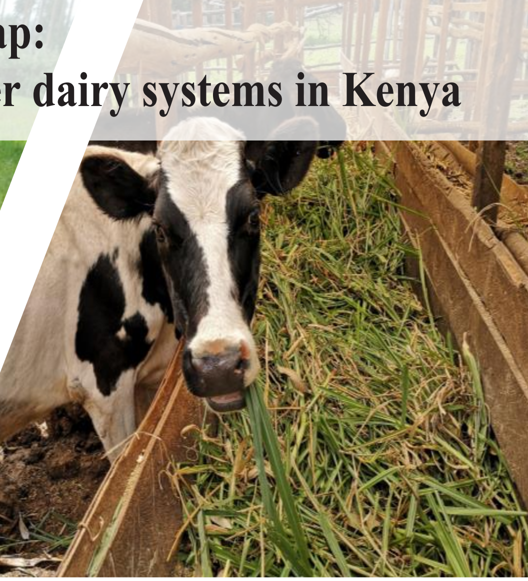
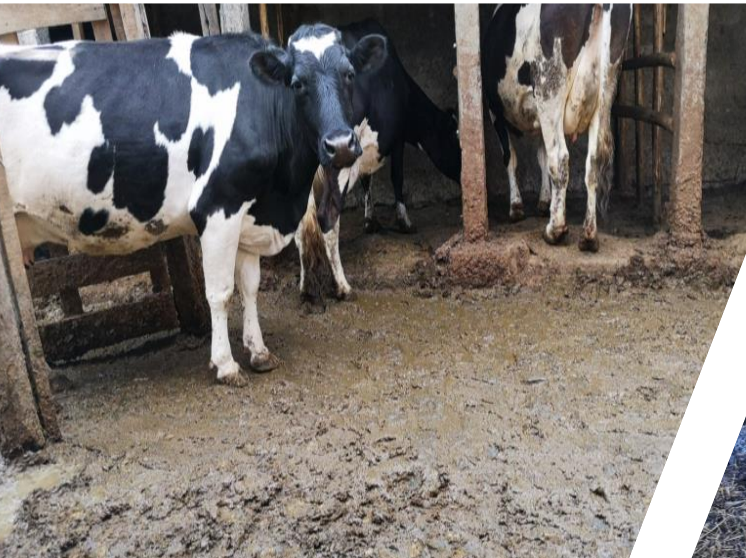
Bridging the gap:
improving milk quality on smallholder dairy systems in Kenya





Simon Ndungu Nyokabi

Propositions

1. Improving milk quality improves food security in Kenya.
   (this thesis)
2. Social networks shape dairy value chain actors' behaviour.
   (this thesis)
3. A one-health approach improves human health and prosperity.
4. Circular agriculture increases the resilience of food systems.
5. Music expresses the words and emotions we struggle to speak.
6. Observing and listening is the best way of learning.

Propositions belonging to the thesis, entitled

Bridging the gap: Improving milk quality on smallholder dairy systems in Kenya

Simon Ndungu Nyokabi

Wageningen, 11 January 2023

Bridging the gap:
improving milk quality on smallholder dairy systems in Kenya

Simon Ndungu Nyokabi

Thesis committee

Promotor

Prof. Dr S. J. Oosting
Professor, Animal Production Systems
Wageningen University & Research

Co-promotors

Dr P. A. Luning
Associate Professor, Food Quality and Design Group
Wageningen University & Research

Prof. Dr Bockline Omedo Bebe
Professor Livestock Production Systems
Egerton University, Kenya

Other members

Prof. Dr C. Leeuwis, Wageningen University & Research
Dr F. Mutua, International Livestock Research Institute, Nairobi, Kenya
Dr J. van der Lee, Wageningen University & Research
Prof. Dr J.H. Trienekens, Wageningen University & Research

This research was conducted under the auspices of the Graduate School of Wageningen Institute of Animal Sciences (WIAS).

Bridging the gap:
improving milk quality on smallholder dairy systems in Kenya

Simon Ndungu Nyokabi

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Wednesday 11th January 2023
at 11 a.m. in the Omnia Auditorium.

Simon Ndungu Nyokabi
Bridging the gap: improving milk quality on smallholder dairy systems in Kenya, 138 pages.

PhD thesis, Wageningen University, Wageningen, the Netherlands (2023)
With references, with summary in English

ISBN 978-94-6447-468-8
DOI https://doi.org/10.18174/579689

This thesis is dedicated, in loving memory, to:

My grandparents, Simon Ndungu Njoroge, John Njuru Ole Suakei and Lucy Gathoni Ole Suakei;
My godmothers, Lucy Waitherero and Winnie Karugu

The thesis is also dedicated to:

My mum, Margaret Nyokabi Njuru;
My sisters, Lucy and Christine Nyokabi, and Florence Waithera;
My nephews, Doneal, Delan and Suezi.

Table of content

Chapter 1: General introduction

1.1 Overview of global dairy farming

Globally, the demand for animal-source foods (ASF), including milk and dairy products has grown in recent decades (Baltenweck et al., 2006; Gakige et al., 2020). This increasing demand for milk and dairy products has been driven by population growth, changing dietary patterns, improved incomes and increased consumer purchasing power leading to, among others, increased milk production (Lukuyu et al., 2007; Gakige et al., 2020). Dairy production, a subsector of livestock production is dominated by smallholder farmers and is considered one of the most important agricultural sectors in low and middle-income countries (LMICs) (Gakige et al., 2020). Dairy production contributes to the food and livelihood security of millions of farmers (Duncan et al., 2013). Milk quality challenges, however, hinder the development of the dairy industry in LMICs (Özkan et al., 2020).

Milk demand in sub-Saharan Africa is projected to triple by 2050 which reflects the important role that the dairy sector can play in providing quality and nutritious milk and dairy products for the growing human population (Özkan et al., 2020). Public health issues related to milk such as aflatoxin, antibiotics and *E. coli* contamination have led to growing awareness of the importance of ensuring that milk in LMICs countries meets market quality standards and is safe for consumption (Grace et al., 2008; Ahlberg et al., 2016; Ondieki et al., 2017; Kagera et al., 2019; Brown et al., 2020). Milk quality is regulated by public and private food quality standards developed and adopted by actors in agri-food chains, to ensure food quality and safety (Kumar et al., 2017). High-quality milk facilitates processing and marketing (Lemma et al., 2018). In LMICs, there is a high emphasis on food safety and standards compliance for products destined for the export market compared to the limited emphasis on compliance with food safety regulations for foods sold in the domestic markets (Unnevehr, 2015).

Currently, poor milk quality constrains the development of the dairy sector, and the improvement of livelihoods of smallholder farmers and other actors along formal and informal dairy value chains (DVCs) in LMICs (Rademaker et al., 2016). Improving milk quality promises to enhance the livelihoods of actors in the dairy sector through improved incomes and reduced post-harvest losses (Duncan et al., 2013; Özkan et al., 2020). Specifically, there is a need to improve milk handling practices along the DVCs to reduce milk contamination caused by unhygienic milk handling and storage (Ledo et al., 2019). There is also a need to improve farm-level practices, the primary food production area, to realise improved milk safety and quality and reduce the risk of foodborne illnesses that are still prevalent in LMICs (Özkan et al., 2020). It is thus crucial to identify strategies that can lead to milk safety and quality improvement across the DVCs.

1.2 Smallholder dairy production and associated value chains

Dairy production in LMICs is dominated by smallholder dairy farming systems and encompasses extensive grazing, semi-grazing semi-intensive systems and intensive zero-grazing systems (Lemma et al., 2018; Migose et al., 2018). Dairy production primarily takes place in peri-urban and rural areas in mixed crop-livestock farming systems (Migose et al., 2018; Onyango et al., 2019). Intensively managed dairy farms that specialise in dairy production are found in urban and peri-urban areas. In contrast, extensive grazing systems are dominant in rural areas (van der Lee et al., 2020).

Milk produced in smallholder dairy systems is marketed through formal and informal dairy value chains (DVCs) (Lemma et al., 2018; Migose et al., 2018). The formal DVC can be defined as a value chain whereby participating actors are regulated and comply with the prescribed milk quality standards and food safety regulations. In contrast, the informal DVC can be defined as a value chain where participating actors are not registered or licenced to operate (Blackmore et al., 2022; Zavala Nacul and Revoredo-Giha, 2022). DVCs are a continuum of activities that connect actors operating at different stages in the value chain, such as the milk trade, and provision of inputs and services among others (Trienekens et al., 2003). These DVC connections can be conceptualised as being either vertically or horizontally integrated into the value chain. Vertical integration is where a lead actor, such as a milk processing company, coordinates the activities of other DVC actors at different levels to control activities, such as milk supply, quality or distribution. In contrast, horizontal integration is the coordination of activities by actors at the same level of the DVC, such as the collective undertaking of joint milk sales, marketing and input procurement through farmer groups of cooperatives (Trienekens, 2011). These value chain arrangements and networks influence the behaviour of actors regarding milk quality (Blackmore et al., 2022; Zavala Nacul and Revoredo-Giha, 2022).

In East Africa, milk quality and safety continue to be important issues due to public health concerns (Özkan et al., 2020). Currently, governing agencies and traders in DVCs fail to ensure food safety in local markets due to the existing policy gaps in milk quality management, lack of context-specific regulations, lack of long-time sustainable interventions, insufficient staffing of regulatory institutions and lack of specialised milk infrastructure i.e. milk collection and cooling facilities (Rademaker et al., 2016; Kumar et al., 2017). Studies, however, continue to focus on milk microbial contamination and the related public health risks and fail to provide practical recommendations that can help smallholder dairy farmers and DVC actors improve milk quality (Lemma et al., 2018; Ledo, 2020). Milk produced by smallholder dairy farmers, traded by other actors along the value chain, and received by processors is still of poor quality and constrains the growth of the dairy sector in LMICs (Alonso et al., 2018; Bebe et al., 2018). Poor milk quality continues to constitute a major challenge for smallholder farmers, undermining their ability to realise improved livelihoods through the intensification of dairy production (Rademaker et al., 2016; Özkan et al., 2020). Smallholder dairy farmers suffer post-harvest losses associated with milk spoilage and cannot supply sufficient good quality raw milk to meet the demand due to a lack of milk collection infrastructure (Özkan et al., 2020).

1.3 Milk safety and quality challenges in LMICs: a hindrance to dairy development

Poor milk quality affects farmers' and other value chain actors' incomes, employment opportunities and welfare, as well as the health of consumers (Unnevehr, 2015; Kumar et al., 2017). Milk safety and quality can be compromised by microbial and chemical contamination, and adulteration (Häsler et al., 2018; Ndambi et al., 2018). Milk physicochemical composition quality refers to the nutritional components of milk such as fat, protein, solids non-fat (SNF), and lactose content among others (Kabui, 2012; Ondieki et al., 2017). Farmers' husbandry management, such as feeding practices, influences milk physicochemical composition (Kabui, 2012; Ondieki et al., 2017). Milk physicochemical composition is important to milk processors as it influences the manufacturing process and determines the types of dairy products that can be manufactured, and the yields and the quality of final dairy products (Chen et al., 2014; Häsler et al., 2018; Ndambi et al., 2018).

Microbial contamination of milk and dairy products is a public health concern for consumers (Häsler et al., 2018; Ndambi et al., 2018). Milk is a favourable medium for the proliferation of pathogenic bacteria that cause foodborne illness and can serve as a conduit for the transmission of zoonoses (Roesel and Grace, 2015; Lemma et al., 2018; Washabaugh et al., 2019). Animal health practices determine the presence of zoonotic pathogens such as *Brucella spp.* and *Mycobacterium bovis* in milk. Additionally, cattle diseases such as clinical and sub-clinical mastitis are associated with high somatic cell count (SCC) in milk (Shitandi, 2004). Mastitis is the udder infection in cows attributed to poor udder health management practices, unhygienic housing and poor milking hygiene (Kashongwe et al., 2017). Microbial contamination of milk supplied to processing companies undermines their capacity to process raw milk; and affects the taste, quality and shelf life of dairy products (Grace et al., 2017).

Chemical contamination constitutes an additional milk safety and quality challenge (Bebe et al., 2018). Non-observance of the post-antibiotic treatment period and non-discarding of milk from treated cows result in antibiotic residues in milk (Ahlberg et al., 2016; Ondieki et al., 2017). Aflatoxin residues have also been reported in milk produced in smallholder dairy farming systems due to poor storage of feeds and the use of contaminated feeds for cattle feeding (Alonso et al., 2018). Milk adulteration has been reported, including the addition of water to increase volume and the addition of chemicals, such as formalin and hydrogen peroxide, to inhibit microbial growth and extend milk shelf life (Bebe et al., 2018).

Farm-level hygiene and management practices play an important role in determining milk quality (Kabui, 2012; Ondieki et al., 2017). Milk safety and quality problems that start at the farm and cascade into dairy value chains have been identified as a public concern that needs policy intervention (Brown et al., 2019; Blackmore et al., 2022). There are different farm-level drivers of milk quality including compliance with good agricultural practices (GAPs), milk quality standards and food safety regulation, milking and handling hygiene practices, milk storage, animal health, environmental hygiene, milk testing and inspection by buyers (Grace et al., 2017; Lindahl et al., 2018; Washabaugh et al., 2019). Personal hygiene practices, i.e. the washing of hands and cleaning and disinfection of milking equipment, also determine milk microbial quality (Chepkoech, 2010). The choice of milking and storage equipment influences milk microbial contamination; for example, milk stored in plastic has been shown to have high microbial contamination compared to the recommended aluminium containers (Kabui, 2012; Grace et al., 2017; Ondieki et al., 2017).

The first step in supplying quality and safe milk processors is to produce good quality milk from healthy animals (Ledo, 2020). Additionally, subsequent maintenance of good handling hygiene could ensure safe milk products of acceptable quality reach the consumer (Muunda et al., 2021). Milk quality management requires policy and legislative support including sufficient infrastructure, properly trained inspectors and good governance to provide a coordinated and preventive approach to food safety management along the milk value chain (Muunda et al., 2021). Testing raw milk quality for physicochemical composition, microbial quality, water adulteration, and SCC is thus a crucial step to ensure safety and quality (Ondieki et al., 2017).

1.4 Smallholder dairy production in Kenya as a case study

Kenya has one of the most developed dairy sectors in Sub-Sahara Africa (Rademaker et al., 2016). The sector contributes an estimated 3.5% of the overall gross domestic product (GDP) and 14% of the agricultural share of GDP (Maina et al., 2020). Furthermore, Kenya has one of the highest levels of milk consumption in sub-Saharan Africa, with an average of 50-150 litres consumed per capita per year (Alonso et al., 2018). An estimated 70% of the total milk marketed in the dairy sector is produced by smallholder dairy farmers (Gakige et al., 2020). Dairy production is an important source of livelihood and income for 600,000-800,000 smallholder farm households that own two to three cows and operate on an average of two hectares of land (Baltenweck et al., 2006). Additionally, the sector employs an estimated 365,000 people – approximately 12% of the national agricultural workforce – with waged jobs created at and beyond the farm level in rural and peri-urban areas (Baltenweck et al., 2006; Wambugu et al., 2011). These jobs relate to the provision of services that support dairy production such as feeds, veterinary, breeding, extension and milk marketing services (Baltenweck et al., 2006; Gakige et al., 2020). Moreover, dairy production provides manure and constitutes a source and form of wealth storage for smallholder households (Baltenweck et al., 2006; Lukuyu et al., 2019).

Milk production and processing in Kenya have grown, driven by increasing demand, with over 4 million tonnes of milk produced in 2016 (see Figure 1.2) (Rademaker et al., 2016; Alonso et al., 2018). Kenya has an estimated national herd of 3.4 million cattle, mainly *Bos taurus* and their crosses with *Bos indicus* (Shitandi, 2004; Muia et al., 2011). Exotic breeds and their crosses are kept by farmers for their high production potential (Migose et al., 2018). Farmers in arid and semi-arid areas prefer local breeds that can cope with the harsh production environments, i.e. high temperature, feed scarcity, poor feed quality and diseases (Lukuyu et al., 2019; Onyango et al., 2019). The growing demand for milk and dairy products has created market opportunities for smallholder farmers in Kenya to safeguard their livelihood security by intensifying and/or increasing dairy production (Gakige et al., 2020). However, seasonality in milk production and intake in Kenya affects milk availability for processing into dairy products (see Figure 1.3) (Rademaker et al., 2016).

The dairy sector in Kenya is composed of a diverse set of stakeholders who operate together in the DVCs from milk production to consumption; it includes farmers, milk collection centres, dairy plants, input and service providers and cooperatives among others (Brown et al., 2019). Milk produced by smallholder dairy farmers in Kenya is commercialised through both formal and informal DVCs (Rademaker et al., 2016). An estimated 30,000 people are employed in the informal DVC in milk

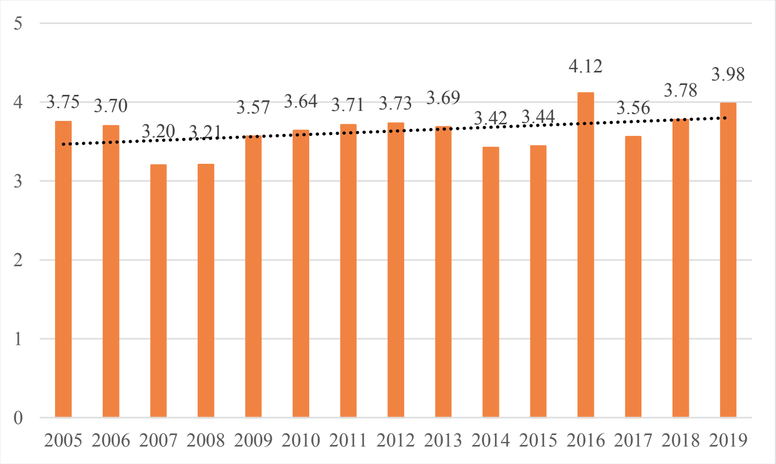


Figure 1.2. Milk production in Kenya from 2001-2019 (in million metric tons) (FAOSTAT 2021)

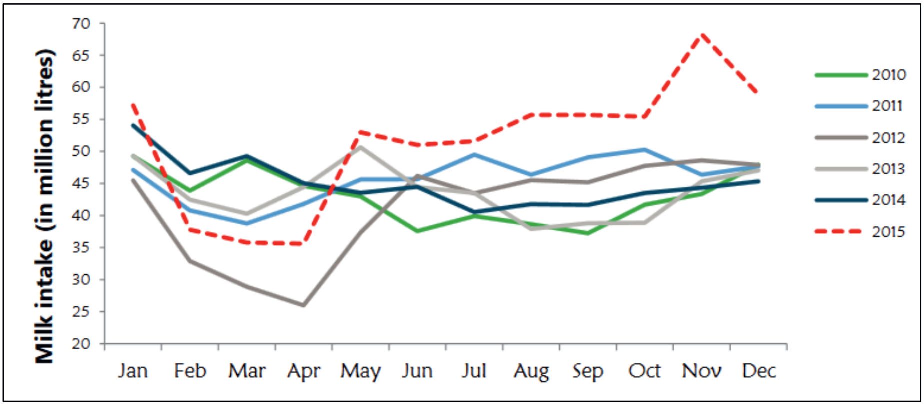


Figure 1.3. Processing companies' seasonal milk intake in Kenya (source: Rademaker et al. 2016)

marketing and processing activities (Baltenweck et al., 2006). The informal DVC is responsible for over 70% of the total milk traded in Kenya, although the formal DVC dominates the pasteurised packaged milk market (Rademaker et al., 2016; Brown et al., 2019). The formal DVC has a higher degree of vertical and horizontal integration of value chain activities; these activities are absent in the informal DVC (Rademaker et al., 2016; Brown et al., 2019; Blackmore et al., 2022).

1.5 Knowledge gap and objective of this thesis

Poor milk quality continues to be a persistent challenge to the Kenya dairy sector (Rademaker et al., 2016). Previous research has explored milk quality, particularly focusing on microbial contamination in both the formal and informal DVCs (Kabui, 2012; Orregård, 2013; Grace et al., 2017; Ondieki et al., 2017; Bebe et al., 2018). However, none of these previous studies has explored the spatial and temporal variation in milk physicochemical composition, microbial contamination and adulteration either at the farm or across the DVCs. Therefore, it is important to understand the current status of milk quality along dairy farming systems and associated value chains in Kenya.

Milk production in Kenya is influenced by the prevailing seasonal conditions including variable and unpredictable rainfall patterns (Onyango et al., 2019). Feed scarcity is a major challenge facing smallholder dairy production in Kenya (Njarui et al., 2021). Feed availability and quality variations in dairy farms are known to affect milk production and physicochemical composition (Moran, 2005). There are a limited number of studies that have explored feed availability and composition in Kenya (Carter et al., 2015; Kashongwe et al., 2017; Lanyasunya et al., 2006; Mburu, 2015; Mutua et al., 2012; Nyaata et al., 2000) Additionally, there a just a handful of mainly cross-sectional studies that have explored milk composition in Kenya (Kabui, 2012; Kabui et al., 2015; Mwendia et al., 2017; Ondieki et al., 2017). However, no longitudinal studies have been conducted to investigate the intra-annual variation of feed and milk composition in a real smallholder dairy farm environment concurrently.

Food handling behaviour of DVC actors is known to influence milk quality (Dongol et al., 2017; Kumar et al., 2017; Brown et al., 2019; Ledo et al., 2019). Moreover, previous research has reported poor attitudes and low knowledge levels among farmers that contribute to low compliance with milk quality standards and food safety regulations (Brown et al., 2019; Ledo et al., 2019). There have been a handful of studies that have explored milk handling practices and they have mainly focused on post-farm-gate milk handling practices in dairy value chains in Kenya (Shitandi, 2004; Kabui, 2012; Orregård, 2013; Grace et al., 2017; Ondieki et al., 2017; Orwa et al., 2017; Alonso et al., 2018; Bebe et al., 2018). Nevertheless, there is a paucity of research in Kenya investigating smallholder farmers' knowledge and attitudes and practices (KAPs) regarding milk quality, microbial contamination, zoonoses and antibiotics residues at the farm level in Kenya.

Milk safety and quality standards, policies and interventions implemented in Kenya often borrow from developed countries. These policies and interventions often fail due to the non-availability of required infrastructure i.e. roads and coolers (Blackmore et al., 2022). Value chain arrangements and relationships that exist between DVC actors influence milk safety and quality management behaviour (Rademaker et al., 2016). The extent of value chain integration and coordination in both the formal and informal DVC can either facilitate or constrain milk quality improvement (Trienekens, 2011). In Kenya, loose vertical integration and coordination of value chain activities such as milk collection, bulking and unrefrigerated transport favour conditions that can lead to milk spoilage and quality deterioration (Kabui, 2012; Rademaker et al., 2016). Low adoption of contracts to guide the milk trade and quality management, such as milk testing, in the informal DVC, presents an opportunity for the trade of low milk quality (Mwambi et al., 2020; Blackmore et al., 2022). To the best of our knowledge, no studies have explored the role of power, value chain integration, DVC actors' relationships and trust in shaping milk quality in the Kenyan dairy sector.

1.5.1 Objectives

The main objective of this PhD thesis was to understand the current state underlying drivers of milk quality in smallholder dairy farming systems in Kenya and identify potential strategies to improve milk quality. In line with this overall research objective, four sub-objectives were formulated:

1. Describe the status of milk quality along dairy farming systems and associated value chains in Kenya using a farming system approach (Chapter 2).
2. Investigate intra-annual variation in feed and milk composition in smallholder dairy farms in Kenya (Chapter 3).
3. Assess the knowledge attitudes and practices of smallholder dairy farmers in Kenya regarding milk quality and hygiene (Chapter 4).
4. Explore the role of power relationships, trust and social networks in shaping milk quality in the dairy sector in Kenya (Chapter 5).

1.5.2 LIQUID research program

This PhD was part of the larger "Local and International business collaboration for productivity and Quality Improvement in Dairy chains in South-East Asia and East Africa (LIQUID)" program that was implemented between 2013 and 2020. This program aimed to improve the performance of emerging dairy chains and to contribute to better livelihoods and improved food and nutrition security in South-East Asia and East Africa. The LIQUID program explored intervention options that create growth opportunities for smallholders and other chain actors to enhance the production of quality and safe dairy products. The project also looked at how selected business models could support innovation toward sustainable dairy farming. This PhD thesis was carried out to fulfil research aim five which looked to investigate how different business models can support on-farm innovations toward more sustainable farming practices (Figure 1.1). More specifically, this PhD thesis looked to identify context-specific approaches and practices which can be implemented by farmers to increase farm productivity and milk quality in a sustainable way.

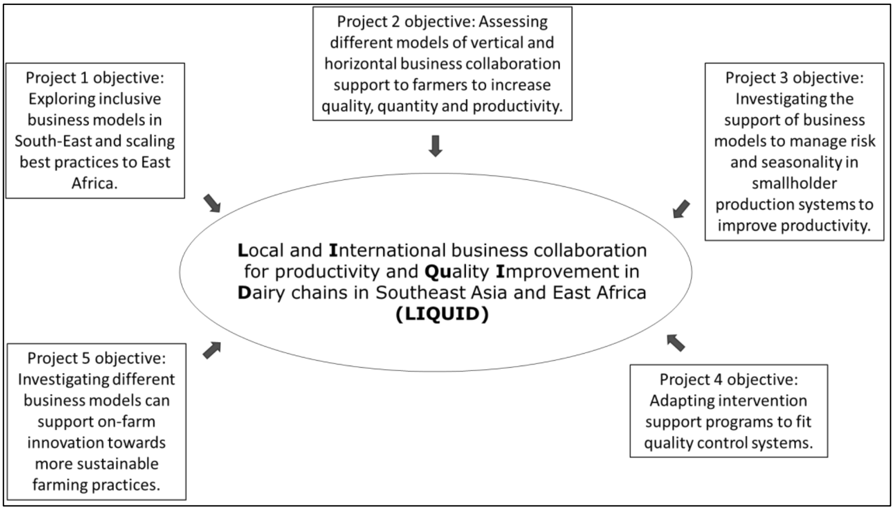


Figure 1.1. LIQUID program overview

1.5.3 Scope of this thesis

This thesis focused on smallholder dairy farming systems which refer to production systems commonly found in sub-Saharan Africa. These dairy farming systems are characterised by small herds of around one to three cows often operating as a mixed crop-dairy farming system (Lemma et al., 2018). These dairy farming systems are characterised by underdeveloped production but with promising potential to intensify dairy production (Ledo, 2020). Milk produced in smallholder dairy farming systems is commercialised through formal and informal DVCs. These DVCs are diverse and fragmented with limited structural organization, and there is a limited formalisation of relationships (i.e. low adoption of contracts) which makes it difficult to improve milk quality (Roesel and Grace, 2014; Ledo, 2020). Informal processing and retailing still dominate the milk trade, with raw unpasteurised milk often sold (Özkan et al., 2020). DVC actors are heterogeneous and include many small-scale dairy actors which makes it difficult to monitor milk quality due to the associated transaction costs (Blackmore et al., 2022). Although milk is easily accessible through the DVCs, poor milk quality associated with low food safety regulations compliance exposes consumers to public health risks (Brown et al., 2019).

1.6 Description of the study area

The research was conducted in Laikipia, Nakuru and Nyandarua counties in Kenya (see Figure 1.5). These counties located in the central highlands of Kenya were selected due to the dairy sector being well-established there and the existence of agricultural policies supporting the sector (Staal et al., 2003; Abdulai and Birachi, 2009; Muia et al., 2011; Migose et al., 2018). The counties have a high density of dairy cattle, a large number of smallholder dairy farmers practising mixed crop-livestock production, and high milk production (van de Steeg et al., 2010; Migose et al., 2018).

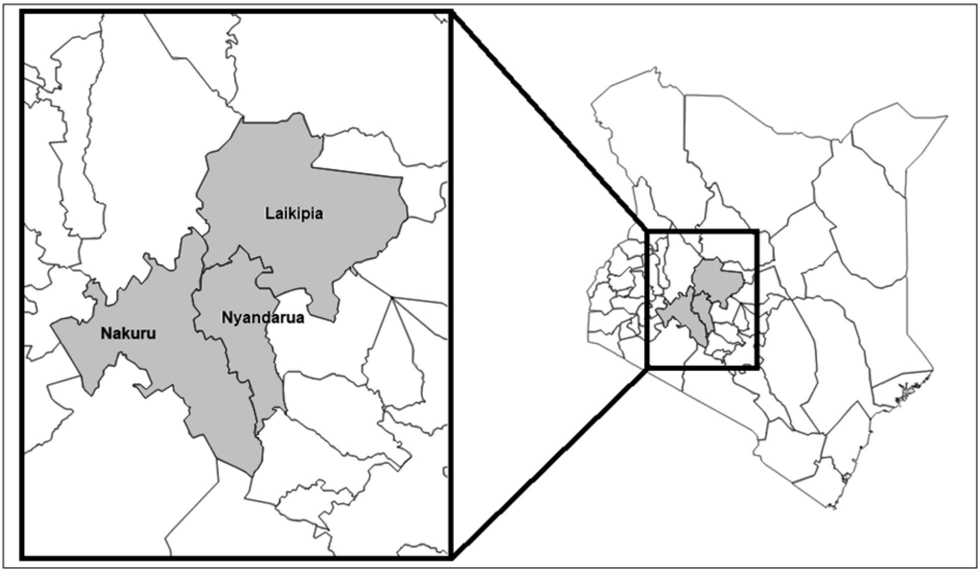


Figure 1.5. Study area location for the study developed with Grass software (QGIS, 2018)

The three counties capture the diversity of agroecological zones found in Kenya and span three climatic zones. Laikipia is a semi-arid zone, while Nakuru and Nyandarua are humid and temperate highland regions respectively (Lukkaine, 2012; Muia et al., 2011; Abdulai and Birachi, 2009; Staal et al., 2003). Intensive zero-grazing systems, that depend on the cut and carry feeding, and mixed crop-livestock production systems are mainly concentrated in the humid and sub-humid regions of Kenya due to the favourable agro-ecological environment, i.e. bi-modal rainfall and low temperatures (van de Steeg et al., 2010; Migose et al., 2018). In arid and semi-arid areas in Laikipia and Nakuru, dairy production is characterised by zebu cattle kept in extensive grazing systems (Njarui et al., 2016).

1.7 Research approach

This research used a mixed-methods and farming system approach. These approaches are employed to determine the current state of milk quality produced by farmers in smallholder dairy production systems and traded in the dairy value chains. Additionally, the approach looks to identify the various factor that influences milk quality in smallholder dairy systems in Kenya.

1.7.1 Mixed method approach

This study employed a mixed-methods approach in collecting data, i.e. use of quantitative and qualitative methods. A mixed-methods approach bridges the divide between the traditional positivist research paradigm (associated with quantitative research methodologies) and the constructivist research paradigm (associated with qualitative research methodologies) (Symonds and Gorard, 2010). The mixed-methods approach has over time emerged as a viable third research paradigm (Denscombe, 2008; Symonds and Gorard, 2010; Creswell, 2015). The approach allows for data triangulation through a variety of complementary techniques which improves the accuracy of the collected data (Symonds and Gorard, 2010). The approach facilitates an exhaustive investigation of the topic under research by combining information from complementary or different data sources, and ideally reduces or avoids the intrinsic biases of single-method approaches and compensates for the specific strengths and weaknesses associated with each particular method (Denscombe, 2008).

A mixed-methods approach allows a researcher to undertake data analysis and build on initial findings using contrasting kinds of data or methods, and draw on the strengths of different disciplines to address research topics (Denscombe, 2008; Creswell, 2015). This makes it an ideal research paradigm for the present study which aimed to identify strategies to improve the quality of milk produced in smallholder dairy systems and traded in DVCs in Kenya from farm to table.

This study employed a combination of methods including document analysis, microbial/chemical analysis of milk samples collected at the farm and DVC levels, key-informant interviews, participant observations, cross-sectional survey of farmers and longitudinal sampling of milk and feeds at the farm level for chemical and nutritional compositional analysis to investigate the current state of milk quality in Kenya and identify the factors that influence milk quality at the farm and DVC levels.

1.7.2. Farming systems approach

The farming systems approach employed in this study has been explained by Duncan et al. (2013), Migose et al. (2018) and van der Lee et al. (2020). It is premised on the idea that there is a spatial gradient that can be used to categorise smallholder dairy farming systems according to their location, i.e. urban location (UL), mid-rural locations (MRL) and extreme-rural locations (ERL), (see Figure 1.4) based on market quality, intensification levels and access to production resources such as land and labour (Migose et al., 2018; van der Lee et al., 2020). Market quality refers to the ease of access and quality of inputs markets and output markets for milk (Duncan et al., 2013).

UL smallholder dairy farming systems are found in urban and peri-urban areas (van der Lee et al., 2020). These farming systems are highly intensive and characterised by exotic breeds and their crosses, and the use of external farm inputs such as feeds (Duncan et al., 2013; Migose et al., 2018). UL farming systems have high market quality as farmers have easy access to inputs markets and outputs market for milk, and access to well-developed and reliable infrastructure, such as roads and electricity supply. UL farmers have low transaction costs for inputs and outputs due to their good access to input and output markets (Migose et al., 2018).

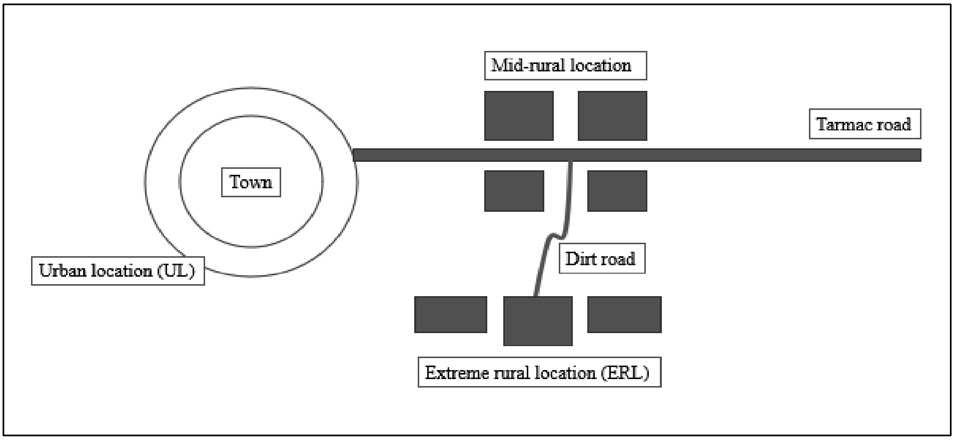


Figure 1.4. Spatial framework indicating the location of dairy farming systems

MRL smallholder dairy farming systems are found in the intermediate distance to urban centres. They are semi-intensive farming systems, characterised by the use of exotic breeds and their crosses (Migose et al., 2018). These farming systems are less dependent on external inputs due to the availability of production resources such as land and labour (Duncan et al., 2013; Migose et al., 2018). MRL farming systems have fairly good access to markets inputs and outputs market for milk due to their proximity to urban centres, and access to well-developed and reliable infrastructure, such as roads and electricity supply (Migose et al., 2018). There is a loose vertical integration and coordination of DVC activities (van der Lee et al., 2020). Farmers are horizontally integrated by producer organisations, i.e. farmer groups and cooperatives, that bulk and sell milk on their behalf (Migose et al., 2018). Production levels are high in the MRL and, as a result, processing companies source the majority of milk from farming systems in this location.

ERL dairy farming systems are semi-intensive or extensive and are found in far rural areas (Migose et al., 2018). These systems are characterised by low dependence on external inputs due to the availability of production resources such as land and labour (van der Lee et al., 2020). Farming systems in the ERL have low market quality due to their poor access to inputs and output markets (Migose et al., 2018). ERL areas have poor road infrastructure which increases transaction costs and which impedes milk bulking and transporting, leading to poor milk quality (Migose et al., 2018; van der Lee et al., 2020).

1.7.3. Social networks and power analysis

The dairy sector comprises a diverse set of actors that are connected in their day-to-day activities. DVCs are thus a continuum of activities and relationships, such as information exchange, access to input and services, milk trade and milk regulation, among others, between actors operating at different stages of the value chain (Trienekens et al., 2003; Oloo, 2010; Mutura, 2015). The vertical or horizontal integration of DVC activities and decision-making relationships can be considered social networks between actors (Trienekens et al., 2003). These relationships can be formal, i.e. contractual arrangements or informal, i.e. reciprocal personal relationships and they influence DVC actors' behaviour regarding milk quality (Konchak and Prasad, 2012; Rademaker et al., 2016).

Depending on the access to and control of resources including finances, expertise, information, services, and market position, among others, DVC actors have varying power to influence the action of other actors (Nyaga et al., 2013; Belaya and Hanf, 2016). There is a high degree of power asymmetry in the formal DVC whereby big actors such as cooperatives and processing companies can influence the behaviour of less-powerful actors such as farmers to comply with their demands. In contrast, the informal DVC tends to have a low degree of power asymmetry between actors (Gereffi and Lee, 2009). The degree of power asymmetry can positively or negatively influence the behaviour of DVC actors, particularly concerning milk quality (Vermeulen, 2005). It is therefore important to understand how the social networks and DVC actors' relationships influence behaviour relating to milk quality management.

1.7.4 Thesis outline

Figure 1.6 presents the outline of the thesis. The thesis consists of the following chapters: an introduction, four research chapters, and a general discussion and summary. Chapter 2 describes the status of milk physicochemical composition, microbial contamination, and adulteration in dairy farming systems and at different nodes along the formal and informal DVCs in Kenya. Milk samples were collected at farm level and DVC level in Laikipia, Nakuru and Nyandarua counties based on the spatial framework and analysed for milk physicochemical composition, microbial contamination, and adulteration. Observations of milk handling hygiene were conducted at farm and DVC levels to determine factors, i.e. KAPs, influencing the microbial quality of milk.

Chapter 3 explores the spatial and temporal variations in milk physicochemical composition and feed quality in smallholder dairy systems in Nakuru county. We used the farming systems approach and spatial framework to assess spatial and temporal variations in milk physicochemical composition and feed quality. We designed and carried out a longitudinal survey that involved monthly milk and feed sampling and analysis to determine composition. Additionally, we explored feed availability, feed processing and coping strategies in periods of scarcity.

Chapter 4 evaluates smallholder farmers' knowledge, attitudes and adoption of milk quality and hygiene practices in Laikipia, Nakuru and Nyandarua counties. We used a cross-sectional survey to investigate how farmers' adoption of milk quality and hygiene practices at the farm level and how farmers' knowledge and attitudes and demographic characteristics shaped their adoption of practices influencing milk quality. We explored the determinants of farm-level adoption using regression modelling to identify drivers of the adoption of milk quality and hygiene practices.

Chapter 5 explores how social networks, power relations and trust between DVC actors and their influence on behaviour related to milk quality in Laikipia, Nakuru and Nyandarua counties. We mapped the social networks of the formal and informal DVCs to explore DVC integration, coordination, and power dynamics and, thereby, explore how these DVC characteristics might influence actors' compliance with milk quality regulations and food safety standards. Chapter 6 integrates the results of Chapters 2-5 and recommends possible milk quality improvement strategies in Kenya that could be adopted at the farm and/or DVC level.

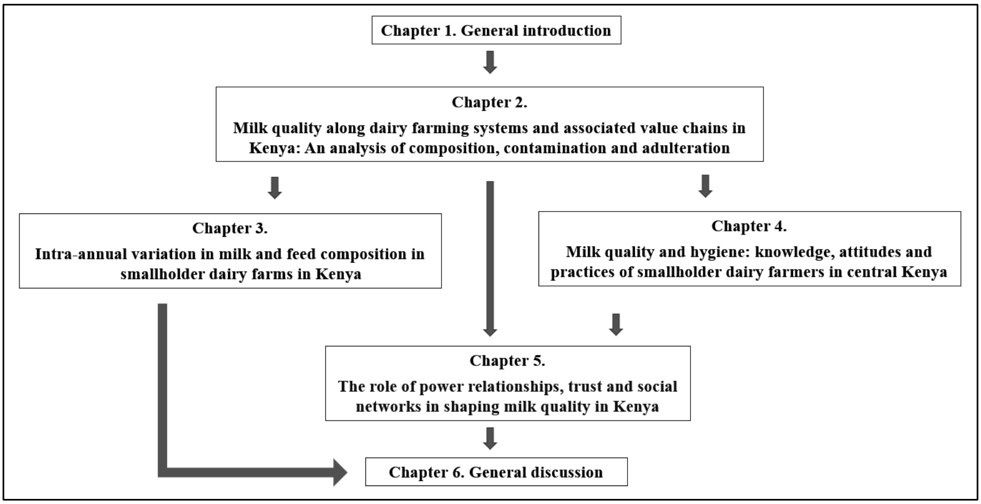


Figure 1.6. Thesis outline

Chapter 2: Milk quality along dairy farming systems and associated value chains in Kenya: An analysis of composition, contamination and adulteration

Nyokabi, S., Luning, P.A., de Boer, I.J., Korir, L., Muunda, E., Bebe, B.O., Lindahl, J., Bett, B. and Oosting, S.J.

Published in Food Control; DOI 10.1016/j.foodcont.2020.107482

Abstract

Poor milk safety constitutes a persistent public health risk in Kenya. Poor milk composition, microbial contamination and adulteration is a constraint to dairy sector development. We hypothesise that variation in milk quality and safety depends on variation between farming systems. We argue that this variation between farming systems is associated with spatial location which affects the agro-ecological conditions and the availability of labour and land.

