12 (11.2)
	Post	**50 (46.7)**	*30 (28.0)*	1 (0.9)	17 (16.8)	9 (8.4)
Intentions [c]						
I will cool the milk immediately after milking to prevent bacteria growth.	Pre	9 (8.4)	7 (6.5)	17 (15.8)	42 (39.2)	32 (29.9)
	Post	2 (1.9)	1 (0.9)	3 (2.8)	*37 (34.5)*	**64 (59.8)**
I will always store the milk in clean containers.	Pre	4 (3.7)	3 (2.8)	8 (7.5)	39 (36.4)	53 (49.5)
	Post			3 (2.8)	*27 (25.2)*	**77 (71.9)**
I always clean the milk storage containers differently every day.	Pre	6 (5.6)		8 (7.5)	33 (30.8)	60 (56.1)
	Post			2 (1.9)	*37 (34.5)*	**68 (63.5)**
I will always deliver the milk to my customers in good quality every day.	Pre	5 (4.7)		10 (9.3)	37 (34.5)	55 (51.4)
	Post			3 (2.8)	*31 (28.9)*	**73 (68.2)**

[a] Bold colour of numbers indicates an increase and italics indicates a decrease in the proportion of farmers
[b] Likert scale for assessing attitudes, subjective norm and perceived behavioural control; 1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree
[c] Likert scale for assessing intentions; 1 = very unlikely to happen; 2 = unlikely to happen; 3 = moderately likely to happen; 4 = likely to happen; 5 = very likely to happen

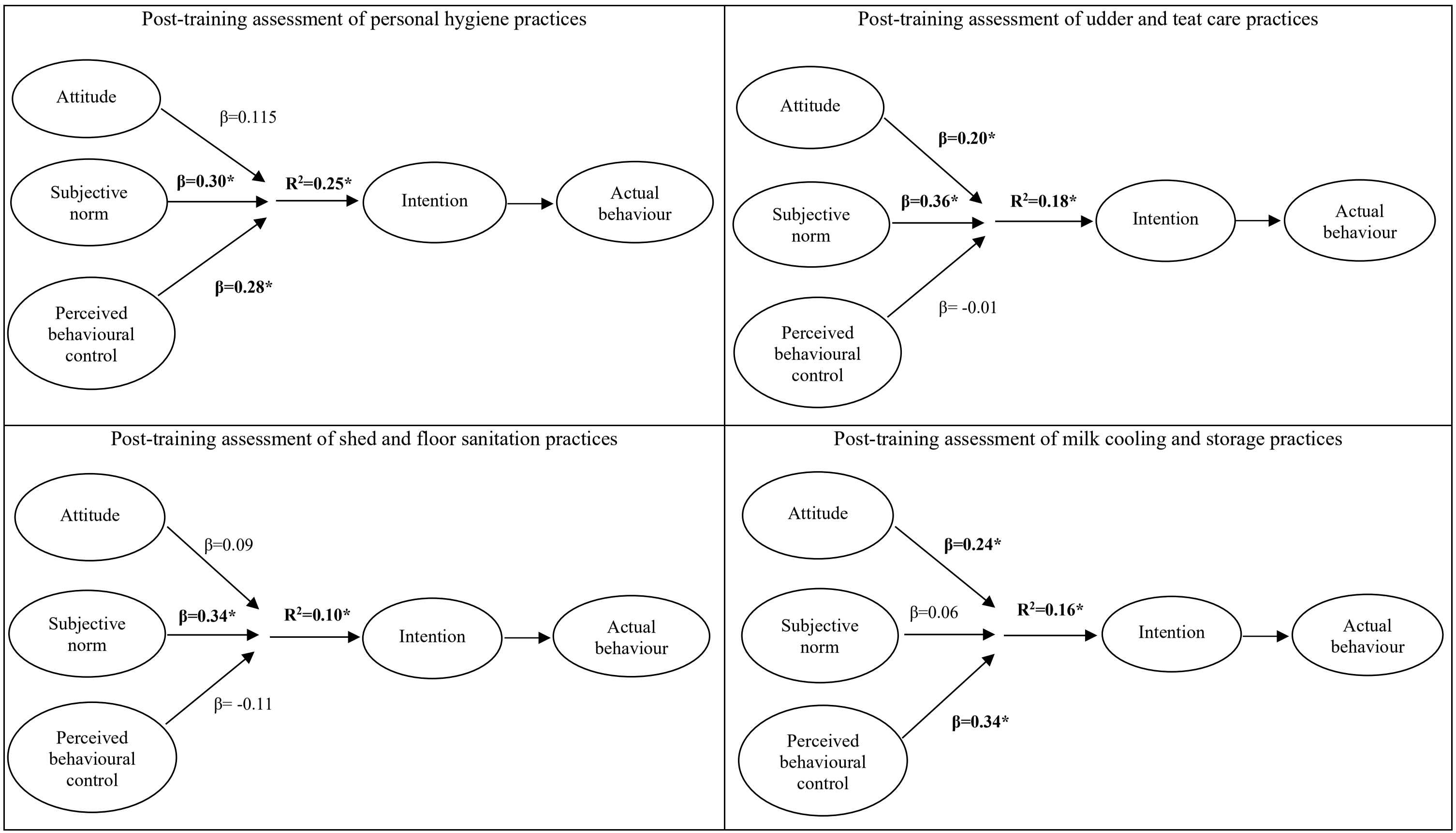

Figure 5.4 Multiple linear regression analysis of theory of planned behaviour components for intention to perform selected safety and hygiene practice
*Significance at $p = 0.05$; **Personal hygiene**: p (subjective norm) < 0.002; p (perceived behavioural control) < 0.003; **Udder and teat care**: p (attitude) < 0.028; p (subjective norm) < 0.001; **Shed and floor sanitation**: p (subjective norm) < 0.001; **Milk cooling and storage**: p (attitude) < 0.012; p (perceived behavioral control) < 0.001

5.4.3 Multiple regression analysis of intention to perform safety and hygiene practices

Figure 4.4 shows the multiple linear regression analysis of the TPB model for the intention to perform the four selected safety and hygiene practices. The TPB model explained 25% of the variance of the intent to perform personal hygiene, 18% of the udder and teat care, 10% of shed and floor sanitation and 16% of milk cooling and storage practices. Different TPB components were significant predictors of intention to perform different practices. However, subjective norm was a significant predictor of intention to perform personal hygiene ($p<0.002$), udder and teat care ($p<0.001$), and shed and floor sanitation ($p<0.001$) practices. The attitude of farmers was a significant predictor of intent to perform udder and teat care ($p<0.028$), and milk cooling and storage ($p<0.012$) practices. On the other hand, perceived behavioural control significantly predicted the intent to perform personal hygiene ($p< 0.003$) and milk cooling and storage ($p<0.001$) practices.

5.5 Discussion

5.5.1 Improvement in knowledge level and benefit of training methods

This study investigated the development and application of a behaviour change theory-based training to fill existing knowledge gaps of farmers concerning on-farm safety and hygiene control practices in an emerging dairy chain. The results of this study demonstrate that the level of farmers' knowledge regarding safety and hygiene control practices improved from pre- to post-training. The mean total knowledge score of the pre-training test was significantly lower from the mean total score of the subsequent days (Table 5.2). However, there was a remarkable increase in the mean total knowledge score after the first day of training (16.9±2.1) compared to the pre-training score (13.8±4.0). The combination of the slides presentation and group discussions may have amplified farmers learning and understanding already on the first day of training. Prislin et al. (1996) found that learning improved when slides presentation was used during training sessions. Because there is evidence that only 5% of information is retained with lectures using slides presentation alone (Wallace et al., 2018), the combination with group discussions may have created an interactive environment for knowledge sharing (Sherson et al., 2002) which together contributed to the increase in the mean score. The increase in the mean total knowledge score after the second day of training using the videos, pictures and story analysis, suggests an amplification of knowledge further beyond the first day of using slides presentation and group discussions. The offering of key messages in the form of videos, pictures and story analysis may have already helped to capture the interest and attention of participants for better comprehension after the first day of training. Our finding is consistent with Soon and Baines (2012) who found that fresh produce farmers' knowledge improved after a tailored training programme involving slides presentation, YouTube videos and practical demonstration. According to Rhoades and Ellis (2010), visuals in the form of videos and pictures have a strong effect on creating interest and attention in communicating food safety messages. Also, stories capture the imagination, places an individual at its centre and creates an experience which makes understanding personal beyond just passing on information (Adamson et al., 2006). Thus, the combination of videos, pictures and story analysis made a significant impact on learning and knowledge gained by participants.

The current study also revealed that differences in mean total knowledge score post-training (after the third day) was not significantly different from the second day ($p<0.083$) although the third day consisted of practical demonstrations. Previous studies have demonstrated that real-life experiences are better methods for food safety and hygiene training as they provide an opportunity for correction and reinforcement of behaviours (Nieto-Montenegro et al., 2008; Medeiros et al., 2011; Grossman et al., 2013). However, because the mean total score after the second day was already high (18.0±1.9), similar to the mean total score post-training (18.4±2.1), it does suggest that demonstration reinforced knowledge already gained in the previous days of training. We reason that since the practical demonstration was away from the farm environment, this may have limited the real-life experience somewhat to increase knowledge further to achieve a significant difference from the videos, pictures and story analysis.

5.5.2 Remarkable changes in TPB components

We investigated whether the training triggered changes in the attitudes, subjective norm, perceived behavioural control and intention concerning personal hygiene, udder and teat care, shed and floor sanitation, and milk cooling and storage practices. Our results indicate that the proportion of strongly agree and strongly disagree increased while the proportion of farmers who agree or disagree with statements decreased for all safety and hygiene control practices (Table 5.3). This outcome indicates that the knowledge gained throughout the training triggered a stronger disposition (i.e., attitude), a better perception of the societal pressure on them (i.e., subjective norm) and better awareness of the control they possess (i.e., perceived behavioural control). These findings are similar to Soon and Baines (2012), who found that fresh produce farmers' responses improved in the positive direction on TPB components after training. We observed a negative health-seeking attitude concerning personal hygiene practices, which was reflected in their strong agreement with the statement (i.e., pre-training (47.7%); post-training (57%)): *"When I fall ill of any sickness, it is not important to seek immediate medical help."* This attitude is consistent with the findings of both Kunda et al. (2007) and Senkoro et al. (2015) who found that people in Tanzania are prone to a self-medication culture rather than seeking immediate professional health care, which obviously could not be overcome by the training.