We used a spatial framework based on the distance to urban markets to distinguish the following farming systems: relatively intensive dairy systems in urban locations (UL), semi-intensive dairy systems in mid-rural locations (MRL) and extensive dairy systems in extreme rural locations (ERL). We aimed to investigate the variation in the quality of raw milk in these dairy farming systems and associated value chains in central Kenya. For this reason, we combined several methods such as participatory rural appraisal, participant observation, and milk physicochemical and microbiological analyses to collect data. Milk samples were collected at the informal and informal value chain nodes - farms, informal collection centres, informal retailing centres including milk vending machines, and formal bulking centres - where milk changes hands between value chain actors. Milk quality was compared to standards recommended by the Kenya Bureau of Standards (KeBS).

There were no differences in the quality of raw milk between locations or between nodes. The overall milk physicochemical composition means (standard error) of the milk were within KeBS standards: fat 3.61 (0.05), protein 3.46 (0.06), solid-not fats 9.18 (0.04), density 1.031 (0.0002) and freezing point −0.597 (0.019). The protein percentage was below KeBS standards at all value chain nodes, except at the formal bulking node. There was significant contamination of milk samples: 16.7% of samples had added water, 8.8% had somatic cell count SCC above 300,000, 42.4% had *E. coli*, 47.9% had *Pseudomonas spp.*, 3.3% had *Staphylococcus spp.* and 2.9% tested positive for brucellosis antibodies. Unsanitary milk handling practices were observed at farms and all value chains nodes. Milk physicochemical composition except for protein content meets the KeBS Standard. High levels of microbial contamination of milk pose a public health risk to consumers and show that urgent action is needed to improve milk quality.

Keywords: milk handling, microbial contamination, milk composition, spatial location, farming systems

1. Introduction

Dairy production plays an important role in supporting livelihoods and economies across East Africa. Kenya produces over five billion litres of milk per year and is the leading milk producer in the region. The dairy sector contributes to approximately 40% of the livestock gross domestic product (GDP), 14% of the agricultural GDP, and 3.5% of the overall GDP in Kenya (Ajwang & Munyua, 2016). Smallholder dairy farmers produce about 75% of Kenya's total milk supply (Chepkoech, 2010). Milk consumption rates in Kenya are among the highest in sub-Saharan Africa: between 50 and 150 L per capita per year (Alonso et al., 2018; Bosire et al., 2017). Rapid population growth, urbanisation and changing food preferences of the middle class have led to a 5% increase per annum in the demand for milk and milk products, over the last decade (Kabui et al., 2015; Ondieki et al., 2017; Wambugu et al., 2011).

Milk is commercialised through both formal and informal value chains in Kenya. The formal value chain accounts for approximately 30% of the total traded milk and is controlled by entities licensed to operate by the Kenya Dairy Board (KDB). These entities pasteurise or ultra-heat treat (UHT) milk, package and commercialise industrially-processed-and-packaged dairy products such as “liquid milk”, yoghurt and ice-cream. The key distinguishing feature of formal dairy value chains is that they sell packaged and branded dairy products (Alonso et al., 2018). Informal value chains account for the remaining 70% of milk traded in Kenya. These informal value chains commercialise dairy products which have not been industrially-processed, i.e. raw and traditionally-pasteurised milk and dairy products. Informal value chains include licensed and unlicensed entities selling milk or dairy products directly to consumers through milk-bars, milk vending machines, corner-shops, street vendors and mobile vendors on bicycles or motorbikes (Alonso et al., 2018; Chepkoech, 2010; Odero-Waitituh, 2017). The proportion of pasteurised milk traded in the informal value chains in Kenya has been increasing due to growing demand for safe milk (Alonso et al., 2018; Bebe et al., 2018). However, milk is often re-contaminated after pasteurisation due to unhygienic milk handling practices (Lindahl et al., 2018).

In formal and informal value chains, milk quality and safety are regulated by the Dairy Industry Act which is enforced by KDB and the Public Health Act which is enforced by the Ministry of Health (MoH) (GOK, 2012). Milk quality refers to characteristics that enhance the acceptability of milk and milk products, i.e. chemical, physical, technological, bacteriological and aesthetic characteristics. It also encompasses milk safety which refers to the state whereby milk is safe for consumption, i.e. its consumption is unlikely to cause harm to the consumer, or the risks associated with consumption are reduced to an acceptable level (Ndambi et al., 2018). A large share of milk produced and traded as unprocessed milk, mainly in the informal value chain, does not meet composition, microbial and chemical contamination standards stipulated by KDB and the Kenya Bureau of Standards (KeBS) (Alonso et al., 2018; Brown et al., 2019).

Milk is a complex mixture of compounds, i.e. water, fat, protein, lactose, enzymes, minerals, organic acids and vitamins (Schwendel et al., 2015). Milk composition is influenced by factors which are specific to a cow and her environment. These factors are breed, age, health status, stage of lactation, diet; the intensity of management; milking interval; and ambient environmental temperature and seasonality, which influences feed availability (Chen et al., 2014; Schwendel et al., 2015). Milk composition determines the economic feasibility of processing (i.e. the yield of butter, or cheese obtained per kg of milk) and affects the quality of dairy products (Chen et al., 2014). Low protein percentage has been reported in a handful of studies investigating milk composition in Kenya (Kabui et al., 2015; Ondieki et al., 2017).

Microbial contamination of milk occurs when bacteria found in the cow's udder (often causing mastitis), or from the cow and her environment, enter the milk through unhygienic milking and handling practices. Milk is handled by multiple value chains actors during bulking and transporting, which increases the risks of microbial contamination. Although milk is usually not cooled during bulking and transporting from the farm, cooperatives and processors in the formal value chain often have a central bulking location, where they collect, bulk and cool milk before transporting it to processing factories. This cooling process reduces microbial growth (Kabui et al., 2015; Nyarugwe et al., 2018). Actors in the informal value chain have numerous collection centres where they bulk milk from farmers, however, they do not necessarily look to cool milk before its sale (Ledo et al., 2019; Nyokabi et al., 2018).

Contamination with bacteria such as *Escherichia coli* and *Salmonella spp.* is a sign of poor milk handling and hygiene practices. Zoonotic bacterial diseases, such as brucellosis and Q-fever (*Coxiella burnetti*), are a major public health concern for consumers in Kenya (Arimi et al., 2005; Njenga et al., 2010; Wanjala et al., 2017). Contamination of milk with lactic acid bacteria is also common in Kenya, and if not controlled by heat treatment or immediate cooling eventually results in sour milk, milk spoilage and reduced shelf life of dairy products (Kabui et al., 2015; Wanjala et al., 2017).

Somatic cell count (SCC), i.e. the total number of cells per ml of milk, is an indirect indicator of microbial contamination and reflects the extent to which white blood cells are produced by the cow's immune system to fight infection of the mammary glands. High SCC levels, caused by clinical and subclinical mastitis, is a major milk quality problem in Kenya (Kabui et al., 2015; Wanjohi, 2014).

Chemical contamination of milk refers to the presence of chemical residues such as pesticides, antibiotics, and preservatives. Biohazards such as aflatoxins are toxic by-products of fungi which contaminate grains and other cattle feeds (Kirino et al., 2016). Pesticide residues enter milk from contaminated feeds and directly from cows inhaling contaminated air (Deti et al., 2014). Contamination with antibiotic residues occurs where the withdrawal period for antibiotic treatments are not obeyed. In some instances, milk is also directly adulterated by value chain actors with antibiotics and inhibitory substances, such as hydrogen peroxide and formalin (Wanjala et al., 2018). Chemical contaminants such as aflatoxin, pesticides and antibiotics affect milk processing; for example, antibiotics residues can inhibit the fermentation process during yoghurt processing. Chemical contamination constitutes a public health risk to consumers of dairy products in Kenya (Ahlberg et al., 2016; Kang'ethe et al., 2005; Shitandi & Sternesjö, 2004).

Milk adulteration is the alteration of the natural composition of milk by (i) the extraction of one or more of its components, such as fat, or (ii) the addition of substances such as water by value chain actors. Adulteration interferes with the compositional and processing quality of milk, but also the hygienic and nutritional quality of milk, while extraction of milk components lowers the value-for-money of milk purchased by processors and consumers. Milk adulteration undermines the quality of milk sold to processors and consumers in Kenya (Ondieki et al., 2017; Wanjala et al., 2017).

Milk production varies among smallholder dairy farming systems depending on their spatial location for two main reasons. First, the spatial location of a farming system determines its agro-ecological conditions, such as climatic characteristics, which could influence milk composition via, for example, fodder quality and availability, breed and ambient temperature. Second, the spatial location of a farm determines the availability of production factors such as land and labour and market quality. Availability of production factors and market quality are associated with distance to urban markets (Duncan et al., 2013; Migose et al., 2018; Van der Lee et al., 2016). Market quality is defined as the attractiveness and reliability of input and output markets (Duncan et al., 2013; Migose et al., 2018). For example, in urban areas, land and labour are more scarce than in rural areas (Migose et al., 2018; Van der Lee et al., 2016). Market quality is good in urban areas, i.e. farms use high amounts of input and they benefit from high output levels and high farm-gate milk prices. In contrast, rural areas farms have medium or low market quality, characterised by low production costs and low production levels due to low use of inputs and low farm-gate milk prices (Duncan et al., 2013; Migose et al., 2018). Milk production, intensification levels and milk prices have been shown to vary depending on spatial location and market quality in Kenya (Duncan et al., 2013; Migose et al., 2018). Given the differences in the farming systems, we hypothesise that milk physicochemical composition, microbial contamination and adulteration also varies.

We used a spatial framework based on the distance to urban markets to distinguish the following farming systems: relatively intensive dairy systems in urban locations (UL), semi-intensive dairy systems in mid-rural locations (MRL) and extensive dairy systems in extreme rural locations (ERL) (Migose et al., 2018; Van der Lee et al., 2016). Intensive UL farms are likely to use a different diet and enforce stricter health control measures than more extensive MRL and ERL farms, which may result in improved milk composition and less contamination. MRL farms participate to a greater extent in formal value chains than UL and ERL farms which may result in improved milk quality; milk quality demands in the formal value chain are higher than in the informal value chain. These farming system characteristics may affect milk quality.

As far as we are aware, variation in milk quality as impacted by farming systems and associated value chains has not been studied in Kenya and elsewhere in sub-Saharan Africa. The main objective of this paper, therefore, was to investigate the variation in milk quality in these dairy farming systems and value chains in central Kenya. Knowledge of the variation of milk quality as it relates to farming systems will facilitate the design of context-specific interventions better addressing farmers' needs.

2. Methodology

2.1. Study area

The three counties selected to capture the diversity of agro-ecological zones found in Kenya were Laikipia, Nakuru and Nyandarua. These counties encompassed agro-ecological zones as varied as semi-arid in Laikipia, to humid and temperate in the highland regions of Nakuru and Nyandarua (Abdulai & Birachi, 2009; Muia et al., 2011; Staal et al., 2003).

2.1.1. Principles of the farming systems spatial framework

We used a spatial framework to distinguish the three main dairy farming systems and their associated value chains, that differ in the availability of production factors such as land and labour, and market quality. Similar to Migose et al. (2018), we used distance to urban markets as a proxy for resource availability and market quality. We expected that intensive, semi-intensive and extensive smallholder dairy farming systems were situated in urban locations (UL), mid-rural locations (MRL) and extreme rural locations (ERL), respectively (Duncan et al., 2013; Migose et al., 2018). Each farming system is part of either a formal or an informal value chain. Milk is marketed in formal and informal value chains through a series of nodes. A node is defined as a value chain stage where milk is moved or exchanged; for example, at any particular node, milk is received from a farm or another value chain actor, and milk is going out to another actor, i.e. trader or consumer. (Baltenweck et al., 1998; Baltenweck & Staal, 2007; Duncan et al., 2013; Migose et al., 2018; Van der Lee et al., 2016; Van der Lee et al., 2018).

2.1.2. Application of the farming systems spatial framework

To understand the farming systems in central Kenya, we conducted a Rapid Rural Appraisal (RRA). As part of this RRA, we visited 50 dairy farms as shown in Table 1. We also interviewed local extensionists: three in Laikipia, three in Nakuru and four in Nyandarua, and veterinarians: two in Nakuru, two in Nyandarua and two in Laikipia. Information was collected about the agro-ecological zones and farm characteristics, e.g. breed, herd size, production factor availability, associated value chains, and access to markets. To determine and define the boundaries between UL, MRL and ERL locations, we combined the RRA information with information from QGIS geographic information system software (QGIS Development Team 2018), HarvestChoice (IFPRI, 2011) and SERVIR (https://servirglobal.net/Data-and-Maps). The boundaries for distinguishing the spatial locations were concluded to be at 20 km and 45 km. Locations closer than 20 km, 20–45 km and above 45 km from towns were identified as UL, MRL and ERL, respectively (Figures 1 and 2).

Table 1. Number of farms sampled and milk samples collected by county, spatial location and node

Number of farms selected for Rapid Rural Appraisal

	Laikipia	Nakuru	Nyandarua
UL	5	5	6
MRL	5	6	5
ERL	6	6	6

Number of milk samples collected according to county, spatial location and node

Laikipia		Nakuru			Nyandarua		
158		209			126		
Urban location		Mid-rural location			Extreme rural location		
141		165			186		
Producer*	IR*	Producer	FB*	IB*	Producer	FB	IB
99	42	33	52	80	80	50	56

* Producer-farmers, IR-informal retailers, FB- Formal bulking and IB- informal collection centres

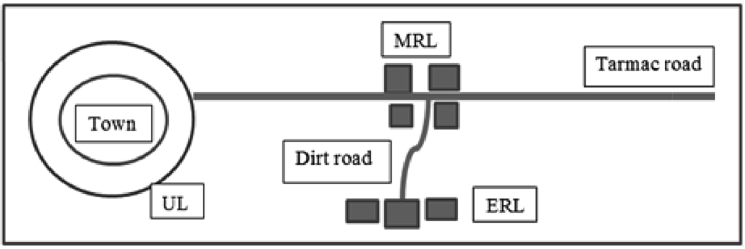


Figure 1. Spatial framework indicating the location of dairy farming systems

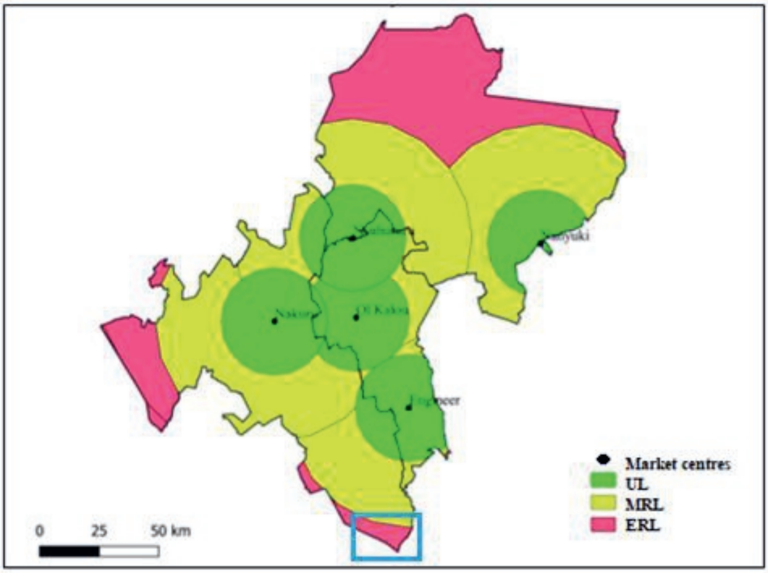


Figure 2. Spatial location for the study developed with Grass software (QGIS, 2018). The blue box indicates the area which was reclassified to MRL

In the three counties, boundaries were determined and agreed in collaboration with the above-named local dairy stakeholders. Towns with good market quality, i.e. large populations or a milk processing factory, were categorised as UL, and included the towns of Nyahururu, Nakuru, Engineer, Nanyuki and Olkalau. MRL and ERL were determined based on the identified UL, using the QGIS software. UL, MRL and ERL were visited and observations conducted before the commencement of the research to verify location validity, reliability and generalisability. After the field visits and observational verification, Soko-Mjinga, Mukeu and Nairobi highway fly-over-junction areas in Nyandarua county (marked in Figure 1 with a blue square) were recategorised as MRL rather than ERL due to their proximity to the neighbouring urban areas of Nairobi and Kiambu.

2.1.3. Collection of milk samples using farming systems spatial framework

In July and August 2017, we collected 493 milk samples voluntarily provided by value chain actors at formal and informal value chains nodes in UL, MRL and ERL (for details see Table 1). Nodes considered by this study were farmers, informal collection centres, informal retailing centres and milk vending machines (ATMs), centralised formal bulking and cooling centres. Milk quality was not assessed at processing and formal retailing nodes in this study as it was pasteurised and processed which could change its physicochemical composition and microbial contamination. Pasteurised milk is also packaged and bears the KeBS mark of quality and assumed to meet milk quality standards (Alonso et al., 2018; Brown et al., 2019).

It was not possible to obtain a list of all farmers and value chain actors operating in the three counties, so we undertook stratified sampling to create an inventory of the roads along which dairy farms and value chain nodes were clustered in each location, using the information provided by farmers, extension officers, veterinarians, traders and transporters. We then randomly selected 10 to 15 roads within each location from this inventory, and collected 3–5 milk samples along each selected road (Table 1).

In addition to collecting milk from farmers, we also collected milk from formal bulking centres and collection centres run by informal bulking agents in all locations. Marketed milk was also purchased in urban centres from licenced milk vending machines and unlicensed informal retailers that purchased milk from UL farmers. Nevertheless, a minor part of the milk sold at such UL retail locations could have come from MRL and ERL. Each sample consisted of 150 ml of milk collected using a sterile syringe. The samples were transferred into sterile sample bottles and carried in cooling boxes with ice packs to avoid microbial multiplication. The samples were transported, within 5 h of collection, to the Regional Veterinary Laboratories (RVL) in Nakuru for analysis.

2.2. Laboratory analyses

Milk samples were first homogenised by shaking, and then split into three sub-samples and analysed for physicochemical composition, somatic cell count (SSC) and microbial contamination. Analyses of the samples were undertaken on the same day of collection.

Milk physicochemical composition was analysed, i.e. freezing point and the percentages of fat, protein, solid non-fats (SNF), density and added water in the Regional Veterinary Laboratories (RVL) in Nakuru, using a rapid milk analyser (Ekomilk milk analyser, Eon Trading, Stara Zagora Bulgaria). Results were compared to the national standards: fat not less than 3.25%, protein not less than 3.50%, solid not fats not less than 8.50%, density 1.028–1.036 g/ml, freezing point −0.525 to - 0.550 °C and added water 0% (Kabui et al., 2015).

The milk SCC analysis was conducted using a rapid somatic cell counter (Ekomilk scan, Eon Trading, Stara Zagora Bulgaria).

Microbial contamination was determined by isolating and identifying bacteria following the National Mastitis Council standard procedure, as described by Wanjohi (2014). Raw milk samples were streaked on blood and MacConkey agar using a sterile loop, then incubated aerobically at 37 °C for 18–24 h. Bacteria on culture-positive plates were identified by colony morphology, haemolysis on blood agar and gram-stain reaction in combination with microscopic examination. In cases where no growth was detected, plates were reincubated at 37 °C for an additional period of 24 h. The procedure enabled detection of the presence of pathogenic microorganisms prevalent in Kenya, such as *Bacillus spp., Staphylococcus spp., Streptococcus spp.* and *Escherichia coli* (Nato et al., 2018).

Additionally, milk samples were analysed for antibodies against *Brucella abortus* using the milk ring test (MRT) following the standard procedure (Desta, 2014; Kamwine et al., 2017; Wanjohi, 2014). Milk samples of approximately 1 ml were put in test tubes of 25 mm height and 3 μl of the standard MRT antigen (*Brucella abortus* antigen stained with hematoxylin) was added to each test tube. The mixture was left for 1 h at 37 °C. Positive reactions occurred when *B. abortus* antibodies in the milk and antigens in the reagent agglutinated, forming antibody-antigen-fat globule complexes which form a blue coloured layer at the top. The tests were considered negative if the colour of the milk remained homogeneously dispersed in the milk column. In the case of inconclusive results, the analyses were repeated until all samples were categorised as either positive or negative for *B. abortus*.

2.3. Farm and value chain milk handling practices observations

To gain insight into farmers' and value chains actors' milk handling behaviour, observations were made using a checklist which covered hygiene practices, animal health, personal hygiene and compliance with regulations on food handling. We visited 50 farms to observe hygiene and milk handling practices at the farm level. Additionally, we visited 11 urban centres: Olkalau, Oljororok and Engineer in Laikipia county, Nakuru town, Njoro, Molo and Elburgon in Nakuru county, Nyahururu, Kinamba, Rumuruti and Nanyuki in Nyandarua county, to observe milk handling at bulking, transport and retailing in both the formal and informal value chains. Non-compliance with regulations was considered to compromise milk quality at farms and at value chains nodes (Lindahl et al., 2018; Ndambi et al., 2018). Ethical approval for the study was granted by the International Livestock Research Institute's (ILRI), Institutional Research Ethics Committee (ILRI IREC) (REF: ILRI-IREC 2017–09). Study participants were informed that they could withdraw from the study at any time. Consent was obtained before human subjects, or their work premises were photographed. Observations were recorded as written notes and photographs that were used to assess farmers' and value chain actors' compliance with milk handling regulations.

2.4. Statistical analysis

The data collected was entered and cleaned in Ms Excel™ 2010 and exported to SPSS (SPSS 20.0 for window 7, SPSS Inc, Chicago, Illinois) statistical software package for analysis. The mean and standard error of means were calculated for milk physicochemical composition: fat, protein, solid non-fats (SNF), added water, density and freezing point. Proportions of positive samples for SCC>300,000, microbial contamination and added water were computed. ANOVA and chi-square ($\chi 2$) test were computed to test for differences between nodes and spatial locations. A p-value ≤ 0.05 was considered statistically significant.

3. Results

3.1. Farming systems

The results of the RRA revealed that farming systems in UL, MRL and ERL varied in agro-ecological conditions, resource availability and market quality. This variation in farming systems across the spatial locations is explained in the section below.

3.1.1. Dairy farming systems in UL

Farming systems in UL were intensive, specialised in dairy production, and characterised by high production levels, zero-grazing and use of external feed inputs. They had a high number of high-producing cows, notably high-grade Friesian crosses. The farmers purchased ingredients to make their mixed feed rations. UL farming systems had good market quality as they had direct access to providers of inputs, such as feed and artificial insemination (AI) and milk consumers, shopkeepers and vendors. They were able to sell morning and evening milk through the informal value chains and received higher milk prices per litre (60 Kenyan shillings equivalent to US$0.60) than farmers in MRL, ERL and formal value chains. UL farms had access to good mainly tarmacked roads which reduced transaction costs for purchasing goods and obtaining services. However, forage and land availability were major constraints in this location.

3.1.2. Dairy farming systems in MRL

Farming systems in MRL were semi-intensive, mixed crop-livestock systems. These MRL systems used both local and improved breeds, had low production levels, fed a limited amount of concentrates and preserved forage for the dry season. Cross-bred cows were fed primarily with farm-grown feeds. Road infrastructure was mainly unpaved gravel roads that connected to secondary roads and these roads were prone to becoming unpassable during the rainy season, which hampered milk collection. MRL farms had access to milk cooling plants run by processors and cooperatives, and the MRL was the spatial location where formal processors primarily sourced their milk.

Farming systems in MRL had medium market quality and were characterised by the presence of both formal and informal value chains, and received lower milk prices than the systems in UL. The formal value chain comprised farmer groups, cooperatives and formal processors operating through business and contractual arrangements. Although they paid a lower milk price per litre (30 Kenya shillings equivalent to US$0.30), formal processors were able to buy large volumes of milk. Processors and cooperatives primarily collected milk in the morning. As farmers did not have cooling equipment to preserve milk, they faced problems in storing evening milk overnight. In contrast, informal value chain actors transacted small volumes of milk and offered farmers relatively high farm gate prices per litre (40 Kenya shillings equivalent to US$0.40).

3.1.3. Dairy farming systems in ERL

Farming systems in the ERL were extensive or semi-intensive mixed crop-livestock production systems. Production factors such as land and labour were relatively abundant, and there was low reliance on purchased external inputs which led to low production costs. Farmers kept local or cross-bred cows adapted to the local environment and with low milk production. ERL farms had relatively low market quality due to poor access to input and milk markets and faced high transaction costs (i.e. transportation costs). Farmers traded milk primarily through the informal value chain, selling to middlemen, who bulked the raw milk and later sold it in the UL. In some parts of the ERL, the formal value chain was present, and milk was sold to cooperatives and processors' milk collection centres. Milk prices per litre in the ERL were the lowest of all three spatial locations; 32 Kenya shillings (equivalent to US$0.30) in the informal value chain and 25 Kenya shillings (equivalent to US$0.25) in the formal value chain. Road infrastructure consisted of unpaved and earth roads connecting to secondary roads, linking rural villages and towns. The poor road infrastructure constrained milk collection and access to markets during the rainy season.

3.2. Raw milk quality and safety

The overall milk physicochemical composition means (standard deviation) were: fat 3.61 (0.05), protein 3.46 (0.06), SNF 9.18 (0.04), density 1.031 (0.0002) and freezing point −0.597 (0.019). Protein percentage at all value chain nodes, except at the formal bulking node, did not meet KeBS standards. There was significant contamination of milk samples: 16.7% of samples had added water, 8.8% had SCC above 300,000, 42.4% had *E. coli*, 47.9% had *Pseudomonas spp.*, 3.3% had *Staphylococcus spp.* and 2.9% tested positive for *Brucella* spp. antibodies with MRT.

3.2.1. Milk composition, microbial contamination and adulteration in the dairy farming systems

Table 2 presents the results of milk composition, microbial quality and adulteration in the UL, MRL and ERL. The percentage of SNF, added water, density and freezing point were within KeBS standards, whereas protein percentage was below the KeBS standard. We found no differences in physicochemical parameters across dairy farming systems. The proportion of samples contaminated with *E. coli, Pseudomonas spp., Staphylococcus spp*. and positive for *Brucella abortus* antibodies (i.e. positive for MRT) differed across farming systems. Milk from MRL farming systems had higher levels of contamination by *E. coli*, *Staphylococcus spp.* and positive for MRT than milk from the other spatial locations.

Table 2. Milk quality in different dairy farming systems

Physicochemical properties **Mean (standard error)**	UL (n=80)	MRL (n=33)	ERL (n=99)
Fat %	3.84 (.12)	3.89 (.24)	3.67 (.11)
Protein %	3.46 (.03)	3.46 (.07)	3.44 (.04)
Solid not fats %	9.17 (.09)	9.16 (.19)	9.12 (.12)
Density (kg/litre)	1.0307 (.0004)	1.0307 (.007)	1.0307 (.0005)
Freezing point ° C	-0.592 (.008)	-0.596 (.012)	-0.595 (.007)
Added water %	2.0 (1.0)	2.0 (1.0)	2.0 (1.0)
Milk adulteration and microbial contamination (positive samples as a percentage of the total)			
Percentage with added water	19.4	21.2	21.8
SCC above 300,000	43.3	39.4	33.8
Escherichia coli	31.3 ^{a}	57.6 ^{b}	47.5 $^{a, b}$
Pseudomonas spp.	64.4 ^{a}	6.1 ^{b}	45.0 ^{c}
Staphylococcus spp.	1.0 ^{a}	15.2 ^{b}	1.2 ^{a}
Milk Ring Test	0.0	12.1 ^{a}	2.5 ^{b}

^{a,b,c} Means and percentages in the same row with different superscript are significantly different (P<0.05)

3.2.2. Milk composition, microbial contamination and adulteration at the value chain nodes

Milk physicochemical quality data including fat, SNF, density and freezing point in UL (Table 3) were within the KeBS standards. Significant differences were found for density and protein percentage between the producer and informal retail nodes. In both nodes, protein percentage was below the KeBS standards. There were cases where water was added to milk in violation of KeBS standards. Significant differences were found in milk contamination between nodes for the proportion of samples with added water, samples with SCC above 300,000, *E. coli* and *Pseudomonas spp.*

Table 3. Milk quality at nodes in the urban location (UL)

Physicochemical properties **Mean (standard error)**	Producers (n=99)	Informal retailing (n=42)
Fat, %	3.84 (.12)	3.75 (.21)
Protein, %	3.46 (.03) ^{a}	3.32 (.05) ^{b}
Solid not fats	9.17 (.09)	8.80 (.13)
Density (kg/litre)	1.0307 (.0004) ^{a}	1.0287 (.0008) ^{b}
Freezing point ° C	-0.592 (.008)	-0.576 (.008)
Added water (%)	2.0 (1.0)	3.0 (1.0)
Milk adulteration and microbial contamination (positive samples as a percentage of the total)		
Percentage with added water	19.4 ^{a}	39.0 ^{b}
SCC above 300,000	43.3 ^{a}	40.5 ^{a}
Escherichia Coli	31.3 ^{a}	59.5 ^{b}
Pseudomonas spp.	64.6 ^{a}	35.7 ^{b}
Staphylococcus spp.	1.0	0.0
Milk Ring Test	0.0	0.0

^{a,b} Means and percentages in the same row with different superscript are significantly different (P<0.05)

Milk quality in the MRL value chain nodes (Table 4) showed no significant differences for fat, SNF, density and freezing point. There were similarly cases of water added to milk in violation of KeBS standards. Formal bulking in the MRL met KeBS standards for protein percentage while significant differences were present between producers and value chain nodes for *E. coli, Pseudomonas spp.,* and positive samples for MRT. Prevalence of positive samples for MRT were high in the producers and informal collection nodes and low in the formal bulking.

Table 4. Milk quality at nodes in the mid-rural location (MRL)

Physicochemical properties Mean (standard error)	Producers (n=33)	Formal bulking (n=52)	Informal milk collection (n=78)
Fat, %	3.89 (.25)	3.40 (.22)	3.50 (.16)
Protein, %	3.45 (.07)	4.06 (.57)	3.48 (.04)
Solid not fats	9.14 (.19)	9.29 (.12)	9.24 (.10)
Density (kg/litre)	1.0306 (.0007)	1.0316 (.0005)	1.0313 (.0005)
Freezing point °C	-0.595 (.012)	-0.608 (.008)	-0.603 (.007)
Added water (%)	2.0 (1.0)	2.0 (1.0)	1.0 (1.0)
Milk adulteration and microbial contamination (positive samples as a percentage of the total)			
Percentage with added water	21.2	19.6	7.9
SCC above 300,000	39.4	23.5	34.6
Escherichia Coli	57.6 ^{a}	17.3 ^{b}	12.8 ^{b}
Pseudomonas spp.	6.1 ^{a}	63.5 ^{b}	73.1 ^{b}
Staphylococcus spp.	15.2	11.5	5.1
Milk Ring Test	12.1 ^{a}	0.0^{b}	10.3 ^{a}

^{a,b} Means and percentages in the same row with different superscript (a, b, c,) are significantly different (P<0.05)

Finally, for the ERL value chain nodes, all physicochemical quality for fat, SNF, density and freezing point (Table 5) were within the KeBS standards. Milk adulteration (i.e. milk with added water), contamination with *E. coli,* and *Pseudomonas spp.* varied significantly across the three value chains nodes. There were significant differences in contamination with *Staphylococcus spp.* and the prevalence of positive samples for MRT between informal milk collecting node when compared with producers and formal bulking nodes. Only formal bulking met the minimum KeBS protein standards.

Table 5. Milk quality at nodes in the extreme rural location (ERL)

Physicochemical properties **Mean (standard error)**	Producers (n=80)	Formal bulking (n=50)	Informal collection (n=56)
Fat, %	3.68 (.10)	3.33 (.07)	3.47 (.12)
Protein, %	3.44 (.04)	3.54 (.03)	3.46 (.03)
Solid not fats	9.12 (.12)	9.41 (.07)	9.17 (.07)
Density (kg/litre)	1.0307 (.0005) [a]	1.0321 (.0003) [b]	1.0311 (.0002) [a, b]
Freezing point ° C	-0.596 (.007)	-0.794 (.184)	-0.595 (.007)
Added water (%)	2.0 (1.0) [a]	0.0 (0.0) [b]	0.0 (0.0) [b]
Milk adulteration and microbial contamination (positive samples as a percentage of the total)			
Percentage with added water	21.8 [a]	2.0 [b]	7.5 [a, b]
SCC above 300,000	33.8	36.0	51.9
Escherichia Coli	47.5 [a]	82.0 [b]	64.3 [a, b]
Pseudomonas spp.	45.0 [a]	16.0 [b]	32.1 [a, b]
Staphylococcus spp.	1.2 [a]	0.0 [b]	0.0 [b]
Milk Ring Test	2.5 [a]	2.0 [a]	0.0 [b]

[a,b] Means and percentages in the same row with different superscript are significantly different ($P<0.05$)

3.3. Milk handling and hygiene practices

3.3.1. Farm-level milk handling and hygiene practices

Observations revealed unhygienic milk handling practices at the farm level (see supplementary material). Some smallholders in MRL and ERL milked their cows in open environments with potential for contamination by flies and dust, which made it difficult to maintain ideal milking hygiene standards. In ERL, we observed that some farmers used calf suckling to stimulate milk to let down which could contaminate milk. In all locations, the majority of farmers cleaned their hands; however, cleaning was not thorough, i.e. with soap, followed by drying. Although farmers cleaned cow udders and teats before milking, they used the same water and drying towels for all cows, which increased the risk for transmission of diseases such as mastitis between cows. The majority of farmers did not perform teat dipping.

Milking was mainly undertaken manually twice a day; in the morning and evening. A few farmers with large-sized farms and herds in UL and MRL invested in technology, such as mechanical milking and cooling tanks. The use of plastic containers for milking and storage of milk was observed in all the farming systems. In the majority of farms, no cold storage of milk was observed. Evening milk in MRL and ERL was kept in water baths as most farmers did not have fridges to cool it, and it was sold separate from, albeit alongside, the morning milk. In contrast, UL farmers sold their evening milk immediately after milking to customers who were mostly neighbours, restaurant/milk kiosk owners, and vendors; they did not store it overnight.

In the majority of farms, farmers did not adhere to regulations as regards proper animal waste disposal (i.e. heaps of manure and open slurry pits), proper handling of chemicals (i.e. chemicals in close proximity to cows and feeds), and animal welfare standards (i.e. muddy and wet floors denied cows resting places). UL farms had concrete floors and iron sheets covered cowsheds, while MRL and ERL farms kept cows in open grazing areas or in mud floored iron sheet roofed cowsheds. Overall, the cleanliness of cowsheds in UL was higher than in MRL and ERL, however, manure disposal was a problem in UL. In UL, MRL and ERL, handling and storage of animal feeds were poor, which exposed feeds to weather elements and increased the risk of growth of aflatoxin producing fungi.

3.3.2. Value chain milk handling and hygiene practices

Post-farm-gate, value chain actors' milk handling practices were also unhygienic (Supplementary material). There was widespread use of plastic containers for bulking and transporting in both formal and informal value chains. There was better compliance with hygienic regulations in MRL and ERL at the formal bulking nodes than at the informal collection nodes. Most cooperatives in the formal value chain had a central plant where milk was bulked and cooled. In contrast, milk in the informal value chain was bulked by small-scale transporters at the sides of the road in unhygienic conditions exposing it to contamination by pollutants and insects. Milk was transported using motorcycles in its uncooled form in a warm environment, which could enable bacterial growth and lead to milk quality deterioration. Transporters and bulking plants in the formal value chain were observed undertaking organoleptic, lactometer and alcohol tests, however, physicochemical and adulteration tests were not performed consistently. Most of the milk was bulked without individual batches being tested.

In the formal, as well as the informal value chains, actors rarely used any protective clothing while handling milk as required by the public health regulations. Some actors operated without the required certificates such as public health certificates and milk movement certificates. In the informal value chain, actors had limited access to sanitation facilities, including toilets and handwashing facilities.

4. Discussion

4.1. Smallholder dairy farming systems

This study used a spatial approach to study farming systems in Kenya. The results of the RRA agree with the findings of Migose et al. (2018), that spatial location is associated with the availability of production factors (i.e. land and labour) in smallholder dairy farming systems in Kenya. UL farming systems were more intensive, had good road infrastructure and sold milk to the informal market, which offered high farmgate prices. UL farmers had good access to extension and inputs such as AI and animal health services. However, farm sizes in UL were small, which led to a year-round scarcity of forages. In contrast, ERL farming systems were extensive and had relatively good access to production factors (i.e. land and labour). ERL farmers primarily sold their milk through the informal channels, but some farmers also sold their milk through the formal value chain. MRL farming systems were in between UL and ERL and had medium market quality and relatively good access to production factors (i.e. land and labour). MRL farmers primarily sold their milk to processors in the formal value chain.

Similar findings regarding farming system characteristics have been reported for Kenya, but also Ethiopia and India (Duncan et al., 2013; Migose et al., 2018; Van der Lee et al., 2018).

4.2. Milk quality in Kenya farming systems and value chains

This study hypothesised that milk quality would vary as a result of differences in farming systems, reflecting differences in agro-ecological conditions, the availability of production factors (i.e. land and forage), and market quality. However, no significant differences in milk composition, microbial contamination and adulteration were found between the farming systems.

The majority of the milk samples analysed met the required KeBS standards for physicochemical composition: fat, density and SNF percentage. Protein percentage was found to be below the KeBS standard in all nodes, except at formal bulking. The lack of significant differences in milk composition could be due to similarities in farming practices, the use of similar breeds of cattle and similar feed management strategies, as suggested by the RRA findings of the current study and reported by Migose et al. (2018). Similar findings as regards milk composition in Kenyan dairy farming systems have been reported by Kabui et al. (2015) and Ondieki et al. (2017). Low protein percentage is a constraint for formal dairy processors producing milk and milk products for export to neighbouring countries, and facing strict regional and international food quality standards (Orwa et al., 2017).

Results of this study reveal high SCC levels and high microbial contamination with *E. coli*, *Pseudomonas spp.*, *Staphylococcus spp.* and *Brucella abortus* (Tables 3–6), in UL, MRL and ERL. Milk contamination in informal and formal value chains is a persistent public health risk in Kenya (Kabui et al., 2015; McDermott & Arimi, 2002; Mwangi et al., 2000, pp. 30–31; Nato et al., 2018; Omore et al., 2004; Wanjala et al., 2017). High SCC and microbial contamination could be due to poor animal health practices, unhygienic milking practices such as the use of calf suckling while milking, unhygienic milk storage and unhygienic milk handling during bulking. As revealed by participant observation, use of personal protective clothing was low, use of non-food grade materials for milking and storage equipment and utensils was common, and there was a failure to cool milk during bulking and transport in both value chains, which compromised milk quality. Non-compliance with standards and codes of hygienic practices leads to poor milk quality problems in developing countries, such as Kenya (Brown et al., 2019;Chepkoech, 2010; Ledo et al., 2019; Nyokabi et al., 2018; Orregård, 2013). Home pasteurisation may reduce some milk-borne zoonoses such as brucellosis, however, it is not always undertaken. Moreover, unhygienic handling after pasteurisation can result in re-contamination (Koyi & Siamba, 2017; Omore et al., 2005). In addition, aflatoxins, heat-stable toxins such as the enterotoxins produced by *Staphylococcus aureus* and heat-resistant spores produced by *Clostridium perfringens* and *Bacillus spp.* can persist after boiling or pasteurisation (Lindahl et al., 2018).

In both value chains, milk was found to be adulterated by water. The amount was low and could be due to residual water in milking and storage containers after cleaning. Ondieki et al. (2017), reported that milk is also adulterated in Kenya to increase its volume (i.e. addition of water) or to extend its shelf life (i.e. addition of inhibitory substances). Milk adulteration with untreated water can introduce contaminants and pathogens and poses a public health risk to consumers.

Although the formal value chain had good milk handling practices and received milk that met the minimum KeBS standards at the cooperatives and processors nodes, the milk could only be processed into pasteurised milk and related dairy products. It could not be used, due to its quality, however, for the production of premium products like cheeses which require high-quality raw milk. In contrast, poor milk handling practices in the informal value chain were found to result in poor quality milk. The findings regarding poor milk handling practices are similar to observations of dairy farmers and subsequent value chain nodes in Tanzania (Ledo et al., 2019). Moreover, the findings agree with Roesel and Grace (2014), who posit that poor food handling practices in agrifood value chains lead to food safety problems in sub-Saharan Africa.

Given the poor quality of milk in Kenya, as observed in this study, there is an evident need for stricter enforcement of regulations by the KDB and other institutions responsible for upholding milk quality. There is also a need, however, to incentivise farmers and other value chain actors to comply with regulations and standards (Janssen & Swinnen, 2019; Ledo et al., 2019). The current lack of quality assurance programs and quality-based payment systems is likely hindering efforts to improve milk quality and safety in Kenya (Kabui et al., 2015;Ledo et al., 2019; Shitandi & Sternesjö, 2004). Quality-based payment systems generate health benefits for consumers, offer farmers new market channels, facilitate greater value chain integration and generate productivity gains which leads to improved income and livelihoods. However, operationalising quality-based payment systems necessitates improving and establishing essential infrastructure, i.e. cooling plants and testing labs, and strengthening logistics infrastructure, i.e. road networks; such infrastructure is currently lacking in the Kenyan dairy sector (Ndambi et al., 2018).

5. Conclusions

The main objective of this paper was to investigate the variation in raw milk quality in dairy farming systems and value chains in central Kenya. The findings of this paper confirm the suitability of using an expanded version of the spatial analytical framework, devised by Migose et al. (2018), to analyse dairy farming systems. In all farming systems and value chain nodes studied, except formal bulking, the milk protein percentage was below the KeBS standards. The risk of contamination with bacteria including *Brucella abortus* (causing brucellosis) was found to be high; this constitutes a major health risk for consumers. The amounts of water added to milk was found to be negligible and could be explained as residual water after cleaning. Although there were no spatial differences were found between farming systems, the results of this study indicate that there is an urgent need to improve milk quality and safety from farm to table in Kenya.

Statement of ethics

This work had ethical approval from the International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI IREC) (REF: ILRI-IREC2017-09). IREC is accredited in Kenya by the National Commission for Science, Technology and Innovation (NACOSTI).

Statement funding

This work was funded by a PhD scholarship as part of the project “Local and International business collaboration for productivity and QUality Improvement in Dairy chains in SE Asia and East Africa (LIQUID)". This project is supported by the Netherlands Organisation for Scientific Research's (NWO) Science for Global Development department (WOTRO) through the Food and Business Global Challenges Programme (GCP) (NOW-WOTRO project number W.08.250.204).

Declaration of competing interest

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

Appendix A. Supplementary data

Table 5. Milk handling practices at the farm level (in percentage)

		UL (n-13)	MRL (n-16)	ERL (n-21)
Use plastic equipment for milking		46.15	87.50	80.95
Use plastic equipment for milking		30.77	81.25	90.48
Perform pre-milking teat cleaning and dipping		15.38	6.25	0.00
Perform post-milking teat dipping		30.77	12.50	4.76
House their animals		84.62	68.75	52.38
Have a milking parlour/area		46.15	18.75	4.76
Had good farm hygiene (clean barns, manure management)		84.62	37.50	9.52
Have milk cooling equipment		7.69	12.50	0.00
Average number of cattle		5	3	3
Cattle breed	Friesian	46.15	50.0	76.19
	Friesian +Ayrshire	53.84	43.75	23.81
	Local breeds	-	6.25	-
Farm sizes	Small up to 1.5 acre	Small	Small	Small
	Medium 1.5-10 acres		Medium	Medium
	Large above 10 acres			Large

Table 6. Milk handling practices at the value chain level

	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*
Use personal protective clothing (PPE)	N**	N	N	N	N	N	N	N	N	N	N
Have milk cooling equipment	N	N	N	N	N	N	N	N	Y	Y	N
Use plastic containers	Y**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Bulk milk in an open area	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Test for milk quality	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Test individual milk batches during bulking	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Traders had public health certificates	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y
Traders/transporters had milk movement certificate	N	N	N	Y	Y	N	N	Y	N	N	N
Bulking agents maintained cold chain	Y	N	N	N	N	N	N	N	Y	Y	N
Bulking areas had sanitation facilities i.e. toilets	N	N	N	N	N	N	N	N	N	N	N
Bulking areas have handwashing facilities	N	N	N	N	N	N	N	N	N	N	N

* 1-Engineer, 2-Molo, 3-Mwisho wa lami, 4-Nakuru, 5-Nanyuki, 6-Njabini, 7-Njoro, 8-Nyahururu, 9-Oljororok, 10-Olkalau, 11-Rongai

** Y- Present / Yes N -No/absent

Chapter 3: Intra-annual variation in feed and milk composition in smallholder dairy farms in Kenya

Ndungu S. Nyokabi[1], Pieternel A. Luning[2], Jody Emile Phelan[3], Jos Creemers [4], Ben Lukuyu [5], Bockline Omedo Bebe[6], Simon J. Oosting[1]

Peer-reviewed and resubmitted to NJAS

Abstract

This longitudinal study explored intra-annual variation in feed availability and the chemical composition of milk and feed resources at smallholder dairy farms in Nakuru county, Kenya. Feed and milk samples were collected for a full year, every last week of the month, from 43 purposively-selected farms. Feed and milk samples were analysed for nutritional composition using near infra-red spectroscopy (NIRS) and Ekomilk milk analyser respectively.

The main basal feeds were indigenous grasses, Napier grass, maize and bean stover and maize silage which farmers supplemented with purchased commercial concentrates and/or purchased or homemade total mixed rations (TMR). Commercial concentrates had the highest crude protein (CP) content (17.4±3.9) % dry matter (DM), while maize stover had the lowest (8.7±3.3 % DM). All the feeds had low metabolisable energy (ME) that ranged from 7.0 ± 0.8 (MJ/kg DM) megajoules per kilogram of dry matter (MJ/kg DM) for maize stover to 8.9±0.8 for dairy meal. Only grasses showed significant seasonal variation in CP and NDF ($P>0.00$).

Milk physicochemical composition was within the range stipulated by the Kenya Bureau of Standards (KEBS). Milk physicochemical composition showed negligible seasonal variations to significantly affect milk processing, which suggests that farmers can cope with feed scarcity.

Nevertheless, seasonal feed availability is a persistent challenge in smallholder dairy farms. There is a need to ensure sufficient feed availability throughout the year in smallholder dairy farms through feed conservation, feeding management and ration preparation to enable consistent milk production and physicochemical composition.

Keywords: feed evaluation, milk quality, NIRS, ruminant nutrition, seasonal availability, organic matter digestibility

1 Introduction

Livestock production is one of the most important agricultural activities in Kenya and contributes substantially to agricultural Gross Domestic Product (GDP) (Anyango et al., 2018; Gakige et al., 2020). Mixed crop-livestock smallholder farmers produce approximately 70% of the total milk marketed in Kenya (Anyango et al., 2018; Onyango et al., 2019). Smallholder dairy farming systems are diverse and include extensive grazing systems, semi-intensive semi-grazing systems and intensive zero-grazing systems (Migose et al., 2018). These dairy farming systems depend on grazed or cut native pastures and grasses, crop residues and agricultural by-products as feed resources (Onyango et al., 2019).

Feed scarcity is one of the major challenges affecting smallholder dairy production in Kenya (Njarui et al., 2021). Feed production in smallholder dairy farms is largely rain-fed, and rainfall patterns are highly variable and often unpredictable; feeds are abundant in the wet and early dry seasons, and scarce in the long dry season. Crop residues are only available immediately after harvesting (Mwendia et al., 2017; Anyango et al., 2018; Mburu et al., 2018; Onyango et al., 2019; Gakige et al., 2020). Feed availability is also influenced by agro-climatic conditions, i.e. feeds are abundant in highlands and scarce in lowlands, arid and semi-arid areas (Onyango et al., 2019). In mixed crop-livestock production systems, feed production can be constrained by small land sizes that create a food-feed production dilemma, i.e. farmers must decide whether to produce human foods or livestock feeds (Gakige et al., 2020). The land is, however, more readily available in rural areas compared to urban and peri-urban locations (Migose et al., 2018). Feed chemical composition is influenced by production, harvest and post-harvest practices such as fertiliser application, cutting interval and stage of plant maturity (Anyango et al., 2018). Feed resources are usually of high quality in the wet season i.e., high crude protein (CP) and a high metabolizable energy (ME) content while in the long dry season feed resources usually are of low quality, i.e. low CP and ME and high fibre and lignin content (Mburu, 2015; Kashongwe et al., 2017).

Both the feed chemical composition and intake levels determine milk yields and composition (Imaizumi et al., 2010). The National Research Council (NRC) (2001) recommends that feeds should have ME content of a least 10 megajoules/kilogram of dry matter (MJ/kg DM) and CP content of at least 15-19% DM to meet a dairy cow's daily feed requirements. Low feed availability leads to reduced feed intake and impacts milk yield particularly when the cow's nutritional requirements are higher than the nutrient intake from feeds (Colmenero and Broderick, 2006; Imaizumi et al., 2010). Dietary fibre content can affect milk fat content (Schwendel et al., 2015). Although milk protein content is mainly influenced by cattle genetics, it can be improved slightly by increasing the dietary CP (Schwendel et al., 2015; Kashongwe et al., 2017). In Kenya, seasonal variation in feed resource availability and feed quality causes seasonal variation in dietary composition and, consequently, milk physicochemical composition (Kashongwe et al., 2017; Onyango et al., 2019). For example, poor quality feeds with high fibre content may lead to elevated milk fat content, although milk production levels may be low (Schwendel et al., 2015).

Seasonal feed availability and quality variations are known to affect milk production and physicochemical composition (Schwendel et al., 2015; Kashongwe et al., 2017). In Kenya, several cross-sectional studies have explored milk physicochemical composition (Kabui, 2012; Kabui et al., 2015; Mwendia et al., 2017; Ondieki et al., 2017) and seasonal feed availability and quality (Carter et al., 2015; Mburu, 2015; Lukuyu et al., 2019). There is, however, a lack of studies investigating feed and milk composition across a whole year in a smallholder dairy farm environment. The objective of this study was, therefore, to simultaneously investigate the intra-annual variation of feed and milk physicochemical composition in smallholder dairy farms in Nakuru county, Kenya. The results of this study will contribute to the literature on feed and milk composition. This literature is currently limited particularly in the case of smallholder dairy systems in Kenya and countries with similar production systems. Understanding annual trends in milk composition in smallholder dairy systems can enable processors make decisions as regards which dairy products to produce.

2 Material and Methods

2.1 Study area

Nakuru county has a favourable agroecological environment for dairy production, a high density of smallholder dairy farmers, and a large population of dairy cattle (van de Steeg et al., 2010; Migose et al., 2018). The county has two cropping seasons a year, reflecting its bimodal rainfall pattern: a long dry season (January, February and March), a long wet season (April, May and June), a short dry season (July, August and September), and a short wet season (October, November and December) (Kinyanjui, 2019).

The study employed the farming system framework explained by Migose et al. (2018) and Nyokabi et al. (2021) to classify smallholder dairy production based on their intensification levels and market quality (access to markets for inputs and milk output). These farming systems include intensive urban and peri-urban dairy farming systems, semi-intensive mid-rural dairy farming systems and extensive, extremely rural dairy farming systems. In Nakuru county, intensive urban and peri-urban dairy farming systems encompassed farms in Nakuru town and Rongai, semi-intensive mid-rural dairy farming systems included farms in Njoro and Elburgon, while extensive, extremely rural dairy farming systems reflected farms in Molo and Keringet.

2.2 Smallholder dairy farms selection

Smallholder dairy farms were purposively selected across Nakuru county, including in Nakuru town, Rongai, Njoro, Egerton, Mwisho wa Lami, Elburgon, Molo and Kapsita. The criteria used to select smallholder dairy farms were: (i) milking cows in early lactation, (ii) a herd size of around five cows to ensure year-round milk supply, and (iii) farmers willing to participate in the study. The study started with 50 farms, however, 7 farmers dropped out and several farmers could not be reached for sample collection in some months due to logistical challenges, i.e., inaccessible roads in the rainy season, selling of animals, farm relocation and security advisory during the election period. Consequently, the results of this study reflect data collected from the remaining 43 farms. We collected the data on farm characteristics, such as cattle breed, feeds grown, farm locations, at the beginning of the study. At the end of the study, we followed up this initial data collection to understand farmers perception of feed availability during the year and how they coped in times of feed scarcity.

2.3 Data collection

2.3.1 Feed resources availability

Feed resource availability was assessed qualitatively through discussions with farmers. We assessed availability based on the quantities of feed available to the farmers to sufficiently feed the cows for a month without the need to source extra feed resources from outside the farm. Feeds were considered scarce when the amount available on the farm was not sufficient to feed cows over the month and the farmer had to actively look for additional feeds beyond the farm to sufficiently feed their animals. This entailed purchasing from external sources such as traders, input and extension providers (commonly known as agrovets) or other farmers. The data was recorded monthly as notes and pictures including feed availability and scarcities and farmer coping strategies, by the first author.

2.3.3 Feed and milk sampling and analysis

Feed sampling

Feed samples were collected during the last week of every month. On each farm, samples of 200-300 g were collected of each feed available in the feed trough for the cows. The feed samples included both dry and fresh feeds. Feed samples were chopped and sun-dried for a week before being stored in sealed plastic bags away from sunlight in a cold room for subsequent analysis. In total, 539 feed samples were collected during the study period. Feeds were categorised into local grasses, Napier grass (*Pennisetum purpureum*), maize silage (*Zea mays*), crop residues (stover), commercial concentrates (dairy meal) and home-made total mixed ration (TMR) i.e., mainly purchased by-products of cereal milling such as maize germ, maize bran, wheat bran, cotton-seed cake, mineral and vitamin additives mixed at home.

Feed laboratory analyses

Laboratory analyses of feed samples were undertaken at the animal nutrition laboratories of the International Livestock Research Institute (ILRI) in Addis Ababa, Ethiopia. Feed samples collected from the farms were oven-dried at 60°C for 24 hours to standardize moisture conditions and ground through a 2 mm sieve screen with a Wiley mill and analysed for crude protein (CP), metabolizable energy (ME), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), and *acid* detergent *lignin (ADL)* using the near-infrared reflectance spectroscopy (NIRS) technique using FOSS Forage Analyzer 5000® with WinISI software package®. NIRS is an indirect analytical method based on empirical models in which the concentration of a feed constituent is predicted from complex spectral data (Ayantunde et al., 2014). The NIRS calibrations and prediction equations used in this study were developed based on wet chemistry analysis of tropical feeds by the ILRI nutrition laboratories in Addis Ababa, Ethiopia.

Milk sampling

Milk samples were collected in the final week of each month over the one-year data collection period. In total, 607 milk samples were collected during the study period. On each farm, 100 ml of milk was sampled from the bulking container after morning milking in sterile bottles and stored in a cooler with ice packs. These samples were transported for analysis to the Regional Veterinary Laboratories (RVL) in Nakuru.

Milk laboratory analyses

Milk samples were homogenised and milk composition analyses were conducted using an Ekomilk milk analyser (Ekomilk milk analyser, Eon Trading, Stara Zagora Bulgaria) for butterfat, solid not fats (SNF), protein, density and freezing point. Milk composition was compared to the Kenya Dairy Standards (KeBS): butterfat not less than 3.25%; protein not less than 3.5%; solid not fats not less than 8.50%; density 1.028-1.036 g/ml and freezing point -0.525- 0.550 ^{0}C.

Milk and feed statistical analyses

Feed and milk data were tested for normality with the Shapiro-Wilk test. The mean and standard errors of feed and milk composition were calculated for the seasons. The data were subjected to a One-Way Analysis of Variance (ANOVA) to compare intra-annual variation in feed and milk chemical composition. Significant variations were declared at $p < 0.05$.

Two mixed models were used to test for seasonal and feed effects, and their interaction in determining feed and milk composition. The feed chemical composition model had CP, ME, OM, NDF, ADF and ADL as the dependent variables, while season and feed categories (feed were categorised into local grasses, Napier grass (*Pennisetum purpureum*), maize silage, crop residues (stover), commercial concentrates (dairy meal) and home-made total mixed ration (TMR)) were designated as independent variables, as shown in model 1:

$Y_{ijk}=\mu+S_i+F_k+e_{ijk}$ Model 1

Where: Y_{ijk} =dependent variable (general observation); μ=the overall mean; Si=effect of the i_{th} season (i= long rainy, short dry, short rainy and late dry seasons); F_k =effect of kth species/feed type (grasses, Napier grass, maize silage, crop residues, dairy meal and TMR); e_{ijk} =error term.

The mixed model for the milk composition had butterfat, protein, solid-not-fats (SNF), density, freezing point, total solids, and fat: protein ratio as the dependent variables and the month and farming system (intensive urban, semi-intensive, and extensive rural dairy systems) and their interaction effects as the independent variables as shown in model 2. Dairy farming systems were chosen because they influence the feeding practices and breeds kept as explained by Migose et al. (2018).

$Y_{ijk}=\mu+S_i+F_k+e_{ijk}$ Model 2

Where: Y_{ijk}=dependent variable (general observation); μ=the overall mean; Si=effect of the i_{th} season (i= long rainy, short dry, short rainy and late dry seasons); F_k=effect of k^{th} farming system (k=intensive urban, semi-intensive, and extensive rural dairy systems); e_{ijk}=error term.

Statistical analyses were conducted using R statistical software version 4.2.1 (R Development Core Team, 2022) within RStudio (RStudio Team, 2022). The mixed models were done using nlme and LME4 statistical packages of R statistical software.

3 Results

3.1 Smallholder dairy farms characteristics

Table 1 summarises the characteristics of the smallholder dairy farms included in this study. The majority of the farmers kept Holstein-Friesian crosses and Ayrshire crosses due to their high milk production potential. Farms in urban and peri-urban areas had small land sizes and were intensive, zero-grazing systems. Farms in rural areas were either semi-intensive cut and carry or extensive semi-grazing systems (such as zero-grazing, tethering or free grazing or the fields with supplementation with concentrates feeds in the morning and evening during milking). Farmers in rural areas had more land, grew their feeds themselves, and were less dependent on purchased feeds than farms in urban areas.

Table 1. Characteristics of sampled smallholder dairy farms in Nakuru county (in percentage)

		UL* (n=14)	MRL* (n=17)	ERL* (n=19)	Average (n=50)
Herd sizes	Small (less than 10 cows)	21.4	58.8	78.9	56.0
	Medium (11-30 cows)	7.1	17.6	15.8	14.0
	Large over 30 cattle	71.4	23.5	5.3	30.0
Breed	Holstein-Friesians and its crosses	35.7	52.9	63.2	52.0
	Ayrshire and its crosses	64.3	41.2	36.8	46.0
	Local breeds	0.0	5.9	0.0	2.0
Farm size	Small (less than 5 acres [2.02 Ha])	14.3	64.3	94.7	62.0
	Medium (50-10 acres [2.02-4.04 Ha])	21.4	17.6	5.3	14.0
	Large (over 10 acres [4.04 Ha])	64.3	17.6	0.0	24.0
Milk prices (Ksh)	Rainy season	40-50	30-35	26-30	-
	Dry season	50-70	35-45	30-40	-

* UL-urban locations, MRL-mid rural locations and ERL-extreme rural location

[1] Kenyan Shilling (Ksh) = 0.0088 United States Dollar

3.2 Feed availability

The main feeds grown by the majority of the farmers were maize (*Zea mays*) and Napier grass (*Pennisetum purpureum*). Four of the sampled farmers grew Rhodes grass (Boma variety) (*Chloris gayana*) and native grasses. Farmers also grew other fodder and legume crops including lucerne (*Medicago sativa*), oats (*Avena sativa*), Bracharia grass (*Brachiaria spp.)*, cabbage and kales (Brassica *oleracea*), barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), sweet potato vines (*Ipomoea batatas*), desmodium (*Desmodium spp*.) and vetch (*Vicia spp.)*. These fodder and legume crops were mixed with the basal feeds but accounted for a small amount of the total feeds supplied to cows.

Table 2 presents seasonal feed resources available in smallholder dairy farming systems compiled from the discussions with the remaining 43 participating farmers. Feed resources, especially the main basal feeds: Napier grass and natural pastures were abundant in the rainy season and early dry season but scarce in the dry season. Farmers described feed resources, available in the rainy season, as being of good quality. In the dry season, feed resources were scarce, and farmers perceived them as being of poor quality and mainly consisting of crop residues, hay, and dry native grasses. Crop residues and dry native grasses were especially important in the dry season in mixed-crop farming systems in rural areas.

Farmers provided the basal feeds (grasses, maize silage, stover and Napier grass) to their cows, supplementing the feeds with the dairy meal and with TMR (homemade concentrates). These concentrates were made of cereal milling by-products such as maize germ and bran, wheat bran, cotton

-

Table 2. Feed resources available for cattle in smallholder dairy farms in Nakuru county (discussions with 43 farmers)

Feed type	Long rainy season			Short dry season			Short rainy season			Long dry season		
	April	May	June	July	August	September	October	November	December	January	February	March
Natural pastures (local grasses)	√	√	√	√			√	√	√			
Napier grass	√	√	√	√			√	√				
Maize silage				√	√	√			√	√	√	√
Crop residues (maize and bean stover)				√	√	√	√	√	√	√		
Concentrates (dairy meal)	√	√	√	√	√	√	√	√	√	√	√	√
Total and partly mixed rations (TMR)	√	√	√	√	√	√	√	√	√	√	√	√

seed cake, minerals and vitamin additives. Although dairy meal and TMR could be purchased throughout the year, the quantity fed to cattle was low. The majority of farmers fed an average of two kilograms of dairy meal or TMR to each cow during milking, in the morning and evening.

Farms in urban and peri-urban areas faced feed production challenges due to small land sizes, usually less than two acres. Some farmers produced fodder and forage on rented or owned land in rural areas and, additionally, fed their cows purchased feeds. In contrast, farmers in rural areas had relatively good access to land and labour, which allowed them to practice mixed farming. Farmers produced feed on their farms as planted strips of fodder, in the same fields where they grew food crops, and they also utilised crop residues from beans, maize, peas, potatoes, bananas, and chicken droppings and weeds. Farmers in rural areas relied less on purchased concentrates and vitamins than peri-urban farmers. Low milk prices in rural areas made it difficult to depend on expensive externally sourced inputs due to their high cost and low-profit margins received. They preferred maize germ, maize bran, and other cereal milling by-products due to their lower cost compared to dairy meal. Cows were also supplemented with mineral salts, provided either in combination with feeds or as a mineral block.

In the dry season, farmers in all locations adopted long-term and short-term strategies to cope with feed shortages. Short-term strategies involved feeding reduced amounts of feed to animals to provide maintenance energy until the feed availability situation improved, although it led to decreased milk production and, hence, reduced income. Farmers purchased crop residues from neighbours who did not keep cattle or were willing to exchange crop residues for manure. Only a handful of farms employed long-term strategies to increase on-farm feed production and conservation. These farmers were particularly those with large herd sizes, capital resources and/or large land sizes to grow feed. The adoption of forage conservation technologies such as hay and maize silage making was low, with only five of the participating farmers conserving feeds.

3.3 Chemical composition of common feed resources

The chemical composition of feed resources is presented in Table 3. Feed chemical composition varied across the different feed resources available in smallholder dairy farms as evidenced by the high standard deviation from the mean. Commercial dairy meal and TMR were the best quality feeds with regards to nutritional value as they had the highest CP and ME, and lowest NDF, ADF and ADL. Maize silage and maize stover had the lowest CP values and considerable high NDF and ADF. There were intra-annual seasonal variations for the feed resources in smallholder dairy farms; only grasses showed significant variation in the CP ($P<0.00$) and NDF content ($P<0.00$) across the seasons.

The results of the mixed model analysis showed that the variation in the feed chemical composition is significantly determined by feed type ($P<0.00$) and not by season (Table 4). Additionally, there was no significant interaction between feed and season that influenced feed chemical composition.

Table 3. Feed chemical composition across the different seasons in smallholder dairy farms in Nakuru county (mean ± standard deviation)

	Season	LDS ^{a}	LWS ^{b}	SDS ^{c}	SWS ^{d}	Average	Pr(>F)
CP (%DM)	Grasses	13.5 ± 5.9	13.6 ± 5.6	15.2 ± 5.2 ^{d}	11.2 ± 5.1	13.4 ± 5.5	**0.00** **
	Napier grass	9.6 ± 5.7	15.0 ± 6.0	12.6 ± 5.7	12.1 ± 8.0	12.0 ± 6.4	0.37
	Maize silage	11.4 ± 4.9	11.7 ± 3.0	11.4 ± 1.5	11.3 ± 3.3	11.4 ± 3.3	0.99
	Maize stover	7.9 ± 2.4	7.1 ± 2.3	8.8 ± 4.6	10.3 ± 3.7	8.7 ± 3.3	0.15
	Dairy meal	15.9 ± 3.0	15.9 ± 5.0	19.2 ± 4.7	17.7 ± 3.5	17.4 ± 3.9	0.14
	TMR	13.4 ± 4.4	13.9 ± 4.8	14.5 ± 4.9	12.4 ± 4.7	13.4 ± 4.7	0.19
ME (%DM)	Grasses	7.4 ± 0.8	7.2 ± 0.8	7.4 ± 0.8	7.0 ± 1.0	7.3 ± 0.9	0.15
	Napier grass	6.7 ± 0.5	7.2 ± 0.4	7.1 ± 0.2	7.3 ± 0.7	7.0 ± 0.5	0.09
	Maize silage	7.3 ± 0.6	6.9 ± 0.7	6.7 ± 0.3	7.1 ± 0.7	7.0 ± 0.6	0.39
	Maize stover	6.8 ± 0.8	6.7 ± 0.4	7.3 ± 0.6	7.3 ± 0.8	7.0 ± 0.8	0.25
	Dairy meal	8.9 ± 0.8	8.1 ± 1.1	9.0 ± 0.6	9.1 ± 0.7	8.9 ± 0.8	0.11
	TMR	7.9 ± 1.0	7.5 ± 1.2	7.8 ± 1.0	7.7 ± 1.1	7.7 ± 1.1	0.47
OM (%DM)	Grasses	83.3 ± 3.9	80.8 ± 3.3	83.1 ± 4.2	83.3 ± 5.0	82.9 ± 4.4	0.10
	Napier grass	77.6 ± 5.5	79.9 ± 3.9	80.7 ± 1.3	78.9 ± 4.1	78.8 ± 4.5	0.70
	Maize silage	88.2 ± 2.1	86.0 ± 4.7	83.2 ± 3.8	86.9 ± 2.5	86.4 ± 3.4	0.07
	Maize stover	88.5 ± 3.8	88.1 ± 4.6	88.0 ± 3.6	88.1 ± 3.0	88.3 ± 3.5	0.99
	Dairy meal	88.4 ± 6.1	86.5 ± 5.0	88.5 ± 10.8	89.8 ± 3.0	88.9 ± 6.2	0.78
	TMR	88.1 ± 4.4	86.1 ± 4.7	87.5 ± 4.7	86.9 ± 4.8	87.2 ± 4.7	0.27
NDF (%DM)	Grasses	61.1 ± 6.8	61.6 ± 7.2	59.2 ± 7.9	64.8 ± 8.2 ^{c}	61.7 ± 8.0	0.00 **
	Napier grass	60.7 ± 4.5	61.0 ± 3.4	58.7 ± 3.2	60.7 ± 4.5	60.6 ± 4.0	0.91
	Maize silage	51.0 ± 9.3	56.0 ± 8.1	65.3 ± 9.8	55.7 ± 10.7	56.4 ± 10.5	0.14
	Maize stover	79.2 ± 8.3	82.2 ± 6.7	75.5 ± 8.6	79.1 ± 8.7	79.1 ± 8.2	0.57
	Dairy meal	41.4 ± 8.3	38.1 ± 4.5	40.4 ± 8.9	41.1 ± 6.5	40.8 ± 7.3	0.87
	TMR	59.2 ± 14.5	62.7 ± 16.1	58.1 ± 17.1	60.6 ± 13.7	60.1 ± 15.1	0.62
ADF (%DM)	Grasses	30.8 ± 8.2	31.5 ± 6.6	31.2 ± 9.2	33.5 ± 9.2	31.9 ± 8.7	0.41
	Napier grass	42.7 ± 5.5	38.3 ± 5.5	36.7 ± 6.8	36.4 ± 7.7	39.4 ± 6.4	0.17
	Maize silage	28.2 ± 5.3	31.8 ± 10.2	42.1 ± 7.9	34.1 ± 8.9	33.8 ± 8.9	0.05
	Maize stover	39.6 ± 10.7	40.3 ± 5.6	35.0 ± 8.3	36.0 ± 7.9	37.9 ± 8.9	0.53
	Dairy meal	18.5 ± 6.2	20.3 ± 1.1	17.8 ± 3.8	18.1 ± 6.2	18.3 ± 5.4	0.88
	TMR	27.5 ± 8.7	29.3 ± 10.7	29.1 ± 10.6	31.3 ± 12.2	29.5 ± 10.8	0.38
ADL (%DM)	Grasses	5.5 ± 1.1	5.8 ± 0.9	5.7 ± 1.6	5.9 ± 1.5	5.8 ± 1.4	0.72
	Napier grass	3.5 ± 2.2	2.7 ± 0.7	2.9 ± 0.9	3.8 ± 1.5	3.3 ± 1.6	0.63
	Maize silage	5.9 ± 1.1	7.4 ± 1.7	7.5 ± 1.3	6.8 ± 1.8	6.8 ± 1.5	0.26
	Maize stover	5.3 ± 2.6	4.8 ± 1.4	3.6 ± 1.8	4.2 ± 2.0	4.6 ± 2.2	0.33
	Dairy meal	5.1 ± 1.2	6.2 ± 0.8	5.3 ± 1.7	4.9 ± 1.3	5.1 ± 1.4	0.38
	TMR	5.2 ± 2.1	5.5 ± 2.1	5.4 ± 1.8	5.7 ± 2.5	5.4 ± 2.2	0.75

* CP – crude protein, ME – metabolisable energy, NDF – neutral detergent fibre, OM – organic matter, ADF – acid detergent fibre, ADL – acid detergent lignin, TMR – total mixed rations, LDS – long dry season (January, February and March), LWS – long wet season (April, May, June), SDS – short dry season (July, August and September), SWS – short wet season (October, November and December)

* Different superscripts indicate significance: '***'P<0.001, P< '**' 0.01, P< '*' 0.05

Table 4. Mixed model analysis results showing effects of feed type, season and feed type-season interaction in smallholder dairy farms in Nakuru county

	Feed type Pr(>Chisq)	Season Pr(>Chisq)	Feed: season Pr(>Chisq)
CP	0.00***	0.22	0.47
ME	0.00***	0.38	0.51
NDF	0.00***	0.74	0.81
OM	0.00***	0.33	0.53
ADF	0.00***	0.98	0.38
ADL	0.00***	0.86	0.63

* CP – crude protein, ME – metabolisable energy, NDF – neutral detergent fibre, OM – organic matter, ADF – acid detergent fibre, ADL – acid detergent lignin.

* Different superscripts indicate significance: '***'P<0.001, '**' P< 0.01, '*' P< 0.05

3.4 Milk composition

Table 5 presents the results of milk physicochemical composition. Milk physicochemical composition meets the Kenyan dairy standards: butterfat not less than 3.25%; protein not less than 3.5%; solid not fats not less than 8.50%; density between 1.028-1.036 g/ml; and freezing point between -0.525 and -0.550 ^{0}C. Milk protein content was higher in the long-wet season compared to other seasons (P<0.02).

Table 6 presents the results of the mixed model analysis which further confirmed that intra-annual seasonal variations affect milk physicochemical composition. There is an interaction of season and farming system with butterfat and the fat to protein ratio (P>0.05 and p> 0.00 respectively). This could be related to the availability and type of feeds in the farming systems during the different seasons of the year such as high NDF content in the long dry season.

Table 5. Milk physicochemical composition (arithmetic mean and standard deviation) across seasons in dairy farms in Nakuru county

	LDS ^{a}	LWS ^{b}	SDS ^{c}	SWS ^{d}	Average	p-value
Butter fat	3.7 ± 0.9	3.5 ± 1.0	3.6 ± 0.8	3.5 ± 0.8	3.6 ±0.9	0.103
Protein	3.5 ± 0.3	3.6 ± 0.3 ^{c}	3.5 ± 0.3	3.5 ± 0.3	3.5 ± 0.3	0.02*
Solid not fats	9.2 ± 0.9	9.5 ± 0.7 ^{c,d}	9.2 ± 0.8	9.2 ± 0.9	9.2 ± 0.8	0.00**
Density	1.031 ± 0.004	1.032 ± 0.003 ^{a,c}	1.031 ± .004	1.031 ± 0.004	1.031 ± .004	0.02*
Freezing point	-0.60 ± 0.07	-0.62 ± 0.05 ^{a,c}	-0.6 ± 0.0	-0.6 ± 0.05	-0.60 ± 0.06	0.01**
Total solids	13.0 ± 1.4	13.0 ± 1.2	12.8 ± 1.2	12.7 ± 1.2	12.8 ± 1.2	0.11
Fat: protein ratio	1.2 ± 0.5	1.1 ± 0.4	1.2 ± 0.5	1.1 ± 0.4	1.1 ± 0.4	0.03*

* Kenya dairy standards (KeBS) define butterfat must be not less than 3.25%, protein must be not less than 3.5%, solid not fats must not be less than 8.50%, density 1.028-1.036 g/ml, and the freezing point should range between -0.525- 0.550 ^{0}C.

^{a,b,c,d} LDS – long dry season (January, February and March), LWS – long wet season (April, May, June), SDS – short dry season (July, August and September), SWS – short wet season (October, November and December).

* Different superscripts indicate significance: '***'P<0.001, '**' P< 0.01, '*' P< 0.05

Table 6. Mixed model analysis showing effects of season, farming system, and season-farming system interaction on the milk physicochemical composition of milk samples from dairy farms in Nakuru county

	Season Pr(>F)	Farming system Pr(>F)	Season: Farming system Pr(>F)
Butterfat (%)	0.09	0.90	0.01 **
Protein (%)	0.02*	0.34	0.28
Solid not fats (%)	0.00**	0.39	0.52
Density g/ml	0.01 *	0.51	0.24
Freezing point °C	0.01**	0.47	0.30
Total solids (%)	0.09	0.58	0.12
Fat: protein ratio	0.01 *	0.90	0.00 **

* Farming systems included intensive urban farming systems, semi-intensive farming systems and extensive rural farming systems.

* Different superscripts indicate significance: '***'P<0.001, '**' P< 0.01, '*' P< 0.04. Discussion

The objective of this study was to investigate the intra-annual variation of feed and milk composition in smallholder dairy farms in Nakuru county, Kenya. The results of this study reveal that the seasonal availability of feed resources is indeed a major challenge for smallholder dairy farmers. Chemical composition varied between the available feed types with dairy meal and TMR having better nutritional value than stover and grasses. Only grasses showed significant seasonal differences in chemical composition for CP and NDF content across the seasons. Concentrates such as dairy meal and TMR used for supplementary feeding had better nutritional value than the main basal feed such as grasses, Napier grass, maize silage and maize stover. Milk physiochemical composition showed negligible seasonal variations across the season.

4.1 Feed resources availability

The type of feed resources available in smallholder dairy farming systems in Nakuru county (Tables 3 and 5) is similar to what has been reported in other studies in Kenya, including Franzel et al. (2004), Njarui et al. (2011), Mutua et al. (2012) and Mburu (2015). Farmers in Kenya mainly depend on Napier grass as a main basal feed (Njarui et al., 2021). In zero-grazing systems, especially in urban and peri-urban areas, farmers rely on "cut and carry" zero-grazing systems, which is a common feeding strategy in Kenya (Lanyasunya et al., 2006).

Our study results revealed that the seasonal availability of feed resources is a major challenge for smallholder dairy production systems in Nakuru county. Results of discussions with farmers further revealed that feed resources were scarce in the long dry season which led to dependence on crop residues and purchased feeds (Table 2). Also, Kashongwe et al. (2017) reported that more than 60% of smallholder dairy farmers in Nakuru County face feed scarcity in the dry seasons. Migose et al. (2018) reported that feed availability in Nakuru county is also influenced by land availability with urban areas having more acute feed resources scarcity compared to rural areas. Although farmers supplemented basal feeding with TMR and concentrate (Section 3.2), other studies in Kenya have been reported to use low quantities of dairy meal and TMR for supplementation of the poor quality basal feeds due to their high cost and low milk prices (Mburu, 2015; Onyango et al., 2019; Sakwa et al., 2021).

The findings of this study reveal limited feed conservation in smallholder farms in Nakuru county which exacerbates the lack of feed, especially in the dry season necessitating supplementary feeding with high-quality feeds (Section 3.2). Previous research has highlighted that smallholder dairy farmers in Kenya lack technical knowledge for forage conservation and silage making which exacerbates the seasonal feed shortages and impacts the availability and quality of feed resources (Mutua et al., 2012; Mburu, 2015). Moreover, the smallholder farmer coping strategy of reducing the amounts of feed given to cows in the dry season negatively affects the performance of dairy cattle (Section 3.2). Reduced feed availability negatively affects dairy cattle as it reduces the availability of crude protein (CP), rumen degradable protein (RDP) and ME needed for milk production and composition (Colmenero and Broderick, 2006; Goopy et al., 2018).

4.2 Feed chemical composition

There were differences in the chemical composition of feed resources in smallholder dairy farms (Table 3). The quality of main basal feeds available in smallholder feeds is of inferior quality compared to TMR and commercial concentrates (Table 3). Moreover, only grass showed seasonal differences in CP and NDF (Tables 3 and 4). In Kenya, poor feed quality in smallholder dairy systems limits dry matter intake, digestibility and cows' performance (Carter et al., 2015; Onyango et al., 2019). The results of this study show that the energy content ranged between 7.0-8.9 MJ/Kg DM which is similar to tropical pastures (Laswai et al., 2013; Löfqvist, 2016). ME content was below the NRC recommendation for lactating cattle of 10 MJ/kg DM. Additionally, all the basal feeds failed to meet the NRC recommendation of CP content of between 15-19% of DM to meet a dairy cow's energy requirements except for dairy meal. Generally, feeds with an NDF content of less than 45% are considered to be of high quality; those between 45-65% are of medium quality; and those over 65% are of low quality (Mpairwe et al., 2002; Bogale et al., 2008). Feeds with ADF below 30% are considered to be of high quality and those above 40% poor quality (Mpairwe et al., 2002).

Grasses CP content in this study was within the range reported by (Mburu et al., 2018) and Löfqvist, (2016). Previous studies have reported quality deterioration in grasses after harvesting and recommended the need for training farmers on haymaking to maintain feed quality during storage (Kashongwe et al., 2017; Akakpo et al., 2020). Grass quality changes as it matures, i.e., from green fodder to dry hay which could explain the variation in chemical composition across the different seasons (Löfqvist, 2016).

The data on maize stover CP (Table 3) was similar to values reported by Mburu et al. (2018). Maize stover is harvested at the post-hard-grain stage and, as a result, most of the dry maize stover available to farmers was of low quality and needs to be treated to improve quality (Kashongwe et al., 2017; Mburu et al., 2018). The low CP of maize stover could be attributed to the stage of harvesting and methods of storage (Mburu, 2015; Akakpo et al., 2020). Mburu et al. (2018) have reported that feed conservation methods used by smallholder farmers expose maize stover to the vagaries of weather and leaf shattering, leading to considerable losses. Previous studies have reported that the chemical composition varies by plant part i.e., maize leaves have higher CP levels (83 g/ kg DM) compared to the stem (66 g/ kg DM) and husks (48 g/ kg DM) (Methu et al., 2001). Maize stover quality can be maintained for longer if harvested with low water content (Methu et al., 2001). Additionally, the maize quality can be improved by soaking it in molasses or mixing it with other better quality feeds (Kashongwe et al., 2017).

Data on maize silage chemical composition (Table 3) was similar to SNV (2019). Maize silage is a good source of energy but has low CP content (Goopy and Gakige, 2016). Compared to Europe, silage ME in smallholder farms in Kenya is thought to be 10-15% below the ME content of the maize silage in Western Europe due to poor crop management and maize silage storage practices (SNV, 2019).

The ME, CP, NDF and ADF contents of Napier grass (Table 3) were within the range reported by previous studies (Orodho, 2006; Mburu et al., 2018; Onyango et al., 2019). There was no significant seasonal variation in Napier grass chemical composition (Tables 3 and 4), which contradicts previous studies that have reported seasonal variations in CP and NDF in Kenya (Orodho, 2006). The lack of seasonal variations could be due to farmers' crop cutting and crop management practices and possibly favourable climatic conditions during the research year (Orodho, 2006; Onyango et al., 2019).

Among the available feed resources, dairy meal and TMR had good chemical composition for dairy cattle (Table 3). The CP and ME values for both dairy meal and TMR were below the values reported in previous studies (Löfqvist, 2016; Moller, 2018). These findings confirm previous studies that have reported the low-quality dairy meals in the Kenyan market including low ME content (Moller, 2018). Previous studies in Kenya and Uganda have expressed concern about the poor quality of and/or sub-standard commercial feeds sold on the market (Moller, 2018). These high-quality feeds are expensive and increase production costs on smallholder dairy farms (Imaizumi et al., 2010; Moller, 2018). An increase in CP beyond 17%, as observed in this study, does not necessarily increase milk production but can influence milk protein content (Imaizumi et al., 2010; Zanton, 2016).

4.3 Milk composition

Milk physicochemical composition (Table 5) was within the range reported in previous studies (Kabui, 2012; Kabui et al., 2015; Ondieki et al., 2017). Butterfat, protein and SNF content showed negligible intra-annual seasonal variations (Tables 5 and 6), which shows that farmers can cope with the variations in feed availability (Table 2). Although negligible, the intra-annual milk physicochemical composition variation could be linked to seasonal feed availability in smallholder dairy farms (Kashongwe et al., 2014). The interaction of season and farming system effect on butterfat and the fat to protein ratio (Table 6) could be due to farm management practices in the farming systems as has been suggested by Migose et al. (2018). Milk physicochemical composition can be influenced by seasonal feed availability and feeding practices i.e., supplementation (Schwendel et al., 2015).

The milk protein content is determined primarily by the cows' genetics but can be marginally improved through feeding (Schwendel et al., 2015). The results of this study are in agreement with Kashongwe et al. (2017), who reported low fibre feeds can depress milk fat production, particularly during the rainy season. Feeding strategies based on the use of feeds high in NDF, such as a Napier grass-based diet (i.e., a high proportion of forages compared to concentrates) lead to more acetate production which is associated with high butterfat content in milk (Laswai et al., 2013; Kashongwe et al., 2014; Sakwa et al., 2021). Additionally, prevailing environmental conditions such as hot weather and high humidity in the dry seasons can affect cows' DM intake which could result in changes in milk composition (Schwendel et al., 2015; Goopy et al., 2018).