Farmers also seem to be more convinced after the training regarding attitudes, subjective norm, perceived behavioural control and intentions towards performing on cow, udder and teat care (Table 5.4). Most farmers improved from pre-training (60.7%) to post-training (66.3%) in their strong agreement with the perception that it is expected of them to milk from clean cows and udders. They became more aware post-training (46.7%) compared to pre-training (40%) that their customers will disapprove if they do not milk from clean cows and udders. This pattern in the subjective norm indicates that the group interactions may have triggered a better perception of the expectation of their customers, as other farmers shared stories of their experience during the training. The perception of social pressure can be a motivator to perform udder and teat care practices better. The changes in attitudes, subjective norm, and perceived behavioural control after the training towards the regular replacement of teat cleaning cloth, teat dipping, and milking from clean cows was reflected in the strong positive intention to perform udder and teat care practices. However, there is no guarantee these would translate into the actual performance on udder and teat care practices, since more effort may be required to transition from currently rudimentary to standard levels (Ledo et al., 2020b). Similarly, we observed an increase in the proportion of strongly agree concerning perceived behavioural control towards maintaining a clean shed and floor for milking (pre-training (48.5%); post-training (62.6%)) (Table 5.5), along with storing milk in clean and appropriate containers (i.e., pre-training (42%); post-training (57%)) (Table 5.6), indicating the willingness of farmers to accept responsibility.

5.5.3 Predictive factors associated with intention to perform safety and hygiene practices

Our results demonstrate that the different TPB components (i.e., attitudes, subjective norm, and perceived behavioural control) significantly predict the intention to perform on most of the practices (Figure 5.4). However, subjective norm was the most consistent predictor of intent to perform personal hygiene ($\beta=0.30$, $p<0.002$), udder and teat care ($\beta=0.36$, $p<0.001$), and shed and floor sanitation practices ($\beta=0.34$, $p<0.001$). The communal and group loyalty dependence of farmers in Tanzania can explain the dominant predictive influence of subjective norm on the intention to perform on safety and hygiene control practices (Olausson et al., 2009; Nyarugwe et al., 2020), which links with the culture of collectivism. Hofstede (2011) posits that in a collective culture, strong, loyal relationships among members dominate and the responsibility for the well-being of others in the group is shared, which exerts societal pressure in decision making. Dairy farmers' intention to perform on the majority of the selected on-farm safety and hygiene control practices in Tanzania and possibly in similar settings, seems to be embedded in the societal pressure felt. This outcome is an important factor to consider in interventions related to safety and hygiene control practices.

Subjective norm and perceived behavioural control were significant predictors of intention to perform personal hygiene practices (Figure 5.4). Although attitudes and perceived behavioural control have been previously reported as significant predictors of food handling practices (Armitage & Conner, 2001; Shapiro et al., 2011; Múnera-Bedoya et al., 2017), our study partly found otherwise. Our findings do, however, agree with Mullan and Wong (2009), where normative influencers were strong predictors of food handling practices, and with Soon and Baines (2012), where farmers' intention to perform handwashing was dependent on the perception of the control they possessed. Thus, for dairy farmers in Tanzania, the intention to perform handwashing, taking appropriate health status measures and wearing clean clothes during milking would happen when they perceive significant others will approve of their actions.

Similarly, attitude (β=0.20, $p<0.028$) and subjective norm (β=0.36, $p<0.001$) significantly predicted the intention to perform udder and teat care in our study. This result is consistent with Jansen et al. (2009), who reported that farmers' attitudes significantly determined the performance on preventive measures such as udder cleaning and teat dipping. Nevertheless, our findings are contrary to the conclusion of Jansen et al. (2009) that farmers' perceived lack of control was a significant factor in udder health management. This difference may originate from the fact that these authors studied Dutch farmers, where the difficulty of udder cleanliness in automatic milking systems is reported as a barrier to effective udder health management (Dohmen et al., 2010; Hovinen & Pyörälä, 2011). A sense of control may be needed to perform these measures much more by Dutch farmers than farmers in Tanzania and other emerging chains, where such barriers may be absent. On the other hand, a study by Mekonnen et al. (2017) of dairy farmers in Ethiopia found that intention to perform udder cleaning and other preventive mastitis control measures was positively associated with the societal pressure dairy farmers felt, which agrees with our study. Thus, the type of dairy chain, developed versus emerging, may explain the differences observed between Dutch farmers, where perceived behavioural control was significant in udder and teat care compared to farmers in Tanzania and Ethiopia, where subjective norm was much more important.

Only subjective norm (β=0.34, $p<0.001$) significantly predicted the intention to perform shed and floor sanitation. This outcome implies that dairy farmers are influenced by the societal pressure they perceived on their actions to clean the shed and use appropriate floor cleaning equipment. Attitude was not a significant predictor, but there was a positive relationship between attitude and intent to maintain shed and floor sanitation. A review by Dufour et al. (2011) found that regular cleaning of the milking parlor influenced udder health and somatic cell count. Therefore, attitudes and norm which support proper cleanliness of the shed and floor are important for udder health. Furthermore, attitude (β=0.24, $p<0.012$) and perceived behavioral control (β=0.34, $p<0.001$) significantly predicted the intention to perform milk cooling and storage practices. Because milk cooling and storage is dependent on the availability of cooling and storage facilities, as well as the willingness to perform cleaning of equipment, these may have accounted for the predictive influence of attitudes and perceived behavioural control. These findings indicate that dairy farmers' intention to store milk in appropriate containers, perform proper cooling in clean storage containers, is dependent on their disposition and perception of hindrances. Improvement in milk cooling and storage practices would require more than knowledge and support for farmers in acquiring appropriate milk containers can further improve performance.

5.6 Conclusions

The findings in this study demonstrate that using tailored teaching and learning methods to deliver a TPB-based training intervention, the knowledge level of dairy farmers improved significantly measuring between pre- and post-training. The improved knowledge triggered changes in the behaviour drivers of specific on-farm safety and hygiene control practices. Videos, pictures and story analysis improved mean total knowledge scores levels, while practical demonstrations seem to reinforce the knowledge gained. Also, the TPB model explained the predictive influence of attitudes, subjective norm and perceived behavioural control on the intention to perform on-farm safety and hygiene practices. Overall, the subjective norm was a significant predictor of intention to execute the majority of the on-farm safety and hygiene control practices. This outcome suggests that dairy farmers are more likely to perform personal hygiene, udder and teat, and shed and floor sanitation practices, when customers and other people they work with will approve or disapprove their actions. Also, the farmers' attitude was a significant predictor of intention to perform udder and teat care, and milk cooling and storage practices, while perceived behavioural control significantly predicted the intention to perform personal hygiene and milk cooling and storage practices. Therefore, consideration of subjective norm in designing interventions in societies like Tanzania, where the culture of loyalty to a group and collective dependence dominates, as well as attitudes and perceived behavioural control related to specific on-farm safety and hygiene practices, is very important. The findings provide valuable inputs to design effective approaches on how to support dairy farmers perform better on-farm safety and hygiene practices in emerging dairy chains.

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Supporting information

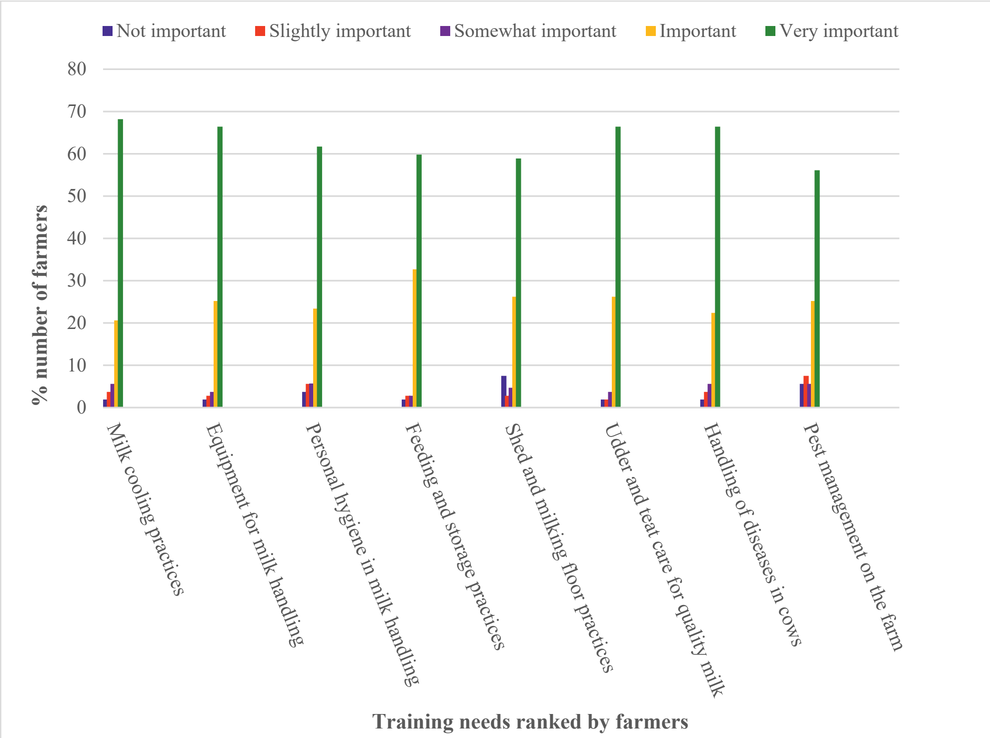

Figure S1 Pre-training needs ranked by dairy farmers

Chapter 6

General discussion

6.1 Introduction

The demand for milk and dairy products is increasing in emerging dairy chains due to growing populations, expanding urban cities and increasing income (Rae & Nayga, 2010; FAO, 2019; IFCN, 2018). The increasing demands require efficient production, processing, and distribution practices along these chains to guarantee consistent delivery of safe, fresh milk of high quality for processing and the consumer. However, in emerging dairy chains, manual handling, a limited cold chain and inadequate pasteurisation, characterise the informal production and distribution practices. The ensuing quality and safety issues, including microbial and chemical hazards (e.g., aflatoxin), are recurring concerns. These are strongly linked to underdeveloped safety and hygiene control practices, starting from the farm but also appearing further in the chain. Ultimately, the consistent guarantee of quality and safety for the consumer is a challenge. There is an urgent need for improvement in technological and people-related aspects of safety and hygiene control practices along emerging dairy chains.

Improvement efforts involving multiple commercial and non-commercial interventions aimed at integrating local chain actors into the formalised production and distribution part of the chain to derive benefits fully have been on-going. But these interventions have not been primarily focused on safety and hygiene control practices (Gülzari et al., 2020). However, to formulate better interventions focused on safety and hygiene control practices, understanding of the underlying technological and people-related factors contributing to the underdeveloped practices is required. Therefore, the objective of this thesis was to gain insight into the current state of safety and hygiene control practices in emerging dairy chains and identify how to improve through a behaviour change theory-based training intervention. A value chain analysis was applied to identify actors and their roles toward quality and safety in the chain. Also, we used the techno-managerial approach involving the integration of technological and managerial theories to analyse the safety and hygiene control practices to gain insight into the causes of recurring quality and safety issues in emerging dairy chains. We chose Tanzania as an example of an emerging dairy chain, because of its prominent informal systems, milk production potential and opportunities to developing (Katjiuongua & Nelgen, 2014; Makoni et al., 2014). This general discussion chapter starts with an overview of the main findings, followed by an integrated discussion of all the findings, a presentation of recommendations and perspectives for future research, and finally, it presents the main conclusions of the research

6.2 Main findings

Table 6.1 presents an overview of the main findings of this thesis. In **Chapter 2**, an analysis was carried out to gain insight into the possible causes of persistently poor quality and safety in emerging dairy chains. The multi-layered nature of the dairy system was examined, as a starting point, to understand the role of actors in the chain concerning quality and safety. The results indicated that the organisation of control activities and enforcement of compliance to requirements on dairy quality and safety is not uniform across the chain. Setting and enforcing milk quality and safety standards is mainly targeted at the formal dairy chain, which accounts for only 3% of the total milk supply (Makoni et al., 2014). However, there was no enforcement in the informal dairy chain. The lack of uniformity in the enforcement of standards was reflected in rudimentary preventive and monitoring control practices at the farm, milk trader and local retail shops, amplifying milk safety risks for consumers. Rudimentary safety and hygiene control practices at the farm mean that teat dipping, milk cooling, mastitis control practices, and proper feed storage facilities are lacking. At the milk collection centres and dairy processing, the results revealed marginal improvements in preventive and monitoring control practices regarding milk cooling, the use of stainless steel storage tanks, and standard tests to check milk quality. Also, an examination was performed of how beneficiary farmers perceived assistance received from two interventions: commercial and non-commercial. The results indicated that farmers perceived better support (strong support) from the non-commercial than those receiving assistance from the commercial (no support) interventions. Despite the favourable perception of support by the farmers of the non-commercial intervention, both the commercial and non-commercial did not directly achieve safety and hygiene control improvements, and this was the same among farmers supplying milk through the formal and the informal chain.

Table 6.1 Overview of the main findings of this thesis

Chapter	Objectives	Main findings
2	To get insight into possible causes of persistent poor quality and safety in emerging dairy chains using Tanzania as an example.	▪ Safety and hygiene control activities are inconsistent across the dairy chain. ▪ Preventive and monitoring safety and hygiene control practices were predominantly basic and rudimentary at the farm, milk trader, and local retail shop levels, increasing milk safety risks for consumers. ▪ Marginal improvement in safety and hygiene control practices were observed at milk collection centres and dairy processing. ▪ The non-commercial intervention was perceived by farmers to be more supportive of on-farm safety and hygiene control practices than the commercial intervention. ▪ Both interventions did not directly achieve safety and hygiene control practices improvements.

3	Develop a customised tool to assess and differentiate performance levels of safety and hygiene control practices crucial for the control of microbial and chemical (i.e., aflatoxin) safety of fresh milk along emerging dairy chains.	▪ The customised assessment tool was able to accurately differentiate safety and hygiene control practices of the farmers into distinct groups.
		▪ Distinctions of the groups demonstrate that;
		  ▪ Most farmers of small scale farms were performing practices at poor to basic level.
		  ▪ The farmers of the large-scale farms were operating at the intermediate to standard level but with basic level performance on crucial practices such as udder and teat care and personal hygiene practices.

4	Investigate if differences in safety and hygiene control practices translate into distinctions in milk quality and safety at the farm, and to analyse the implication for actors further in the chain.	▪ Differences in safety and hygiene control practices (i.e., poor and basic level) did not translate into differences in microbial safety and aflatoxin M1 (AFM1) occurrence in fresh milk. ▪ The occurrence of AFM1 in farm milk was such that 22% exceeded the maximum limit of the United States Food and Drug Authority Standard. ▪ The microbial load of the farm milk already exceeded maximum limits of the East Africa Community standard to the extent that no continued growth was observed further in the chain.
5	Develop a training intervention based on the theory of planned behaviour (TPB) principles and analysis of its effectiveness to fill existing knowledge gaps and influence underlying drivers of dairy farmers' behaviour to perform safety and hygiene control practices.	▪ Tailored teaching and learning methods on specific on-farm safety and hygiene control practices improved the knowledge level of dairy farmers significantly. ▪ Videos, pictures and story analysis improved mean total knowledge scores levels, while practical demonstrations reinforced the knowledge gained. ▪ Knowledge gained triggered a stronger disposition (i.e., attitude), a better perception of the societal pressure that others may have on them (i.e., subjective norm) and awareness of the control they possessed (i.e., perceived behavioural control).

The lack of differentiation among farmers in the first empirical study (**Chapter 2**) informed the need to develop an assessment tool to precisely discriminate practices as the basis for tailored improvement. Therefore, in **Chapter 3**, the aim was to develop a customised assessment tool which would differentiate performance levels of safety and hygiene control practices crucial for the control of microbial and chemical (e.g., aflatoxin) safety of fresh milk along emerging dairy chains. Principles of diagnostic tool development were applied to identify crucial practices and their indicators related to microbial and AFM1 contamination. A four-level assessment grid was developed (i.e., describing poor, basic, intermediate and standard safety and hygiene control practices) based on, the type of equipment used, the degree of performance of actual practices, and the extent of documentation of procedures and data recording. A pilot study in Tanzania to test the customised tool using the four-level assessment grid, revealed three distinct clusters of farmers based on their performance on safety and hygiene control practices. The two clusters compromising most of the small-scale dairy farms were performing practices at the poor to basic level with very few practices at an intermediate level. The cluster composed of the large-scale farms, on the other hand, were operating mainly at the intermediate to standard level. However, for all the three clusters, a basic level performance was observed for both large and small-scale farmers on crucial practices such as milk safety monitoring method, udder and teat care, and personal hygiene.

In **Chapter 4**, a follow-up study was conducted to investigate whether differences in safety and hygiene control practices translated into distinctions in milk quality and safety at the farm, and to investigate the implication for actors further in the chain. The customised assessment tool for emerging dairy chains was applied to distinguish practices and concurrently analyse fresh milk for TBC, coliforms, *Staphylococcus aureus* and AFM1 of fresh milk. Analysis of the fresh milk samples indicated that overall, the fresh milk was of poor microbial quality and safety. Over 90% and 70% of the tested milk samples exceeded the maximum microbial limit (grade 3) for TBC and coliforms (below good), respectively, according to the East African Community standard for all chain actors. For *Staphylococcus aureus*, more than half of the tested samples from milk traders, milk collection centres and local retail shops were above the limit of the EU standard, while for samples from farmers this was slightly below half. Analysis of the farm milk for AFM1 indicated that about 22% of the samples (32/144) exceeded the USFDA maximum limit of 0.5 μg/L. The results of the cluster analysis of on-farm safety and hygiene control practices generated two clusters, with major differences mainly being observed regarding udder and teat care and disease detection practices, where farmers in cluster 1 performed at the poor level compared to the intermediate level in cluster 2. Likewise, poor to basic level performance dominated practices further in the chain, except at the milk collection centres where they performed milk safety monitoring methods and personal hygiene practices at an intermediate level. However, the differences observed between practices below the standard level were not reflected in clear differences in microbial or AFM1 load in the farm milk. The microbial load of the farm milk was so high that further increase of the microbial load could not be observed further in the chain, although safety and hygiene control practices were also below the standard level.

The results in **Chapters 2, 3** and **4** demonstrated knowledge gaps in the performance of on-farm safety and hygiene control practices and provided thus a good basis for a tailored training intervention. However, the approach of targeting underlying behaviour drivers using behaviour change theories to design and implement training for farmers in emerging dairy chains needed to be researched. Therefore, in **Chapter 5**, the aim was to develop a training intervention based on the theory of planned behaviour (TPB) and analyse its effectiveness to fill existing knowledge gaps. Additionally, the aim was to investigate the influence of the training on the underlying drivers of dairy farmers' behaviour to perform safety and hygiene control practices. The results showed that the mean total score of the farmer's knowledge improved from pre-training (13.8 ± 4.0) to after day 1 (16.9 ± 2.1, $p<0.001$) to after day 2 (18.0 ± 1.9, $p<0.001$) and post-training (18.4 ± 2.1, $p<0.001$). The methods for teaching and learning that used slides presentation and group discussions, and videos, pictures, and story analysis improved the mean total knowledge scores. Besides, practical demonstrations seemed to reinforce the knowledge gained. Also, the knowledge gained throughout the training triggered a stronger disposition (i.e., attitude), a better perception of the societal pressure that others may have on them (i.e., subjective norm) and higher awareness of the control they possessed (i.e., perceived behavioural control). A multiple linear regression analysis was performed to determine the predictive influence of the TPB model on the intention to perform safety and hygiene control practices. The results revealed that the TPB model explained 25% of the variance of the intention to perform personal hygiene, 18% of the udder and teat care, 10% of the shed and floor sanitation, and 16% of milk cooling and storage practices. Importantly, the subjective norm was the most consistent predictor of intention to perform personal hygiene ($\beta=0.30$,

$p<0.002$), udder and teat care ($\beta=0.36$, $p<0.001$), and shed and floor sanitation practices ($\beta=0.34$, $p<0.001$). The TPB has demonstrated its usefulness for understanding dairy farmers' intention to perform safety and hygiene practices, as a basis for meaningful support in emerging dairy chains.