4.4 Possible limitations of the research approach

This study was undertaken in Nakuru county, in the highlands of Kenya, which may not be indicative of feed resources abundance and composition in the lowlands. The accuracy of feed composition analyses depends on the sampling procedure and the parts of feed resources sampled (Mburu et al., 2018). Concentrates and TMR have to be thoroughly mixed for the collection of a representative sample which can be difficult, particularly for home-mixed TMR. NIRS offers a quick, cheap and non-destructive approach for feed analysis and enables a more rapid analysis of a large number of samples than wet chemistry. NIRS accuracy depends on the calibration of the equipment using wet chemistry data. Currently, there are no extensive databases for feeds in Kenya and East Africa which constrains NIRS calibration (Ayantunde et al., 2014; Akakpo et al., 2020). As the results of wet chemistry become more available, NIRS calibration and equations used for feed chemical predictions will become more accurate in predicting feeds composition in Kenya and East Africa (Laswai et al., 2013; Ayantunde et al., 2014).

4.5 Conclusions and recommendations

This research contributes to the literature and data on feeds and milk composition in Kenya. The study demonstrated that the prevailing seasonal conditions affected the availability of feed, and feed chemical composition varied between these feeds. In the long dry season, regular feed resources are scarce, in short supply and of low quality, which requires farmers to use supplementary feed resources. The study suggests that, in Nakuru county, feed resources type and availability are more important for dairy production than the intra-annual variation in feed chemical composition. Intra-annual seasonal milk physicochemical composition variations were present, but they were negligible to significantly affect milk processing which suggests that farmers can cope with feeds scarcity in the dry season. The variation in chemical composition between the different feeds shows the imperative to improve feed quality through intercropping different fodder crops to increase feed diversity and diversify nutrient sources. Further, feed availability is a persistent challenge in smallholder dairy farms and thus there is a need for local context- and season-specific solutions to improve cattle feeding strategies. We propose further research on feed composition across the different ecological zones in Kenya involving a larger sample size to compare variations and add additional perspectives.

Statement of ethics

This work had ethical approval from the International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI IREC) (REF: ILRI-IREC2017-09). IREC is accredited in Kenya by the National Commission for Science, Technology and Innovation (NACOSTI).

Statement Funding

This work was funded by a PhD scholarship as part of the project “Local and International business collaboration for productivity and QUality Improvement in Dairy chains in SE Asia and East Africa (LIQUID)". This project is supported by the Netherlands Organisation for Scientific Research’s (NWO) Science for Global Development department (WOTRO) through the Food and Business Global Challenges Programme (GCP) (NOW-WOTRO project number W.08.250.204)

Chapter 4: Milk quality and hygiene: knowledge, attitudes and practices of smallholder dairy farmers in central Kenya

Nyokabi, S., Luning, P.A., de Boer, I.J., Korir, L., Muunda, E., Bebe, B.O., Lindahl, J., Bett, B. and Oosting, S.J.

Published in Food Control; DOI 10.1016/j.foodcont.2021.108303

Abstract

Milk production is an important livelihood source for smallholder dairy farmers in low-to-middle-income countries (LMICs) such as Kenya. However, milk quality and safety are a challenge due to unhygienic handling and non-adherence to food safety standards. The objective of this study was to investigate the knowledge, attitudes and adoption of milk quality and food safety practices by smallholder farmers in Kenya. Ten Focus Group Discussions (FGDs), involving 71 smallholder farmers, were held to collect qualitative data on knowledge, attitudes and practices (KAPs) of smallholder dairy farmers in Laikipia, Nakuru, and Nyandarua counties. Additionally, data were collected through a cross-sectional administered to 652 smallholder farming households.

The results of the study revealed low knowledge level and negative attitudes towards respecting antibiotics treatment withdrawal periods, milk quality standards and food safety regulations. Farmers stated they had received low levels of training on milk quality and safety standards. The majority of farmers adopted animal health measures and hygienic measures such as hand washing and udder cleaning. However, unhygienic milking environments, the use of plastic containers, the use of untreated water, and the lack of teat dipping compromised milk quality and safety. Currently, milk production, handling and consumption could expose actors along the dairy value chain to health risks. The adoption of milk quality and food safety practices was influenced by farmers' knowledge, socioeconomic characteristics, and choice of marketing channel.

There is a need to improve farmers' knowledge and attitudes and implement hygienic control, disease control and antibiotic residue control practices in the milk production process to meet required milk quality and food safety standards. Awareness campaigns and training programmes for smallholder dairy farmers could foster behavioural change and lead to an improvement in milk quality in Kenya.

Keywords: dairy, fresh milk, food safety, food security, value chains, good agricultural practices (GAPs)

1. Introduction

Milk plays an important role in diets globally (Kamana et al., 2014). Milk is a complex mixture of macro and micro-nutrients and a rich source of fats, proteins, carbohydrates, minerals and vitamins such as calcium, vitamin B12 and riboflavin (Dugum & Janssens, 2015). Milk and dairy products are the most affordable animal source foods in low-to-middle-income countries (LMICs) (Alonso et al., 2018; Muunda et al., 2021).

Milk production is an important source of livelihood for smallholder dairy farmers (Kamana et al., 2014; Msalya, 2017). Demand for dairy products in LMICs is growing, driven by population growth, rising in-comes and changing lifestyles. There is an imperative for smallholder farmers to produce milk that meets food safety standards to take advantage of this growing demand for milk and dairy products (Lemma et al., 2018).

Milk contamination results from improper handling, and poor hygiene and sanitation conditions in the milking environment (Olivier et al., 2005). Contaminated milk could be a conduit for pathogens such as bacteria, viruses, parasitic agents and chemical residues responsible for foodborne diseases which negatively affect consumers' health and nutrition status (Amenu et al., 2019). Milk is a highly perishable product, and its safety and quality deteriorate quickly if not handled under hygienic conditions (Kamana et al., 2014). Poor milk quality and food safety risks are a major challenge in the dairy sector in LMICs with weak food safety management systems and low compliance with food safety standards (Amenu et al., 2019; Kussaga et al., 2014). There is a need for an integrated approach to milk quality and safety that guarantees its integrity from 'farm to glass' (Grace et al., 2007).

Smallholder dairy farmers' low knowledge levels and poor attitudes influence their behavioural practices regarding compliance with milk quality standards and food safety regulations (Brown et al., 2019; Ledo et al., 2019). Empirical evidence has linked improved knowledge, training and positive attitudes to improved hygienic milk handling practices at the farm-level (Lindahl et al., 2018). Improved knowledge and compliance with milk quality standards and food safety regulations are crucial for the mitigation of milk-borne diseases (Dongol et al., 2017; Kumar et al., 2017). Farmers adopt milk quality and safety practices that are economically viable, technically feasible, and socio-culturally acceptable (Hermans et al., 2017).

Only a few studies have assessed knowledge, attitudes and practices (KAPs) regarding milk quality and safety of smallholder dairy farmers, namely in India and Nepal (Dongol et al., 2017; Kumar et al., 2017). There is a need to understand the drivers of KAPs regarding milk quality to improve milk quality in LMICs, particularly in Africa (Dongol et al., 2017; Kumar et al., 2017).

The current study focuses on Kenya, which has one of the highest levels of milk production in Africa (Alonso et al., 2018). Over 4 million tonnes of milk were produced in 2016, primarily by smallholder dairy farmers (Alonso et al., 2018). Kenya has a per capita milk consumption of 50–150 L per year (Bosire et al., 2017). The current state of milk quality and safety is a public health concern (Nyokabi et al., 2021) (Muunda et al., 2021). Zoonoses such as brucellosis and pathogens such as cryptosporidium and E. coli have repeatedly been reported in milk (Grace et al., 2008; Wanjala et al., 2017). Antibiotic residues levels exceeding the maximum residue limits (MRLs) have also been found frequently in milk (Ahlberg et al., 2016; Ondieki et al., 2017).

To date, research in Kenya has focused on post-farm-gate milk handling practices in dairy value chains (Alonso et al., 2018; Grace et al., 2008; Nato et al., 2018; Orregård, 2013). To our knowledge, this is the first study to document smallholder farmers' KAPs regarding microbial contamination, zoonoses and antibiotics residues at the farm-level.

2. Materials and methods

2.1. Study location

The study was conducted in Laikipia, Nakuru and Nyandarua counties in Kenya (Figure 1) due to a large number of smallholder dairy farmers and well-established dairy sector (Migose et al., 2018; Muia et al., 2011; Staal et al., 2003). The counties were stratified to capture farming systems and agroclimatic diversity using a farming systems spatial framework, explained by Nyokabi et al. (2021). The framework characterises farms based on their market quality and intensification of their dairy systems. These systems were classified as intensive dairy systems in urban and peri-urban locations (UL), semi-intensive dairy systems in mid-rural locations (MRL) and extensive dairy systems in extreme-rural locations (ERL).

In Nakuru, we purposively selected Nakuru town and Rongai as UL, Njoro and Subukia as MRL, and Molo Elburgon, Keringet, Maili-sita and Kampi ya moto as ERL. In Nyandarua, we considered Olkalau, Oljoro- orok and Engineer as UL, Njabini and Miharati as MRL and Ndaragwa and Olbolosat as ERL. In Laikipia, Nyahururu town and Nanyuki were selected as UL, Marmanet and Ngarua as MRL, and Rumuruti and Kinamba as ERL.

2.2. Research design

This study used focus group discussions (FGDs) and individual interviews to investigate smallholder dairy farmers' KAPs regarding milk quality and safety.

2.3. Focus group discussions (FGD)

FGDs were used to collect qualitative data before the collection of quantitative data. Smallholder dairy farmers were purposively selected to participate in FGDs with the help of county livestock production and veterinary officials. The inclusion criteria for FGDs discussants were: (1) above 25 years old, (2) experience in smallholder dairy farming, and (3) resided in the community for over 3 years. The inclusion criteria were meant to include farmers with experience, made farm decisions and participating in milk production. Each FGDs consisted of between 6 and 9 participants conducted as either male or female and mixed groups. FGDs were held in the villages in one of the smallholder farmers' homesteads and lasted between 60 and 75 min and were recorded using digital recorders with the consent of the discussants. FGDs were conducted using a semi-structured interview guide with open-ended questions and were facilitated by a moderator, with a note-taker in the local languages and the national languages Kiswahili and English. In total 10 FGDs (4 men only, 4 women only, and 2 mixed groups) were held with 71 smallholder farmers, i.e. 37 males and 34 female discussants, respectively.

FGDs explored farmers' knowledge regarding milk quality standards and food safety regulations, animal diseases, zoonoses, microbial contamination, and antibiotics residues risks. FGD participants were asked general questions such as "what makes milk bad?" or/and "what qualifies as good milk?" to assess knowledge and perceptions of milk quality and safety due to the difficulties of directly translating scientifically understood terms of microbiological quality or safety, as also explained by Amenu et al. (2019). FGDs participants were asked to explain and elaborate on practices adopted at the farm to prevent milk microbial contamination during milking and storage; animal health and zoonoses; and antibiotics prevention. The practices included milking parlour cleanliness, hand and udder cleaning, milking and storage containers, cleaning of milk containers, cow's vaccination and treatment and discarding milk from sick or treated cows.

2.4. Questionnaire survey

2.4.1. Identified KAPs and indicators related to milk quality and safety

We explored milk quality, food safety and good agricultural practices (GAPs), as recommended by Kumar et al. (2011), (2017) and FAO (2004), to identify good milk quality hygiene and safety practices. A milk hygiene index was developed using four indicators: (i) washing of udder before milking (ii) washing hands before milking (iii) cleaning of milking area, and (iv) containers used for milking and storage (aluminium/metal or plastic). Vaccination was used as an indicator to analyse animal health practices that could prevent zoonoses such as brucellosis. Farmers' observation of withdrawal period for milk from sick and treated cows was identified as an indicator for prevention of antibiotics residues (FAO, 2004; Kumar et al., 2017, 2011; Orregård, 2013; Yobouet et al., 2014). These indicators were used as proxies for the adoption of milk quality and safety practices at the farm-level.

The survey questionnaire had open and closed-ended questions and was based on the FGD's findings and good agricultural practices (GAPs) recommended by FAO (2004). The first part of the questionnaire captured respondents' general information, e.g., county of residence, the gender of household head, education level, farming experience, gender and age of milker, farmer groups membership, herd size, choice of milk marketing channel, milk price, amount of milk sold, amount of milk consumed at home, access to water and access animal health.

The second part captured farmers' knowledge and attitudes including knowledge of milk quality standards and regulations, milk quality parameters, animal diseases and milk-borne diseases, milk quality tests, antibiotic residues risk, access to milk quality information and training on milk quality handling and hygiene, animal health-seeking behaviour and drug withdrawal period. Questions regarding attitudes towards milk quality and food safety regulations explored whether farmers were complying or willing to comply with milk quality standards and regulations; whether they placed importance on animal health advice-seeking behaviour, control of milk-borne disease, compliance with withdrawal period for treated cows, use of treated water; and their views towards milk quality-based payment systems.

The third part captured farm-level adoption of practices aimed at preventing milk contamination, zoonoses and antibiotic residues including milking and storage practices, milk quality testing, deworming, vaccination, self-treatment of cows with purchased drugs, mastitis tests, teat disinfection, udders and hand cleaning and drying, use of treated water, use of milking cream, milking and storage container (aluminium or plastic), discarding milk from treated cows, cleaning of milking parlour and cowshed, control flies and other vectors.

2.4.2. Sample size and respondent selection

Sample size calculation was undertaken using a single proportion estimation for a finite population as explained by Pham-Duc et al. (2019). The sample size was determined with the assumption that 50% of the population of smallholder farmers implemented good milk quality and handling practices. The study considered a 5% precision and 15% added to cover for non-response, which resulted in a sample size of 460 households. To increase the external validity of the survey findings and due to the availability of resources, we proportionately increased the sample in each county leading to a total sample of 652 households, as explained by Mutua et al. (2017). Survey respondents were identified through purposive sampling in the UL, MRL and ERL farming systems (section 2.1). First, the study counties were stratified using the framework explained in section 2.1. A list of farmers was compiled with the help of livestock and extension officers in the farming systems in each county. Farmers were selected from the list using random numbers generated using an online software. The selected farmers were interviewed based on their willingness to participate. In cases of non-consenting farmers, a similar farm in close proximity was selected as a replacement. The questionnaire was administered to the household head or, in cases where that was not possible, to an informed member of the household, i.e. male or female, aged 18 years or above.

2.4.3. Data collection

Smallholder farmers' data were gathered using a structured quantitative questionnaire. The questionnaire was pre-tested with 25 respondents in areas with similar characteristics to study sites and revisions were made before data was collected. The questionnaire was administered by trained enumerators who could speak Swahili, Kalenjin and Kikuyu and lasted approximately 45–60 min.

The interviews were conducted between May and July 2018. Ethical approval for the study was granted by the Institutional Research Ethics Committee (IREC) of the International Livestock Research Institute (ILRI) (REF: ILRI-IREC2017-09). Participants were informed about the project and that they could withdraw from the study at any time, and those who chose to proceed were asked to review and sign a consent form.

2.5. Data management and analysis

2.5.1. Qualitative data analysis

The audio recordings of the FGDs were transcribed verbatim. Transcription of the data into English was undertaken by a trained research assistant with a good command of the local languages, English and Swahili. The transcripts were compared against the original recordings and notes taken during the interviews to ensure consistency and minimise the loss of ideas or concepts during translation.

The data analysis process was as described by Green et al. (2007), and involved reading and re-reading of the transcripts for familiarisation with the data. Themes were identified and grouped according to the questions guide. Emerging themes were identified and added as appropriate, for example, information regarding sick animals and milk from sick and treated animals. Verbatim quotes of the FGDs participants were identified and used to support the important findings.

2.5.2. Quantitative data analysis

Descriptive statistics were calculated for farmers' demographic characteristics, knowledge, attitudes and adopted practices. To compare KAPs between counties, analysis of variance (ANOVA) was calculated for continuous variables and Chi-square test for frequencies and categorical variables.

Farm-level indicators, i.e. milk hygiene index, vaccination and observation of withdrawal period, were used in the linear and logit regression models to identify the determinants of adoption. The hygiene index comprised: (i) wash udder before milking (yes =1/no =0), (ii) wash hands before milking (yes =1/no =0), (iii) clean milking area (yes =1/no =0), and (iv) milking and storage containers (aluminium/ metal =1/plastic =0). The hygiene index was the sum of the scores of these indicators, i.e. a maximum score of 4 and a minimum score of 0.

The milk hygiene index was used in an Ordinary Least Squares (OLS) model to test farmers' adoption of milk quality and safety practices as explained in Model 1.

$$yi=\alpha+\beta ixi.... \beta nxn+\varepsilon i \qquad \text{(Model1)}$$

Where yi is the farm-level indicator for household i, α is the intercept, βi .... βn are coefficients to be estimated, Xi ... Xn is a vector of farm characteristics, and εi is the error term.

Logistic regression was used to evaluate the effect of smallholder dairy farmers' demographic characteristics on adoption of vaccination (yes =1/no =0; model 2), discarding of poor-quality milk (yes =1/no =0; model 3) and influence of milk market channel on farmers' KAP. Logit regression predicting the binary dependent outcome was specified by the following equation:

$$\log[p/p-1] = \beta 0 + \beta 1X1 + \beta 2X2 + \ldots + \beta nXn + e \qquad \text{(Models 2, 3 and 4)}$$

Where: p =predicted probability that a farmer adopts zoonoses or antibiotics residues prevention practices, β0 ... βn =estimated parameters; X1 ... Xn =independent predictor variables (farm characteristics); e =the random error term.

The predictors evaluated in all three models were county; milk marketing channel; knowledge of hygiene regulations; training on milk quality; the age of milker; experience of farming; gender of milker; ac-cess to water; access animal health; pay to access water; the amount of milk sold; average milk price; herd size; the number of milking cows; the amount of milk consumed; cow breed; awareness of milk-borne zoonoses; gender of household head; membership of cooperative; animal health advice-seeking behaviour; and knowledge of milk quality standards parameters. Multicollinearity tests were performed on the predictor variables and only those with values below 5 were kept in the final models. All statistical analyses were conducted using R statistical software version 3.6.2 (R Core Team, 2019). OLS and logit regressions were undertaken using lm, bayes glm and polr functions in R, respectively.

3. Results

3.1. Smallholder dairy farmers' socio-economic and demographic characteristics

The characteristics of smallholder farmers in the three counties are presented in Table 1. The majority of farmers were aged between 30 and 60 years and practised mixed crop-livestock farming. Farmers primarily kept Holstein-Friesian crosses due to their high milk production potential. However, local breeds were preferred in arid and semi-arid locations due to their adaptability to the harsh environment. Most of the milk produced in urban and peri-urban locations was sold through the informal value chain. Farmers in rural locations sold their milk collectively through farmer groups and cooperatives to processors. However, a significant share of the milk was also sold in the informal value chain through small-scale traders and middlemen.

Table 1. Smallholder dairy farmers' socioeconomic demographic characteristics

Demographic characteristics		Laikipia ^{a} (n= 211)	Nakuru ^{b} (n=220)	Nyandarua ^{c} (n=221)
Proportion of farmers using different milk marketing channels	Subsistence	17.1	24.1 ^{c}	11.8
	IVC	60.2 ^{c}	55.5 ^{c}	31.7
	FVC	20.4	16.4	55.7 $^{a, b}$
	IVC &FVC	2.4	4.1	0.9
Milker gender	Male	45.0	43.6	51.6
	Female	55.0	56.4	48.4
School levels	No formal education	14.2	8.2	8.1
	Primary level education	42.7	36.4	42.1
	Secondary level education	32.2	43.2	38.5
	Post-secondary level education	10.9	12.3	11.3
Percentage who were members of a cooperative		27.5	23.6	38.5 $^{a, b}$
Experience in farming (years)	<10	13.7	22.3	23.5 ^{a}
	10-20	28.9	28.6	33.0
	21-30	19.0	19.0	17.7
	>30	38.4 ^{c}	30.0	25.8
Percentage with access to a source of water		73.0	89.1 ^{a}	82.8 ^{a}
Percentage with access to animal health services		98.6	95.5	99.6 ^{b}
		$\bar{X}$ (se)	$\bar{X}$ (se)	$\bar{X}$ (se)
Amount of milk sold (litres/farm/day)		8.11 (0.67)	9.56 (1.07)	15.04 (2.55) ^{a}
Milker age (years)		47.91 (1.23) ^{a}	41.76 (0.96) ^{b}	42.55 (0.93) ^{b}
Total number of cows (heads of cow/farm)		3.76 (0.22)	5.53 (0.45) $^{a, c}$	4.32 (0.30)
Milking cows (heads of cow/farm)		2.16 (0.13)	2.80 (0.22) ^{a}	2.30 (0.15)
Average milk price (Ksh/litre)		33.50 (0.48)	37.49 (0.50) $^{a, c}$	33.25(0.23) ^{a}
Amount of milk consumed (litres/farm/day)		2.46 (0.15)	2.22 (0.12)	2.92 (0.19) ^{b}

* IVC-Informal value chains, FVC- Formal value chains.

^{a,b,c} Means or percentages in the same row with different superscript are significantly different (P<0.05)

3.2. Focus group discussion results

Table 2 summarises FGD results regarding milk quality knowledge and attitudes. FGD participants knew the existence of milk quality standards and milk quality parameters and tests used by milk buyers such as density, smell, alcohol and organoleptic tests to determine milk quality. They knew animal diseases and milk-borne zoonoses such as brucellosis and symptoms such as diarrhoea and vomiting. Tick-borne diseases were common in extensive grazing systems practised in Nyandarua and Laikipia counties. FGD participants reported that mastitis was common in zero-grazing systems compared to open-grazing systems. FGD participants knew the negative impacts of animal diseases on milk quality, i.e. clots and blood in milk. There was, however, little knowledge of risks from antibiotic residues and a misconception that these were diluted during bulking or degraded by boiling at home or by

Table 2. Focus groups' results of knowledge and attitudes relating to milk quality

		Finding	Respondents' explanation/ comments
Knowledge	Milk quality	• Knowledge of milk quality regulations, parameters and tests used by milk buyers	• *Sure, you're told not to drink it for 72 hours*" (FGD Oljororok)
	Animal diseases and zoonoses	• There was knowledge of animal diseases and milk-borne zoonoses	• Animal diseases e.g. pneumonia, mastitis, foot and mouth, black quarter, anaplasmosis diarrhoea and east coast fever, parasitic worms and anthrax outbreaks. Milk borne zoonoses e.g. brucellosis, diarrhoea and vomiting
	Antibiotics residues	• Low knowledge of antibiotic residues risks. Some farmers knew that some drugs could be detected by organoleptic tests, i.e. smell test	• "*Trodax (used to treat flukes) when administered, don't drink the milk because it changes the look of the milk"* (FGD Oljororok) • "*We sell it there is no need to lie to you [...] I think there's is no harm, the milk will be mixed with other milk and it will neutralize the antibiotics, and also the processing will take care of it with boiling, pasteurization and whatever else they do in the processing plants*" (FGD Nakuru)
Attitudes	Milk quality	• Farmers had positive attitudes towards milk quality requirements • Increased knowledge leads to a positive attitude and compliance with milk quality standards.	• "*cleaning [..] is too much work. Even the wood for warming that water is not here [...] farmers are very stubborn and even when we know the benefits or the dangers [...] we'll still ignore opting for shortcuts*." (FGD Engineer) • "*The plastics are cheaper [...] cost for the metal containers is too high [...] 5 thousand and the same in plastic is one hundred, definitely I will opt for the cheaper one due to the economic issues [...] aluminium ones are good [...] but also the prices of the same milk... is not allowing it*." (FGD Mutarakwa)
	Animal diseases and zoonoses	• Farmers had a positive attitude towards the control of animal diseases because of their impact on milk production and quality	• "*We don't treat all the cows simultaneously [...] I don't treat all of them I leave some for home consumption and after the withdrawal period I treat those that I hadn't been treated*" (FGD Oljororok) • "*The loss is felt by the farmer [...] the milk should not be consumed for 72 hours [...] you can imagine for three days that's a lot of money you'll lose*" (FGD Nakuru)
	Antibiotics residues	• Farmers had negative attitudes regarding antibiotic residue risks • Farmers deriving most of their income from milk production found it difficult to discard poor quality milk	• "*I'm the only person who knows I had given the antibiotics [...] they don't test antibiotics, or even return the milk that had antibiotics [...] It's not like farmers don't know that it's wrong [...] and as they say when you go to Rome you do as they do, you won't pour your milk while you know everyone else is selling their milk with antibiotics*" (FGD Engineer)

Table 3. Focus groups’ results of adopted practices relating to milk quality

	Finding	Observation and explanations
Milk quality	• Farmers practised hand milking and just a handful of big farmers with big herds used machine milking. • Farmers used warm water to wash udders, hands and milk utensils • Majority of farmers used the same water and towel to clean all cows’ udders. • Milking containers and hand towels were washed with soap or detergent. • Majority of farmers did not sieve their milk to remove dirt • Evening milk was cooled in a cold-water bath to preserve it. • Majority of farmers used plastic containers for milking and storage. • Farmers had access to water such as wells, rivers or piped water although, in some areas, availability was seasonal	• Famers avoided mixing evening and morning milk to minimize milk spoilage. • Plastic containers were cheap and easily available, while aluminium containers were expensive. • In Oljoro-orok area in Nyandarua county, farmers depended on water from a water pan which they reported had liver flukes (*Fasciola hepatica*). • There were also reports of sub-standard aluminium containers that rusted being traded in the markets. • Farmers without piped water did not treat their water due to a lack of knowledge, or resources to buy water treatment agent.
Animal diseases and zoonoses	• Teat dipping was not widely adopted in all the counties. • Farmers vaccinated cows and boiled milk to prevent zoonoses. • There was a lack of monitoring of purchased drug and likely misuse by untrained farmers who administered them • Private practitioners were driven by money and did not strictly emphasis the observation of withdrawal period.	• Animal health services were easily accessible through the subsidised public extension, private veterinary practitioners and self-treatment with purchased drugs • Government-subsidised services focused on high economic impacts contagious diseases but were inefficient to respond to farmers needs due to understaffing and underfunding
Antibiotic residues	• Majority of farmers did not strictly comply with the mandatory withdrawal period for drug residues, such as discarding milk from sick or treated cows. • Only a handful reported feeding such milk to calves or dogs. • Some farmers with large herds treated their cows in batches (several cows are treated, and their milk discarded, while some are left untreated for milking).	• Farmers opined that poverty and economic loses made them disobey or disregard food safety standards. • There was also no insurance mechanism in place to compensate for the loss of income or motivate farmers to obey rules

pasteurisation and heat treatment during processing. The majority of the FGD participants had acquired knowledge from training, and from milk buyers, NGOs and media i.e. television, radio, and social networks including fellow farmers, cooperatives and farmer groups.

Farmers had varying attitudes toward animal diseases and milk-borne zoonoses. FGD participants reported positive attitudes towards milk standards and quality parameters used by buyers. The majority of the FGD participants reported good animal health-seeking behaviour and looked to minimise zoonoses risks, i.e. they looked to improve animal health through deworming and vaccination for East coast fever (ECF) and foot and mouth disease (FMD). However, there were negative attitudes towards antibiotic residues risk, expressed by farmers' reluctance to discard milk from treated cows to avoid economic losses. The mandatory withdrawal period was not observed by farmers, partly due to the knowledge that milk was rarely tested for antibiotic residues and was unlikely to be rejected.

FGD participants' adoption of milk quality practices at the farm level is summarised in Table 3. The majority of FGD participants had adopted some hygienic milking and storage practices, animal diseases and zoo-noses prevention practices and antibiotic risk reduction practices. However, farmers used plastic containers because aluminium containers were too expensive to purchase. Moreover, they did not discard milk from sick animals or treated cows and reported that poor farmers disregard laws to avoid economic losses. Some FGD participants opined that greed and ignorance were the main reasons why farmers sold rather than discarded poor quality milk. The adoption of milk quality practices at the farm level was influenced by the market channel requirements, availability of economic resources and labour availability. Farmers selling to cooperatives and dairy companies faced strict milk quality requirements. However, they received information, training and incentives such as bonuses which could have influenced their milk hygiene behaviour.

3.3. Survey results

The overall results of the survey evaluating farmers' knowledge and attitudes regarding milk quality are presented in Table 4. Farmers knew the milk quality regulations and believed it was important to observe and comply with standards. Farmers were aware of milk parameters used by buyers to judge milk. However, approximately half of the farmers did not know of drug withdrawal periods, milk quality parameters and milk-borne diseases. The majority of farmers were not trained on milk quality and hygienic handling. Furthermore, the majority of farmers thought it was important to have a quality-based payment system.

Table 4. Smallholder farmers' knowledge and attitudes regarding milk quality (% of farmers)

Demographic characteristics		Laikipia ^{a} (n= 211)	Nakuru ^{b} (n=220)	Nyandarua ^{c} (n=221)
Proportion of farmers using different milk marketing channels	Subsistence	17.1	24.1 ^{c}	11.8
	IVC	60.2 ^{c}	55.5 ^{c}	31.7
	FVC	20.4	16.4	55.7 $^{a, b}$
	IVC &FVC	2.4	4.1	0.9
Milker gender	Male	45.0	43.6	51.6
	Female	55.0	56.4	48.4
School levels	No formal education	14.2	8.2	8.1
	Primary level education	42.7	36.4	42.1
	Secondary level education	32.2	43.2	38.5
	Post-secondary level education	10.9	12.3	11.3
Percentage of farmers who were members of a cooperative		27.5	23.6	38.5 $^{a, b}$
Experience in farming (years)	<10	13.7	22.3	23.5 ^{a}
	10-20	28.9	28.6	33.0
	21-30	19.0	19.0	17.7
	>30	38.4 ^{c}	30.0	25.8
Percentage with access to a source of water		73.0	89.1 ^{a}	82.8 ^{a}
Percentage with access to animal health services		98.6	95.5	99.6 ^{b}
		$\bar{X}$ (se)	$\bar{X}$ (se)	$\bar{X}$ (se)
Amount of milk sold (litres/farm/day)		8.11 (0.67)	9.56 (1.07)	15.04 (2.55) ^{a}
Milker age (years)		47.91 (1.23) ^{a}	41.76 (0.96) ^{b}	42.55 (0.93) ^{b}
Total number of cows (heads of cow/farm)		3.76 (0.22)	5.53 (0.45) $^{a, c}$	4.32 (0.30)
Milking cows (heads of cow/farm)		2.16 (0.13)	2.80 (0.22) ^{a}	2.30 (0.15)
Average milk price (Ksh/litre)		33.50 (0.48)	37.49 (0.50) $^{a, c}$	33.25(0.23) ^{a}
Amount of milk consumed (litres/farm/day)		2.46 (0.15)	2.22 (0.12)	2.92 (0.19) ^{b}

* IVC-Informal value chains, FVC- Formal value chains.

^{a,b,c} Means or percentages in the same row with different superscript are significantly different ($P<0.05$)

3.4. Milk quality practices adopted by smallholder farmers

Table 5 presents the adoption of milk quality and safety practices by smallholder farmers. Farmers widely adopted animal health practices such as deworming, vaccination and self-treating cows with purchased drugs. Results in Table 7 (supplementary material) show that majority of farmers, 72.1%, had not received training related to milk quality and hygienic handling and only 12.3% of the respondents had received training in the last six months. Moreover, only 21.2% of farmers kept farm records i.e. animal health and production records, while 46.9% did not keep any records.

Table 5. Milk quality practices adopted by smallholder farmers (percentages of farmers)

		Laikipia n=211	Nakuru n=220	Nyandarua n=224
Animal health practices				
Farmer regularly deworms cows		87.7	86.8	90.5
Farmer has vaccinated cows		91.0 $^{b, c}$	76.8	81.9
Farmer self-treat cows with purchased drugs		62.1^{b}	46.8	72.4
Farmer performs mastitis test		47.4	52.7	50.7
Farmer performs teat disinfection before milking		30.3	21.4	25.3
Farmer performs teat disinfection after milking		33.2 $^{b, c}$	17.3	21.3
Farmer uses treated or treats water used for household		20.9	22.3	23.3
Hygienic milking and handling practices				
Milker washes udders before milking		94.3	88.6	97.3 ^{b}
Milker washes hand before milking		93.8	89.5	96.8 ^{b}
Milker dries udders after washing & before milking		93.8 ^{b}	79.1	96.4^{b}
Milker uses milking cream during milking		87.2	79.1	95.9 $^{a, b}$
Milker dries hands before milking		84.4 ^{b}	67.3	84.6 ^{b}
Milking and storage container	Aluminium	43.1	46.8	56.1 ^{a}
	Plastic	56.9 ^{c}	53.2	43.9
Milker uses different towels for cleaning and drying each cow		33.6 ^{b}	23.2	34.8 ^{b}
Farmer discards milk from treated cows		4.7	5.0	10.4
General hygienic practices				
Farmer cleans milk area before milking		56.9	50.5	46.2
Farmer regularly cleans cow shed		44.1	34.1	23.5
Farmer controls flies and other vectors		26.5	37.7	20.8

^{a,b,c} Means in the same rows with different superscript are significantly different ($P<0.05$)

Although the majority of farmers had access to water sources (Table 1), 33% of farmers paid to access treated water for farm and household use (Table 7, supplementary material). Table 7 shows that a majority of farmers, 85%, cleaned cow udders with water only, and only 9% used water with soap or disinfectant. The majority of farmers washed cow udders and used a reusable cloth or towel to dry cow udder. 87% of farmers cleaned the reusable cloth or towel daily.

Nearly half of the farmers used plastic containers for milking and storage. The majority of farmers, 91%, used water and soap to clean milking and storage containers, and 61% of farmers dried these containers in the open. Hand washing was common, with 93% of the farmers practising it. After washing their hands before milking, 53% used a reusable towel to dry their hands, 24% used the towel used to dry udders, and 23% did not dry their hands. Some farmers, 6%, used calf suckling to stimulate milk release during milking.

The self-reported milk-borne zoonoses awareness was low in all three counties, with only 51.6% knowing milk-borne zoonoses. Farmers who knew zoonoses mentioned brucellosis (44.2%), diarrhoea (2.9%), tuberculosis (2.8%) and vomiting (1.8%). Milk quality testing was low with only 26.8% of farmers having their milk tested which led to low milk rejection due to poor quality. The most common milk tests included clot on boiling (11.8%) and density using a lactometer (7.8%).

3.5. Determinants of farm-level adoption of practices regarding milk quality

The regression analysis results are presented in Table 6. In the regression models, Laikipia was used as the base county, while subsistence consumption was used as a base milk marketing channel. The results indicate the important determinants of the adoption of milk quality practices. Adoption of milk quality hygiene practices was significantly lower in Nakuru and Nyandarua counties ($p < 0.001$ and $p = 0.001$, respectively) when compared to Laikipia. Farmers with knowledge of hygiene regulations and knowledge of milk quality standards and quality parameters adopted more measures compared to counterparts with little knowledge. Similarly, access to water increased the adoption of milk quality hygiene practices. However, there was low adoption of milk hygiene measures by farmers with animal health-seeking behaviour, access to animal health and those with high on-farm consumption (i.e. high proportion consumed at home).

Adoption of vaccination as a practice for preventing zoonoses and animal diseases was significantly lower in Nakuru and Nyandarua counties ($p < 0.000$ and $p = 0.008$, respectively) when compared to Laikipia. Adoption of vaccination increased with larger herd sizes. However, the results also show that farmers with knowledge of milk quality standards and parameters were less likely to vaccinate their cows.

The adoption of antibiotic residues prevention by discarding milk from sick and treated cows was widely adopted in farms that sold to formal value chains (processors and cooperatives), and farms with access to water. High milk prices also led to increased discarding of milk from sick and treated animals.

Table 6. Determinants of farm-level adoption of practices regarding milk quality at farm-level

Explanatory variables	Milk hygiene (Model 1)		Vaccination (Model 2)		Discarding poor quality milk (Model 3)	
	Coefficients (Std. Error)	P-value	Coefficients (Std. Error)	P-value	Coefficients (Std. Error)	P-value
Intercept	1.68 (0.28)	< 0.001***	1.13 (1.00)	0.257	-6.39 (1.78)	0.000 ***
County Nakuru	-0.24 (0.07)	0.001**	-1.07 (0.30)	0.000***	0.03 (0.47)	0.948
County Nyandarua	-0.32 (0.08)	< 0.001***	-0.85 (0.32)	0.008 **	0.55 (0.42)	0.193
Sell to informal value chain	0.11 (0.08)	0.176	0.53 (0.30)	0.082	1.53 (0.85)	0.073
Sell to formal value chain	0.11 (0.10)	0.264	0.02 (0.37)	0.950	2.30 (0.88)	0.009 **
Sell to informal & formal value chain	-0.08 (0.20)	0.700	0.77 (0.75)	0.306	1.48 (1.26)	0.240
Know hygiene regulations	1.99 (0.12)	< 0.001***	0.05 (0.44)	0.913	-0.23 (0.96)	0.810
Training milk quality	-0.10 (0.07)	0.130	0.18 (0.27)	0.512	0.05 (0.36)	0.895
Gender of milker	-0.10 (0.06)	0.085	0.10 (0.23)	0.677	0.06 (0.35)	0.873
Have access to water	0.16 (0.08)	0.034 *	-0.03 (0.32)	0.931	-0.79 (0.38)	0.038 *
Have access to animal health	-0.53 (0.20)	0.007 **	1.01 (0.59)	0.086	-0.15 (0.97)	0.880
Amount of milk sold	-0.00 (0.00)	0.541	-0.00 (0.00)	0.672	0.01 (0.01)	0.063
Average milk price	-0.00 (0.00)	0.382	-0.01 (0.02)	0.508	0.05 (0.03)	0.049 *
Total number of cattle	-0.01 (0.01)	0.113	0.16 (0.06)	0.007 **	-0.04 (0.05)	0.473
Number of milking cows	0.01 (0.02)	0.747	-0.03 (0.10)	0.798	0.04 (0.09)	0.691
Amount of milk consumed	-0.4 (0.01)	0.006 **	0.13 (0.07)	0.060	0.09 (0.05)	0.079
Zoonoses knowledge	0.08 (0.06)	0.197	-0.44 (0.23)	0.057	0.59 (0.36)	0.099
Member of cooperative	-0.03 (0.07)	0.715	0.23 (0.29)	0.417	-0.02 (0.39)	0.962
Sought animal health advice	-0.12 (0.06)	0.046 *	-0.33 (0.23)	0.149	0.36 (0.34)	0.288
Knowledge of milk quality standards & parameters	0.25 (0.06)	<0.001 ***	-0.49 (0.23)	0.036 *	-0.03(0.36)	0.943
	p-value: <0.001					
	Adjusted R-squared: 0.3654					

* Laikipia is the base county, subsistence production and consumption is the base marketing channel

* Significance codes: '***' 0.001 '**' 0.01 '*' 0.05

4. Discussion

The main objective of this study was to investigate the smallholder dairy farmers' knowledge, attitudes and adoption of milk quality practices in central Kenya.

4.1. Smallholder dairy farmers' milk quality knowledge and attitudes

The results of this study reveal that the majority of smallholder dairy farmers knew milk quality regulations and standards due to their interaction with buyers, e.g. cooperatives and processors, who had high milk quality demands and used milk quality tests to measure quality aspects, i.e. density and alcohol tests as reported by Ndambi et al. (2020). Farmers had limited knowledge of animal diseases and milk-borne zoonoses, which likely limited compliance with hygienic milk handling practices, as also noted by Dongol et al. (2017), Kumar et al. (2017) and Lindahl et al. (2018). Limited knowledge of zoonoses and milk safety risks is of particular importance because Salmonella spp., Escherichia coli O157: H7 and brucellosis have been reported repeatedly in Kenya (Kang'ethe et al., 2012; Mutua et al., 2017; Ng'ang'a et al., 2016; Njeru et al., 2016; Nyokabi et al., 2018). On the other hand, farmers had a positive attitude towards milk quality regulations and standards and milk quality testing as well as disease prevention, which could reduce zoonoses risks (Lindahl et al., 2018). Furthermore, the results (Table 7) reveal low levels of training crucial for improving farmers' knowledge and understanding regarding milk quality. Alonso et al. (2018) and Lindahl et al. (2018) have reported that training increases the adoption of hygienic milk handling practices. The results in Tables 3 and 4 also revealed that training farmers could increase the adoption of milk quality practices as knowledge was disseminated through farmers' social networks, diffusing from trained farmers to untrained peers (Muange & Schwarze, 2014).

4.2 Adoption practices related to milk quality at farm level

The findings in Table 5 demonstrated a high adoption of animal health practices that could prevent milk-borne zoonoses. Given that other research has reported endemic zoonoses in Kenya, e.g. Q-fever and brucellosis (Kang'ethe et al., 2012; Njeru et al., 2016), the findings of high adoption of animal health practices observed in this study is thus paradoxical. The practice of treating cows in batches (Table 2) violates animal welfare standards, may lead to disease transmission by sick asymptomatic untreated cows and could lead to diseases transmission within herds (FAO, 2004). Reports of mastitis in smallholder dairy farming systems could be due to poor hygiene in zero-grazing housing units as also suggested by Shitandi (2004).

The results in Table 5 reveal a compliance gap in the adoption of hygienic milking and milk handling practices which is similar to findings reported in India (Kumar et al, 2011, 2017; Lindahl et al., 2018), Nepal (Dongol et al., 2017) and Tanzania (Ledo et al., 2019, 2020). Table 5 results revealed that nearly half of the farmers contravened milk quality standards and food safety regulations by using non-food grade plastic containers for milking and storage which is similar to the findings of Muloi et al. (2018) and Orregård (2013). The low adoption of the recommended steel and aluminium containers by farmers could be due to their high price as also reported by Wanjala et al. (2017).

Results in Table 5 show the urgent need to increase compliance with good agricultural practices and hygienic practices to reduce milk contamination. Low compliance with hygienic practices is associated with contamination with Salmonella spp., Escherichia coli O157: H7, and Staphylococcus aureus (Lindahl et al., 2018). Improvements in milk microbiological quality will hinge on improving the hygienic conditions of cow housing (Abera et al., 2012), and increasing access to refrigerators or cold storage facility by farmers (Lindahl et al., 2018; Mwangi et al., 2016). Additionally, there is a need for improved hygiene of utensils, hygienic milk handling and storage and increases access to clean water which could reduce the risk of milk contamination with bacteria (Lindahl et al., 2018; Muloi et al., 2018).

The results in Tables 2–4 show limited knowledge and misconception regarding antibiotics residues risks, they assume that antibiotics residues are diluted by bulking or degraded by pasteurisation which is in agreement with the findings of Ondieki et al. (2017) and Shitandi and Sternesj ̈o (2004). This could suggest that the risks were not widely understood or even acknowledged as also reported by Shitandi and Sternesj ̈o (2004). The majority of farmers did not discard milk from sick and treated animals (Table 2), which could explain the antibiotic residues above the maximum residue limits as reported by Ondieki et al. (2017) and Shitandi and Sternesj ̈o (2004) in milk sampled at farm and value chains. Milk boiling as reported by the farmers in this study does not make it completely safe, and there is still a risk of recontamination due to unhygienic handling (Lindahl et al., 2018; Muunda et al., 2021). Moreover, boiling and pasteurisation does not eliminate contaminants such as aflatoxins, antibiotics residues, pesticide residues and bacterial enzymes, which can lead to spoilage of the packaged milk and pose a public health risk to consumers (Ahlberg et al., 2016; Lindahl et al., 2018).

4.3. Determinants of adoption of practices related to milk quality at farm level

Regression models results (Tables 6 and 8) suggest that improving knowledge of milk quality and safety standards could lead to increased adoption of milk quality hygiene practices. Increasing milk quality standards compliance requires the provision of information and training of smallholder farmers who often lack managerial skills such as hygienic milk handling and record-keeping (Handschuch et al., 2013). Additionally, stricter enforcement of milk quality regulations, such as that observed in the formal value chain could lead to improved farmers' knowledge through increased advice-seeking behaviour and the formation of cooperatives and farmer groups which are a source of information, training and other benefits.

This study shows that the adoption of milk quality and hygiene practices at the farm level entails recurrent and non-recurrent costs (Table 5). Non-recurrent costs are usually fixed costs involving one-time initial investments, i.e. purchase of milking equipment. In contrast, recurrent costs are incurred regularly and vary depending on farm size i. e. water payment and extra labour costs. These costs may be beyond the resources available to smallholder dairy farmers in LMICs (Handschuch et al., 2013). Farmers' socio-economic factors, such as access to resources and milk prices, also influence the adoption of hygienic milk practices and compliance with milk quality and food safety standards. Similar observations have been reported for smallholder farmers in India, by Lindahl et al. (2018). Compliance with milk quality and food safety standards is a challenge for smallholder farmers due to high transaction costs associated with low production (Kumar et al., 2011). Smallholder farmers are often reluctant to make high-risk investments due to the lack of necessary resources needed to implement such milk quality practices (Handschuch et al., 2013). The results reveal that smallholder farmers preferred accessible and easy to implement milk quality practices, which is similar to observations made by Nyokabi et al. (2018).

The results show, in the three counties, smallholder farmers differ in their knowledge and attitudes towards milk quality and their choice of milk marketing channels (Tables 6 and 8). Nakuru and Nyandarua have well-established dairy sectors. Farmer cooperatives and groups and processing plants playing an important role in exposing smallholder farmers to training, information and knowledge regarding milk quality management compared to their peers in Laikipia, a county which prioritises tourism and pastoralism (Nyokabi et al., 2021; van de Steeg et al., 2010). The quality of infrastructure such as road networks and access to water and animal health services could affect farmers' behaviour regarding the implementation of hygiene and animal health practices (Migose et al., 2018; Nyokabi et al., 2021).

5. Conclusion

This research on smallholder dairy farmers' KAPs regarding milk quality in Low and Middle-Income Countries (LMICs) provides practical, empirical and theoretical contributions to the literature on milk quality. The findings of this study indicate that farmers in Kenya have low knowledge and negative attitudes regarding zoonoses and antibiotics residues as reflected by their disregard for milk regulations and standards. Low adoption of important milk quality practices can lead to milk contamination and exposes milk consumers to health risk. As the first step in ensuring farm to table milk quality and safety is producing quality milk under hygienic conditions from healthy animals, there is an imperative for downstream actors such as non-governmental, govern-mental institutions and supply chain actors, such as processors, to help smallholder dairy farmers comply with milk quality standards and improve their milk handling practices. Training and provision of incentives, e.g. a milk quality-based payment system, could result in behavioural change and ensure that consumers have access to clean, safe milk and dairy products.

Statement of ethics

This work had ethical approval from the International Livestock Research Institute's (ILRI) Institutional Research Ethics Committee (ILRI IREC) (REF: ILRI-IREC2017-09). IREC is accredited in Kenya by the National Commission for Science, Technology and Innovation (NACOSTI).

Statement funding

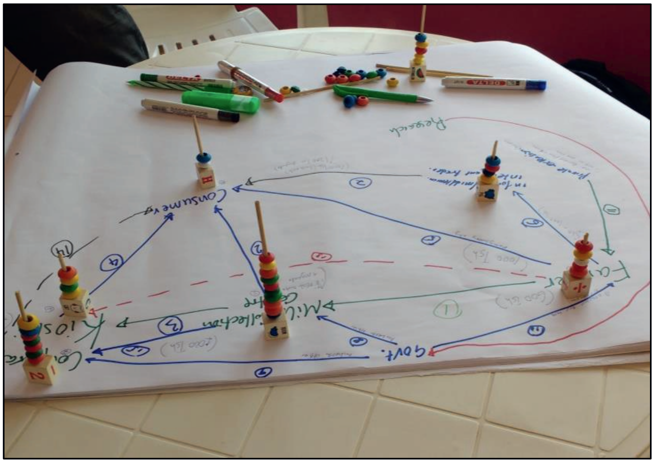
This work was funded by a PhD scholarship as part of the project "Local and International business collaboration for productivity and QUality Improvement in Dairy chains in SE Asia and East Africa (LIQUID)". This project is supported by the Netherlands Organisation for Scientific Research's (NWO) Science for Global Development department (WOTRO) through the Food and Business Global Challenges Programme (GCP) (NOW-WOTRO project number W.08.250.204).

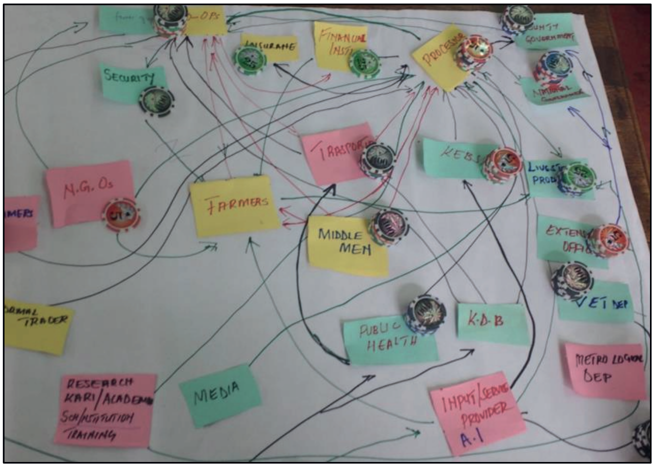
Declaration of competing interest

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

Chapter 5: The role of power relationships, trust and social networks in shaping milk quality in Kenya

Simon Nyokabi[1*], Imke J. M. de Boer[1], Jos Bijman[2], Bockline Bebe[3], Norman Aguilar-Gallegos[4,5], Lisette Phelan[6], Johanna Lindahl[7,8,9], Bernard Bett[10], Simon Oosting[1]





Peer-reviewed and resubmitted to NJAS

Abstract

The objective of this study was to examine social networks in dairy value chains (DVCs) in Kenya and understand how DVC actors' power relationships and trust influence their behaviour regarding milk quality. We conducted a stakeholder analysis using the Net-Map tool in Laikipia, Nakuru and Nyandarua counties in Kenya. VisuaLyzer software was used to analyse the social networks. Thematic content analysis of the discussions, recorded during the mapping exercise, was undertaken using ATLAS.ti.

Formal DVC had more actors and dense social networks characterised by vertical and horizontal integration, high levels of power asymmetries between actors, limited trust and short-term contractual arrangements. Informal DVC was characterised by fewer actors and less dense social networks, low levels of power asymmetries between actors, and a high level of trust due to the existence of reciprocal personal relationships.

Milk was perceived to be of higher quality in the formal value chain reflecting top-down enforcement of milk standards, bottom-up collective action, power asymmetries, and contractual relationships. Poor milk quality management in the informal DVC underscores the need for powerful actors, e.g., regulatory agencies, and buyers such as processors, to influence other DVC actors' behavioural change.

Understanding and leveraging DVC social networks and actors' power and addressing power asymmetries and enhancing trust between actors will increase compliance with milk quality standards. There is an urgent imperative to design policies and interventions which empower DVC actors, by providing economic incentive, enhancing their skills and knowledge and their access to infrastructure which facilitates milk quality improvement.

Keywords: Dairy value chains, food safety, trust, social capital, collective action, quality management, power (a)symmetry, developing countries, agri-food industry

1 Introduction

Demand for milk and milk products in low and middle-income countries (LMICs) is growing, driven by population growth, economic development, and changing dietary patterns (Lemma et al., 2018). At the same time, dairy sector growth in LMICs is constrained by poor milk quality due to weak food safety management systems (Alonso et al., 2018). The majority of milk traded in these countries is produced by smallholder farmers and commercialised through formal and informal dairy value chains (DVCs) (Alonso et al., 2018; Bebe et al., 2018). The formal DVC comprises licensed actors selling industrially-processed-and-packaged milk and milk products. The informal DVC trades traditionally-pasteurised milk and milk products that have not been industrially processed (Alonso et al., 2018; Blackmore et al., 2022). DVC actors perform value-addition activities such as bulking, transportation and processing (Stein and Barron, 2017). These actors operate in an institutional environment that includes regulations, social norms and customs, civil-society organisations, local and national politics, trade agreements and supporting industries such as transport and finance (Trienekens, 2011).

Understanding social networks in DVCs is key to improving milk quality in LMICs (Gorton et al., 2015). DVC actors are embedded within social networks and their behaviour is shaped by the relationships within these networks. Relationships can be formal, i.e. contractual arrangements, or informal, i.e. reciprocal personal relationships (Konchak and Prasad, 2012). Vertical relationships exist between actors situated at different levels of a DVC, i.e., production, bulking, transporting, processing, and distribution. Horizontal relationships exist between actors at the same level of a DVC, e.g. among farmers in a producer organisation (Bijman et al., 2016). The degree of vertical and horizontal relationships that exist between individuals and between groups influence their behaviour regarding the management of milk quality (Vermeulen, 2005).

Social networks differ in their composition, size and density (Borgatti and Li, 2009). Density is a measure of the closeness of relationships and a measure of access to social capital in a network (Borgatti and Li, 2009). In a social network, the core DVC actors have extensive relationships with other stakeholders while peripheral actors have few relationships despite some playing an integral part in the network (Borgatti, 2006). Social capital refers to the actual and potential resources that are embedded within social networks; it is derived from the social norms and reciprocal behaviour among actors (Fafchamps, 2006). Through feedback loops, social capital facilitates the strengthening of social networks and influences information flow and collective action, all of which are critical to the functioning of DVCs (Gorton et al., 2015).

Contingent on their positions within networks and access to resources, value chain actors have differing levels of power. Power constitutes a competitive advantage and can be defined as the ability to determine one's actions and influence the behaviour of others in a network (Belaya and Hanf, 2012). Powerful DVC actors exert their power in cooperation with others, or without the consent of the less powerful actors (Vermeulen, 2005). Power can be a tool for coordinating value chain activities and for enforcing compliance with norms (Belaya and Hanf, 2016, 2012). However, unbalanced or asymmetric power relationships, i.e. when some actors are more powerful than others, affect actors' levels of social relationships and willingness to cooperate and coordinate activities (Belaya and Hanf, 2012; Carbone, 2017). Formal value chains are characterised by a high degree of power asymmetry compared to informal value chains (Gereffi and Lee, 2009). In DVCs, less powerful actors are vulnerable to exploitation by powerful opportunistic and/or monopolistic actors which can lead to conflict and disaffection (Gorton et al., 2015).

The organisation and overall performance of the dairy sector is dependent on trust and cooperation (Dries et al., 2009; Msaddak et al., 2018). Trust is the expectation that another individual or firm will not act opportunistically (Martino, 2010). Social networks with regular contact are associated with high levels of trust (Fisher, 2013). Building trust reduces the transaction costs in contractual arrangements and provides opportunities for cooperation and the building of social capital between DVC actors (Fisher, 2013; Martino, 2010). Trust and cooperation can emerge even in the absence of supporting incentive mechanisms and thus can be an important mechanism for managing milk quality in the DVC (Cabon-Dhersin and Ramani, 2007). Trust and non-contractual long-term relationships are a viable alternative for the absence or lack of stricter vertical coordination and integration in value chains.

DVC actors' behaviour impacts milk quality (Nyokabi et al., 2018). Long-term purchase commitments and collaboration between DVC actors facilitate the creation of trust which can underpin milk quality improvements (Indrawan et al., 2018). Social networks provide access to information, financial capital, human capital, and other resources required to realise quality improvements in value chains (Bijman and Bitzer, 2016). Moreover, social networks foster business relationships which provide an imperative to improve milk quality and serve to reduce the risks associated with investments in milk quality improvements (Gorton et al., 2015; Trienekens, 2011). Realising high milk quality entails additional compliance costs and thus the milk price should be high or an additional premium can be paid to farmers if the milk handling behaviour is improved and maintained (Rademaker et al., 2016; Saenger et al., 2013).

Milk is a perishable product which requires hygienic handling to guarantee its quality during production, bulking, transport and cooling (Ledo et al., 2019). Milk quality refers to the chemical, physical, technological, bacteriological, aesthetic and safety characteristics of milk (Ndambi et al., 2018). Milk quality can be regulated through top-down and bottom-up approaches. A top-down approach involves direct regulation by government agencies through rules, procedures and inspection to force value chain actors to comply with food safety standards (Luning and Marcelis, 2007). In contrast, a bottom-up approach reflects regulation through private agreements among DVC actors (Rao et al., 2016).

This study uses Kenya as a case study, in examining the social networks in formal and informal DVCs, for a number of reasons. Firstly, the country is a major milk producer in sub-Saharan Africa and has a well-established dairy sector (Ajwang and Munyua, 2016). Secondly, the dairy sector contributes significantly to Gross Domestic Product (GDP) and plays an important role in food and nutrition security (Alonso et al., 2018). Thirdly, sector growth is currently constrained by poor quality milk due to unhygienic milk handling, low DVC integration, weak institutions and a lack of economic incentives for milk quality improvement (Ndambi et al., 2018; Nyokabi et al., 2018). Finally, DVC mapping has been undertaken in Kenya to identify actors, product flows, and milk quality to capture value chain governance structures (Kiambi et al., 2018; Muloi et al., 2018). The influence of social networks and social network relationships, e.g., power asymmetries and trust, on DVC actors' behaviour regarding milk quality, however, has not been assessed.

The objective of this study was to examine social networks in the formal and informal DVCs in Kenya and understand how the social network structure, as well as DVC actors' power relationships, trust and influence their behaviour regarding milk quality.

2 Conceptual framework

The conceptual framework employed in this study draws on several strands of literature including Social Network Analysis (SNA) (Borgatti and Li, 2009; Hauck et al., 2015; Hauck and Schiffer, 2008; Scheiterle et al., 2018), Value Chain Analysis (VCA) (Kaplinsky, 2000; Rich et al., 2011), and Actor-Network Theory (ANT) (D'Haese et al., 2007; Hauke and Cadilhon, 2018). Moreover, this conceptual framework is influenced by the game theory insights on the importance of trust and cooperation between actors to solve social dilemmas such as how to improve milk quality (Green, 2002; Kollock, 1998). Business relationships in the DVC face the potential risk of opportunism, i.e. non-respect of business or contractual commitments (Cabon-Dhersin and Ramani, 2007; Kollock, 1998). Opportunism is a distinctive feature of individual motivation that can lead to uncooperative behaviour between actors (Green, 2002; Kollock, 1998; Martino, 2010). Cabon-Dhersin and Ramani, (2007) have theorised trust using two classic paradigms: the prisoner's dilemma and the game of chicken. In the context of the prisoner's dilemma, trust is contingent on the probability of having a cooperative non-opportunist partner. In the game of chicken, trust is purely dependent on the outcomes (Cabon-Dhersin and Ramani, 2007). To address the poor milk quality dilemma, it is important to build trust and strong business relationships between the DVC actors (Mehta et al., 2011). Trust and interpersonal relationships are more important than price in business-related decision-making (Mehta et al., 2011). The conceptual framework presented in Figure 1 outlines how the social network structure of a DVC, power relationships and trust influence actors' behaviour regarding milk quality.

Social network structure includes both vertical and horizontal integration among the DVC actors. Vertical integration reflects the alignment or coordination of DVC activities and decisions at different

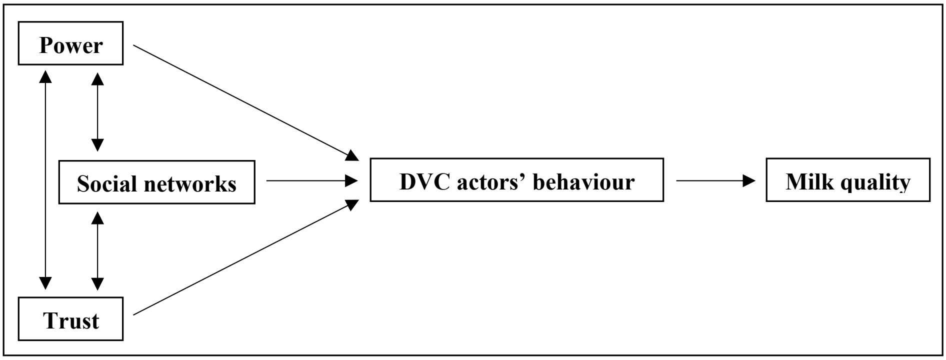


Figure 1. Conceptual framework (source: author's conceptualisation)

stages of the value chain; there is a continuum from weak alignment to very strict alignment (Trienekens et al., 2003). Vertical integration involves a lead actor coordinating other actors' behaviour to control milk supply or distribution, to increase their power in the marketplace, reduce costs and earn a high income (Trienekens, 2011). Horizontal integration reflects collective action in undertaking DVCs activities, e.g. joint milk sales and joint input procurement, as a mechanism to overcome market-related challenges relating to small-scale production and heterogeneous product quality (Bijman et al., 2016). Farmers are often horizontally integrated through producer organisations (POs), e.g., farmer groups and cooperatives. Collective action, however, can create social dilemmas, i.e., free-rider problems which occur when individuals want to enjoy the benefits of improved milk quality without contributing to the collective action of maintaining or improving milk quality. Free-rider problems, if not addressed, reduce social capital and trust among DVC actors (Gorton et al., 2015).

The density of a social network structure is the number of connections between actors (the level of DVC integration and coordination) and is a proxy for the number of horizontal and vertical links (Borgatti and Li, 2009). A highly dense network develops when trust exists between DVC actors (Morgan and McVay, 2012). Actors' relative importance in a social network structure is determined based on their degree of centrality, i.e., 'in-degree' (incoming) and 'out-degree' (outgoing) linkages to others. Actors who are linked to many nodes are considered more powerful and have higher visibility within a social network structure. Closeness centrality refers to how close an actor is to all other actors in a social network, i.e., lower values indicate more central actors. Betweenness centrality reflects the ability of an actor to serve as an intermediary. Intermediaries connect actors and have the power to control the flow of material and non-material resources, i.e., capital, information, advice, and trust. The diameter of a network is the shortest distance between the two most distant nodes in a network (Borgatti, 2005; Borgatti and Li, 2009).

DVC actors have varying levels of power, reflecting their access to and control of resources including finances, expertise, information, services, market position and access to political decision-makers

(Belaya and Hanf, 2016; Nyaga et al., 2013). Formal DVCs are characterised by a high degree of power asymmetry, while there is a low degree of power asymmetry between actors in informal DVCs (Gereffi and Lee, 2009). Power asymmetries can be used to positively influence the behaviour of less powerful actors and to achieve desired outcomes such as improved milk quality (Vermeulen, 2005). However, if power is used negatively to exploit other actors, it can be the antithesis of trust (Belaya and Hanf, 2016; Gorton et al., 2015).

The density of a social network structure and its power asymmetry determine the levels of trust between DVC actors (Monastyrnaya et al., 2017; Trienekens et al., 2003). Trust reflects an optimistic expectation or belief regarding others' behaviour (Fafchamps, 2006). The presence or absence of trust in a social network structure influences its density and can explain why some networks are characterized by integration, coordination, cooperation, solidarity and reciprocity, whereas others are characterised by corruption, discord and opportunistic behaviour (Gereffi and Lee, 2009). Based on trust, social network structure and power asymmetries, it is possible to explore the perceptions of DVCs actors regarding milk quality management behaviour and how these perceptions influence milk quality and food safety.

In Kenya, the factors that were assumed to influence DVC actors' relationships within the structure of the social network and, therefore, their behaviour regarding milk quality, were information exchange, access to input and services, milk trade and regulation regarding milk quality (Mutura, 2015; Oloo, 2010). DVC actors' behaviour reflects their 'lived' experiences of managing milk quality and those of their peers in social networks (Muange and Schwarze, 2014; Vishnu et al., 2019).

3 Materials and methods

3.1 Study area

This study was conducted between June and August 2017 in Laikipia, Nakuru and Nyandarua counties in Kenya. These counties are important centres of milk production and have agricultural policies at the county level to support the dairy sector (Abdulai and Birachi, 2009; Migose et al., 2018; Muia et al., 2011; Staal et al., 2003).

3.2 Selection of dairy sector stakeholders

With the help of county extension and livestock departments, we selected and invited actors in each county to participate in the Net-Map exercise, based on purposive sampling. The inclusion criteria for actors were: (1) resident in the county, (2) experienced and currently involved in the dairy sector, and (3) willing to participate in the Net-Map exercise. Actors selected included farmers, milk transporters, processors, input providers, extension officers, veterinary officers and representatives of farmer groups, co-operatives, county livestock development departments, public health departments, Kenya Bureau of Standards (KeBS), the Kenyan Dairy Board (KDB), and county and national governments. In total, 16 dairy sector stakeholders were selected in Laikipia, 18 stakeholders in Nakuru and 15 stakeholders in Nyandarua.

3.3 Data collection

The conceptual framework was operationalised in the three counties using the Net-Map tool which is a participatory tool for visual mapping (Haggblade and Theriault, 2012; Ilukor et al., 2015; Schiffer and Waale, 2008). Qualitative and quantitative data were collected using a participatory mapping technique outlined by the Net-Map tool, based on in-depth interviews and visualisation of social networks (Hauck et al., 2015; Hauck and Schiffer, 2008). The Net-Map tool was implemented as explained by Scheiterle et al. (2018) and Schiffer and Hauck (2010).

The Net-Map exercise **meetings** involved the following steps:

1. The researcher pointed out the purpose of the research and explained that the goal of the meeting was to map, describe and understand the function and role of each actor in the dairy sector and the links, i.e. relationships, existing between actors. Before the start of the Net-Map exercise, informed consent was obtained from participants.

2. A blank A2 size sheet of paper placed in the middle of the floor was used to draw the social network map. Net-Map exercise participants were asked to identify all actors involved in the Kenyan dairy sector, in both the formal and informal DVC. Coloured sticky notes were used to depict the actors identified and to categorize them into different groups, e.g., private or public institutions, or international actors. These notes were fixed to the A2 sheet.

3. Participants were asked to identify the relations between the different actors (milk trade, exchange of information and advice, procurement of services and inputs, and milk quality regulation). The relationships were drawn, and colour coded (using markers) for the different types of relationships, taking into consideration the direction of the relationship. A legend was drawn beside the map to describe the relationships represented by the different coloured lines.

4. After completing the social network map, participants were asked to review whether all institutions and actors in the dairy sector were included and whether there was a need to add any further relationships to the map.

5. Participants were asked to rank the actors included in the map according to their perceived power to determine milk quality and power to influence milk quality in the DVCs. This study defined power to determine milk quality as the ability or authority of an actor to dictate what quality parameters the final product should meet. Power to influence milk quality was defined as the ability of an actor to change or improve milk quality parameters in the final product (during production, handling, transportation,

storage, and packaging). Actors' power to determine milk quality and power to influence milk quality was scored on a scale from 0-10, (0 - no power to 10 - very powerful). Visualisation of ranking was undertaken using a tower of coins (corresponding to the assigned ranking score) placed beside each actor on a sheet of paper. The maximum possible height of this tower was 10 coins. The final scores were arrived at by a consensus of all participants at the meeting.

6. The final step of the Net-Map exercise was a discussion with participants to follow up with questions about the roles of different actors and opportunities and bottlenecks in the sector.

In addition to mapping the complex value chain processes in which the formal and informal DVC actors engaged (Hauck and Schiffer, 2008; Raabe et al., 2010), the Net-Map exercise in each county facilitated the gathering of descriptions or "network narratives" which provided in-depth insight into actors' perception of formal and informal relationships and their impact on milk quality (Hauck et al., 2015; Hauck and Schiffer, 2008). Each iteration of the Net-Map process was audio-visually recorded for documentation purposes, with participants' consent, using a dictaphone and camera.

3.4 Data analysis

The Net-Map data, relating to DVC actors, relationships, power to influence and determine milk quality, was entered into an Excel spreadsheet as described by Schiffer et al. (2010) and Scheiterle et al. (2018). The data was exported for analysis to VisuaLyzer 2.2 software (Medical Decision Logic Inc, 2014). Net-Map diagrams were developed and compared to the original drawings to ensure reliability. Similar DVC actors were grouped using colours. Actors' relationships were represented by arrows indicating the direction of the relationships which were also colour-coded. The Net-Maps developed in collaboration with stakeholders in the three counties were combined to develop social network maps for the formal and informal DVCs indicating the relationships which existed between actors.

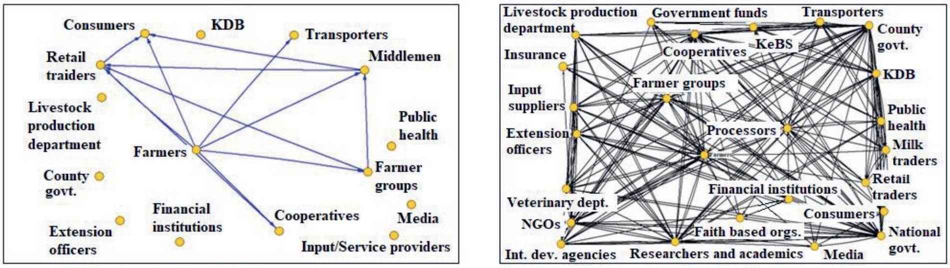
The social network structure was assessed, using VisuaLyzer software, to determine network density and node degree, closeness and betweenness centralities (Freeman, 1978).

The recorded discussions were transcribed verbatim in Swahili and translated to English by a research assistant with a good command of both languages. The transcripts were compared against the original recordings and notes taken during the Net-Map exercise to ensure the accuracy of ideas was maintained during transcription and translation. Inductive content analysis was undertaken using ATLAS.ti software (ATLAS.ti Scientific Software Development GmbH, 2019). Inductive content analysis process was implemented as described by Green et al. (2007) and involved familiarisation with the data through reading and re-reading of the transcripts. Unique and recurring themes related to social networks and milk quality management in the Kenyan dairy sector were identified and grouped. Emerging themes were identified and added as appropriate, for example, the use of milk rejected in the formal DVC due to poor quality.

4 Results

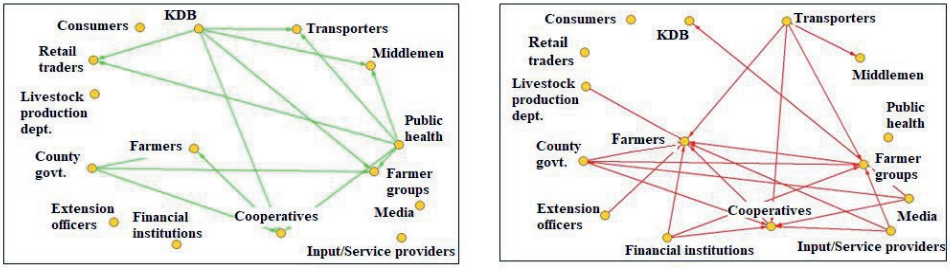
4.1 DVC social networks maps

Social networks existing in the formal and informal DVCs in Kenya are presented in Figures 2 and 3. The dairy sector social networks existing at a county-level, i.e., Laikipia, Nakuru and Nyandarua counties, are presented in Figures 6, 7 and 8 (supplementary material). The properties of these county-level social networks, i.e., actors, their centrality measures, and the number and direction of relationships, are summarised in Tables 1 and 2 (supplementary material).



Milk trade in the informal DVC

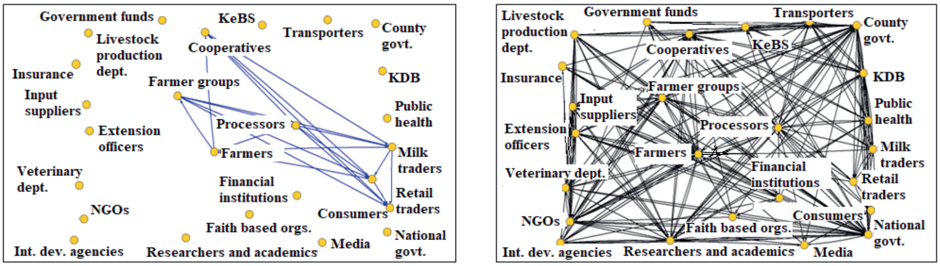
Information exchange in the informal DVC



Milk quality regulation in the informal DVC

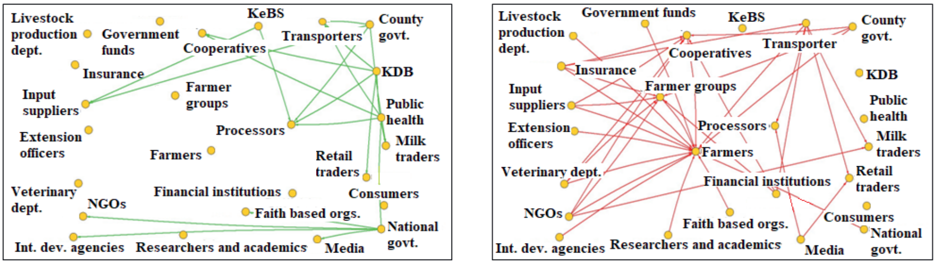
Services and trade in the informal DVC

Figure 2. Social networks in the formal DVC



Milk trade in the formal DVC

Information exchange in the formal DVC



Milk quality regulation in the formal DVC

Services and trade in the formal DVC

Figure 3. Social networks in the informal DVC

The social network structure of the formal DVC

The formal DVC encompassed a diverse set of actors and a large number of actors linked by extensive social networks (Figure 2). These actors dominated the pasteurised milk and processed dairy products markets and were connected by direct and indirect linkages: supply of inputs and services, information sharing, milk quality regulations, and milk trade activities such as producing, bulking and transporting. Information exchange and the supply of inputs and services created the majority of the linkages between formal DVC actors. Milk trade and milk quality regulation only created linkages between actors producing and handling milk.

In all three counties, the dairy sector stakeholders who participated in the Net-Map exercise reported that the majority of the formal DVC actors who handled milk were licenced by the KDB and traded milk that was destined for processing, pasteurisation, and packaging. Processed, packaged, and branded milk and dairy products sold by processing companies had the KeBS mark of quality indicating they met milk quality standards. Net-Map exercise participants reported that vertical integration and coordination of DVC activities by formal DVC actors were loose and changed seasonally. In rural locations, some supporting actors were reported as missing or absent, i.e., KeBS and KDB, while in urban locations, some supporting actors were reported as present but underfunded or/and understaffed to carry out their mandates, i.e., the public health department and KDB.

In urban areas, farmers sold milk directly to consumers. In rural locations, milk trade was based on short-term contracts, with long-term commitments avoided due to seasonal price volatility. Processors primarily purchased milk from farmers and POs. A small number of independent transporters, however, collected milk from farmers on behalf of POs and processors. It was difficult for POs and processors to contract these transporters as they were not organised. Moreover, it was difficult to engage and train them on milk handling practices.

In highly-productive rural areas, POs served as a platform for DVC integration, pooling and selling milk at a negotiated price on behalf of their members. They supplied several processors at any given time on a contractual basis to prevent dependence on a single processor and to secure a good producer price. Moreover, POs acted as saving and credit cooperatives (SACCOs), encouraging farmers to save proceeds from their milk sales and allowing them to obtain loans for school fees, inputs and equipment purchases and to cover emergency costs. They used milk supplies as collateral for loans advanced. In addition, they acted as intermediaries and guarantors in contractual relationships between farmers, financial institutions, and inputs and extension providers. POs facilitated a check-off system whereby farmers received inputs and services on credit and paid at a later date from the proceeds from milk sales.

The Net-Map exercise participants reported, however, that POs were inefficient. They attributed this inefficiency to intra-group challenges such as bad leadership, poor meeting attendance, limited information exchange, particularly relating to milk prices and quality requirements, and lack of farmer training on milk quality handling and hygiene practices. PO leaders were reported as often attending government meetings for personal gain rather than to champion the interests of farmers.

The social network structure of the informal DVC

Figure 3 presents the social network structure of the informal DVC. The value chain was characterised by a high number of individual actors selling small quantities of milk. Informal DVC had less diversity of actors and a less-dense DVC social network. Linkages between DVC actors were formed through information-sharing, supply and procurement of services and inputs, milk trade and milk quality regulation. Similar to the formal DVC, milk trade and milk quality regulation created the most social networks between informal DVC actors.

Vertical and horizontal integration and coordination of activities were almost non-existent in the informal DVC. Formal contractual relationships were absent and, instead, business agreements were based on verbal and on-spot contracts, personal relationships, and trust. Although Net-Map exercise participants reported that, in the wider dairy sector, informal DVC actors were perceived as periphery actors due to their low centrality measures, these actors dominated the milk trade in the three counties, selling raw milk and, in some case, pasteurised milk.

Farmers in both urban and rural areas perceived the informal DVC as a lucrative market channel as it offered higher milk prices. In urban areas, farmers sold their milk directly to retailers, traders, middlemen and consumers. In rural areas, the majority of farmers were members of POs which bulked and marketed milk on their behalf. Other than farmers, the informal DVC actors involved in milk bulking and transporting activities were traders. These traders were unable to purchase milk in large volumes but offered farmers and POs comparatively higher milk prices than other actors and did not have strict milk quality demands.

Unlike formal DVC actors, informal DVC actors, e.g., farmers, retailers, traders, and middlemen, were unable to collectively negotiate with or lobby the government agencies, such as KeBS, to influence the distribution of resources allocated to the dairy sector, e.g., milk cooling tanks which were considered key to improving milk quality. This was due to the absence of collective organisations beyond farmer-level organisations, e.g., SACCOs or trade unions.

4.2 DVC actors and their roles

Table 1 summarises the structure of the social networks in the formal and informal DVCs and highlights the core actors and supporting and regulatory actors. Based on their centrality measures, the core actors in both DVCs were identified as: farmers, processors, consumers, and POs. These actors produced, transformed, and sold milk and dairy products to consumers. Supporting actors included input and service providers, extension service providers, NGOs and development agencies. Regulatory actors included the national and county governments and government agencies responsible for monitoring, certifying and enforcing milk quality standards and public health regulations.

Supporting actors provided services, information and, in some cases, inputs to help farmers improve dairy production and comply with milk quality standards and regulations. Farmers obtained inputs and extension from private and public service providers. In the three counties, the cost of public services was, in some instances, subsidised through national- or county-government initiatives, e.g., vaccination, disease control and farmer training. The national government provided financial assistance specifically to female and young farmers through women and youth funds, to invest in milk production inputs, quality breeds and farm equipment, while the national meteorological department provided weather information and forecasts to help all farmers in planning production.

The Net-Map exercise participants perceived public sector extension services as inefficient and of poor quality, and private sector extension service providers as profit-driven and, therefore, unaffordable. Supporting actors, e.g., NGOs and development agencies, were viewed as playing an important role in bridging the services delivery gap in the dairy sector, supporting farmers and other small-scale DVC actors, e.g., transporters and traders. However, their interventions were regarded as short-term in nature and as not guaranteeing sustained adoption of technologies and innovations.

Table 1. Social network properties of DVCs in Laikipia, Nakuru, Nyandarua counties

Network characteristics	Laikipia	Nakuru	Nyandarua
Links* (number of social networks)	58	62	55
Nodes* (number of actors)	19	19	21
Network diameter* (steps)	3	3	4
Number of links in the social networks in the dairy sector			
Milk trade	13	13	12
Exchange of information exchange	25	25	23
Procurement of inputs and extension services	8	12	14
Milk quality regulation	12	12	6
Actors in the DVCs			
Formal DVC	Farmers, Transporters, Farmer groups, Farmer cooperatives, Marketing cooperatives, Processors, Consumers, Retail traders, Government livestock and extension departments, Formal retail channels, National and county governments, Public health department, Kenya Dairy Board (KDB), Kenya Bureau of Standards (KeBS), Non-governmental organisations (NGOs), Local and foreign development agencies, Church-based organisations, Private input suppliers, Private extension providers, Academia, Insurance companies, and Media.		
Informal DVC	Farmers, Middlemen, Retail traders, Public health department, KDB, Transporters, Consumers		
Core actors	Laikipia	Nakuru	Nyandarua
Based on centrality measures	Farmers, Processors, Consumers	Farmers, Processors, Consumers, Transporter, Cooperatives	Farmers, Consumers, Processors, Transporters, Financial institutions

* Links - relationships between actors, Nodes - DVC actors, Network diameter- maximum distance between any pair of actors in a network.

4.3 Power (a)symmetries in DVCs

Figure 4 summarises the Net-Map exercise participants' perceptions of DVC actors' relative power to determine milk quality. Consumers were perceived as the actor most powerful in determining milk quality through their purchasing behaviour. Government regulatory agencies were also considered powerful as they enforced milk quality standards and public health regulations. Security agencies, i.e., police, enforced milk movement regulations and helped other agencies, i.e., KeBS and KDB, execute their mandates. Processors and POs were powerful actors as they only purchased milk which met quality standards based on milk density, organoleptic and alcohol tests. Supporting actors, i.e., NGOs and development agencies, were perceived as having limited power to determine milk quality.

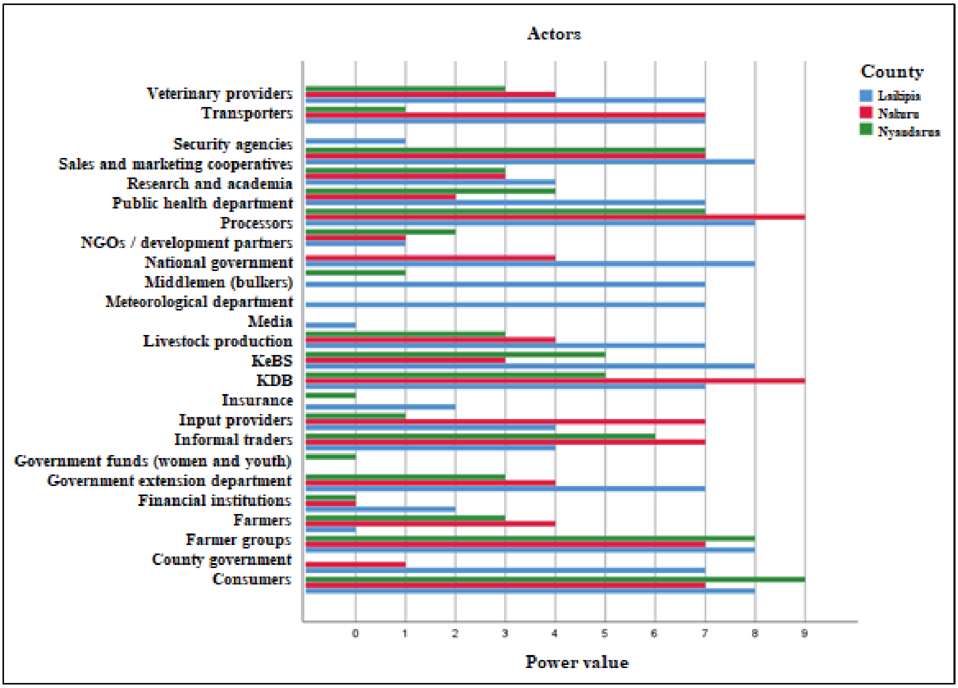


Figure 4. Perceptions of power to determine milk quality in Laikipia, Nakuru and Nyandarua counties (scored 0-10, 0 no power and 10 very powerful)

Figure 5 summarises Net-Map participants' perceptions of DVC actors' power to influence milk quality. DVC actors who handled milk, such as farmers and transporters, were perceived as having the power to influence and improve milk quality. Farmers' adoption of good feeding strategies, improved milk handling and animal health practices were viewed as contributing to improved milk quality. Farmers' abilities to invest in milk quality improvements, however, were limited by delayed milk payments from milk buyers and low milk prices. Transporters, traders, and processors failed to buy all of the milk available during the rainy season, leading to economic losses and undermining the long-term collaboration and milk quality improvements.