6.3 Insights for achieving better milk quality and safety in emerging dairy chains

The findings presented in each chapter provided specific answers to the formulated research questions outlined in **Chapter 1**. Collectively, the findings are discussed to demonstrate their implications for the persistent challenges in achieving safe and quality fresh milk, their contribution to tailored training interventions in emerging dairy chains, and the added value to the methodological considerations applied. Finally, we proposed a stepwise approach for improvement of safety and hygiene control practices in emerging dairy chains.

6.3.1 Persistent challenges in achieving safe and quality fresh milk in emerging dairy chains

Figure 6.1 shows the expanded version of the analytical framework of this research as presented in **Chapter 1** (Figure 1.3). It describes the micro-level actors, their specific chain activities (i.e., farming, trading, collection/bulking and local retailing), and the identified preventive and monitoring safety and hygiene control practices. It also shows the tailored TPB-based training intervention and how it links with farm control practices. The supportive, advisory and research roles of the meso level actors, and the regulatory, enforcement and policy formulation role of the macro-level actors are highlighted, as they directly influence micro-level activities. The arrows also represent the interaction between the different actors. This thesis focused on unravelling the causes of persistent challenges in realising safe and quality fresh milk along emerging dairy chains. The findings in Chapters 3 and 4 indicated that differences observed in the performance of farmers on specific safety and hygiene control practices below the standard level were not reflected in clear differences in microbial and AFM1 load in farm milk and further in the chain. Previous studies have demonstrated the direct relationship between specific farm practices and microbial quality of fresh milk (Elmoslemany et al., 2009; Dufour et al., 2011; Esguerra et al., 2018; Islam et al., 2018).

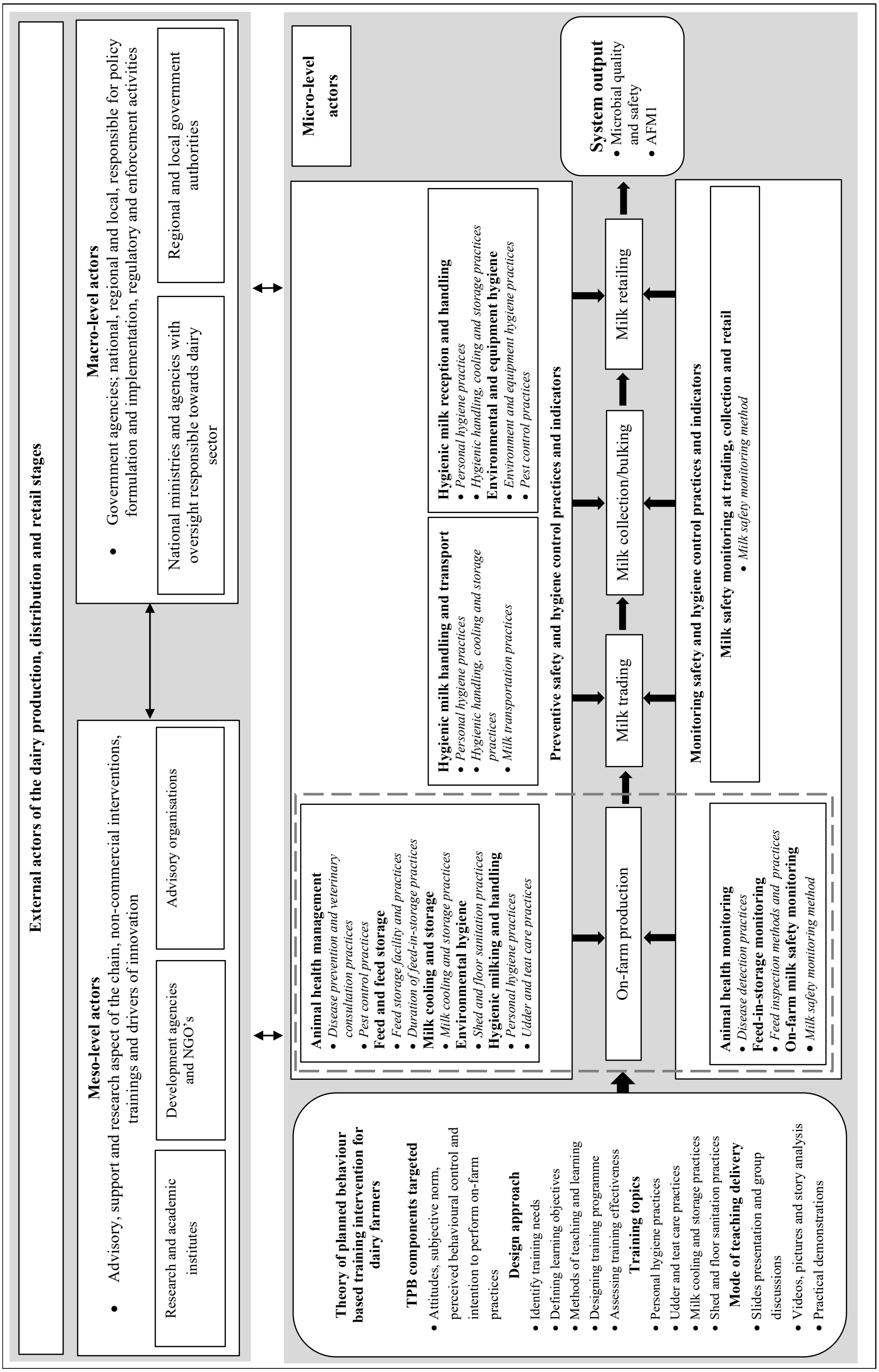

Figure 6.1. The expanded analytical framework of thesis research developed based on Springer-Heinze (2007)

For instance, Elmoslemany et al. (2009) found a significant association between udder health management and microbial quality, while Vissers et al. (2007) demonstrated the relationship between dirt attached to the teat and microbial load in milk. Similarly, other studies (Gizachew et al., 2016; Ferrão et al., 2017; Anyango et al., 2018) have highlighted the association between particular risk factors such as seasonality, type of feed, and storage practices with AFM1 load in farm milk. Yet, the results of our study show that mitigating microbial and AFM1 contamination at the farm and along the chain is more complex, involving multiple control practices at the same time as microorganisms can originate from different sources (Vissers & Driehuis, 2009; Velázquez-Ordoñez et al., 2019). Thus, improvement of specific practices that are performed below the standard level, although necessary, only contributes to a limited improvement of safe and quality fresh milk, if other practices are still performed below the minimum standard level.

Furthermore, the results in **Chapter 3** revealed differences in safety and hygiene control practices, as reflected in improved milk cooling and storage tanks, facilities for feed storage, and preventive disease practices at the large-scale compared to the small-scale farms. Several empirical studies (Akudugu et al., 2012; Kumar et al., 2011; Njage et al., 2018; Valeeva et al., 2007) have indicated the association between large herd size and compliance to food safety measures on dairy farms. Ruben et al. (2017) posited that the average milk output per cow of small-scale farms is often too low in emerging dairy chains to achieve the scale in production needed to recover the investment cost in better technologies, compared to large-scale farms. The herd size on the large-scale farms in our study (>20 milking cows), compared to the small-scale farms (<5 milking cows), may therefore have accounted for the differences observed regarding available facilities and compliance to practices. Moreover, because the large-scale farms are directly linked to the formal dairy chain, in contrast to the small-scale farms, there may be a higher motivation to implement practices to keep the cow healthy, increase yield and store the milk correctly to meet customer demands. Kumar et al. (2011) found that participation of dairy farms within the formal dairy chain reduced transaction costs and enhanced on-farm safety and hygiene control practices, as opportunities for knowledge and skills transfer are more readily available, facilitating better compliance. Our study, however, shows that udder and teat care, milk safety monitoring, and personal hygiene practices of the large-scale farms were still at poor to basic levels, similar to the small-scale farms, despite their advantage of the herd size and participating in the formal chain. Besides, our study also demonstrated that irrespective of whether dairy farms supplied milk through the formal or informal chain, on-farm safety and hygiene control practices were still dominated by poor to basic practices (**Chapter 2, 3 and 4**). For instance, preventive animal health management practices lacked crucial aspects, like regular follow up on treated cows, teat dipping, and single-use of udder cleaning cloths. At the same time, hygienic milk handling, feed storage control and milk safety monitoring were far from standard level practices (FAO & IDF, 2011; Ledo et al., 2020a; Ledo et al., 2020b). The result suggests that the availability of economic opportunities for dairy farmers may in itself not be adequate to trigger full compliance to safety and hygiene control practices to achieve safe and quality fresh milk at the farm gate. Likewise, Kebebe (2019) and Janssen and Swinnen (2019), when they studied factors influencing technology adoption in dairy chains in Ethiopia and India, concluded that economic opportunities alone lack the stimulus for technology uptake by dairy farmers.