Power asymmetries between DVC actors were perceived to influence the equitability of benefit sharing and value creation in the formal DVC. Farmgate milk prices were perceived as low (Ksh 20-35, approximately US $0.30) compared to prices in the informal DVC (Ksh 30-40 approximately US $0.35). Retail prices for pasteurised and unpasteurised milk in the informal DVC were lower (Ksh. 60, approximately US $0.50) than pasteurised and packaged milk in the formal DVC (Ksh 110, approximately US $1.00). Processors reported that the farmgate milk price was low due to low demand for premium dairy products, e.g., cheese, high processing costs, marketing costs and taxes.

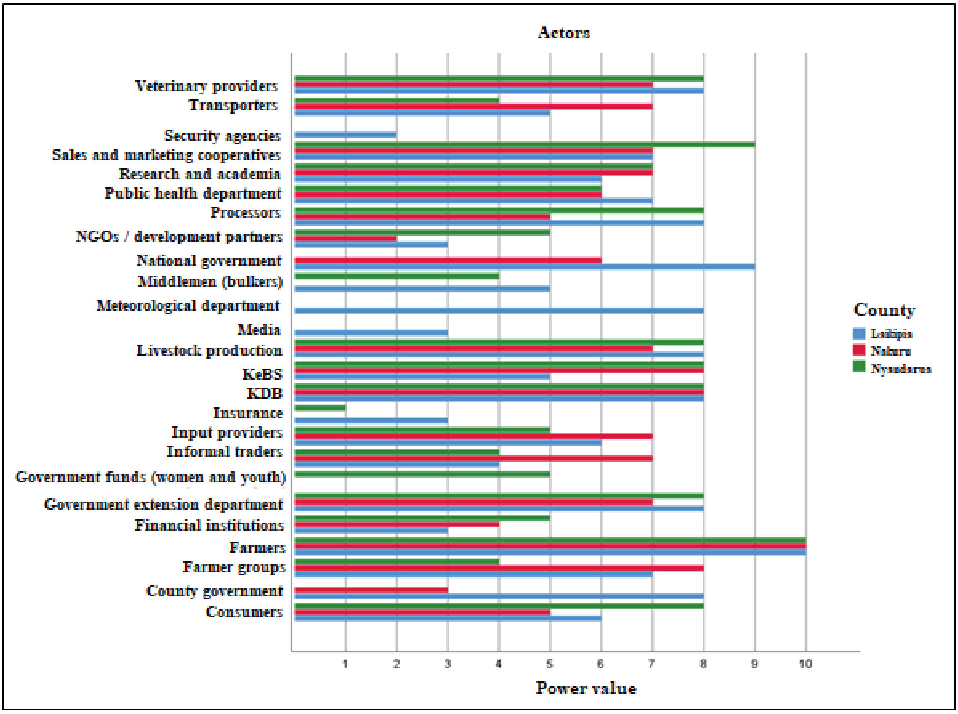


Figure 5. Perceptions of power to influence milk quality in Laikipia, Nakuru and Nyandarua counties (scored 0-10, 0 no power and 10 very powerful)

The majority of formal DVC actors viewed processors as not transparent regarding milk prices and as fixing milk prices without consulting or negotiating with farmers. Milk prices varied depending on the distance to markets and the quality of infrastructure, i.e., roads and cooling plants. Milk prices were also influenced by seasonality, with high prices offered in the dry season and low prices offered during the rainy season. The formal DVC had strict milk quality requirements. However, a milk quality-based payment system and/or economic incentives for milk quality improvement were lacking in both the formal and informal DVC.

4.4 Trust between DVC actors

Dense social networks in the formal DVC facilitated trust creation between actors. Trust between formal DVC actors was based on formal instruments such as contracts which specified product quality and legal recourse in case of breach and led to horizontal and vertical integration and coordination. Trust also reflected the social capital shared between a set of actors, i.e., trust between farmers led to horizontal integration of DVCs activities and the formation of POs. Trust, however, was limited in the formal DVC due to power asymmetry between actors and processing companies' preference for short-term contracts due to milk price volatility.

In the informal DVC, trust was based on social capital and personal relationships as there were no formal instruments to enforce milk quality requirements. Instead, milk quality reflected mutual trust developed between actors over a period of time.

There was distrust between formal and informal DVCs actors. Informal DVC actors perceived national and county governments and government agencies as biased and favouring formal DVC actors. Informal DVC actors were not involved in the policy development process at the county or national levels. Large processing companies had the ability to lobby the government and its agencies, which resulted in the introduction of laws that favoured formal DVC actors and undermined informal DVC actors. Net-Map exercise participants reported that mergers and acquisitions among processing companies had consolidated power into a few companies, created an oligopsony and reduced competition, to the detriment of farmers, consumers, and less powerful actors such as traders in the informal DVC.

4.5 Influence of social network structure power structures and trust on milk quality management

Social networks, i.e., DVC integration and coordination, power structures and trust, affect DVC actors' behaviour related to milk quality. Government regulatory agencies, i.e., KDB, KeBS and the public health department, use their power vested by the law to enforce milk quality standards and food safety regulations stipulated by the Kenya Dairy Act. Milk quality monitoring, licensing, and certification by these agencies occurred regularly in the formal DVC and infrequently in the informal DVC. Regulatory agencies such as KDB, KeBS and the public health department were, however, underfunded and understaffed to properly carry out their mandates.

Milk quality was also regulated by processors and buyers who demanded POs and farmers meet strict milk quality standards. Milk quality tests, i.e., density and alcohol tests, were commonly conducted in the formal DVC but only occasionally in the informal DVC. The use of verbal, on-spot and short-term contracts made it difficult to specify quality requirements to be met by individual farmers.

Recent devolution of functions from the national government to county government units was viewed as having improved service provision at a grassroots level. However, it was not clear to Net-Map exercise participants which functions were the responsibility of the national and/or county governments. County-level institutions such as regulatory agencies and extension services were described as chronically underfunded and understaffed to fulfil their mandates and have an ageing workforce. Limited collaboration between the national and county governments and their agencies, and quality surveillance laboratories also constrained milk quality improvements.

Formal DVC actors had the public health certificates required to handle milk, i.e. milk transporters had milk movement certificates required to transport milk and milk retailers had public health and business certificates mandatory for running milk bars, vending machines (ATMs) and retail shops. Some actors in the informal DVC, however, operated without obtaining mandatory public health, milk movement and business certificates.

Net-Map exercise participants reported that poor quality milk rejected by processors and PO cooling plants was often traded in the informal DVC. As the enforcement of milk standards by regulatory agencies was low in informal DVC, governments and processors' power to determine milk quality was negated and circumvented which impeded milk quality improvement.

In both DVCs, poor quality road infrastructure increased the transaction costs associated with access to information, extension services, farm inputs, milk markets and hindered milk collection logistics, particularly during the rainy season. The majority of Net-Map exercise participants believed that the government should facilitate the purchase of aluminium containers, equipment to test milk and facilitate the purchase of motorcycles (*'boda boda'*) to transport milk in order to reduce post-harvest losses and poor milk quality caused by slow transportation due to poor road conditions.

5 Discussion

The objective of this study was to examine social networks in the formal and informal DVCs in Kenya and understand how DVC actors' power relationships and trust influence their behaviour regarding milk quality.

Social network structure of the formal and informal DVCs in Kenya

The results of this study indicate that the formal and informal DVCs in Kenya differ in their social network structure. The formal DVC encompasses a more diverse set of actors and has a dense social network structure. Formal DVC actors are dependent on contractual relationships which facilitate collaboration, and integration and coordination of DVC activities; they place little emphasis on building and leveraging personal trust in undertaking activities. In contrast, the informal DVC comprises a less diverse set of actors, has a less dense social network structure, and shows lower integration and coordination of activities. Informal DVC actors rely on short-term relationships that change from season to season and are highly dependent on personal trust.

In both DVCs, the absence of supporting actors such as KeBS and KDB, and understaffing or/and underfunding of regulatory institutions, such as the agricultural extension service and the public health department, result in institutional voids which undermine milk quality management. Missing horizontal and vertical linkages between DVCs actors constrain collaboration and coordination of DVC activities; in particular, vertical integration of activities such as logistics, cooling, and bulking affects milk quality.

Influence of social network structure on DVC actors' behaviour relating to milk quality

The social network structure of the formal and informal DVCs in Kenya influences actors' behaviour regarding milk quality. The results of this study corroborate with Gorton et al. (2015) who reported that low emphasis by formal DVC actors on building and relying on personal trust in undertaking activities undermines their willingness to commit to long-term collaboration and adversely impacts milk quality management. Although formal DVC actors rely on contractual relationships, they solely dominate the pasteurised milk and processed dairy products market. In contrast, informal DVC actors dominate the milk trade in the three counties, selling raw milk and, in some case, pasteurised milk. Current low adoption of contracts in the dairy sector in Kenya, notably in the informal DVC, could be addressed by increasing vertical linkages between actors and vertical integration of activities, and redressing the short-term orientation of business relationships, as suggested by the findings of Abdulai and Birachi (2009). Formal contracts could be used to increase compliance with milk quality standards as they explicitly specify the required milk quality. In Vietnam, the adoption of formal contracts has led to increased compliance with food safety regulations by DVC actors and has led to improved milk quality (Saenger et al., 2013).

The results of this study underline an urgent imperative for addressing the loose vertical integration of activities in both DVCs that results in value chain inefficiencies and high transaction costs, as also reported by Trienekens (2011). Lead actors, such as processors and supermarket chains, could provide technology, extension services and inputs to help farmers meet milk quality standards (Trienekens, 2011). Increased vertical integration could facilitate farmers' access to high-value, niche markets which offer lucrative prices but demand high-quality milk (Delgado, 1999). Farmers in Kenya are currently dependent on the informal DVC as the main market channel as they cannot meet the quality and quantity demands of the formal DVC. Similar findings regarding smallholder farmers' inability to access the economic resources required to secure quality services and inputs and, thus, ensure high-quality milk in other emerging economies, have been reported by (Trienekens, 2011).

Increased horizontal integration could equally enable farmers to derive greater socio-economic benefits from their participation in DVCs, by enhancing their access to credit facilities, inputs, and extension. POs facilitate the collective sale of milk and enable farmers to negotiate access to milk markets offering farm gate prices which can improve their livelihoods (Mwambi et al., 2020). The results of this study indicate that increased horizontal linkages between actors and integration of activities in the DVCs in Kenya could increase farmers' market participation and benefits derived from milk value addition. In addition to enhancing farmers access to inputs, credit, information, extension and innovation support services, increased horizontal integration could reduce the transaction costs (Kilelu et al., 2017; Rao et al., 2016).

Influence of power and trust on DVC actors' behaviour relating to milk quality

The results of this study reveal actors' behaviour regarding milk quality is influenced by a high degree of power asymmetry in the formal DVC and a low degree of power asymmetry in the informal DVC. Power asymmetry, when abused by powerful DVC actors, can serve as a disincentive for smaller DVC actors' to invest in milk quality improvements (Rademaker et al., 2016). Farm-gate milk prices and profit margins are low in DVCs in Kenya due to high production costs (Mutura, 2015). In contrast, retail prices for milk and dairy products are high and inelastic, which can be attributed to weak coordination and integration in the DVCs activities and lack of competition between the limited number of processors operating in the Kenyan dairy sector (Birachi, 2006).

Powerful actors such as processors and POs are in a position to shape the behaviour of actors in their sphere of influence to conform to the stipulated standards and regulations (Chepkoech, 2010; Kilelu et al., 2017). However, the results of this study indicate that processors are more concerned about protecting their market share, as evidenced by their preference for short-term contracts and oligopolistic practices than leveraging their power to improve milk quality, which is in agreement with Rademaker et al. (2016).

Milk quality management in DVCs

The results of this study underscore that a top-down milk quality management approach has the potential to influence formal and informal DVC actors' behaviour and compliance with milk quality regulations via rules, procedures and through inspections. This is in agreement with the findings of Chepkoech (2010) and Oloo (2010). However, the results of this study are also in agreement with previous research which suggested that, although a legal framework exists for formalising the informal DVC in Kenya, actors' low adoption of certification inhibits their behaviour in managing milk quality (Alonso et al., 2018; Blackmore et al., 2022). The current top-down approach to milk management in the dairy sector in Kenya is constrained by understaffing and underfunding of agencies mandated with enforcing milk quality regulations, e.g. public health department and KDB (Blackmore et al., 2022). The major constraint to operationalising a top-down approach to milk quality improvement in Kenya is that standards formulated in the context of developed economies have been domesticated without concurrent investment in infrastructure, i.e., roads and cooling plants (Blackmore et al., 2022). This has made it difficult for DVC actors to comply with expected milk quality standards and food safety regulations (Jacxsens et al., 2015; Omiti et al., 2006).

The results of this study indicate a bottom-up approach, which relies on POs and the collective action of DVC actors, could be more effective in improving milk quality management than the current top-down approach adopted by stakeholders in the dairy sector in Kenya. Collective action by DVC actors is key to effecting behaviour change where formal institutions are absent or not functioning (Abdulai and Birachi, 2009). Research on dairy platforms in East Africa, i.e., dairy hubs, indicates that farmers' collective action can lead to improved milk quality. Regulation of milk quality by POs is important, as is PO coordination and organisation of bulking and/or chilling of milk, and PO initiatives aimed at increasing farmers' use of inputs and services and access to loans and training (Rao et al., 2016).

The results of this study reveal that social networks influence trust-building processes and shapes DVC actors' individual perceptions and reciprocal expectations. Trust based on contractual instruments and high-power asymmetry enables powerful actors, through actions such as rejection of poor-quality milk, to initiate behavioural change regarding milk quality management among farmers, transporters, and bulking agents. Trust can determine DVC actors milk quality management practices and their willingness to either have binding contractual arrangements or spot market contracts (Mehta et al., 2011). However, long-term collaboration is undermined when powerful actors are perceived as abusing their power, for example, in setting milk prices. Farmers' current perception that there is a lack of transparency in price setting and that they receive too low milk prices undermines their willingness to improve milk quality. The results of this study indicate there is an imperative to address the short-term orientation of business relationships and the opportunistic behaviour of processors. This will facilitate increased collaboration between DVC actors and integration of DVC activities crucial to sustained improvements in milk quality (Birachi, 2006).

It is crucial that regulatory and core actors in the dairy sector, such as the Kenyan government and cooperatives and processors leverage their influence on informal DVC actors to promote milk quality improvements as personal relationships and trust and low power asymmetry were not considered sufficient enough to enforce behavioural change. In order to improve milk quality in the Kenyan dairy sector, there is an urgent need in the informal DVC to eliminate the trade of poor quality milk rejected by actors in the formal DVC, as also reported by Chepkoech (2010).

6 Policy implications

Poor milk quality in DVCs and public health concerns have led consumers to demand improved milk quality in Kenya (Ndambi et al., 2018). There is a need to engage informal DVC actors in policy-making and milk quality improvement initiatives rather than regard them as periphery actors as they dominate milk trade in the Kenyan dairy sector (Rademaker et al., 2016; Roesel and Grace, 2015). Realising sustained milk quality improvements will require leveraging power, trust, bottom-up and top-down milk quality management approaches to improve DVC actors' behaviour regarding milk quality. There is scope to empower DVC actors with skills and the provision of infrastructure to enable milk quality improvement. Increasing transparency and participation in policy-making and implementation processes will create a conducive policy environment for sustained milk quality improvement.

In addressing the issue of milk quality through policies and behaviour change interventions, it is important to understand that DVC actors' perceptions of milk quality differ depending on their role in the value chain, i.e. producing, processing, trading and consuming milk and milk products (Bijman and Bitzer, 2016; Ndambi et al., 2018). For example, processors are concerned about milk composition, microbial and chemical contamination, and adulteration, whereas informal traders are primarily concerned about the microbial contamination of milk. DVC actors in Kenya currently perceive few economic incentives to improve milk quality due to the absence of quality-based payment systems, i.e. a bonus for producing or trading consistent high-quality milk and a price penalty for low-quality milk (Rademaker et al., 2016).

The strength of the conceptual framework used in this study stems from the synergies between the different concepts and theories. Social network analysis provides a framework to study the roles of, and relationships between DVC actors and allows for the identification of the visible and invisible ties in a network of stakeholders (Haggblade and Theriault, 2012; Trienekens, 2011). Participatory visual methods such as Netmap captures the activities and processes along formal and informal value chains, from input supply to production, processing, handling, transportation, storage, packaging and marketing of the final product to consumers (Trienekens, 2011). Netmap allows for the investigation of the stakeholders' actual and perceived power between DVC actors (Birner et al., 2010; Schiffer et al., 2010). Data collected thorough participatory, collaborative and visual research is credible and acceptable to all stakeholders and can support the development of local context specific solutions. The research process produces participant directed data created away from the direct influence of the researcher (Birner et al., 2010; Schiffer et al., 2010).

The main limitation the research approach is that due to the number of interrelated concepts, it can be tedious and requires considerable planning and time management skills (Birner et al., 2010; Schiffer et al., 2010). There is a need for reflexivity by the researcher to understand that factors such as class, age, and gender, can influence the data collected and it is thus all the stakeholders including the less powerful are involved in the research process and allowed agency to tell their stories (Migliorini and Rania, 2017).

7 Conclusion

This research contributes to the empirical and theoretical literature on the role of social networks in DVCs in Kenya and similar LMICs. Our results show that understanding DVC social network structure, power (a)symmetry, and trust, can contribute to the design of policies and interventions which have the capacity to increase DVC actors' compliance with milk quality standards and food safety regulations. Inclusive policy-making and implementation processes hinge on participatory research, co-generation of knowledge, and social learning are key to improving DVC actors' adoption of policies and technologies and realising sustained behaviour change regarding milk quality.

The results of this study provide a platform for further research on milk quality and DVCs in LMICs. It is important to capture the views and opinions of all DVC actors, not just those actors which are powerful due to their position within the value chain and have the ability to influence policy-making through lobbying, but also those small and less powerful actors which, despite often being overlooked in policy-making and implementation processes, are important dairy sector stakeholders, e.g. informal DVC actors. Participatory and visual research approaches to data collection and the use of tools such as

Net-Map are inclusive and easy-to-use and can capture the opinions of different actors in a sector, social network or value chain. Participatory approaches facilitate the development of context-aware interventions that are attuned to the social, cultural, and economic environments in which DVC actors are engaged in producing, processing, and trading milk and milk products. Policies and interventions are more likely to be accepted by the DVC actors targeted if these actors are given the opportunity to participate in and influence their design and implementation.

Supplementary material

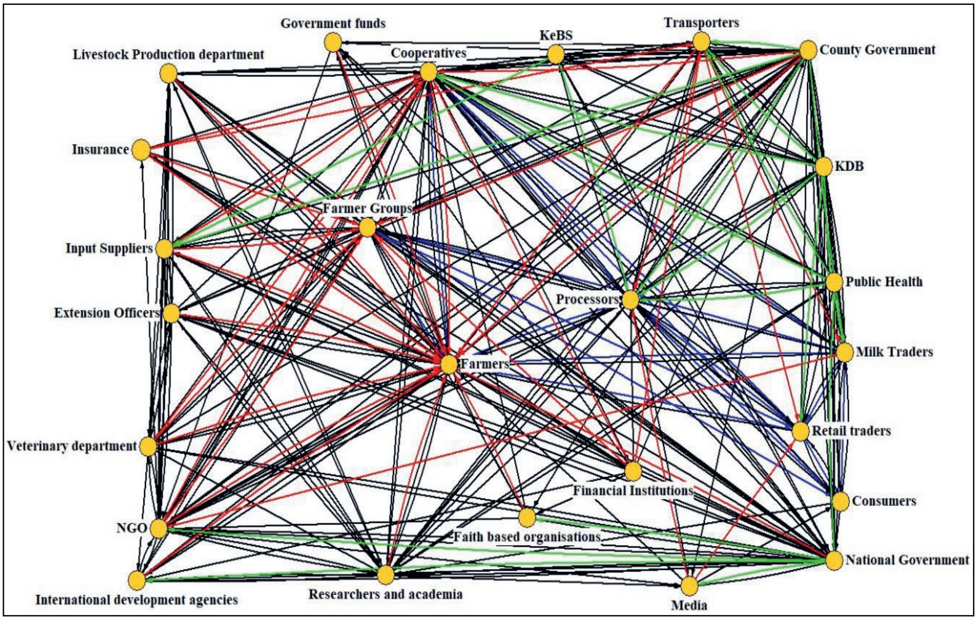


Figure 6. Social network map for the formal DVC

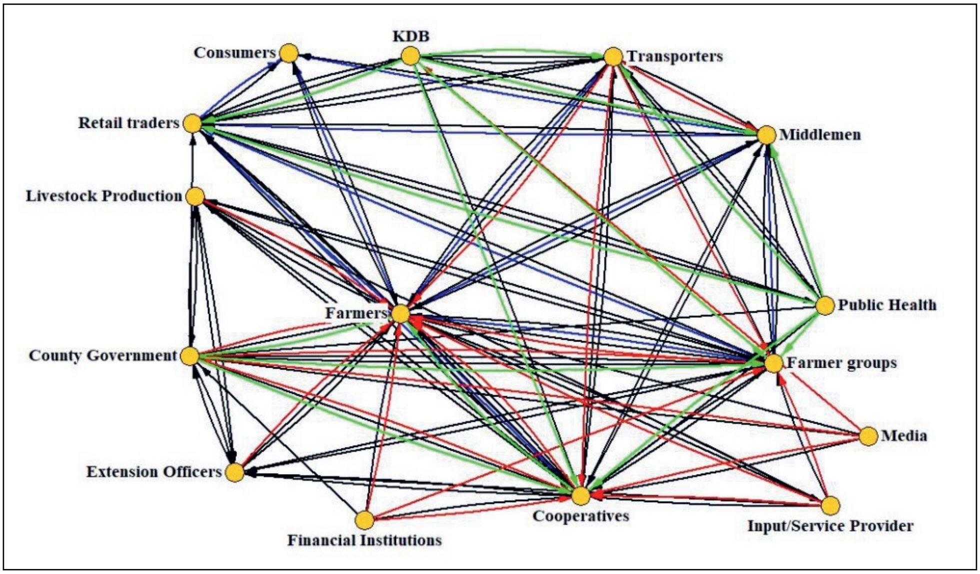


Figure 7. Social network map for the informal DVC

Chapter 6: General discussion

6.1 Introduction

This PhD thesis explores the current state of milk quality and safety and factors that influence milk quality produced in smallholder dairy farms and traded in dairy value chains (DVCs) in Kenya to identify improvement strategies. I chose Kenya as a case study as it has one of the highest levels of milk production and consumption in sub-Saharan Africa (Alonso et al., 2018; Brown et al., 2019). To address the main objective of this thesis, I formulated four sub-objectives to guide the research process: (i) describe the status of milk quality in smallholder dairy farms and associated DVCs in Kenya using a farming system framework (Chapter 2); (ii) investigate seasonal variations in feed availability and impact on milk physicochemical composition and microbial quality (Chapter 3); (iii) assess farmers' knowledge, attitudes and practices (KAPs) regarding milk quality in smallholder dairy farming systems (Chapter 4); and (iv) explore social networks, power relations and trust between DVCs actors and their influence on farmers' behaviour related to milk quality (Chapter 5).

This general discussion starts with a summary of the main findings, followed by an in-depth discussion of the main results, the constraints to improving milk quality, and potential strategies to improve milk quality, and, finally, presents the main conclusions of the thesis.

6.2 Summary of main findings

In Chapter 2, I investigated the variation in the quality of raw milk in dairy farming systems and associated value chains in central Kenya. I used a spatial framework based on the distance to urban markets to distinguish the following farming systems: relatively intensive dairy systems in urban locations (UL), semi-intensive dairy systems in mid-rural locations (MRL), and extensive dairy systems in extremely rural locations (ERL). I hypothesised that there would be a variation in raw milk quality and safety in these dairy farming systems and associated value chains in central Kenya. The study combined several methods such as participatory rural appraisal, participant observation, and laboratory analyses to explore this hypothesis. Milk samples were collected at the informal and informal value chain nodes - farms, informal collection centres, informal retailing centres including milk vending machines, and formal bulking centres - where milk changes hands between value chain actors. Milk was analysed for physicochemical and microbial contamination. The results of milk quality were compared to standards recommended by the Kenya Bureau of Standards (KeBS).

The data collected revealed that farm intensification varied by location and was influenced by the availability of production factors (i.e., land and labour) and by market quality (i.e., access to input markets and output markets). However, there were no differences in the quality of raw milk between locations or between nodes. The overall milk physicochemical composition (mean± standard error) consisted of fat (3.61±0.05), protein (3.46 ±0.06), solids non-fat (9.18 ±0.04), density (1.031±0.0002), and freezing point (−0.597±0.019), all were within the Kenya Bureau of Standards recommendations.

The protein percentage was below KeBS standards at all value chain nodes, except at the formal bulking node. There was significant contamination of milk samples: 16.7% of samples had added water, 42.4% had *E. coli*, 47.9% had *Pseudomonas spp.*, 3.3% had *Staphylococcus spp.* and 2.9% had brucella. Raw milk samples had a high somatic cell count (SCC) (8.8% of samples above SCC 300,000). The high microbial contamination reflects a possible link with the unsanitary milk handling practices observed at farms and all value chain nodes.

In Chapter 3, through a longitudinal study, I investigated intra-annual feed resource availability, the chemical composition of feed resources, and the physicochemical composition of milk produced by smallholder dairy farms in Nakuru county, Kenya. This is the first study investigating intra-annual variation in the milk physiochemical composition in Kenya in a real farm context rather than a controlled experimental setting. Feed and milk samples were collected every last week of the month for 1 year from 43 purposively selected smallholder dairy farms. Feed samples were analysed for chemical composition using Near Infra-Red Spectroscopy (NIRS) and milk samples were analysed for physicochemical composition using a milk scan.

The data revealed that the main basal feeds were indigenous grasses, Napier grass, maize stover, bean stover, and whole crop maize silage which were supplemented with purchased commercial concentrates and/or purchased or homemade total mixed rations (TMR). Feed resource availability was influenced by seasonal changes with abundance in the wet season and scarcity in the dry season. Feeds chemical composition varied by the feed category. Commercial concentrates had the highest crude protein (CP) (mean ± standard deviation) 17.4±3.9 % dry matter (DM) while maize stover (8.7±3.3 % DM) had the lowest. Metabolisable energy (ME) ranged from 7.0±0.8 (MJ/kg DM) to 8.9±0.8 (MJ/kg DM) for maize stover and dairy meal, respectively. Neutral detergent fibre (NDF) ranged from 40.8±7.3 % DM to 79.1±8.2 % DM for dairy meal and maize stover, respectively. Only grasses showed seasonal variation in CP; 15.2 ± 5.2 % in the short dry season compared to 11.2 ± 5.1 % in the short-wet season; and NDF 64.8 ± 8.2 % in the short-wet season compared to 59.2 ± 7.9 % in the short dry season) ($P>0.00$, respectively).

Milk physicochemical composition consisted of (mean ± standard deviation); butterfat 3.6 ± 0.9 %, protein 3.5 ± 0.3 %, solids non-fat (SNF) 9.2 % ± 0.8 % and total solids 12.8 ± 1.2 %, and the density was 1.031 ± 0.004, the freezing point -0.6 ± 0.1°C, and the milk fat to protein ratio was 1.1 ± 0.4. Milk physicochemical composition did not show significant seasonal variation except for butterfat significant differences were found but the differences were very small (circa 1%).

In Chapter 4, I investigated the knowledge, attitudes, and adoption of milk quality and food safety practices by smallholder farmers in Kenya. This study was informed by the results of the investigation on the current state of raw milk quality and safety and their drivers in the dairy farming systems and associated value chains in central Kenya (Chapter 2). Ten focus group discussions (FGDs), involving 71 smallholder farmers, were held to collect qualitative data about smallholder dairy farmers' knowledge attitudes and practices in Laikipia, Nakuru, and Nyandarua counties. Additionally, I performed a cross-sectional study by administering questionnaires to 652 smallholder farming households.

The results revealed that the majority of farmers (58.6%) had low knowledge levels regarding antibiotic withdrawal periods, and the majority of farmers (54.5%) lacked knowledge regarding milk quality standards and food safety regulations. Moreover, farmers had negative attitudes toward compliance with antibiotic withdrawal periods. Nearly a third of farmers had not received training (27.9%) related to hygienic handling of milk and milk quality standards and food safety regulations. Most farmers adopted animal health measures and hygienic measures such as hand washing and udder cleaning. However, there was also prevalent practices such as unhygienic milking environments, the use of plastic containers, the use of untreated water, and the lack of teat dipping. The results confirmed the need to improve farmers' knowledge and attitudes and implement hygienic control, disease control, and antibiotic residue control practices in the milk production process to meet required milk quality and food safety standards.

In Chapter 5, I explored how DVC actors' power relationships and trust within the social network of the Kenyan dairy value chain influenced their behaviour regarding milk quality. A stakeholder analysis was conducted using the Net-Map tool to map DVC actors, social network relationships, and perceived power dynamics, in three counties in Kenya (i.e., Laikipia, Nakuru, and Nyandarua). The results reveal that the social networks of the formal DVC are characterised by vertical and horizontal integrations, high power asymmetry, and limited trust between actors due to short-term contractual arrangements. In contrast, the informal DVC had less dense social networks, lower power asymmetry between actors, and a higher level of trust between actors due to the existence of reciprocal personal relationships than the formal DVC. There was better milk quality management in the formal value chain through a combination of top-down enforcement of milk quality standards, bottom-up collective action, power, and contractual relationships which were absent in the informal DVC. Poor milk quality management in the informal DVC shows the need for a powerful actor such as a consumer organisation or the government to influence DVC actors' behavioural change. Besides, the results show the need to understand and leverage the social networks, power dynamics between DVCs actors', and DVC actors' trust in policy formulation and intervention strategies to increase compliance with milk quality standards and food safety regulations.

6.3. Understanding the current status of milk quality in the Kenyan dairy chain and its implications

The findings of the thesis are further discussed and milk quality improvement options both at and beyond the farm level in the DVCs are proposed.

6.3.1. The state of milk physicochemical composition

No major milk physicochemical composition differences were observed across the smallholder farming systems (Chapter 2). There was intra-annual variation in feed availability and variation in the chemical composition within feed types but limited variation in intra-annual milk physiochemical composition (Chapter 3). These results contradict studies such as from Migose et al. (2018) and van der Lee et al. (2020) who suggested that farmers in urban and peri-urban areas, who have good access to inputs, extension services, information and milk markets, are likely to have good milk production and quality compared to their peers in rural areas.

A reason for the small variation in milk physicochemical composition across the various farming systems could be due to cattle having similar genetic make-up. Cattle breeds in Kenya are mainly crosses of exotic breeds such as Holstein-Friesian which, coupled with similar climatic conditions across the study areas, could lead to similar cattle physiological performance and milk physicochemical composition (Kabui et al., 2015; Ondieki et al., 2017). Furthermore, smallholder farmers tend to have similar farm management practices which could lead to small variations in the physicochemical composition as well (Mutua et al., 2012; Mburu, 2015; Njarui et al., 2021). The small variation in milk physicochemical composition could also be due to limited seasonal feed variations (Chapter 3). Milk physicochemical composition changes have been shown to occur when there is a rapid change in the diet of cows e.g. with changing weather conditions (Heck et al., 2009). For example, in the Netherlands and the United Kingdom, when cows move from stall feeding in the winter season to grazing in the summer season, these dietary changes influence milk physicochemical composition (Heck et al., 2009; Chen et al., 2014). These conditions are absent in the tropics where there are no major seasonal differences and the majority of farmers practice zero grazing (Moran, 2005).

The lack of intra-annual milk physiochemical composition variation throughout the year could be due to a lack of variation in livestock feeds across the farming systems (Mutua et al., 2012; Mburu, 2015; Njarui et al., 2021). The majority of smallholder farmers in Kenya practice “cut and carry” zero-grazing. They depend mainly on Napier grass, local grasses and stover as basal feeds, supplementing this with concentrates in the dry season when feed scarcity occurs. This feeding practice seems sufficient to maintain the physicochemical composition of milk.

Milk protein content of 3.32 - 3.46 % (as reported in Chapter 2) was below the stipulated KeBS standards, whereas in the study in Chapter 3 it met the stipulated KeBS standards. The KeBS specifies that milk physicochemical composition should be: fat not less than 3.25%, protein not less than 3.50%, SNF not less than 8.50%, density 1.028–1.036 g/ml, freezing point −0.525 to - 0.550 °C and added water 0% (Kabui et al., 2015). The milk protein findings of Chapter 2 content are in agreement with previous studies which have reported content below the KeBS stipulated standards (Kabui et al., 2015; Ondieki et al., 2017). The data reported in Chapter 3, however, contradicts these studies which could be because milk was sampled throughout the year within a small pool of farmers. This lead to more observation points and thus less bias by one-time sampling (Heck et al., 2009; Chen et al., 2014). The milk protein content is influenced by feed availability, feed chemical composition, the cows' genetics and the stage of lactation (Schwendel et al., 2015; Kashongwe et al., 2017). Previous studies of smallholder dairy systems in Kenya have reported that poor feed quality, i.e. feeds with high NDF and low CP content, can affect milk physiochemical composition (Carter et al., 2015; Onyango et al., 2019). Nevertheless, the milk protein content findings in this research (Chapters 2 and 3) are similar to data reported in other countries, for example, countries such as Poland, the United Kingdom and the Netherlands, where milk is also produced by Holstein-Friesian cows and their crosses (Table 1). Our findings suggest that the current KeBS milk protein standard may be too strict for the breeds that are commonly used for milk production in Kenya.

Table 1. Milk protein content for Holstein-Friesian in selected countries

Breed	Protein content	Country	Reference
Polish Holstein-Friesian Black-White variety Polish Holstein-Friesian Red-White variety Simmental Jersey	3.54 (0.50) 3.43 (0.44) 3.64 (0.45) 4.08 (0.51)	Poland	(Kedzierska-Matysek et al., 2011)
Holstein-Friesian	3.29 ± 0.16 Range 2.89–3.56	United Kingdom	(Chen et al., 2014)
Crossbred dairy cattle	3.20 ± 0.6	Tanzania	(Cheruiyot et al., 2018)
RG = (Norwegian Red X Frisian, Norwegian Red X Guernsey, and Norwegian Red X Jersey);	3.26 ± 0.5		
RH = (Holstein X Norwegian Red and Norwegian Red X Holstein);	3.26 ± 0.5		
RZ = (Norwegian Red X Zebu and Norwegian Red X N'Dama),	3.18 ± 0.4		
ZR = (Zebu X GIR, Zebu X Norwegian Red, and Zebu X Holstein).			
Holstein-Friesian	3.30 (1.9) Range 3.21- 3.38	Netherlands	(Heck et al., 2009)
Exotic crosses (Holstein-Friesian, Guernsey and Jersey)	3.53 Range (2.26-5.27)	Kenya	(Ondieki et al., 2017)
Exotic crosses (Holstein-Friesian, Guernsey and Jersey)	3.02-3.64	Kenya	(Kabui et al., 2015)
Exotic crosses (Holstein-Friesian, Guernsey and Jersey)	3.32 - 3.46	Cross-sectional study	This thesis Chapter 2
Exotic crosses (Holstein-Friesian, Guernsey and Jersey)	3.5- 3.6	Longitudinal study	This thesis Chapter 3

* The Kenya Bureau of Standards (KeBS) specifies that milk physicochemical composition has: fat not less than 3.25%, protein not less than 3.50%, solid not fats not less than 8.50%, density 1.028–1.036 g/ml, freezing point −0.525 to - 0.550 °C and added water 0% (Kabui et al., 2015)

6.3.2. Microbial and chemical safety of milk- a concern for consumers and milk processors?

Data from my research confirm that milk microbial contamination and other health risks are not exclusive to the informal DVC but also occur in the formal DVC (Chapter 2). High microbial contamination with *E. coli, Pseudomonas spp., Staphylococcus spp.* and *Brucellosis spp.* pose a public health risk to consumers and affect milk processors. Also, high SCC, which could be linked to intra-mammary bacteria causing mastitis infection, exceeded the KeBS stipulated limits (Chapters 2 and 3). My findings regarding poor milk quality and safety are in agreement with previous studies conducted in Kenya. The studies have reported microbial contamination of raw and pasteurised milk in both the formal and informal DVCs (Shitandi and Sternesjö, 2004; Kabui, 2012; Orregård, 2013; Bebe et al., 2018; Brown et al., 2019; Blackmore et al., 2022; Hoffmann et al., 2022). Poor milk quality and safety thus continue to be a persistent challenge for the dairy sector in Kenya.

There is an imperative to improve milk quality and safety in both the formal and informal DVC from a public health perspective (Kang'ethe et al., 2020; Ledo, 2020; Blackmore et al., 2022). In the formal DVC, microbial contamination constitutes health implications for consumers as well as negative effects for milk processors (Chapters 2 and 3). Milk quality and safety can be maintained and assured through raw milk testing, pasteurisation and sterile packaging. Pasteurisation (heating milk at 71–74◦C for 15–40 seconds) and boiling milk can kill and deactivate heat-susceptible bacteria but may not eliminate the health implications associated with chemical residues, i.e. aflatoxins and heat-resistant bacteria spores such as those of *Clostridium botulinum* or *Bacillus cereus*, which can survive pasteurisation (Bebe et al., 2016; Hoffmann et al., 2022). Furthermore, microbial enzymes can persist and lead to the spoilage of dairy products (Boor et al., 2017; Blackmore et al., 2022). Poor milk quality negatively affects the quality, taste and shelf life of processed dairy products (Kang'ethe et al., 2020; Blackmore et al., 2022).

Findings from my research also confirm poor milk quality and health risks for consumers in the informal DVC (Chapter 2). The informal DVC is short and milk is primarily sold in its raw and unpasteurised state to consumers which poses a health risk, particularly to infants and immunocompromised individuals (Kang'ethe et al., 2020; Blackmore et al., 2022; Hoffmann et al., 2022). Studies have reported that the majority of households in Kenya boil milk purchased from the informal market before consumption which likely reduces health risks of exposure to foodborne bacteria such as *E. coli* and *Brucellosis spp.* (Orregård, 2013; Hoffmann et al., 2022). However, boiling milk does not eliminate the risk of milk recontamination, heat-resistant bacteria spores, bacteria enzymes and chemical residues i.e. those of antibiotics and aflatoxins (Boor et al., 2017; Hoffmann et al., 2022). Furthermore, milk rejected in the formal DVC is often sold through informal DVC due to the absence of milk testing and lax enforcement of milk quality and food safety standards by DVC actors (Chapter 5), which can lead to similar risks as described above.

Data about smallholder farmers' milking, storage and handling practices also demonstrated inadequacies in hygiene practices, failure to comply with antibiotics withdrawal periods, and adulteration which all could imply potential public health risks (Chapters 2 and 4). The data confirmed the link between knowledge, attitudes and practices and the behaviour of farmers and value chain actors regarding milk quality and safety (Chapter 4). Previous studies conducted in East Africa have reported high milk microbial contamination associated with unhygienic milk handling and storage practices (Nyokabi et al., 2018; Ledo et al., 2019). There is thus an imperative to provide training and information to improve knowledge, and technical and managerial skills, change the negative attitudes and nudge farmers and DVC actors to improve compliance with milk quality standards and food safety regulations.

Smallholder farmers and DVC actors' low compliance with milk quality standards and food safety regulations could be linked to the absence of a quality-based payment system in Kenya (Chapter 5). In Kenya, smallholder farmers and DVC actors lack economic incentives to justify incurring additional costs associated with compliance with milk quality and food safety standards (Handschuch et al., 2013; Blackmore et al., 2022). Other studies have shown that compliance with such standards necessitates investment in additional or new equipment, time and labour to improve current practices (Handschuch et al., 2013; Ndambi et al., 2018; Blackmore et al., 2022). Moreover, Handschuch et al. (2013) have documented that farmers are risk-averse and reluctant to adopt new practices, inputs, or services that require high initial costs or high recurrent costs. There is thus a need to enable farmers and DVC actors to access resources such as capital to procure equipment or services and cover costs related to complying with milk quality standards and food safety regulations, as has been also suggested by Handschuch et al. (2013) and Blackmore et al. (2022).

My studies demonstrate that farmers and DVC actors are still constrained by poor road infrastructure, low access to clean piped water, limited access to milk collection and cooling facilities, and low access to electricity which contributes to milk microbial contamination in Kenya (Chapters 2 and 4). Poor quality of road infrastructure and low access to the collection and cooling infrastructure hinder the delivery of milk to processors markets which favours milk quality deterioration (Orregård, 2013; Rademaker et al., 2016; Wafula et al., 2016; Özkan et al., 2020). Lindahl et al. (2018) reported that untreated water drawn from water pans, wells and storage tanks has a high microbial contamination level. They also demonstrated the link between untreated water and milk quality. So, there is a need for government investment in road infrastructure, milk collection and cooling facilities, and water and sanitation infrastructure, which are critical to improving milk quality and safety throughout the DVCs.