The sub-standard performance of both the small and large-scale farms suggests that other factors could explain the persisting gaps in the safety and hygiene control practices. Factors such as technical knowledge, access to information, consumer demand for safe dairy, and inspection to enforce conformity with safety and hygiene of practices, and product specifications (Kumar et al., 2011; Akudugu et al., 2012; Kebebe, 2019; Tebug et al., 2015) could influence the implementation and compliance to safety and hygiene control practices on the dairy farms. Adequate technical knowledge enhances farmers' decision making and empowers their capacity to implement specific practices appropriately (Jabbar et al., 2003), while the lack of it can be a hindrance to the better performance of on-farm practices (Rovai et al., 2016; Ritter et al., 2017). The persisting lack of knowledge of dairy farmers on safety and hygiene control practices in emerging dairy chains is often highlighted (Bell et al., 2005; Swai et al., 2010; Cadilhon et al., 2016) as a limiting factor for better performance. Inadequate knowledge could be attributed to the limited human resources and technical capacity constraints associated with extension services in developing countries (Birthal et al., 2007; Sanga et al., 2016; Hoffmann et al., 2019; Kebebe, 2019). Besides, farmers' access to information to enhance their capability is limited. Moreover, Makoni et al. (2014) posited that the disconnect between district authorities with responsibility for dairy extension services and the technical support of the oversight Ministry in Tanzania limits the delivery of adequate extension services to farmers. Consequently, the gap in knowledge regarding on-farm safety and hygiene control practices has been wide, which seems to contribute to farmers' lack of capability to apply good food safety and hygiene control practices.

Consumer preferences for safe dairy products can also be an important factor influencing the efforts to achieve adequate safety and hygiene control practices by dairy farmers and other actors in the chain. In developed countries, there is evidence that consumer demand for safe food products sparked the growth of food safety measures along food production chains (Henson & Reardon, 2005; Gereffi & Lee, 2009; Escanciano & Santos-Vijande, 2014; King et al., 2017). Suggestions have been proposed for developing country food chains (Francesconi et al., 2010; Henson & Humphrey, 2010; Jaffee et al., 2011) and particularly in emerging dairy chains (Hall et al., 2004; Ruben et al., 2017; Janssen & Swinnen, 2019). However, the fragmented and informal dairy market does not seem to compensate dairy farmers for improved safety (Roesel & Grace, 2014; Hoffmann et al., 2019), which is thus not an incentive for better practices at the farm level. But the growing middle-class, increasing income, as well as consumer awareness of safe and hygienic fresh milk could drive rapid improvements in safety and hygiene control practices in Tanzania in the near future.

Furthermore, inspection to enforce conformity with safety and hygiene control practices can also influence the adequate implementation of food safety practices and compliance to requirements (Omore & Baker, 2011; Blackmore et al., 2015; Alonso et al., 2016; Kumar et al., 2017). Typically, the food regulatory function is a shared responsibility among different ministries and government agencies at the national and local levels (Nguz, 2007; Oloo et al., 2018). Authors have demonstrated that this situation creates duplication of regulatory functions, excessive bureaucracy, fragmentation of the activities, and lack of coordination between the different institutions, leading to ineffective enforcement of food control requirements (Makoni et al., 2014; Bingi & Tondel, 2015; Nguz, 2007). In our study (**Chapter 2**), we noticed improved milk monitoring practices at the milk collection and processing stages in Tanzania. The prominent enforcement at the dairy processors by governmental regulatory agencies in Tanzania

(Kussaga, Jacxsens, et al., 2014; Urassa et al., 2017) could be an incentive to perform better in meeting regulatory requirements. For example, at the Milk collection centres, we noticed improved monitoring practices for fresh milk (**Chapter 2)**, which could be attributed to the market link with dairy processing companies who demand basic quality checks at milk reception (Nell et al., 2014). However, despite the perceived dominant enforcement at the dairy processing stage, research shows that many dairy processors are not well-performing on food safety practices and dairy product quality and safety in Tanzania (Kussaga et al., 2015). Similarly to the farmers, milk collection centres, milk traders, and local retail shops did not comply with the standard for hygienic milk handling and environmental hygiene practices (**Chapter 4**). This pattern suggests limitations in the oversight function of regulatory authorities to enforce conformity in requirements along the whole dairy chain and by dairy companies for their milk collection centres in Tanzania (Häsler et al., 2019) and in other emerging dairy chains (Kumar et al., 2011; Makoni et al., 2014; Kamana et al., 2017; Kiambi et al., 2020). Besides, the institutional capacity constraints of regulatory authorities in most developing countries limits regular inspection to enforce conformity to existing regulation (Nguz, 2007; Unnevehr, 2015). Moreover, there is no specific regulatory framework for dairy farming in Tanzania, similar to emerging dairy chains in other countries (Bingi & Tondel, 2015; Islam et al., 2018; Kiambi et al., 2020), which limits monitoring of on-farm safety and hygiene control practices. Hence, the constraints in the regulatory functions along the chain, particularly when the informal dairy chain is not covered, can be a major bottleneck for improvement of safety and hygiene control practices.

Extending the capacity of regulatory authorities to enforce existing standards and supporting farmers and other chain actors is thus necessary. This could be achieved through collaborative initiatives involving meso and macro-level actors to trigger better performance of practices to realise safe fresh milk (Figure 6.1). A similar approach applied in Kenya, where evidence of training from a non-governmental organisation was required to obtain a licence to operate, has contributed to improvement in hygiene practices and microbial quality (Blackmore et al., 2015). However, the enforcement efforts at the level of the farmer, milk trader, collection centres and local retail shops, would need to consider the financial burden for these actors, so it would not act as a barrier to improve on practices to achieve safe milk according to Hoffmann et al. (2019). Thus, mitigating the persistent challenges in emerging dairy chains needs to consider all the above-elaborated factors in an integrated fashion to achieve safe and quality fresh milk.

6.3.2 Tailored training interventions for safety and hygiene control practices

This thesis aimed to find appropriate ways to design tailored training interventions using behaviour change theory for improving safety and hygiene control practices in emerging dairy chains. Reaching that aim required understanding the structure and perceived support of dairy farmers of current interventions towards on-farm safety and hygiene control practices. Findings in **Chapter 2** revealed that the non-commercial intervention was designed to provide both training and technical support, such as containers for storing and transporting milk. In contrast, the commercial intervention only provided training on demand. However, although dairy farmers perceived stronger support from the non-commercial than commercial intervention, both interventions did not translate into better on-farm practices.

There are indications that interventions directly focused on specific food safety practices in dairy chains have led to an improvement of on-farm safety and hygiene control practices (Bayemi & Webb, 2009; Blackmore et al., 2015; Ndambi et al., 2018; Gülzari et al., 2020). Possible reasons given by the authors for their successes include an integrated approach in the intervention implementation, multi-stakeholder involvement, policy changes of the operating environment, and monetary benefit derived by farmers from the upgrade in practices. However, an assessment performed by Kilelu et al. (2017) on the impact of the non-commercial intervention revealed that improvements in milk quality and safety could not be achieved. This observation indirectly links with our finding that the perceived support of the farmers for the non-commercial intervention did not translate into better on-farm safety and hygiene control practices (**Chapter 2**). Moreover, the training activities were generic, covering animal production and breeding practices, feed conservation, and business skills (Kilelu et al., 2017), without specific emphasis on food safety and hygiene control practices and may not, therefore, trigger improvement in these practices (Prager & Creaney, 2017; Seaman, 2010). Likewise, the commercial intervention offered training on demand in response to poor quality milk from their supplying farmers, which seems very reactive and not structured to address the multiple causes likely to lead to poor quality and safety (**Chapter 2**). Thus, although both types of interventions offered training, they did not seem to concentrate on crucial safety and hygiene control practices (e.g., udder and teat care, milk cooling, shed and floor sanitation), and therefore failed to lead to improvements. Moreover, there is no indication whether behaviour drivers (e.g., attitudes, norms and perceived behavioural control) underlying the actual execution of these practices were considered in the training design.

According to Egan et al. (2007), effective food safety and hygiene training must target specific behaviour linked to food safety risks to achieve better food safety outcomes. Prestwich et al. (2015) argue that behaviour change theories provide a framework to understand psychosocial and external factors that influence behaviour. Moreover, behaviour change theories seem more effective to improve food safety and hygiene practices when used to design training interventions, since the relationship between drivers of behaviour can be specified and targeted (Nieto-Montenegro et al., 2008; York et al., 2009; Mullan & Wong, 2010; Young et al., 2018). Therefore, in **Chapter 5**, we developed a tailored training for dairy farmers using the theory of planned behaviour. We concluded that this training approach improved knowledge of dairy farmers significantly, although there is evidence that knowledge alone does not guarantee a direct change in behaviour (Clayton et al., 2002; Yu et al., 2018). Yet, an increase in knowledge is still relevant as it enhances the ability of those involved in food production to make appropriate choices towards better performance of specific practices (Bell et al., 2005; Young et al., 2010; Dodunski, 2014). Bell et al. (2005) demonstrated that improved knowledge through training on mastitis management enhanced the capacity of farmers in Tanzania to take steps to prevent mastitis occurrence in their herd. Thus, the improved knowledge seen in our study on specific safety and hygiene control practices is a necessary foundation for effective decision making.

Furthermore, we observed in our study that the significant increase in knowledge seems to have triggered a positive disposition, a better perception of the societal pressure, awareness of the control they possessed, and a positive intention to perform on-farm safety and hygiene control practices (**Chapter 5**). This pattern shares similarity with the findings of Soon and Baines (2012), who found a shift in mean responses of fresh produce farmers towards the positive end of the scale concerning all TPB components.

Ajzen (2011) posits that underlying beliefs influence an individual's attitude, subjective norm, and perception of behavioural control regarding a behaviour. These beliefs could be positive or negative beliefs regarding a behavioural outcome (i.e., attitude), the belief of the social expectation of others (i.e., subjective norm) and the belief about possible factors that may support or impede the performance of behaviour (i.e., perceived behavioural control). In our study, we carefully targeted specific beliefs regarding attitudes, subjective norms, and perceptions of behavioural control influencing intention to perform personal hygiene, udder and teat care, shed and floor sanitation, and milk cooling and storage practices in the training design. Hence, our approach seems to have helped to trigger the participating farmers to reposition their beliefs, given the knowledge shared, which may have led to the pattern observed. This finding seems to agree with Steinmetz et al. (2016) that earmarking specific underlying beliefs in an intervention design using TPB leads to successful outcomes.

Also, the utility of TBP, which enables the unravelling of the relative contribution of attitudes, subjective norms and perceived behavioural control on the intention to execute safety and hygiene control practices, was tested in our study. The results demonstrated that subjective norm significantly explained the variation in the intention to perform the majority of practices studied (**Chapter 5**). This implies that social pressure influences farmers to perform personal hygiene ($\beta=0.30$, $p<0.002$), udder and teat care ($\beta=0.36$, $p<0.001$), and shed and floor sanitation practices ($\beta=0.34$, $p<0.001$). The findings are contrary to those of Soon and Baines (2012), who found that subjective norm was not a significant predictor of handwashing intention among fresh produce farmers in the United Kingdom. There seems to be a lack of consistency in the predictive influence of subjective norm when TPB has been used (Armitage & Conner, 2001; Clayton & Griffith, 2008; Mullan & Wong, 2010) suggesting differences in its effect on behaviour intention. Manning (2009) demonstrated that the predictive influence of subjective norm on behavioural intention and actual behaviour is strongly linked to the societal approval or disapproval regarding that behaviour. Differences in approval or disapproval regarding behaviour in one society can reflect in the predictive influence of subjective norm. Therefore, in settings where communal loyalty is inherent and societal pressure plays a major role in an individual’s decision making, like in Tanzania (Hofstede, 2011; Manning, 2009; Rezaei et al., 2018), subjective norm seem to have a better predictive effect on the intention to perform on-farm practices than in societies where individualistic decision making dominates. Thus, the TPB provides a useful framework to unravel these underlying mechanisms on safety and hygiene control practices to deliver interventions in a tailored way.

Additionally, Michie et al. (2013) emphasised that a well-specified method is crucial to achieve an intervention, enable evaluation of its effectiveness and replication by others. Since TPB is not based on a particular method to deliver interventions (Ajzen, 2011), it is quite versatile in accommodating different methods based on the intervention aim to be achieved (Steinmetz et al., 2016; Young et al., 2018). Medeiros et al. (2011) found that food safety training interventions tend to mainly aim for developing skills, increasing food safety and hygiene knowledge, and persuading changes in attitudes and behaviour. The authors also highlighted the popularity of interactive media, audiovisual materials, videos, lectures and recreational activities as useful methods for teaching and learning as they contribute to enhancing skills, increasing knowledge, and encouraging attitudes and behaviour change. Moreover, participants in these trainings mostly preferred the use of interactive media, videos, and hands-on demonstrations (Medeiros et al., 2011; Soon & Baines, 2012). In this thesis we employed three methods: 1) slides presentation and group discussion, 2) videos, pictures and story analysis, and 3) practical demonstration, in a sequential manner by each day focusing one method to cover all the selected safety and hygiene control practices (i.e., personal hygiene, udder and teat care, shed and floor sanitation, and milk cooling and storage). Authors have demonstrated that individuals advance in learning from verbal towards visual and doing when multiple methods of teaching are used in a sequence (Tight, 2012; Hamilton & Tee, 2016; Prager & Creaney, 2017). Importantly, the transition from verbal, to visual and to doing, tend to make learning more dynamic and experiential leading to better learning outcomes. Likewise, Young et al. (2015) found that food safety training interventions, which incorporate more than one session using multiple methods, enhance information exposure leading to behaviour change. The progressive increase in knowledge by dairy farmers and the subsequent influence on attitude, subjective norm, perceived behavioural control, and intention to execute on-farm control practices in our study demonstrates the usefulness of the sequential approach in delivering the TPB-based intervention. Our study supports earlier recommendation by Jaffee et al. (2018) to use theory-based training interventions to accelerate better food safety outcomes in developing countries.

6.3.3 Methodological considerations

Techno-managerial approach for food quality and safety research

This thesis used the techno-managerial approach for food quality and safety management research. This approach involves the integrated use of technological and managerial science theories to understand the dynamic food and human behaviour (Luning & Marcelis, 2006). In our research, we used the techno-managerial approach to unravel the causes of the underdeveloped state of applying safety and hygiene control practices to identify technical factors (e.g., equipment, crucial production practices and product analysis) and people-related factors (e.g., availability of procedures, monitoring of processes, documentation and data recording) in **Chapters 2-4**. The approach also enabled the application of behaviour change theory in the design and implementation of the training intervention (**Chapter 5**), which demonstrated that peoples' decision-making behaviour, together with technological factors, could have consequences for fresh milk safety. Altogether, the approach helped to delineate the persisting challenges in realising better milk safety from a holistic perspective rather than from only a technological or managerial angle.

The customised assessment tool

The principles of diagnostic tool development have been used extensively by previous authors (Kussaga et al., 2014; Kirezieva et al., 2015; Kussaga et al., 2015; Luning et al., 2015; Nanyunja et al., 2015). Previous tools developed to assess food safety management systems for animal-based food industries and fresh produce chains have been based on the assumption of public and private requirements as the minimum standard. In the present thesis, similar to the approach used to develop previous assessment tools to elaborate core control activities for food safety management systems (Kirezieva et al., 2013; Kussaga et al., 2015; Luning et al., 2008), we identified preventive and monitoring safety and hygiene control practices specific to fresh milk (**Chapter 2-3**). This distinction was necessary to analyse the practices aimed at preventing entry of pathogens (i.e., preventive practices) and those geared toward gathering information on the status of process conditions for corrective action and system improvement (i.e., monitoring practices) (Luning et al., 2008). Also, we utilized the findings in **Chapter 2** as basis to identify common equipment used and how actual safety and hygiene control practices were being executed, helped us to formulate the four-level grids; poor, basic, intermediate and standard, unique for emerging dairy chains. This approach strengthened the usefulness of the customised assessment tool to precisely differentiate safety and hygiene control practices in the pilot study in Tanzania. Furthermore, unlike previous diagnostic tools for assessing FSMS where multiple external (e.g., comprehensiveness of external evaluation, types of microbiological food safety complaints) and internal (e.g., advancedness of product sampling, type of hygiene and pathogen non-conformities) food safety performance indicators were identified and assessed (Jacxsens et al., 2010; Sampers et al., 2012; Luning et al., 2015), our customised tool focused on specific milk safety parameters, microbial load and AFM1, as a system output measure. The customised tool thus provides a distinct way to determine the level of practices and direct relationships with specific milk safety parameters towards more dedicated interventions. However, applying the tool in multiple emerging dairy chains in different countries may be necessary to test the robustness of the discriminating scales developed.

Method triangulation for validity of findings

Method triangulation involving different qualitative and quantitative data collection methods was applied throughout this research (**Chapter 2-5**) to gain in-depth insight into the current state of safety and hygiene control practices in emerging dairy chains. According to Thurmond (2001), the use of method triangulation decreases potential biases in research, increases the validity, strength, and interpretative ability of a study. In food safety research, it has been used to realise convergence in data to draw valid conclusions, increase the credibility of scientific knowledge, consistency and generalizability of findings, as also stressed by other researchers (Ball et al., 2010; Stenger et al., 2014; Jespersen & Wallace, 2017; Nyarugwe et al., 2018). In our study, we combined multiple data sources to increase the validity of the data. For example, in **Chapter 2**, we performed focus group discussions with farmers, face-to-face interviews and onsite observation to verify the self-reported farm practices in Tanzania. Also, in **Chapter 4**, we performed data collection using the customised assessment tool by conducting interviews, onsite observations and laboratory analysis for microbial load and AFM1 occurrence in fresh milk along the chain. This approach helped to determine the level of execution of safety and hygiene control practices of actors and determine where there was a relation between practices and the milk safety parameters assessed. Using these multiple methods meant that our sample size was small in the studies reported in **Chapters 2, 3** and **4**. But this enabled detailed analysis of the available equipment, the actual execution of practices and the extent of documentation for reliability and validity of our findings.

Detection of AFM1 in fresh milk using a rapid analytical method

The rapid assay method used in this thesis to detect the load of AFM1 in fresh milk is based on the technology of the immunochromatographic test using a dipstick (Zheng et al., 2006). The dipstick is composed of a sample pad, conjugate pad, a membrane, an absorbent pad and adhesive backing, which allows for single antigenic determinants such as aflatoxins to be competitively separated when present in the milk sample (Zheng et al., 2006; Bahadır & Sezgintürk, 2016). It has the advantage of being user-friendly, rapid (i.e., results in 20 mins), sensitive, reliable and robust, adapted to specific regulations and stable over a wide range of climates (Zheng et al., 2006; Bahadır & Sezgintürk, 2016; Unisensor, 2016). Moreover, AflaSensor Quanti does not require sample processing, cleaning or extraction like the conventional methods such as high-pressure liquid chromatography (HPLC) and enzyme-linked immunosorbent assay (ELISA) (Mosiello & Lamberti, 2011; Unisensor, 2016), which makes it easy to operate with minimal technical experience. Whereas many examples of this type of assay have been mostly qualitative or semi-quantitative, and not very accurate (Anfossi et al., 2013; Bahadır & Sezgintürk, 2016), the AflaSensor Quanti used in our study included a read sensor, which accurately reads the actual concentration of AFM1 present in the milk samples detected by the dipstick. However, the dipstick used in this study was based on the USFDA standard, which therefore was unable to detect AFM1 at the EU maximum limit of 0.05 µg/L. This choice limited our ability to compare in more detail all our samples with the EU standard (**Chapter 4**) with a stricter upper limit. But using the USFDA standard helped to capture the extent of the risk of AFM1 for the consumer.

6.3.4 Practical steps towards progression on safety and hygiene control practices

The developed grids of the customised tool discriminated the safety and hygiene control practices of farmers, traders, milk collection centres and local retail shops, in a stepwise manner (i.e., poor, basic, intermediate and standard) based on the type of equipment, the degree of performance of actual practices and the extent of documentation of procedures and data recording. This stepwise distinction revealed the structural adjustments, technical inputs, and the level of investment needed to progress towards the standard level (**Chapter 3**). However, the small-scale operation of most chain actors in emerging dairy chains would require that other actors in the broad dairy food system are involved in achieving significant and sustainable progress towards the standard level practices in the entire chain. Figure 6.2 shows the practical steps that would be needed for progression on safety and hygiene control practices of chain actors and the supporting role of meso- and macro-level actors. The described practical steps are to be taken together by farmers, milk traders, milk collection centres, and local retail shops, to ultimately reach the standard level, as sub-standard practices are insufficient for better milk safety outcomes (**Chapter 4**).