6.3.3. The dilemmas and opportunities on how to improve milk quality and safety

The findings of my research about the current dairy stakeholder network (Chapter 5) revealed low trust and high-power asymmetry in the formal DVC which could hinder long-term collaboration between DVC actors. In contrast, the informal DVC showed high trust and low power asymmetry between actors which is based on personal relationships that make it easier for actors to work together. Furthermore, the Kenyan government and its regulatory institutions have an adversarial relationship with informal DVC actors characterised by a lack of trust and misunderstanding (Chapter 5). The lack of trust among DVC actors, particularly in the formal DVC, leads to unnecessary transaction costs, and missed opportunities for enhancing livelihoods and improving milk quality and safety (Rademaker et al., 2016; Blackmore et al., 2022). Trust-based systems are an important mechanism for moderating behaviours between DVC actors and addressing milk quality and safety issues (Blackmore et al., 2022). Government policy has long focused on the formalisation of the informal DVC through licensing and enforcement of regulations, issuance of fines, confiscation of milk or closing of premises, particularly for informal actors (Brown et al., 2019; Blackmore et al., 2022). However, licensing levels of informal DVC actors remain low, reflecting a regulation–reality gap that needs bridging (Blackmore et al., 2022; Zavala Nacul and Revoredo-Giha, 2022). Previous studies have attributed low compliance with milk quality standards to understaffing and underfunding of government regulatory agencies and the reluctance of DVC actors to comply with regulations due to low-profit margins (Nyokabi et al., 2018; Blackmore et al., 2022; Zavala Nacul and Revoredo-Giha, 2022).

The results of my research also confirm that poor milk quality in the informal DVC is related to the absence of effective milk quality compliance checks by the regulatory institutions (Chapters 2 and 5). In Kenya, the informal DVC is well-established and more common than the formal DVC as it offers higher producer prices, consumer milk at lower prices, and smaller quantities that better suit the purchasing power of low-income consumers. Informal DVC also offers milk and dairy products that meet socio-cultural expectations, i.e. traditional dairy products (Brown et al., 2019; Kang'ethe et al., 2020; Blackmore et al., 2022). However, poor milk quality in the informal DVC can be linked to a lack of contact and control by the regulatory authorities, DVC actors' lack of accountability, unhygienic milk handling and storage practices, poor quality of milk collection and cooling infrastructure in the entire DVC, and consumers' and DVC actors' lack of awareness regarding milk safety (Brown et al., 2019; Kang'ethe et al., 2020; Blackmore et al., 2022; Hoffmann et al., 2022). Blackmore et al. (2022) reported that informal DVC actors are likely to be unlicensed, do not pay taxes, and often receive little support from the public sector which constrains milk quality improvement.

In the formal DVC, milk is tested and pasteurised which could likely reduce the public health risks associated with microbial contamination (Chapter 5). Previous research has, however, reported microbial contamination of pasteurised and ultra-heat-treated packaged milk sold in formal DVC (Hoffmann et al., 2022). Blackmore et al. (2022) have reported that pasteurisation processes, undertaken to satisfy regulators, are suboptimal and thus do not necessarily ensure milk quality and safety. There are opportunities to increase the market share for pasteurised milk which is perceived as safe by consumers (Blackmore et al., 2022; Hoffmann et al., 2022). That, however, creates a dilemma, namely, how to pay better producer prices to farmers to ensure sufficient quality volumes of milk are delivered to factories and at the same time ensure that milk retail prices are consumer-friendly.

Furthermore, the findings of my research (Chapter 5) revealed low levels of value chain integration and coordination in both the formal and informal DVC which constrains milk quality improvement. Loose vertical integration and coordination of value chain activities such as milk collection, bulking and transport undermines the stringent enforcement of milk quality standards by DVC actors which favour conditions that can lead to milk spoilage and quality deterioration (Birachi, 2006; Kabui, 2012; Rademaker et al., 2016). Increased horizontal integration, such as the formation of farmer cooperatives for purchasing inputs in bulk to take advantage of economies of scale, and bulking and marketing of milk, could be key to addressing the high transactions costs associated with the production and trade of small quantities of milk of heterogeneous quality, as has also been suggested by Mwambi et al. (2020).

In both the formal and informal DVCs, there was low adoption of contracts to guide the milk trade. Personal and contractual relationships are fluid and change from season to season. The lack of contractual arrangements and quality management, such as milk testing, in the informal DVC presents an opportunity for the trade of low milk quality (Chapter 5). Information asymmetry, market failures, lack of transparency, and weak legal enforcement of contracts, could be responsible for the low adoption of contracts in the Kenyan DVCs (Birachi, 2006; Chepkoech, 2010; Orregård, 2013; Mailu et al., 2014; Wafula et al., 2016; Nyokabi et al., 2018).

Food safety risks associated with poor milk quality have been used to justify tighter regulations, particularly calls for the formalisation of the informal DVC, even though poor milk quality has also been documented in the formal DVC (Brown et al., 2019; Blackmore et al., 2022). Overall, there is thus a need for stricter governance and regulation, especially in the informal DVC. In Kenya, this presents a dilemma given the important role that the informal DVC plays as a source of income, livelihood and full-time employment opportunities (Chapter 5). Improving milk quality in the DVC in Kenya necessitates the development of new approaches for communication and engagement to facilitate an inclusive and more constructive dialogue between policy-makers, regulatory authorities, and formal and informal DVC actors (Brown et al., 2019; Blackmore et al., 2022). There is also a need to acknowledge the good interventions already being undertaken by DVC actors and the development of approaches and interventions that can lead to further milk quality improvement while taking into the contextual factors that constrain behaviour change, such as low access to capital, and market imperfections (Rademaker et al., 2016; Blackmore et al., 2022).

6.4 Implications of the thesis for policy formulation

It is imperative that the Kenyan government implements policies to improve milk quality as well as dairy products to increase value addition and market opportunities for farmers and processors (Rademaker et al., 2016). However, the government could better support and create an enabling policy environment that facilitates smallholder dairy farmers’ access to animal health services, information, milking and storage equipment, financial services, insurance services, training opportunities and feed conservation technologies. These services and technologies enable smallholder farmers to adopt milk quality and food safety practices as suggested by Kumar et al. (2017) and Lindahl et al. (2018). The findings of this study (Chapters 2 and 5) are in agreement with Roesel and Grace (2015) who argued that a risk-based approach is needed when considering milk quality in DVCs, given that milk in the formal value chain is not necessarily safe and milk quality in the informal DVC is not necessarily unsafe. A risk-based approach is a proactive approach that looks to identify potential food hazards and risks along the production, distribution, and handling chain and help actors avoid food-safety incidents or reduce food safety risks (Roesel and Grace, 2014; Ledo, 2020)

Moreover, there is a need for policies that make recommended food-grade containers, i.e. aluminium containers, more accessible and affordable as has also been suggested by Handschuch et al. (2013) and Nyokabi et al. (2018). The use of non-food grade plastic containers and utensils highlighted in Chapter 2 contravenes food safety standards. Non-food-grade containers and unhygienic milk handling during milking and storage can contribute to microbial milk contamination (Lindahl et al., 2018).

The Kenyan government should also enact policies to support horizontal and vertical integration including the formation of producer organisations and DVCs development to reduce transaction costs related to accessing information, inputs, and markets. Improving the level of integration and coordination of DVC activities will necessitate the provision of infrastructure, such as roads to enable increased cooperation and collaboration between actors (Trienekens, 2011; Msaddak et al., 2017).

For all the above suggestions, it is crucial that the government takes a participatory approach to policy-making to engage and involve all dairy sector stakeholders in the policy process and ensure that the needs of all the DVC actors are considered in the design and implementation of milk quality and safety laws. The government should present itself as an honest arbitrator and should not allow lobbying by big companies to influence policy decisions at the expense of comparatively small and/or less-powerful actors (Msaddak et al., 2020). Improving milk quality through behaviour change requires interventions and policies that are context-specific and tailored to address local realities and constraints, i.e. specific socioeconomic realities (Duncan et al., 2013; Msaddak et al., 2020). Market quality plays an important role in the performance of farming systems including intensification. Each farming system location faces its unique challenges and requires a set of unique interventions to improve compliance with milk quality standards and food safety regulations (Migose et al., 2018; van der Lee et al., 2020). Taxing and licensing of different actors in the DVCs should also be context-sensitive as a one size fits all model is not appropriate given the varying scale of business operations and capital resources available to different actors (Kiambi et al., 2018; Brown et al., 2019).

6.5 Methodological considerations

This thesis adopted a mixed-method interdisciplinary approach to data collection. Mixed methods research is an approach that involves collecting, analysing, and interpreting quantitative and qualitative data in a single study or a series of studies to exhaustively investigate the same research phenomenon (Denscombe, 2008; Leech and Onwuegbuzie, 2009). This approach has multiple benefits. A mixed-method approach encourages researchers to actively move away from the prevailing model of single "silo" discipline research toward interdisciplinary and transdisciplinary research (Denscombe, 2008; Symonds and Gorard, 2010). The use of multiple datasets collected using different tools and methods allows for triangulation throughout the research process and enables the validation of data (Mertens and Hesse-Biber, 2012). For example, in this study, the use of the cross-sectional method enabled the gathering of data that provided a snapshot of what was happening at that moment in time regarding milk production and milk quality management by smallholder dairy farmers and other DVC actors in Kenya. Longitudinal data complemented the cross-sectional data and captured the intra-annual seasonal dynamics of milk physicochemical composition and feed availability and composition.

However, the cost of logistics and time constraints associated with mixed methods poses a challenge to conducting research, especially in low- and middle-income countries (LMICs), such as Kenya, with poor infrastructure and insecurity (Collins et al., 2007). Mixed methods research can be expensive and tedious especially if several data collection methods are employed (Collins et al., 2007; Hitchcock and Onwuegbuzie, 2020). Also, the collection of longitudinal data is associated with limitations because it is labour intensive (Mburu et al., 2018) and prone to participant fatigue and dropout which can lead to unbalanced data (Manzana et al., 2014). Finally, logistics, especially in areas with poor quality infrastructure such as roads and laboratories, is a major challenge in conducting research in LMICs (Mburu et al., 2018; Migose et al., 2018; van der Lee et al., 2020). These challenges were addressed by working closely with local extension officers and farmers to get their buy-in and align the research visits with farmers' work routines.

6.6 Recommendations for further research

This study contributes to the theoretical and empirical body of research relating to social networks, the application of a farming systems approach in analysing smallholder dairy systems, and the assessment of food safety risks in DVCs in LMICs. The study has provided empirical evidence on the current state of milk physicochemical composition, microbial contamination, and adulteration and revealed the drivers of better milk quality at the farm and further in the formal and informal DVCs.

The key findings of this study, outlined in Chapters 2-5, highlight the need for more sector-wide studies to tackle the current constraints to realising improvements in milk quality in Kenya. Mixed method and interdisciplinary research approaches could be used to better investigate the constraints in farming systems and recognise the complexity of food safety and quality challenges.

There is a need for more interdisciplinary research using a risk-based approach to address the low milk quality standards and food safety regulations compliance highlighted in this thesis given the fact that microbial contamination is a significant health risk. There is a need for research that acknowledges local constraints and generates socially acceptable and economically viable interventions and knowledge that actors are likely to embrace. Participatory approaches must be taken by researchers investigating milk quality to ensure that DVC actors have the agency to tell their stories and contribute to the identification and design of solutions to constraints faced in realising milk quality improvements. Participatory research empowers and gives research participants agency to contribute and partake in the research process as active rather than passive subjects in a study.

Policy-makers could focus more on milk improvement strategies efforts on behaviour change at the farm and DVC level and develop and implement interventions and policies that are context-specific and tailored to address local realities and constraints. Given that research can inform policy-making, participatory approaches to research have a key role to play in realising milk quality improvements in Kenya.

6.7 Conclusions

The main conclusions of this PhD thesis are:

- Farming systems' differential access to production factors (i.e., land and labour) and market quality by location apparently do not translate into significant differences in physicochemical milk composition.
- High microbial contamination could be a potential risk to public health.
- Although, there is intra-annual variation in the availability of high-quality feeds, farmers are ingenious and cope with this variability and produce milk with small variations in milk physicochemical composition.
- Overall, smallholder farmers have low levels of knowledge and poor attitudes towards compliance with milk quality standards and food safety regulations which leads to high microbial loads and increases the risk of antibiotic residues in milk.
- Smallholder farmers' demographic characteristics (i.e., gender and age), education levels, and socio-economic factors (i.e., access to land) influence their adoption levels of hygiene and safety practices regarding milk quality.
- Milk quality improvement interventions, including the formalisation of the informal value chain and commercialisation of dairy farming, have been initiated over the last two decades in Kenya yet, as the results of this thesis underscore, poor milk quality continues to constitute a challenge to dairy sector growth.

Summary

Milk and dairy products are easily accessible and affordable animal source food (ASFs). They form an important part of most diets globally and equate to a rich source of vitamins, proteins and essential minerals. Dairy production constitutes an important livelihood source for smallholder farmers in Kenya. Growing demand for milk and dairy products - driven by population growth, changing dietary patterns, improved incomes and increased consumer purchasing power - has created opportunities for smallholder farmers in Kenya to increase dairy production. Milk quality in Kenya is poor, and places consumers at risk and constrains milk processors. The term 'milk quality' refers to the physicochemical composition of milk which influences the nutritional value of dairy products. It also includes microbial and chemical contamination and adulteration, and is influenced by the hygiene level of handling practices and exposure to environmental conditions during milking, collection, storage, distribution and consumption. This PhD thesis explores the current state of milk quality and safety and factors that influence milk quality produced in smallholder dairy farms and traded in dairy value chains (DVCs) in Kenya to identify improvement strategies.

In Chapter 2, I employed a farming systems approach to explore the current state of milk quality, including milk composition, microbial contamination and adulteration, in Laikipia, Nakuru and Nyandarua counties. I stratified smallholder dairy farming systems into intensive farming systems in urban locations (UL), semi-intensive farming systems in mid-rural locations (MRL) and extensive dairy farming systems in the extreme-rural locations (ERL). This stratification was based on market quality (access to input markets and output markets for selling milk) and access to production resources (for example, labour and land). Milk samples were collected at the informal and informal value chain nodes - farms, informal collection centres, informal retailing centres including milk vending machines, and formal bulking centres - where milk changes hands between value chain actors. Milk samples were analysed for physicochemical composition, i.e., fat, protein, solid-non fats, density and freezing point, microbial contamination and adulteration. Milk quality was compared to standards recommended by the Kenya Bureau of Standards (KeBS). Observations were also made regarding milk handling and storage by farmers and value chain actors. The results revealed that, in each farm location (i.e., UL, MRL, ERL), farm intensification varied based on the availability of production factors, i.e., land and labour, and market quality, i.e., access to input markets and output markets. There were no differences in raw milk quality between farming systems locations or between the value chain nodes. The overall milk physicochemical composition (means and standard error) of the milk were within KeBS standards: fat 3.61 (0.05), protein 3.46 (0.06), solid-not fats 9.18 (0.04), density 1.031 (0.0002) and freezing point ?0.597 (0.019). The protein percentage was below KeBS standards at all value chain nodes, except at the formal bulking node. There was significant contamination of milk samples: 16.7% of samples had added water, 8.8% had somatic cell count SCC above 300,000, 42.4% had E. coli, 47.9% had Pseudomonas spp., 3.3% had Staphylococcus spp. and 2.9% tested positive for brucellosis antibodies.

Unhygienic milk handling and storage practices were observed at farms and all value chains nodes. The high levels of milk microbial contamination pose a public health risk to consumers and a constraint for milk processors and shows that action is needed to improve milk quality.

In Chapter 3, I employed a longitudinal study to explore the intra-annual variation in feed availability and the chemical composition of milk and feed resources in smallholder dairy farms in Nakuru county, Kenya. I collected feed and milk samples for a year, on every last week of the month, from 43 purposively-selected farms and analysed them for nutritional composition using near infra-red spectroscopy and Ekomilk milk analyser, respectively. The results showed that the main basal feeds were indigenous grasses, Napier grass, maize and bean stover, and whole maize crop silage which farmers supplemented with purchased commercial concentrates and/or purchased or homemade total mixed rations (TMR). Among the feeds, commercial concentrates had the highest crude protein (CP) content of 17.4±3.9 % dry matter (DM), while maize stover had the lowest (8.7±3.3 % DM). All the feeds had low metabolisable energy (ME) that ranged from 7.0 ± 0.8 megajoules per kilogram of dry matter (MJ/kg DM) for maize stover to 8.9±0.8 for dairy meal. Only grasses showed significant seasonal variation in CP and NDF ($P>0.00$). Milk physicochemical composition was within the range stipulated by the Kenya Bureau of Standards and showed small seasonal variations to significantly affect milk processing. The results reveal that although there was a challenge of seasonal feed availability, farmers were able to maintain consistent milk physicochemical composition. This study did not, however, investigate the impact of feed availability on milk production in smallholder dairy farms which was not within the scope of this research.

In Chapter 4, I investigated the knowledge, attitudes and adoption of milk quality and food safety practices by smallholder farmers in Kenya. I administered a cross-sectional survey to 652 smallholder farming households and ten focus group discussions involving 71 smallholder farmers, in Laikipia, Nakuru and Nyandarua. Results showed that smallholder farmers had low knowledge level and negative attitudes towards respecting antibiotics treatment withdrawal periods, milk quality standards and food safety regulations. Farmers stated they had received limited training on milk quality and safety standards. The majority of farmers adopted animal health measures and hygienic measures such as hand washing and udder cleaning. However, unhygienic milking environments, the use of plastic containers, the use of untreated water, and lack of teat dipping nevertheless compromised milk quality and safety. The adoption of milk quality and food safety practices was positively influenced by farmers’ knowledge hygiene, access to water, knowledge of milk quality standards & parameters, high average milk price and participation in the formal value chain. Currently, milk production, handling and consumption could expose actors along the dairy value chain to health risks. There is thus a need to improve farmers’ knowledge and attitudes to increase compliance with hygienic, disease and antibiotic residue control practices in the milk production process to meet required milk quality and food safety standards.

Awareness campaigns and training programmes for smallholder dairy farmers could foster behavioural change and lead to an improvement in milk quality in Kenya.

Finally, in Chapter 5, I explored how social networks in Kenyan dairy value chains (DVCs), DVC actors' power relationships and trust influence their behaviour regarding milk quality. I conducted a stakeholder analysis using the Net-Map tool to map DVC actors, social network relationships, and perceived power positions, in Laikipia, Nakuru and Nyandarua counties in Kenya and used VisuaLyzer software to analyse these social networks. The formal DVCs had more dense social networks characterised by vertical and horizontal integration, high power asymmetries between actors and limited trust between actors due to the short-term orientation of contractual arrangements. Unlike the formal DVC, the informal DVC had low milk quality demands. It therefore constitutes a lucrative and alternative milk marketing channel that offers comparatively higher farmgate milk prices. The informal DVC also had less dense social networks, low power asymmetries between actors and a higher level of trust between actors due to the existence of reciprocal personal relationships. Better milk management was observed in the formal value chain, resulting from a combination of top-down enforcement, bottom-up collective action, power and contractual relationships which were absent in informal DVC. In both DVCs, loose social networks and low trust among DVC actors' constraints long-term oriented efforts to improve milk quality while the dominant use of verbal and on-spot contracts made it difficult for processors and traders to stipulate and specify quality demands to be met by farmers and other DVC actors. The results underscore an urgent need for milk quality improvement in DVCs given the low compliance with milk quality standards and food safety regulations. The results reveal that there are opportunities to leverage the power dynamics, trust and contracts in the DVCs to improve milk quality.

The results of this thesis reveal poor milk quality at farm and value chain level which shows the need to improve milk quality in Kenya. The thesis identifies the drivers of milk physicochemical composition, milk handling, microbial contamination and adulteration which can be targeted to improve milk quality. The thesis also shows that seasonal feed availability constrains dairy production although it has small impact on milk physicochemical composition. The findings reveal that there is a chance to leverage the dairy sector structure including DVC actors' social networks, power and power asymmetry and trust to design policies and interventions to increase milk quality standards compliance.

Bibliography

Abdulai, A. and Birachi, E.A., 2009. Choice of Coordination Mechanism in the Kenyan Fresh Milk Supply Chain Review of Agricultural Economics, 31, 103–121

Abera, M., Habte, T., Aragaw, K., Asmare, K. and Sheferaw, D., 2012. Major causes of mastitis and associated risk factors in smallholder dairy farms in and around Hawassa, Southern Ethiopia Tropical Animal Health and Production, 44, 1175–1179

Ahlberg, S., Korhonen, H., Lindfors, E. and Kang'ethe, E., 2016. Analysis of antibiotic residues in milk from smallholder farms in Kenya African Journal of Dairy Farming and Milk Production, 3, 152–158

Ajwang, F. and Munyua, C., 2016. The Influence of State of Road and Ownership of Means of Transport to Smallholder Dairy Farmers' Choice of Milk Marketing Outlet in Kipkaren Division of Nandi County in Kenya Asian Journal of Agricultural Extension, Economics & Sociology, 9, 1–6

Akakpo, D.B., de Boer, I.J.M., Adjei-Nsiah, S., Duncan, A.J., Giller, K.E. and Oosting, S.J., 2020. Evaluating the effects of storage conditions on dry matter loss and nutritional quality of grain legume fodders in West Africa Animal Feed Science and Technology, 262, 114419 (Elsevier)

Alonso, S., Muunda, E., Ahlberg, S., Blackmore, E. and Grace, D., 2018. Beyond food safety: Socio-economic effects of training informal dairy vendors in Kenya Global Food Security, 18, 86–92 (Elsevier B.V.)

Amenu, K., Wieland, B., Szonyi, B. and Grace, D., 2019. Milk handling practices and consumption behavior among Borana pastoralists in southern Ethiopia Journal of health, population, and nutrition, 38, 6 (Journal of Health, Population and Nutrition)

Anyango, G., Mutua, F., Kagera, I., Andang`O, P., Grace, D. and Lindahl, J.F., 2018. A survey of aflatoxin M1 contamination in raw milk produced in urban and peri-urban areas of Kisumu County, Kenya Infection Ecology and Epidemiology, 8 (Taylor & Francis)

Arimi, S.M., Koroti, E., Kang'ethe, E.K., Omore, A.O. and McDermott, J.J., 2005. Risk of infection with Brucella abortus and Escherichia coli O157:H7 associated with marketing of unpasteurized milk in Kenya Acta Tropica, 96, 1–8

Baltenweck, I. and Staal, S., 2007. Beyond One-Size-Fits-All: Differentiating Market Access Measures for Commodity Systems in the Kenyan Highlands Journal of Agricultural Economics, 58, 536–548

Baltenweck, I., Staal, S.J., Owango, M.O., Muriuki, H.G., Lukuyu, B., Gichungu, G., Kenyanjui, M., Njubi, D., Tanner, J. and Thorpe, W., 1998. Intensification and Competitiveness of Smallholder Dairy Production Systems in the Greater Nairobi Milk- Shed

Baltenweck, I., Yamano, T. and Staal, S.J., 2006. Dynamic Changes in Dairy Technologies Uptake in the Kenya Highlands In:, International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, (Gold Coast, Australia)

Bebe, B.O., Lee, J. Van Der and Kilelu, C.W., 2016. Quality compliance of traded milk in urban retail outlets in Kenya, (Wageningen)

Bebe, B.O., Lee, J. Van Der, Kilelu, C.W., van der Lee, J. and Kilelu, C.W., 2018. Milk Retailing Innovation in Kenya and Consumers Perceptions of Safety, (Wageningen, The Netherlands)

Bebe, B.O., van der Lee, J. and Kilelu, C.W., 2018. Milk Retailing Innovation in Kenya and Consumers Perceptions of Safety, (Wageningen, The Netherlands)

Belaya, V. and Hanf, J.H., 2012. Managing Russian agri-food supply chain networks with power Journal on Chain and Network Science, 12, 215–230

Belaya, V. and Hanf, J.H., 2016. The dark and the bright side of power: implications for the management of business-to-business relationships Agricultural and Food Economics, 4 (Agricultural and Food Economics)

Bijman, J. and Bitzer, V., 2016. Quality and innovation in food chains, 1st ed. J. Bijman and V. Bitzer (eds), (Wageningen Academic Publishers: The Netherlands, The Netherlands)

Bijman, J., Muradian, R. and Schuurman, J., 2016. Cooperatives, economic democratization and rural development, First J. Bijman , R. Muradian , and J. Schuurman (eds), (Edward Elgar Publishing Ltd: Cheltenham, United Kingdom)

Birachi, E.A., 2006. Determinants of Coordination and Supply Chain Performance: The Case of Fresh Milk Supply Chains in Kenya (University of Kiel, Germany)

Birner, R., McCarthy, N., Robertson, R., Waale, D. and Schiffer, E., 2010. Increasing access to irrigation: Lessons learned from investing in small reservoirs in Ghana Paper presented at the workshop on "Agricultural Services, Decentralization, and Local Governance," 9

Blackmore, E., Guarin, A., Vorley, W., Alonso, S. and Grace, D., 2022. Kenya's informal milk markets and the regulation–reality gap Development Policy Review, 1–15

Bogale, S., Melaku, S. and Yami, A., 2008. Potential use of crop residues as livestock feed resources under smallholder farmers conditions in bale highlands of ethiopia Tropical and Subtropical Agroecosystems, 8, 107–114

Boor, K.J., Wiedmann, M., Murphy, S. and Alcaine, S., 2017. A 100-Year Review: Microbiology and safety of milk handling Journal of Dairy Science, 100, 9933–9951 (American Dairy Science Association)

Borgatti, S.P., 2005. Centrality and network flow Social Networks, 27, 55–71

Borgatti, S.P., 2006. Identifying sets of key players in a social network Computational and Mathematical Organization Theory, 12, 21–34

Borgatti, S.P. and Li, X., 2009. On social network analysis in a supply chain context Journal of Supply Chain Management, 45, 5–22

Bosire, C.K., Lannerstad, M., de Leeuw, J., Krol, M.S., Ogutu, J.O., Ochungo, P.A. and Hoekstra, A.Y., 2017. Urban consumption of meat and milk and its green and blue water footprints—Patterns in the 1980s and 2000s for Nairobi, Kenya Science of the Total Environment, 579, 786–796 (Elsevier B.V.)

Brown, K., Mugoh, M., Call, D.R. and Omulo, S., 2020. Antibiotic residues and antibiotic-resistant bacteria detected in milk marketed for human consumption in Kibera, Nairobi PLoS ONE, 15, 1–8

Brown, L.H., Alonso, S., Lindahl, J., Varnell, H., Hoffmann, V. and Delia, G., 2019. Regulatory compliance in the Kenyan dairy sector: Awareness and compliance among farmers and vendors, (Washington DC)

Cabon-Dhersin, M.L. and Ramani, S. V., 2007. Opportunism, trust and cooperation: A game theoretic approach with heterogeneous agents Rationality and Society, 19, 203–228

Carbone, A., 2017. Food supply chains: coordination governance and other shaping forces Agricultural and Food Economics, 5, 0–23 (Agricultural and Food Economics)

Carter, N.A., Dewey, C.E., Lukuyu, B., Grace, D. and De Lange, C.F.M., 2015. Nutrient composition and seasonal availability of local feedstuffs for pigs in western kenya Canadian Journal of Animal Science, 95, 397–406

Chen, B., Lewis, M.J. and Grandison, A.S., 2014a. Effect of seasonal variation on the composition and properties of raw milk destined for processing in the UK Food Chemistry, 158, 216–223 (Elsevier Ltd)

Chen, B., Lewis, M.J. and Grandison, A.S., 2014b. Effect of seasonal variation on the composition and properties of raw milk destined for processing in the UK Food Chemistry, 158, 216–223 (Elsevier Ltd)

Chepkoech, B., 2010. Milk Quality Control and Regulation in Dairy Production : A Case of Dairy Producers in Kikuyu Division , Kabete District, Central Province - Kenya Poster presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010

Cheruiyot, E.K., Bett, R.C., Amimo, J.O. and Mujibi, F.D.N., 2018. Milk Composition for Admixed Dairy Cattle in Tanzania Frontiers in Genetics, 9, 1–12

Collins, K.M.T., Onwuegbuzie, A.J. and Jiao, Q.G., 2007. A Mixed Methods Investigation of Mixed Methods Sampling Designs in Social and Health Science Research Journal of Mixed Methods Research, 1, 267–294

Colmenero, J.J.O. and Broderick, G.A., 2006. Effect of Dietary Crude Protein Concentration on Milk Production and Nitrogen Utilization in Lactating Dairy Cows Journal of Dairy Science, 89, 1704–1712 (Elsevier)

Creswell, T., 2015. Mixed Methodology Across Disciplines 3–6

D'Haese, M., Francesconi, G.N. and Ruben, R., 2007. Network management for dairy productivity and quality in Ethiopia Quality Management in Food Chains, 185–197

Delgado, C.L., 1999. Sources of Growth in Smallholder Agriculture Integration of Smallholders With Processors in Sub-Saharan Africa: the Role of Vertical and Marketers of High Value-Added Items Agrekon, 38, 165–189

Denscombe, M., 2008. Communities of Practice: A Research Paradigm for the Mixed Methods Approach Journal of Mixed Methods Research, 2, 270–283

Desta, H., 2014. Hygienic Practices During Milking and Bacteriological Quality of the Milk in Raw Bovine Bulk Milk in the Selected Milk Collection Centers: Smallholder Dairy Processing Ethiopia (Università Degli Studi di Milano)

Deti, H., Hymete, A., Bekhit, A.A., Mohamed, A.M.I. and Bekhit, A.E.-D.A., 2014. Persistent organochlorine pesticides residues in cow and goat milks collected from different regions of Ethiopia Chemosphere, 106, 70–74 (Elsevier Ltd)

Dongol, P., Thapa, G. and Kumar, A., 2017. Adoption of milk safety measures and its impact on milk acceptance by buyers in Nepal Agricultural Economics Research Review, 30, 93

Dries, L., Germenji, E., Noev, N. and Swinnen, J.F.M., 2009. Farmers, Vertical Coordination, and the Restructuring of Dairy Supply Chains in Central and Eastern Europe World Development, 37, 1742–1758 (Elsevier Ltd)

Dugum, B. and Janssens, G.P.J., 2015. Assessment of Dairy Farmers' Hygienic Milking Practices and Awareness of Cattle and Milk-Borne Zoonoses in Jimma, Ethiopia Food Science and Quality Management, 45, 114–121

Duncan, A.J., Teufel, N., Mekonnen, K., Singh, V.K., Bitew, A. and Gebremedhin, B., 2013. Dairy intensification in developing countries: effects of market quality on farm-level feeding and breeding practices animal, 7, 2054–2062

Fafchamps, M., 2006. Development and social capital Journal of Development Studies, 42, 1180–1198

FAO (Food and Agriculture Organization), 2004. Guide to good dairy farming practice, (International Dairy Federation and the Food and Agriculture Organization of the United Nations: Rome)

Fisher, R., 2013. “A gentleman’s handshake”: The role of social capital and trust in transforming information into usable knowledge Journal of Rural Studies, 31, 13–22 (Elsevier Ltd)

Franzel, S., Wambugu, C. and Tuwei, P., 2004. The Adoption and Dissemination of Fodder Shrubs in Central Kenya Agricultural Successes in the Greater Horn of Africa, 1–11

Freeman, L.C., 1978. Centrality in social networks conceptual clarification Social Networks, 1, 215–239

Gakige, J.K., Gachuri, C., Butterbach-bahl, K. and Goopy, J.P., 2020. Sweet potato (Ipomoea batatas) vine silage: a cost-effective supplement for milk production in smallholder dairy-farming systems of East Africa? Animal Production Science, 60, 1087

Gereffi, G. and Lee, J., 2009. A Global Value Chain Approach to Food Safety and Quality Standards, (Durham, United States of America)

GOK, (Government of Kenya), 2012. Dairy Industry Act : CAP 336 (Nairobi, Kenya)

Goopy, J.P. and Gakige, J.., 2016. Smallholder dairy farmer training manual (International Livestock Research Institute (ILRI): Nairobi, Kenya)

Goopy, J.P., Onyango, A.A., Dickhoefer, U. and Butterbach-Bahl, K., 2018. A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa – Results for Nyando, Western Kenya Agricultural Systems, 161, 72–80 (Elsevier)

Gorton, M., Angell, R., Dries, L., Urutyan, V., Jackson, E. and White, J., 2015. Power, buyer trustworthiness and supplier performance: Evidence from the Armenian dairy sector Industrial Marketing Management, 50, 69–77 (Elsevier Inc.)

Grace, D., Alonso, S., Lindahl, J., Ahlberg, S. and Deka, R.P., 2017. Detecting pathogens in milk on dairy farms: key issues for developing countries (Burleigh Dodds Science Publishing Limited), 27–42

Grace, D., Omore, A., Randolph, T., Kang’ethe, E., Nasinyama, G.W. and Mohammed, H.O., 2008. Risk Assessment for Escherichia coli O157:H7 in Marketed Unpasteurized Milk in Selected East African Countries Journal of Food Protection, 71, 257–263

Grace, D., Randolph, T.F., Omore, A., Schelling, E. and Bonfoh, B., 2007. Place of food safety in evolving pro-poor dairy policy in East and West Africa Revue d’élevage et de médecine vétérinaire des pays tropicaux, 60, 153–162

Green, J., Willis, K., Hughes, E., Small, R., Welch, N., Gibbs, L. and Daly, J., 2007. Generating best evidence from qualitative research: the role of data analysis Australian and New Zealand Journal of Public Health, 31, 545–550

Green, K.C., 2002. Forecasting decisions in conflict situations: a comparison of game theory, role-playing, and unaided judgement International Journal of Forecasting, 18, 321–344

Haggblade, S. and Theriault, V., 2012. A Conceptual Framework for Promoting Inclusive Agricultural Value Chains by Table of Contents Small, 0–37

Handschuch, C., Wollni, M. and Villalobos, P., 2013. Adoption of food safety and quality standards among Chilean raspberry producers – Do smallholders benefit? Food Policy, 40, 64–73 (Elsevier Ltd)

Häsler, B., Msalya, G., Garza, M., Fornace, K., Eltholth, M., Kurwijila, L., Rushton, J. and Grace, D., 2018. Integrated food safety and nutrition assessments in the dairy cattle value chain in Tanzania Global Food Security, 18, 102–113 (Elsevier B.V.)

Hauck, J. and Schiffer, E., 2008. Between intuition and indicators – Using Net-Map for visual and qualitative social network analysis In:, Knoten und Kanten 2.0. Soziale Netzwerkanalyse in der Medienforschung und der Kulturanthropologie, (Bielefeld), 231–257

Hauck, J., Stein, C., Schiffer, E. and Vandewalle, M., 2015. Seeing the forest and the trees: Facilitating participatory network planning in environmental governance Global Environmental Change, 35, 400–410 (Elsevier Ltd)

Hauke, D. and Cadilhon, J., 2018. The role of trust and networks in developing Nicaraguan farmers ’ agribusiness capacities Journal of Agriculture and Rural Development in the Tropics and Subtropics, 119, 65–78

Heck, J.M.L., van valenberg, H.J.F., Dijkstra, J. and van Hooijdonk, A.C.M., 2009. Seasonal variation in the Dutch bovine raw milk composition Journal of Dairy Science, 92, 4745–4755 (Elsevier)

Hermans, F., Sartas, M., Van Schagen, B., Van Asten, P. and Schut, M., 2017. Social network analysis of multi-stakeholder platforms in agricultural research for development: Opportunities and constraints for innovation and scaling PLoS ONE, 12

Hitchcock, J.H. and Onwuegbuzie, A.J., 2020. Developing Mixed Methods Crossover Analysis Approaches Journal of Mixed Methods Research, 14, 63–83

Hoffmann, V., Simiyu, S., Sewell, D.K., Tsai, K., Cumming, O., Mumma, J. and Baker, K.K., 2022. Milk Product Safety and Household Food Hygiene Influence Bacterial Contamination of Infant Food in Peri-Urban Kenya

Frontiers in Public Health, 9, 1–12

Ilukor, J., Birner, R., Rwamigisa, P.B. and Nantima, N., 2015. The provision of veterinary services: who are the influential actors and what are the governance challenges? a case study of Uganda Experimental Agriculture, 51, 408–434

Imaizumi, H., Santos, F.A.P., Bittar, C.M.M., Correia, P.S. and Martinez, J.C., 2010. Diet crude protein content and sources for lactating dairy cattle Scientia Agricola, 67, 16–22

Indrawan, D., Rich, K.M., van Horne, P., Daryanto, A. and Hogeveen, H., 2018. Linking Supply Chain Governance and Biosecurity in the Context of HPAI Control in Western Java: A Value Chain Perspective Frontiers in Veterinary Science, 5, 1–12

Jacxsens, L., Van Boxstael, S., Nanyunja, J., Jordaan, D., Luning, P. and Uyttendaele, M., 2015. Opinions on fresh produce food safety and quality standards by fresh produce supply chain experts from the global south and north Journal of Food Protection, 78, 1914–1924

Janssen, E. and Swinnen, J., 2019. Technology adoption and value chains in developing countries: Evidence from dairy in India Food Policy, 83, 327–336 (Elsevier)

Kabui, K.K., 2012. Assessment of milk quality and the potential of a quality based system in small holder farm in Limuru and Eldoret, Kenya (University of Nairobi)

Kabui, K.K., Arimi, S.M., Kang'ethe, E.K., Omore, A., Makokha, S., Nduhiu, G., Mainga, A.O. and Macharia, J.K., 2015. A Determination of Raw Milk Quality and the Most Suitable Microbiological Test at the Milk Collection Level in Two Regions of Kenya International Journal of veterinary science, 5, 44–47

Kagera, I., Kahenya, P., Mutua, F., Anyango, G., Kyallo, F., Grace, D. and Lindahl, J., 2019. Status of aflatoxin contamination in cow milk produced in smallholder dairy farms in urban and peri-urban areas of Nairobi County: a case study of Kasarani sub county, Kenya Infection Ecology and Epidemiology, 9 (Taylor & Francis)

Kamana, O., Ceuppens, S., Jacxsens, L., Kimonyo, A. and Uyttendaele, M., 2014. Microbiological Quality and Safety Assessment of the Rwandan Milk and Dairy Chain Journal of Food Protection, 77, 299–307

Kamwine, M., Orikiriza, P., Taseera, K., Iramiot, J.S., Ojuka, P., Ikiriza, S., Atwebembeire, J., Otieno, D., Tweshengyereze, S., Mwanga-Amumpaire, J., Bazira, J. and Boum, Y., 2017. Prevalence of antibodies to Brucella species in commercial raw bovine milk in Southwestern Uganda BMC Research Notes, 10, 1–5 (BioMed Central)

Kang'ethe, E., Grace, D., Roesel, K. and Mutua, F., 2020. Food safety landscape analysis : The dairy value chain in Kenya, (Nairobi, Kenya)

Kang'ethe, E.K., Aboge, G.O., Arimi, S.M., Kanja, L.W., Omore, A.O. and McDermott, J.J., 2005. Investigation of the risk of consuming marketed milk with antimicrobial residues in Kenya Food Control, 16, 349–355

Kang'ethe, E.K., Mulinge, E.K., Skilton, R.A., Njahira, M., Monda, J.G., Nyongesa, C., Mbae, C.K. and Kamwati, S.K., 2012. Cryptosporidium species detected in calves and cattle in Dagoretti, Nairobi, Kenya Tropical Animal Health and Production, 44, 25–31

Kaplinsky, R., 2000. Globalisation and Unequalisation: What Can Be Learned from Value Chain Analysis? Journal of Development Studies, 37, 117–146

Kariuki, J.N., 1998. The potential of improving napier grass under smallholder dairy farmers´ conditions in Kenya (Universiteit Wageningen)

Kashongwe, Olivier B., Bebe, B.O., Matofari, J.W. and Huelsebusch, C.G., 2017. Associations between milking practices, somatic cell counts and milk postharvest losses in smallholder dairy and pastoral camel herds in Kenya International Journal of Veterinary Science and Medicine, 5, 57–64 (Faculty of Veterinary Medicine, Cairo University)

Kashongwe, O. B., Bebe, B.O., Matofari, J.W. and Huelsebusch, C.G., 2017. Effects of feeding practices on milk yield and composition in peri-urban and rural smallholder dairy cow and pastoral camel herds in Kenya Tropical Animal Health and Production, 49, 909–914 (Tropical Animal Health and Production)

Kashongwe, O.B., Migwi, P., Bebe, B.O., Ooro, P.A., Onyango, T.A. and Osoo, J.O., 2014. Improving the nutritive value of wheat straw with urea and yeast culture for dry season feeding of dairy cows Tropical Animal Health and Production, 46, 1009–1014

Kedzierska-Matysek, M., Litwińczuk, Z., Florek, M. and Barłowska, J., 2011. The effects of breed and other factors on the composition and freezing point of cow's milk in Poland International Journal of Dairy Technology, 64, 336–342

Kiambi, S., Alarcon, P., Rushton, J., Murungi, M.K., Muinde, P., Akoko, J., Aboge, G., Gikonyo, S., Momanyi, K., Kang'ethe, E.K. and Fèvre, E.M., 2018. Mapping Nairobi's dairy food system: An essential analysis for policy, industry and research Agricultural Systems, 167, 47–60 (Elsevier)

Kilelu, C.W., Klerkx, L. and Leeuwis, C., 2017. Supporting smallholder commercialisation by enhancing integrated coordination in agrifood value chains: experiences with dairy hubs in Kenya Experimental Agriculture, 53, 269–287

Kinyanjui, K.J., 2019. Effects of Climate Variability on Maize Yield in Nakuru (Kenyatta University)

Kirino, Y., Kohei, M., Delia, G. and Lindahl, J., 2016. Survey of informal milk retailers in Nairobi, Kenya and prevalence of aflatoxin M1 in marketed milk African Journal of Food, Agriculture, Nutrition and Development, 16, 11022–11038

Kollock, P., 1998. Social Dilemmas: The Anatomy of Cooperation Annual Review of Sociology, 24, 183–214

Konchak, C. and Prasad, K., 2012. Incorporating social network effects into cost-effectiveness analysis: A methodological contribution with application to obesity prevention BMJ Open, 2

Koyi, N.P. and Siamba, D.D.N., 2017. Effect of Marketing Strategies on the Dairy Value Chain Returns and Food and Nutrition Security in Bungoma County, Kenya IOSR Journal of Agriculture and Veterinary Science, 10, 45–56

Kumar, A., Thapa, G., Roy, D. and Joshi, P.K.K., 2017. Adoption of food safety measures on milk production in Nepal: Impact on smallholders' farm-gate prices and profitability Food Policy, 70, 13–26 (Elsevier Ltd)

Kumar, A., Wright, I.A. and Singh, D.K., 2011. Adoption of Food Safety Practices in Milk Production: Implications for Dairy Farmers in India Journal of International Food and Agribusiness Marketing, 23, 330–344

Kussaga, J.B., Jacxsens, L., Tiisekwa, B.P. and Luning, P.A., 2014. Food safety management systems performance in African food processing companies: a review of deficiencies and possible improvement strategies Journal of the Science of Food and Agriculture, 94, 2154–2169

Lanyasunya, T.P.T.P., Mukisira, E.E.A., Abdulrazak, S., Ayako, W.W.O., Wang, H.R., Mukisira, E.E.A., Abdulrazak, S. and Ayako, W.W.O., 2006. Effect of seasonality on feed availability, quality and herd performance on smallholder farms in Oljoro-orok location Nyandarua district, Kenya Tropical and Subtropical Agroecosystems, 12, 139–143

Laswai, G.H., Mgheni, D.M., Mtenga, L.A., Ndikumana, J. and Zziwa, E., 2013. Chemical Composition and Nutritional Values of Feed Resources for Ruminants: Eastern and Central Africa (ECA) Table for Ruminants 2013, (ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa): Entebbe)

Ledo, J., 2020. An approach towards improving safety and hygiene control practices in emerging dairy chains : the case of Tanzania (Wageningen University)

Ledo, J., Hettinga, K.A., Bijman, J. and Luning, P.A., 2019. Persistent challenges in safety and hygiene control practices in emerging dairy chains: The case of Tanzania Food Control, 105, 164–173 (Elsevier)

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

Leech, N.L. and Onwuegbuzie, A.J., 2009. A typology of mixed methods research designs Quality & Quantity, 43, 265–275

Lemma, D.H., Mengistu, A., Kuma, T., Kuma, B., Lemma, H.D., Mengistu, A., Kuma, T., Kuma, B., Lemma, D.H., Mengistu, A., Kuma, T. and Kuma, B., 2018. Improving milk safety at farm-level in an intensive dairy production system: Relevance to smallholder dairy producers Food Quality and Safety, 2, 135–143

Lindahl, J.F., Deka, R.P., Asse, R., Lapar, L. and Grace, D., 2018. Hygiene knowledge, attitudes and practices among dairy value chain actors in Assam, north-east India and the impact of a training intervention Infection Ecology & Epidemiology, 8, 1555444 (Taylor & Francis)

Löfqvist, 2016. Nutritional value of pastures in enclosure systems in semi-arid rangelands of Chepareria, West Pokot, Kenya

Lukkaine, J., 2012. A comparison of extension methods used by different agricultural extension service providers in Nyandarua County, Kenya.