Transition from the poor to the basic level concerns minimizing avenues for microbial and AFM1 contamination on the farm and further in the chain. Investment in basic equipment, improvement in practices and documentation would be required by farmers as well as actors further in the chain. For the farmers, investment in food-grade containers and lactometers for basic quality checks would be necessary. Simultaneously, efforts to make the execution of on-farm practices more regular is needed to shift from inadequately performed practices based on wrong understanding, no documentation and no data reporting. Similarly, the milk traders, milk collection centres and local retail shops would need to invest in hygienic storage equipment, improved capability to monitor milk quality and safety, and accurate recording of data on basic quality parameters. Also, milk handling practices further in the chain must be based on knowledge about limiting microbial contamination. Training on the appropriate equipment to use and precise execution of practices is required to help the farmers, milk traders, milk collection centres and local retail shops, acquire the basic knowledge for change. Dairy companies can take the lead in training farmers, milk traders and milk collection centres and complemented by meso-level actors. Also, the training of local retail shops must be led by macro-level actors and complemented by meso-level actors, as dairy companies do not have any direct responsibility towards them. Policy changes at the national level to license the activities of all actors may be necessary to formalize their participation in the chain and facilitate their identification for training.

Progress from the basic to the intermediate level is aimed to further reduce AFM1 occurrence on the farm and microbial contamination in the entire chain. Investment in equipment and facilities which are specific for dairy, such as Mazzican or aluminium containers at the farm level and further in the chain, would be required. Concurrently, practices must be well-described, performed systematically based on precise knowledge to mitigate avenues for microbial contamination starting from the farm and continuing further in the chain. For instance, pre-milking routines at the farm must include fore-stripping, teat cleaning and pre-teat dipping to mitigate contamination with mastitis-causing bacteria. Likewise, compliance with hygienic milk reception to prevent further contamination is required by milk traders, milk collection centres and local retail shops to achieve the intermediate level. Moreover, milk collection centres would need to invest in cooling tanks with cleaning-in-place systems to limit manual cleaning, while local retail shops should improve on pest control systems and drainage around the facility. Continuous training of farmers and actors further in the chain to reinforce knowledge to perform safety and hygiene control practices precisely is crucial, and this can be supported by collaboration between dairy companies and meso-level actors. Furthermore, regular inspection of the activities of farmers, milk traders, milk collection centres, and local retail shops by macro-level actors, and complemented by dairy companies, and meso-level actors would facilitate compliance to safety and hygiene control practices.

Ultimately, the goal is to stimulate all actors in the chain to progress from the intermediate to standard level on all safety and hygiene control practices. The standard level is typified by full compliance to common standard requirements for equipment, and practices are all performed in a systematic and precise manner with well-described procedures, relevant data collection and proper reporting (**Chapter 3**).

Level	Actors	Poor → **Basic**	Basic → **Intermediate**	Intermediate → **Standard**
Micro	Farmers	• Improvised to basic equipments and facilities and milking floors with drainage. • Regular execution of practices. • Recognize the importance of record keeping and well-described protocols.	• Basic equipment and facilities hygienically designed for dairy. • Systematic execution of practices. • Using well-described work protocols and keeping basic records.	• Invest in standard equipments and facilities. • Actual practices are systematic, regular, and performed precisely. • Well-described protocols and accurate record keeping that are constantly updated.
	Milk traders	• Rapid means of transporting milk to MCC with containers to avoid exposure to dust. • Adherence to basic milk handling practices, and acquire lactometer to monitor milk temperature and density. • Records data on basic quality parameters.	• Using motorcycles and trucks for transporting milk products with aluminum containers. • Systematic adherence to milk handling practices. • Monitoring and data recording of milk quality parameters.	• Standard milk transporting cooling trucks with stainless steel containers. • Systematic and precise adherence to milk handling practices. • Accurate milk quality monitoring with rapid tests and accurate quality record keeping.
	Milk collection centres	• Hygienically designed cooling tanks and facilities. • Regular compliance to hygienic milk reception and handling. • Lactometer tests to monitor basic milk quality parameters and data recording.	• Hygienically designed cooling tanks and facility floors with cleaning in place and calibrated thermometers. • Systematic and precise compliance to hygienic milk reception and handling. • Work protocols described, monitor and record data on basic quality parameters.	• Invest in standard cooling tanks and facility floors with drainage and pest control system. • Complete compliance to all safety and hygiene control practices based on precise knowledge. • Work protocols described, quality monitored, detailed data recording and specific milk safety checks.
	Dairy companies	• Training suppliers to MCC and support them with basic equipments. • Initiate inspection of supplier premises and reward for better quality.	• Support MCC to acquire more automated cooling tanks and quality test kits. • Regular inspection of suppliers, reinforce training and reward openly for better practices.	• Continuous training and investment in MCC to perform rapid milk safety checks. • Accurate data recording on suppliers and reward schemes for well-performing suppliers.
	Local retail shops	• Invest in hygienic environment and equipments for storing milk. • Initiate monitoring of suppliers of milk on basic quality parameters.	• Using hygienically designed equipment for storing milk and facility environment is designed with drainage and traps. • Monitoring of milk suppliers with basic quality equipment.	• Invest in standard hygienic equipment and facility floors with good drainage and pest control system. • Monitor milk suppliers and regular external milk safety checks.
Meso	Advisory, development agencies, NGOs, research & academic institutes	• Theory-based training of farmers and other actors consistently on safety and hygiene control practices. • Technical support and facilitate basic equipments acquisition.	• Promote further training of actors on quality checks and record keeping. • Offer inspection services and technical advice on best practices.	• Continue to facilitate training and technical support to actors along the chain. • Research institutes support specific pathogenic tests at reduced rates to encourage food safety compliance.
Macro	National/regional/local government authorities	• Initiate policy shift involving license of actors in the chain.	• Support local authorities to inspect the activities of chain actors.	• Using training certification as a means to maintain participation in the chain.

Figure 6.2 Practical steps toward progression on safety and hygiene control practices for an emerging dairy chain (MCC = milk collection centre)

All farmers would have to invest in more hygienic equipment such as stainless steel containers, while large-scale farms have to invest in cooling tanks with accurate thermometers for monitoring milk temperature. Farmers would need to be supported with continuous training to maintain full compliance to safety and hygiene control practices. Dairy companies can take the responsibility to support farmers with continuous training, which can be complemented by meso-level actors such as research and academic institutes using theory-based training to earmark specific beliefs around safety and hygiene control practices (**Chapter 5**). This collaboration for training can be extended to actors in the entire chain. Besides, milk traders, milk collection centres, and local retail shops would need to monitor milk quality and safety when receiving milk, using standard equipment as a motivation for farmers to comply to standard practices. For these actors, investments in rapid standard tests such as the Resazurin test for microbial contamination and qualitative strip tests for AFM1 is important. Support from dairy companies, meso- and macro-level actors (Figure 6.2) to make these milk quality and safety monitoring equipment available at the doorstep of farmers and actors further in the chain to periodically check microbial load, specific pathogenic bacteria, and AFM1 is required. This periodic monitoring can serve as a requirement for licensing to maintain participation in the chain. Also, at the milk trading stage, investment into stainless steel containers and trucks with cooling capability, would be a significant improvement to minimize microbial proliferation during transportation. Likewise, milk collection centres would have to invest in hygienically designed cooling tanks with thermometers to guarantee adequate monitoring of the temperature of stored milk. Dairy companies directly linked to these centres can provide financial assistance needed to acquire the cooling tanks. Overall, national governments would need to initiate and enforce policy changes which support actors to obtain licensing based on evidence of inspection of activities, periodic quality and safety checks, and training, to maintain participation in the chain. Altogether, the steps towards the progression of safety and hygiene control practices would involve the collaboration of all actors at the micro-, meso- and macro-levels.

6.4 Recommendations for further research

In this thesis, the underdeveloped state of safety and hygiene control practices in an emerging dairy chain has been studied in detail. Besides, we demonstrated the application of the theory of planned behaviour in the design and implementation of a training intervention for dairy farmers in an emerging dairy chain. Based on this, we recognise potential opportunities for further research. The following are recommendations for further research based on this thesis:

- Throughout this research, we have implicitly assumed that practices performed at the standard level would lead to acceptable milk safety. However, we could not test this assumption in this thesis, as there were no such farms available in the study locations. Empirical research is necessary to test this assumption among dairy farmers operating all safety and hygiene control practices at the standard level, by testing the microbial load and AFM1 level in their milk.
- A limitation of this study in applying the theory of planned behaviour was the inability to perform an extensive longitudinal study of the implication of the training on actual practice performance. Future studies are needed to investigate how knowledge and its triggers on underlying behaviour drivers such as attitudes, subjective norms, and perceived behavioural control, translate into the positive intentions of farmers and their execution of actual practices. This future study can be compared with other countries to investigate the differences in the influence of the subjective norms on safety and hygiene control practices. Furthermore, investigating whether the improved knowledge and triggers in behaviour drivers would in the end lead to better milk safety is required.
- We conducted this research in Tanzania under the broad classification of emerging dairy chain. The possibility of differences between countries within the same classification of emerging dairy chain regarding the levels of safety and hygiene control practice performance and implication for microbial and AFM1 safety may, however, exist. Therefore, multi-country studies which cut across different continents are necessary to position these findings adequately.

6.5 Conclusions

The main conclusions of the research presented in this thesis are:

- Solving the persistent challenges in achieving safe fresh milk in emerging dairy chains require that multiple factors are considered concurrently.
- The differentiated assessment of the customised tool provides an added value to analyse safety and hygiene control practices toward targeted improvement.
- Improvement of specific practices that are performed below the standard level, although necessary, does not contribute to increased safety of fresh milk, if practices are still performed below the minimum standard level.
- Interventions that concentrate on safety and hygiene control practices could lead to improvements in such practices.
- TPB is a useful theoretical framework to target specific behaviour drivers and incorporate different training methods to achieve significant improvements in knowledge of, and intention to, execute on-farm safety and hygiene control practices.

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Link to SDCP video for training http://www.youtube.com/watch?v=aJnL73h9wSs

Summary

There is a growing demand for milk and dairy products in developing countries due to population growth and improving income. Increased dairy production is necessary to meet processing and consumption demands. However, dairy chains in such countries, which we describe as emerging dairy chains, are characterized by prominent informal production and distribution systems, which seems to hinder the capacity of these chains to meet the growing demands. Meanwhile, quality and safety issues commonly depicted by microbial and chemical hazards (e.g., aflatoxin) of fresh milk are recurring concerns. The underdeveloped state of these chains have been implicated as the underlying reasons for the constant quality and safety challenges. Multiple interventions have been implemented, usually led by dairy companies, developmental agencies, governments or by a combination of organisations, covering training, technical assistance and infrastructure development. However, it is not clear if existing interventions have translated into an improvement in safety and hygiene control practices. Moreover, there is doubt whether these interventions have been specific enough to trigger the improvement needed in safety and hygiene control practices, limit the constant milk quality and safety problems, and safeguard the consumer. This thesis therefore, aimed to gain insights into the underdeveloped state of safety and hygiene control practices in emerging dairy chains and identify how to improve these practices through a behaviour-based training intervention.

In **Chapter 2**, using multiple data collection tools such as in-depth interviews, focus group discussions and systematic on-site observations, the possible causes of persistent challenges in safety and hygiene control practices in an emerging dairy chain, using Tanzania as an example, was investigated. We found a lack of uniform organisation of control activities and enforcement on milk quality and safety along the chain. The formal dairy chain was mainly targeted regarding setting and enforcement of requirements on quality and safety, while this was completely absent in the informal dairy chain. This was reflected in basic preventive and monitoring safety and hygiene control practices at the farm such that teat dipping, milking cooling, mastitis control practices and proper feed storage facilities were commonly lacking. Similarly, basic practices were observed in the operation of milk traders and local retail shops, exacerbating public health

risks. However, milk collection centres and dairy processing companies seem to have improved preventive and monitoring control practices reflected in hygienically designed cooling tanks and standard tests for milk quality. Specific pathogenic bacteria checks were absent across the chain. Additionally, dairy farmers' perception of two existing interventions, commercial and non-commercial, on the extent of support toward on-farm safety and hygiene control practices was also investigated. We found that the non-commercial intervention, which combined training and provision of milk storage containers, was perceived by farmers to be more supportive of on-farm safety and hygiene control practices than the commercial intervention, which only offered training on demand. However, both interventions did not directly reflect in better safety and hygiene control practices.

In **Chapter 3**, the aim was to develop a customised tool to assess and differentiate performance levels of safety and hygiene practices crucial for the control of microbial and chemical (i.e., aflatoxin) safety of fresh milk along emerging dairy chains. The principles for diagnostic tools was used to identify crucial control practices and indicators linked to microbial load and aflatoxin M1 (AFM1) occurrence in fresh milk. Poor, basic, intermediate and standard level differentiation grids were developed based on the type of equipment used, the degree of performance of actual practices, and the extent of documentation of procedures and data recording. A range of small and large scale dairy farms were selected to test the customised tool in a pilot study in Tanzania. Three distinct clusters were identified based on practice performance. However, for all the three clusters, basic level performance was observed for crucial control practices of dairy farmers of both large and small-scale farms such as milk safety monitoring method, udder and teat care, and personal hygiene. Although the tool is an important step to estimate more accurately the performance of practices towards dedicated interventions, it was not clear what the differences in practices meant for microbial and AFM1 safety.

Therefore in **Chapter 4**, an investigation into whether differences in safety and hygiene control practices translated into distinctions in milk quality and safety at the farm, and the implication for actors further in the chain was conducted in Tanzania. Safety and hygiene control practices at the farm, during milk trading, milk collection/bulking, and during local retailing were differentiated using the customised assessment tool. This was followed with milk sampling to analyse for AFM1 at the farm and selected microbial parameters (i.e., total bacteria count, coliforms and *Staphylococcus aureus*) along the chain. The microbial analysis of fresh milk at the farm indicated that the milk already exceeded maximum limits to the extent that no further growth was observed along the chain, irrespective of the level of practice performance, while between poor and basic level performances, there was no clear difference in milk quality and safety. High levels of AFM1 were observed among farmers who stored feed longer with limited measures to control mould growth.

As a result of the findings of the previous studies, in **Chapter 5** the goal was to develop a training intervention based on the theory of planned behaviour and analyse its effectiveness to influence behaviour drivers of dairy farmers towards safety and hygiene control practices. The training program targeted personal hygiene, udder and teat care, shed and floor sanitation, and milk cooling and storage practices. A three-day training scheme was designed involving three teaching and learning methods: i) teaching with slides presentation and group discussions, ii) videos, pictures and story analysis, and iii) practical demonstration to cover the four practices for each day. The implementation of the training program in Tanzania, which covered 107 dairy farmers, demonstrated that by using easy-to-understand training materials and multiple learning activities, dairy farmers significantly progressed in knowledge above pre-training levels significantly. The improved knowledge triggered better attitudes, improved perception of the social pressure that others have on them to perform the practices, better awareness of the control they possessed, and positive intentions to perform on-farm safety and hygiene control practices. A multiple linear regression analysis was performed to test the predictive influence of the components of the theory of planned behaviour on farmers' intention to perform the practices. The results showed that the subjective norm was the most consistent predictor of the intention to perform personal hygiene ($\beta=0.30$, $p<0.002$), udder and teat care ($\beta=0.36$, $p<0.001$), and shed and floor sanitation practices ($\beta=0.34$, $p<0.001$). The theory of planned behaviour was thus a useful model for understanding dairy farmers intention to perform safety and hygiene control practices.

Chapter 6 provided a summary of the findings of this thesis and a broader perspective for achieving better milk quality and safety in emerging dairy chains. Overall, the persistent challenges in emerging dairy chains are linked to multiple factors ranging from actual performance of practices to other external factors such as technical knowledge, access to information, consumer demand for safe dairy, and inspection to enforce conformity with safety and hygiene practices and products. All these factors must be positively aligned simultaneously to reduce the persisting poor quality and safety issues. A tailored training intervention based on behaviour change theory is a valuable approach to accelerate better food safety practices in emerging dairy chains. A proposal was made for a collaborative approach involving all actors in the dairy food system to help actors progress from sub-standard level along the dairy chain. Furthermore, follow up studies were suggested, including, among others, a cross country studies to investigate the robustness of the customised tool for different emerging chain contexts and the implication for microbial and AFM1 safety. Altogether, this thesis provided a unique approach towards improving milk quality and safety in emerging dairy chains.

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About the author

James Ledo was born in Amedzofe, Ghana, on November 20th 1980. After completing secondary school in 1999 at Bishop Herman College in Kpando, Ghana, He enrolled in the Bachelor of Science degree programme in Biochemistry and Nutrition and completed in 2005. After a year of national service as a research assistant in CSIR-Food Research Institute, He proceeded to pursue a master's degree in Dietetics and graduated in 2009. After completion, he worked for a year in the 37th Military Hospital, Ghana under the supervision of the Chief Dietitian and qualified to practice in 2010. He worked professionally as a dietitian till May 2013, when he got admission to Wageningen University and Research to pursue the MSc in food quality management with specialization in food safety with a NUFFIC scholarship. For his thesis, James researched on assessing the influence of food safety culture on food handler hygiene behaviour in dairy processing establishments in Zimbabwe. He collected data in Zimbabwe, which contributed to a published paper. He completed in August 2015 and immediately got a sandwich PhD position under the LIQUID project in January 2016. His research was in Tanzania, which became his third home during his four years of his research work. The thesis is the outcome of his four-year scientific research journey. James enjoys political debates, watching football, and enjoys running as a way to reflect. He is married to Selorm Aku Ledo.

Ledo, J., Hettinga, K. A., Bijman, J., & 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.

Ledo, J., Hettinga, K. A., & Luning, P. A. (2020). A customized assessment tool to differentiate safety and hygiene control practices in emerging dairy chains. Food Control, 111, 107072.

Ledo, J., Hettinga, K. A., Kussaga, J.B., & Luning, P. A. (2020). Implications of differences in safety and hygiene control practices for milk safety in an emerging dairy chain**.** Food Control, 118, 107453.

Ledo, J., Hettinga, K. A., Bijman, J., Kussaga, J.B., & Luning, P. A. (Submitted). A tailored food safety and hygiene training approach for dairy farmers in an emerging dairy chain.

Discipline-related activities	Graduate school/Organization	Year
Courses and conferences		
Multidisciplinary perspectives on quality improvement in value chains	WASS, Wageningen, NL	2016
3rd International Conference on Global Food Security	Elsevier, Cape Town, SA	2017
Qualitative Data Analysis	WASS, Wageningen, NL	2017
Dairy Protein Biochemistry	VLAG, Wageningen, NL	2018
LIQIUD Educational Workshop	Egerton University, Njoro, KE	2018
Towards a global one health; an interdisciplinary lens to explore synergies, trade-offs and pathways for food systems transitions	WIAS, Wageningen, NL	2018
Tropentag	University of Kassel, GE	2019
LIQUID Educational Workshop	Sokoine University of Agriculture, Morogoro, TN	2019
General Courses		
Essentials of Scientific Writing and Presenting	WGS, Wageningen, NL	2016
Competence Assessment	WGS, Wageningen, NL	2019
Career Perspectives	WGS, Wageningen, NL	2019
Philosophy and Ethics of Food Science and Technology	VLAG, Wageningen, NL	2020
Project and Time Management	WGS, Wageningen, NL	2020
Optional Courses		
Preparation of PhD proposal	VLAG, Wageningen, NL	2016
3rd Wageningen PhD Carousel, Convener	WGS, Wageningen, NL	2016
Weekly group meetings	FQD, Wageningen, NL	2016 - 2020
PhD study trip (Oral and poster presentations)	FQD, Australia	2018
Annual LIQUID Project Meetings	BMO, Wageningen, NL	2016 – 2019
Organizing field trip for supervisors	Sokoine University of Agriculture, Morogoro, Tanzania	2019

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