Lukuyu, M., Romney, D., Ouma, R., Sones, K. and Sones, and K., 2007. Feeding dairy cattle: A manual for smallholder dairy farmers and extension workers in East Africa, (Nairobi, Kenya)

Lukuyu, M.N., Gibson, J.P., Savage, D.B., Rao, E.J.O., Ndiwa, N. and Duncan, A.J., 2019. Farmers' Perceptions of Dairy Cattle Breeds, Breeding and Feeding Strategies: A Case of Smallholder Dairy Farmers in Western Kenya East African Agricultural and Forestry Journal, 83, 351–367 (Taylor & Francis)

Luning, P.A. and Marcelis, W.J., 2007. A conceptual model of food quality management functions based on a techno-managerial approach Trends in Food Science and Technology, 18, 159–166

Mailu, S., Will, M., Mwanza, R., Nkanata, K. and Mbugua, D., 2014. Milk supply contracts and default incidence in Kenya,

Maina, F., Mburu, J., Gitau, G. and VanLeeuwen, J., 2020. Factors influencing economic efficiency of milk production among small-scale dairy farms in Mukurweini, Nyeri County, Kenya Tropical Animal Health and Production, 52, 533–539 (Tropical Animal Health and Production)

Manzana, N.P., McCrindle, C.M.E., Sebei, P.J. and Prozesky, L., 2014. Optimal feeding systems for small-scale dairy herds in the North West Province, South Africa Journal of the South African Veterinary Association, 85, 1–19

Martino, G., 2010. Trust , Contracting , and Adaptation in Agri - Food Hybrid Structures 4, 305–317

Mburu, L., Gachuiri, C., Wanyoike, M. and Mande, J., 2018. Forage and In Vitro Dry Matter Digestibility Quality of Native Species in Coastal Lowlands of Kenya Int J Anim Sci., 2

Mburu, L.M., 2015. Effect of seasonality of feed resources on dairy cattle production in coastal lowlands of Kenya (University of Nairobi)

Mburu, L.M., Gachuiri, C.K., Wanyoike, M.M. and Mande, J.D., 2018. Forage and In Vitro Dry Matter Digestibility Quality of Native Species in Coastal Lowlands of Kenya

McDermott, J.J. and Arimi, S.M., 2002. Brucellosis in sub-Saharan Africa: Epidemiology, control and impact Veterinary Microbiology, 90, 111–134

Medical Decision Logic Inc, 2014. VisuaLyzer 2.2. Software for network data visualization (Medical Decision Logic, Inc.: Baltimore, Maryland)

Mehta, K., Semali, L. and Maretzki, A., 2011. The primacy of trust in the social networks and livelihoods of women agro-entrepreneurs in northern Tanzania Ajfand, 11, 2011–2011

Mertens, D.M. and Hesse-Biber, S., 2012. Triangulation and Mixed Methods Research: Provocative Positions Journal of Mixed Methods Research, 6, 75–79

Methu, J.N., Owen, E., Abate, A.L. and Tanner, J.C., 2001. Botanical and nutritional composition of maize stover, intakes and feed selection by dairy cattle Livestock Production Science, 71, 87–96

Migliorini, L. and Rania, N., 2017. A qualitative method to “make visible” the world of intercultural relationships: the photovoice in social psychology Qualitative Research in Psychology, 14, 131–145 (Routledge)

Migose, S.A., Bebe, B.O., de Boer, I.J.M. and Oosting, S.J., 2018. Influence of distance to urban markets on smallholder dairy farming systems in Kenya Tropical Animal Health and Production, 50, 1417–1426 (Tropical Animal Health and Production)

Moller, M., 2018. Feeding routines and feed quality on small-scale dairy farms in Baringo , Kenya

Monastyrnaya, E., Bris, G.Y. Le, Yannouc, B. and Petitd, G., 2017. A template for sustainable food value chains International Food and Agribusiness Management Review, 20, 461–475

Moran, J., 2005. Tropical dairy farming : feeding management for small holder dairy farmers in the humid tropics, First ed. (Landlinks Press: Collingwood VIC Australia)

Morgan, M. and McVay, M., 2012. Social networks and value chain development

Mpairwe, D.R., Sabiiti, E.N., Ummuna, N.N., Tegegne, A. and Osuji, P., 2002. Effect of intercropping cereal crops with forage legumes and source of nutrients on cereal grain yield and fodder dry matter yields African Crop Science Journal, 10, 1–14

Msaddak, M., Ben-Nasr, J. and Zaibet, L., 2020. Dynamics of Trust and Cooperation in the Dairy Value Chain: A Game Simulation Approach Journal of International Food & Agribusiness Marketing, 0, 1–21 (Routledge)

Msaddak, M., Ben-Nasr, J. and Zaibet, L., 2018. Role of trust and cooperation in the dairy value chain using gaming simulation 1, 53

Msaddak, M., BenNasr, J., Zaibet, L. and Fridhi, M., 2017. Social networks for the sustainability of the dairy sector: The role of cooperatives Livestock Research for Rural Development, 29, 1–12

Msalya, G., 2017. Contamination Levels and Identification of Bacteria in Milk Sampled from Three Regions of Tanzania: Evidence from Literature and Laboratory Analyses Veterinary Medicine International, 2017, 1–10 (Hindawi)

Muange, E. and Schwarze, S., 2014. Social networks and the adoption of agricultural innovations: The case of improved cereal cultivars in Central Tanzania Socioeconomics Discussion Paper Series, 1–30

Muia, J.M.K., Kariuki, J.N., Mbugua, P.N., Gachuiri, C.K., Lukibisi, L.B., Ayako, W.O. and Ngunjiri, W. V., 2011a. Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities Livestock Research for Rural Development, 23, 1–15

Muia, J.M.K., Kariuki, J.N., Mbugua, P.N., Gachuiri, C.K., Lukibisi, L.B., Ayako, W.O. and Ngunjiri, W. V., 2011b. Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities Livestock Research for Rural Development, 23, 5–6

Muloi, D., Alarcon, P., Ombui, J., Ngeiywa, K.J., Abdullahi, B., Muinde, P., Karani, M.K., Rushton, J. and Fèvre, E.M., 2018. Value chain analysis and sanitary risks of the camel milk system supplying Nairobi city, Kenya Preventive Veterinary Medicine, 159, 203–210 (Elsevier)

Muraguri, G.R., McLeod, A. and Taylor, N., 2004. Estimation of milk production from smallholder dairy cattle in the Coastal Lowlands of Kenya Tropical Animal Health and Production, 36, 673–684

Mutua, E.N., Bukachi, S.A., Bett, B.K., Estambale, B.A. and Nyamongo, I.K., 2017. “We do not bury dead livestock like human beings”: Community behaviors and risk of Rift Valley Fever virus infection in Baringo County, Kenya PLoS Neglected Tropical Diseases, 11, 1–17

Mutua, F.K., Dewey, C., Arimi, S., Ogara, W., Levy, M. and Schelling, E., 2012. A description of local pig feeding systems in village smallholder farms of Western Kenya Tropical Animal Health and Production, 44, 1157–1162

Mutura, J.K., 2015. Analysis of vertical and horizontal integration as determinants of market channel choice among smallholder dairy farmers in lower central Kenya (Kenyatta Univeristy)

Muunda, E., Mtimet, N., Schneider, F., Wanyoike, F., Dominguez-Salas, P. and Alonso, S., 2021. Could the new dairy policy affect milk allocation to infants in Kenya? A best-worst scaling approach Food Policy, 102043 (Elsevier Ltd)

Mwambi, M., Bijman, J., Mshenga, P. and Oosting, S., 2020. Adoption of food safety measures: The role of bargaining and processing producer organizations NJAS: Wageningen Journal of Life Sciences, 92, 1–9 (Elsevier B.V.)

Mwangi, A., Arimi, S.M., Mbugua, S., Kangethe, E.K. and Omore, A.O., 2000. Assurance of marketed milk quality in Kenya In:, Faculty of Veterinary Medicine, University of Nairobi, Kenya, Biennial Scientific Conference, 30-31 August, (University of Nairobi: Nairobi, Kenya)

Mwangi, L.W., Matofari, J.W., Muliro, P.S. and Bebe, B.O., 2016. Hygienic assessment of spontaneously fermented raw camel milk (suusa) along the informal value chain in Kenya International Journal of Food Contamination, 3, 18 (International Journal of Food Contamination)

Mwendia, S.W., Maass, B.L., Njenga, D.G., Nyakundi, F.N. and Notenbaert, A.M.O., 2017. Evaluating oat cultivars for dairy forage production in the central Kenyan highlands African Journal of Range and Forage Science, 34, 145–155

Nato, S.M., Matofari, J.W., Bebe, B.O. and Huelsebusch, C., 2018. Effect of predisposing factors on microbial loads in camel milk along the pastoral dairy value chain in Kenya Pastoralism, 8, 16 (Pastoralism)

Ndambi, A., Dido, S. and Gülzari, Ş.Ö., 2020. Milk quality assurance in smallholder-dominated dairy chains : Lessons from Uganda and Kenya, (Wageningen, The Netherlands)

Ndambi, A., Njiru, R., van Knippenberg, C., van der Lee, J., Kilelu, C. and Ngigi, M., 2018. Private and public costs and benefits of implementing a quality-based milk payment system in Kenya Private and public costs and benefits of implementing a quality-based milk payment system in Kenya, (Wageningen)

Ndambi, A., Njiru, R., van Knippenberg, C., Van Der Lee, J., Kilelu, C. and Ngigi, M., 2018. Private and public costs and benefits of implementing a quality-based milk payment system in Kenya, (Wageningen, The Netherlands)

Ng'ang'a, C.M., Bukachi, S.A. and Bett, B.K., 2016. Lay perceptions of risk factors for Rift Valley fever in a pastoral community in northeastern Kenya BMC Public Health, 16 (BMC Public Health)

Njarui, D.M.G., Gatheru, M., Ndubi, J.M., Gichangi, A.W. and Murage, A.W., 2021. Forage diversity and fertiliser adoption in napier grass production among smallholder dairy farmers in Kenya Journal of Agriculture and Rural Development in the Tropics and Subtropics, 122, 245–256

Njarui, D.M.G., Gatheru, M., Wambua, J.M., Nguluu, S.N., Mwangi, D.M. and Keya, G.A., 2011. Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya Livestock Research for Rural Development, 23, 1–11

Njarui, D.M.G., Gichangi, E.M., Gatheru, M., Nyambati, E.M., Ondiko, C.N., Njunie, M.N., Ndungu-Magiroi, K.W., Kiiya, W.W., Kute, C.A.O. and Ayako, W., 2016. A comparative analysis of livestock farming in smallholder mixed crop-livestock systems in Kenya: 2. Feed utilization, availability and mitigation strategies to feed scarcity Livestock Research for Rural Development, 28, 2009–2010

Njenga, M.K., Paweska, J.T., Lederman, E.R., Mutonga, D., Sharif, S.K., Anyangu, A.S., Katz, M., Schnabel, D., Nguku, P.M., Gould, L.H., Feikin, D.R., Hightower, A., Rao, C.Y., Omolo, J.O. and Breiman, R.F., 2010. Risk Factors for Severe Rift Valley Fever Infection in Kenya, 2007 The American Journal of Tropical Medicine and Hygiene, 83, 14–21

Njeru, J., Wareth, G., Melzer, F., Henning, K., Pletz, M.W., Heller, R. and Neubauer, H., 2016. Systematic review of brucellosis in Kenya: disease frequency in humans and animals and risk factors for human infection BMC Public Health, 16, 853 (BMC Public Health)

Nyaata, O.Z., Dorward, P.T., Keatinge, J.D.H. and O'Neill, M.K., 2000. Availability and use of dry season feed resources on smallholder dairy farms in central Kenya Agroforestry Systems, 50, 315–331

Nyaga, G.N., Lynch, D.F., Marshall, D. and Ambrose, E., 2013. Power asymmetry, adaptation and collaboration in dyadic relationships involving a powerful partner Journal of Supply Chain Management, 49, 42–65

Nyarugwe, S.P., Linnemann, A., Nyanga, L.K., Fogliano, V. and Luning, P.A., 2018. Food safety culture assessment using a comprehensive mixed-methods approach: A comparative study in dairy processing organisations in an emerging economy Food Control, 84, 186–196 (Elsevier Ltd)

Nyokabi, S., Birner, R., Bett, B., Isuyi, L., Grace, D., Güttler, D. and Lindahl, J., 2018. Informal value chain actors' knowledge and perceptions about zoonotic diseases and biosecurity in Kenya and the importance for food safety and public health Tropical Animal Health and Production, 50, 509–518 (Tropical Animal Health and Production)

Nyokabi, S.N., de Boer, I.J.M., Luning, P.A., Korir, L., Lindahl, J., Bett, B. and Oosting, S.J., 2021. Milk quality along dairy farming systems and associated value chains in Kenya: An analysis of composition, contamination and adulteration Food Control, 119, 107482 (Elsevier Ltd)

Odero-Waitituh, J.A., 2017. Smallholder dairy production in Kenya; a review Livestock Research for Rural Development, 29, 1–7

Olivier, S.P., Jayarao, B.M. and Almeida, R.A., 2005. Foodborne Pathogens in Milk and the Dairy Farm Environment: Food Safety and Public Health Implications Foodborne Pathogens and Disease, 2, 115–137

Oloo, J., 2010. Food Safety And Quality Management In Kenya : An Overview Of The Roles Played By Various Stakeholders African Journal of food agriculture nutrition and development, 10, 4379–4397

Omiti, J., McCullough, E., Otieno, D., Madelon, M., Nyanamba, T. and Murage, A., 2006. Participatory Prioritization of Issues in Smallholder Agricultural Commercialization in Kenya Kenya Institute for Public Policy Research and Analysis (KIPPRA), KIPPRA Dis

Omore, A., Lore, T., Staal, S., Kutwa, J., Ouma, R., Arimi, S. and Kang'ethe, E., 2005. Addressing the public health and quality concerns towards marketed milk in Kenya, (Nairobi, Kenya)

Omore, A.O., Arimi, S.S.M., Kang'ethe, E.K. and McDermott, J.J., 2004. Analysis of public health risks from consumption of informally marketed milk in Kenya Kenya Veterinarian, 27, 15–17

Ondieki, G.K., Ombui, J.N., Obonyo, M., Gura, Z., Githuku, J., Orinde, A.B. and Gikunju, J.K., 2017. Antimicrobial residues and compositional quality of informally marketed raw cow milk, Lamu West Sub-County, Kenya, 2015 The Pan African medical journal, 28, 5

Onyango, A.A., Dickhoefer, U., Rufino, M.C., Butterbach-Bahl, K. and Goopy, J.P., 2019. Temporal and spatial variability in the nutritive value of pasture vegetation and supplement feedstuffs for domestic ruminants in Western Kenya Asian-Australasian Journal of Animal Sciences, 32, 637–647

Orodho, A.B., 2006. The role and importance of Napier grass in the smallholder dairy industry in Kenya Food and Agriculture Organization, Rome) Retrieved August, 24, 29

Orregård, M., 2013. Quality analysis of raw milk along the value chain of the informal milk market in Kiambu County , Kenya (Swedish University of Agricultural Sciences)

Orwa, J.D., Matofari, J.W., Muliro, P.S. and Lamuka, P., 2017. Assessment of sulphonamides and tetracyclines antibiotic residue contaminants in rural and peri urban dairy value chains in Kenya International Journal of Food Contamination, 4, 1–11 (International Journal of Food Contamination)

Özkan, Ş., Ombaka, J., Asaah, O., Özkan Gülzari, Ş., Owade, J.O. and Ndambi, O.A., 2020. A review of interventions and parameters used to address milk quality in eastern and southern Africa Food Control, 116, 107300 (Elsevier)

Pham-Duc, P., Cook, M.A., Cong-Hong, H., Nguyen-Thuy, H., Padungtod, P., Nguyen-Thi, H. and Dang-Xuan, S., 2019. Knowledge, attitudes and practices of livestock and aquaculture producers regarding antimicrobial use and resistance in Vietnam PLoS ONE, 14, 1–21

Raabe, K., Birner, R., Sekher, M., Gayathridevi, K.G., Shilpi, A. and Schiffer, E., 2010. How to Overcome the Governance Challenges of Implementing NREGA : Insights from Bihar Using Process-Influence Mapping, (Washington DC)

Rademaker, C.J.C., Bebe, B.O., Lee, J. Van Der, Kilelu, C., Tonui, C., Omedo Bebe, B., van der Lee, J., Kilelu, C. and Tonui, C., 2016. Sustainable growth of the Kenyan dairy sector : a quick scan of robustness, reliability and resilience,

Rao, E.J.O., Omondi, I., Karimov, A.A. and Baltenweck, I., 2016. Dairy farm households, processor linkages and household income: the case of dairy hub linkages in East Africa International Food and Agribusiness Management Review, 19, 95–108

Rich, K.M., Ross, R.B., Baker, A.D. and Negassa, A., 2011. Quantifying value chain analysis in the context of livestock systems in developing countries Food Policy, 36, 214–222 (Elsevier Ltd)

Roesel, K. and Grace, D., 2015. Food Safety and Informal Markets, 1st ed. K. Roesel and D. Grace (eds), (Routledge: New York)

Roesel, K. and Grace, D., 2014. Food safety and informal markets: Animal products in sub-Saharan Africa, 1st ed. K. Roesel and D. Grace (eds), (Routledge: London)

Saenger, C., Qaim, M., Torero, M. and Viceisza, A., 2013. Contract farming and smallholder incentives to produce high quality: Experimental evidence from the Vietnamese dairy sector Agricultural Economics (United Kingdom), 44, 297–308

Sakwa, B., Ondiek, J., King'ori, A. and Ndambi, O., 2021. Effects of fodder conservation and ration formulation interventions on dairy performance in Kenya International Journal of Agricultural Research, Innovation and Technology, 10, 76–83

Scheiterle, L., Ulmer, A., Birner, R. and Pyka, A., 2018. From commodity-based value chains to biomass-based value webs: The case of sugarcane in Brazil's bioeconomy Journal of Cleaner Production, 172, 3851–3863 (Elsevier Ltd)

Schiffer, E., Hartwich, F. and Mario, M., 2010. Who has Influence in Multistakeholder Governance Systems? 44

Schiffer, E. and Hauck, J., 2010. Net-Map: Collecting Social Network Data and Facilitating Network Learning through Participatory Influence Network Mapping Field Methods, 22, 231–249

Schiffer, E. and Waale, D., 2008. Tracing Power and Influence in Networks : Net-Map as a Tool for Research and Strategic Network Planning Food Policy, 17

Schwendel, B.H., Wester, T.J., Morel, P.C.H., Tavendale, M.H., Deadman, C., Shadbolt, N.M. and Otter, D.E., 2015. Invited review: Organic and conventionally produced milk-An evaluation of factors influencing milk composition Journal of Dairy Science, 98, 721–746 (Elsevier)

Schwendel, B.H.H., Wester, T.J.J., Morel, P.C.H.C.H., Tavendale, M.H.H., Deadman, C., Shadbolt, N.M.M. and Otter, D.E.E., 2015. Invited review: Organic and conventionally produced milk—An evaluation of factors influencing milk composition Journal of Dairy Science, 98, 721–746 (Elsevier)

Shitandi, A., 2004. Risk factors and control strategies for antibiotic residues in milk at farm level in Kenya (Swedish University of Agricultural Sciences)

Shitandi, A. and Sternesjö, Å., 2004. Factors Contributing to the Occurrence of Antimicrobial Drug Residues in Kenyan Milk Journal of Food Protection, 67, 399–402

SNV, 2019. Assessment of KMDP Forage Interventions in North Rift, Kenya: The Case of Agricultural Contracting and Baling of Maize Silage, (Nairobi and Leeuwarden)

Staal, S.J., M. Waithaka, L. Njoroge, D.M. Mwangi, Njubi, D., Wokabi, A., Waithaka, M., Njoroge, L., A., W., Njubi, D., Wokabi, A., S. J. Staal, M. Waithaka, L. Njoroge, D.M. Mwangi, D.N. and A.W., D M Mwangi, Njubi, D. and Wokabi, A., 2003. Costs of milk production in Kenya: Estimates from Kiambu, Nakuru and Nyandarua Districts 1–30 (Nairobi, Kenya)

Stein, C. and Barron, J., 2017. Mapping actors along value chains: integrating visual network research and participatory statistics into value chain analysis Mapping actors along value chains: integrating visual network research and participatory statistics into value chain analysis, doi: 10.5337/2017.216

Symonds, J.E. and Gorard, S., 2010. Death of mixed methods? Or the rebirth of research as a craft Evaluation & Research in Education, 23, 121–136

Trienekens, J.H., 2011. Agricultural value chains in developing countries a framework for analysis International Food and Agribusiness Management Review, 14, 51–82

Trienekens, J.H., Hagen, J.M., Beulens, A.J.M. and Omta, S.W.F., 2003. Innovation through (international) food suppy chain development: A research agenda International Food and Agribusiness Management Review, 6, 84–98

Unnevehr, L., 2015. Food safety in developing countries: Moving beyond exports Global Food Security, 4, 24–29 (Elsevier)

van de Steeg, J.A., Verburg, P.H., Baltenweck, I. and Staal, S.J., 2010. Characterization of the spatial distribution of farming systems in the Kenyan Highlands Applied Geography, 30, 239–253 (Elsevier Ltd)

van der Lee, J., Klerkx, L., Bebe, B.O., Mengistu, A. and Oosting, S., 2018. Intensification and upgrading dynamics in emerging dairy clusters in the East African highlands Sustainability (Switzerland), 10

van der Lee, J., Oosting, S. and Klerkx, L., 2016. Market quality gradients in smallholder dairy farming systems: How spatial factors affect smallholder production and marketing strategies in the East African highlands: Conceptual framework paper In:, 12th European International Farming Systems Association (IFSA) Symposium, Social and technological transformation of farming systems: Diverging and converging pathways, 12-15 July 2016, Harper Adams University. International Farming Systems Association), (Newport, Shropshire, UK)

van der Lee, J., Oosting, S., Klerkx, L., Opinya, F. and Bebe, B.O., 2020. Effects of proximity to markets on dairy farming intensity and market participation in Kenya and Ethiopia Agricultural Systems, 184, 102891 (Elsevier)

Vermeulen, S., 2005. Power Tools: Handbook to tools and resources for policy influence in natural resource management, 1st ed. (International Institute for Environment & Development (IIED): London)

Vishnu, S., Gupta, J. and Subash, S.P., 2019. Social network structures among the livestock farmers vis a vis calcium supplement technology Information Processing in Agriculture, 6, 170–182 (China Agricultural University)

Wafula, W.N., Matofari, W.J., Nduko, M.J. and Lamuka, P., 2016. Effectiveness of the sanitation regimes used by dairy actors to control microbial contamination of plastic jerry cans' surfaces International Journal of Food Contamination, 3, 9 (International Journal of Food Contamination)

Wambugu, S., Kirimi, L. and Opiyo, J., 2011. Productivity Trends and Performance of Dairy Farming in Kenya, (Nairobi, Kenya)

Wanjala, G.W., Mathooko, F.M., Kutima, P.M. and Mathara, J.M., 2017. Microbiological quality and safety of raw and pasteurized milk marketed in and around Nairobi region African journal of food, agriculture, nutrition and developement, 17, 11518–11532

Wanjala, G.W., Mathooko, F.M., Kutima, P.M. and Mathara, J.M., 2018. Prevalence of Adulteration and Inhibitory Substances in Raw and Pasteurized Milk Marketed in Nairobi Region Asian Food Science Journal, 3, 1–8

Wanjohi, G.M., 2014. Occurrence of subclinical mastitis, brucellosis and factors responsible for camel milk contamination in Garissa and Wajir districts of north-eastern Kenya (University of Nairobi)

Washabaugh, J.R., Olaniyan, O.F., Secka, A., Jeng, M. and Bernstein, R.M., 2019. Milk hygiene and consumption practices in the Gambia Food Control, 98, 303–311 (Elsevier)

Yobouet, B.A., Kouamé-Sina, S.M., Dadié, A., Makita, K., Grace, D., Djè, K.M. and Bonfoh, B., 2014. Contamination of raw milk with Bacillus cereus from farm to retail in Abidjan, Côte d'Ivoire and possible health implications Dairy Science and Technology, 94, 51–60

Zanton, G.I., 2016. Analysis of production responses to changing crude protein levels in lactating dairy cow diets when evaluated in continuous or change-over experimental designs 1 4398–4410 (American Dairy Science Association)

Zavala Nacul, H. and Revoredo-Giha, C., 2022. Food safety and the informal milk supply chain in Kenya Agriculture & Food Security, 11, 8 (BioMed Central)

Acknowledgements

They say, it takes a village to raise a child. Similarly, this PhD research was only possible, in large part, due to the efforts of a lot of people. I would however like to acknowledge the invaluable contribution and involvement of the following individuals and institutions:

I will like to thank the amazing team of enumerators who helped with data collection William Waciuma, Victoria, Margaret, Gideon, Kennedy Banda, Sydney, Lilian, William Wambugu, Julius, Mwas, Dan, Geoffrey. To the amazing extension and animal health professional in the three counties: Peter, Dr. Kayla, Dr. Auma, Dr. Karite Ndirangu, Dr. Omanga, Dr. Wanjohi, Kibe Ndungu, Salako (Nakuru) Mary Wokabi, Rukawaro, Dr. Kiguru, Dr. Mwai, Ambrose (Laikipia West), Dr. Thuo, Mureithi and Ndungu (Nyandarua) for their support reaching farmers and with laboratory work.

I would like to sincerely thank Ymkje Tammiga and Lia Verhjn for always being the beating heart of APS and for always being there when I needed help. Speacial thanks to Fokje with help formatting this thesis. Special regards to Brain and Sally for being family away from home. Special mention to the APS family Imke, Simon, Eddie, Aart, Cindy, Pablo, Akke, Windy, Titis, Theo, Charles.

To Wilson and Andrea thank you for trusting me with supervision, it was a great experience.

Special recognition to the members and partners of the LIQUID project including Mercy, James, Pieternel, Kasper, Gea, Jos Bijman, Bebe, Mshenga, Jamal and Twine. Special thanks to Jan van der lee, Aasah, Kilelu for the many discussions and referrals, am forever grateful.

To Lisette, thank you for the many hours of help you have shared with me in this journey. To amazing souls who kept me company through the journey Shimels, Pride, Juliet, James, Emily, Bram and family, Abbas, Abdi and Taufiq, Thank you all for your unwavering friendship.

I am forever grateful to Isabelle Baltenweck and her amazing team (Policies Institutions and Livelihoods team at ILRI) including Nicoline, Ken, Joseph, Vivian, Rao, Juliet, Nils, Turere, Vivian, Auma, Luke and Githinji for giving me a home at ILRI-PIL. I am also forever indebted to the amazing scholars and staff of ILRI who made life fun during the PhD work: Bett, Johanna, Mwau, Korir, Yonas, Nick, Okoth, Sammy, Itangata, Roba, Kevin, Lilian, Purity, Jedidah, Valerie, Karis, Mwangi, Brayo, Luka and Dorcas Gemenet thanks for the many memorable nights at Enkare,

To the big Kenyan family in WUR: Faith, Irene, Emily, Tele, Nathaniel, Norman, Kirina, Jackie, Cate, Moha, Mercy, Daniel, Amos, Lazarus, Asaph, Jasper, Bilha, Emma, Alex, Monica, Lekishon, Kenana, Robert, Jared, Eunice, Felix, Migose, Richard, Tabby thank you for the friendship and amazing moments.

To Joshua and the Friday kitchen Africa family; Joshua, Steve, Prof, Sepherin, Wilson, Shaphan and UCAS family than you all for the friendship.

About the author

Simon Ndungu Nyokabi was born in Kajiado county, just south of Nairobi, in Kenya in 1987. He obtained a Bachelor of Science (BSc) degree in Biological Sciences (Botany major and Zoology minor) in 2011 from Egerton University, Njoro, Kenya. After graduating, he briefly worked as an intern at the National Agricultural Research Laboratories (NARL) of the Kenya Agricultural & Livestock Research Organization (KALRO), contributing to ongoing pollination, ecology and entomology research. Thereafter, he taught financial accounting for one year.

In 2012, Nyokabi decided to pursue an MSc degree in Agriculture in the Tropics and Subtropics at the University of Hohenheim, Stuttgart, Germany. He conducted his MSc. thesis research, while based at ILRI's regional offices in Nairobi, Kenya, as part of the Dynamic Drivers of Disease in Africa Consortium (DDDAC) project, exploring the adoption of biosecurity measures in informal dairy and meat value chains and implication for public health.

In 2016, he joined the Animal Production Systems Group of Wageningen University, the Netherlands. His research, which informs this thesis, was conducted under the auspices of the Local and International business collaboration for productivity and Quality Improvement in Dairy chains in Southeast Asia and East Africa (LIQUID) project.

In 2020, Nyokabi took up a post-doctoral research associate position at the Institute for Global Prosperity (IGP), University College London (UCL), United Kingdom. His current research is focused on enhancing the adoption of biosecurity measures at farm level in Ethiopia. Additionally, he is leading a team of citizen scientists in Kenya undertaking research on value chains, food safety, regenerative agriculture and prosperity. He continues to be driven by a desire to improve food safety and security, and livelihood security and prosperity of dairy value chain actors, including smallholder farmers engaged in dairy production, in low- and middle-income countries (LMICs) such as Kenya.

Publication list

Peer-reviewed journal publications

Nyokabi, S., Birner, R., Bett, B., Isuyi, L., Grace, D., Güttler, D. and Lindahl, J., 2017. Informal value chain actors' knowledge and perceptions about zoonotic diseases and biosecurity in Kenya and the importance for food safety and public health. Tropical Animal Health and Production, doi: 10.1007/s11250-017-1460-z (Tropical Animal Health and Production)

Nyokabi, S.N., de Boer, I.J., Luning, P.A., Korir, L., Lindahl, J., Bett, B. and Oosting, S.J. (2021) Milk quality along dairy farming systems and associated value chains in Kenya: An analysis of composition, contamination and adulteration. *Food Control*, *119*, p.107482.

Nyokabi, S., Luning, P.A., de Boer, I.J., Korir, L., Muunda, E., Bebe, B.O., Lindahl, J., Bett, B. and Oosting, S.J. (2021) Milk quality and hygiene: knowledge, attitudes and practices of smallholder dairy farmers in central Kenya. *Food Control*, p.108303.

Nyokabi, S.N., de Boer, I.J.M., Bijman, J., Bockline, B., Aguilar-Gallegos, N., Phelan, L., Bett, B., Lindahl, J., Oosting, S.O. (2021) Understanding the Role of Social Networks on Milk Quality: Evidence from the Kenyan Dairy sector. (revised and res*ubmitted to NJAS*)

Nyokabi, S., Luning, P.A., de Boer, I.J.M., Korir, L., Bett, B. and Oosting, S.J. (2021) Seasonal milk composition, feed quality and availability in smallholder dairy farm systems. (*Accepted NJAS*)

Ndungu S. Nyokabi, Lilian Korir, James L. N. Wood, Lisette Phelan, Gizachew Gemechu, Stefan Berg, Johanna Lindahl, Adane Mihret, Henrietta L. Moore (2023) Adoption of Food Safety Measures in Smallholder Dairy Systems in Ethiopia: Implications for Food Safety and Public Health (*Submitted to food security*)

Ndungu S. Nyokabi, Lisette T. Phelan, Gizachew Gimechu, Stefan Berg, Johanna Lindahl, Adane Mihret, James L. N. Wood, Henrietta L. Moore (2023) From Farm to Table: Exploring Food Handling and Hygiene Practices of Meat and Milk Value Chain Actors in Ethiopia (*Submitted to BMC public health*)

Simon N. Nyokabi, James L. N. Wood, Gizachew Gemechu, Stefan Berg, Adane Mihret, Henrietta L. Moore (2023) Exploring syndromic knowledge and treatment practices of cattle diseases among veterinary practitioners in Ethiopia (*Submitted to One Health*)

Simon Nyokabi, Henrietta Moore, Stefan Berg, Johanna Lindahl, Lisette Phelan, Gizachew Gimechu, Adane Mihret, James Wood (2023) - Implementing a One Health approach to strengthen the management of zoonoses in Ethiopia (Submitted to One Health)

Selected conference oral presentations

Simon N. Nyokabi, S.J. Oosting, Bockline Omedo Bebe, Luke Korir, Bernard Bett, Johanna Lindahl, I.J.M. de Boer- Assessment of milk quality in smallholder dairy systems in Kenya and the impact of social networks on stakeholders' behaviours and practices in the value chain. Agriculture, Nutrition & Health Academy week ANH, Accra Ghana (25th – 29th of June 2018).

Simon Ndungu Nyokabi, Simon Oosting, Imke de Boer - Food safety in smallholder dairy value chains: towards realising food security and SDGs Kenya. 5th Wageningen PhD Symposium (WPS 2018). Bridging science & society: unifying knowledge Wageningen university and research (17th May 2018).

Simon N. Nyokabi, The 5th LCIRAH conference at London School of Hygiene and Tropical Medicine. "Biosecurity Measures in Meat and Milk Value Chains: A Study in Bura sub-county, Kenya" (3rd – 5th of May 2015)

Simon N. Nyokabi, - The annual ELLS student conference Warsaw University of Life Sciences, Warsaw (SGGW-WULS). “Improving Food Safety in Informal Markets through adoption of Biosecurity Measures” (14th – 15th November 2014)

Conference papers

Lisette Tara Phelan**, Simon Ndungu Nyokabi**, Amanda Berlan - Photovoice: A Research Method for Farmer-Driven Knowledge Production- 14th European IFSA Symposium Farming Systems Facing Climate Change and Resource Challenges. Conference to be held in Evora, Portugal (20th – 26th of March 2020)

Nyokabi, Simon; Oosting, S.J.; Omedo Bebe, Bockline; Phelan, Lisette; Bett, Bernard; Lindahl, Johanna; de Boer, I.J.M. - Impact of Stakeholder Power on Milk Quality: A Social Networks Analysis of the Kenya Dairy Sector - 13th European IFSA Symposium Farming systems: facing uncertainties and enhancing opportunities. Conference held in Chania, Crete, Greece (1st – 5th of July 2018)

Posters

Simon N. Nyokabi, Imke J.M. de Boer, Johanna Lindahl, Bernard Bett and Simon J. Oosting- Foodborne pathogens in Kenyan dairy value chains: food safety security and public health implications. 6th World One Health Congress in Edinburgh, Scotland 30 Oct 2020 – 3 Nov 2020

Simon Nyokabi, S.J. Oosting, Bockline Omedo Bebe, Bernard Bett, Johanna Lindahl, I.J.M. de Boer- Improving Milk Quality in Smallholder Dairy Systems: Towards Realising Food Safety and Food Security in Kenya. Tropentag 2018: Global food security and food safety: The role of universities. Conference held in Ghent, Belgium (17th – 19th of September 2018)

S. N. Nyokabi, W. C. Wilson and S. Oosting- Assessing the influence of social networks on milk quality in the southern highlands of Tanzania. Wageningen Institute of Animal Science (WIAS) Science Day (February 2017)

S. N. Nyokabi - Adoption of Biosecurity measures along the livestock value chain: a study in Bura sub-county, Kenya. One Health for the Real World: zoonoses, ecosystems and wellbeing. Conference held in London, United Kingdom (17th – 18th of March 2016)

S. N. Nyokabi- Biosecurity Measures in Meat and Milk Value Chains: A Study in Bura Sub-County, Kenya. Annual Tropentag Conference held in Humboldt University, Berlin, Germany (16th – 18th of September 2015)

Education Certificate

Completed Training and Supervision Plan

EDUCATION AND TRAINING	Year	Credit
The Basic Package		**3.7**
WIAS Introduction Day	2016	
Scientific Integrity & Ethics in Animal Sciences	2018	
Course on Essential Skills	2016	
Disciplinary Competences		**11.0**
Qualitative Data Analysis with Atlas.ti: a hands -on practical	2016	
Project and Time Management (PTM)	2016	
Towards a Global One Health	2018	
WIAS research proposal	2016	
Multidisciplinary perspectives on quality improvement in value chains	2016	
Professional Competences		**8.1**
Feed Assessment Tool (FEAST)	2016	
Systematic approaches to reviewing literature	2016	
Competence Assessment (COA)	2016	
WIAS course on High Impact Writing in Science	2019	
Career assessment (CA)	2018	
Reviewing scientific paper	2018	
WIAS course on The Final Touch: Writing the General Introduction and discussion	2019	
Presentation Skills		**4.0**
One Health for real world conference (Poster), London UK	2016	
WIAS Science Day conference (Poster), Wageningen, The Netherlands	2016	
WPC PhD symposium (Poster), Wageningen, The Netherlands	2018	
IFSA conference (Oral), Chania, Greece	2018	
ANH conference (Poster), Accra, Ghana	2018	
Annual Tropentag conference (Poster), Ghent, Belgium	2018	
Teaching competences		**5.5**
LIQUID Project teaching courses	2019	
Masters students' supervision	2017-2019	
Education and Training Total (minimum 30 credits)		**32.3***

* With the activities listed, the PhD candidate has complied with the requirements set by the Graduate School of Wageningen Institute of Animal Sciences (WIAS) of Wageningen University & Research, which comprises a minimum of 30 ECTS (European Credit Transfer and Accumulation System). One ECTS equals a study load of 28 hours.

Colophon

The research described in this thesis was financially supported by the Netherlands Organisation for Scientific Research Science for Global Development (NWO-WOTRO) through the Food and Business Global Challenges Programme (GCP), Grant award number W08.250.204.

Financial support from Wageningen University for the printing of this thesis is gratefully acknowledged.

Cover design by Lisette Phelan and Simon Ndungu Nyokabi.

Images used in this thesis were taken by Simon Ndungu Nyokabi.

Printing by Proefschriftmaken (www.proefschriftmaken.nl).


02
110
NY 150