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

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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.

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

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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 bicycle or motorbike (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 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 (Fig. 1) (see Fig. 2).

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 Fig. 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.

Table 1
Number of farm samples and milk samples collected according to 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

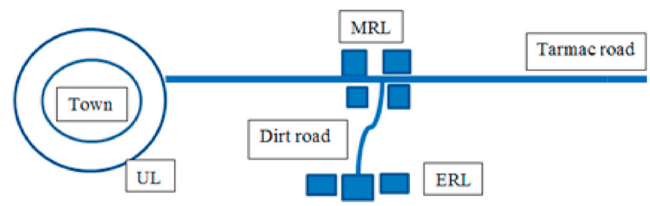

Fig. 1. Spatial framework indicating the location of dairy farming systems.

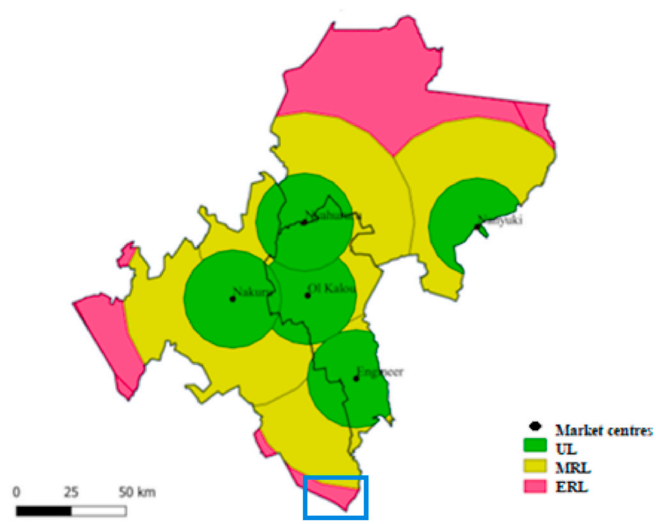

Fig. 2. Spatial location for the study developed with Grass software (QGIS, 2018). The blue box indicates the area which was reclassified to MRL.

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 Kenya Bureau of Standards (KeBS) standards 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 $\leq$ 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 ^{o} 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]

Means and percentages in the same row with different superscript (a, b, c) 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.*

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.

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

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 ^{o} 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

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

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

Physicochemical properties	Producers	Formal bulking	Informal milk collection
Mean (standard error)	(n = 33)	(n = 52)	(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]

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

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

Physicochemical properties	Producers	Formal bulking	Informal collection
Mean (standard error)	(n = 80)	(n = 50)	(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]

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

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.

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* (Table 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).

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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

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2020.107482.

References

Abdulai, A., & Birachi, E. A. (2009). Choice of coordination mechanism in the Kenyan fresh milk supply chain. *Review of Agricultural Economics, 31*(1), 103–121. https://doi.org/10.1111/j.1467-9353.2008.01428.x.

Ahlberg, S., Korhonen, H., Lindfors, E., & Kang'ethe, E. (2016). Analysis of antibiotic residues in milk from smallholder farms in Kenya. *African Journal of Dairy Farming and Milk Production, 3*(4), 152–158.

Ajwang, F., & 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*(2), 1–6. https://doi.org/10.9734/AJAEES/2016/22089.

Alonso, S., Muunda, E., Ahlberg, S., Blackmore, E., & Grace, D. (2018). Beyond food safety: Socio-economic effects of training informal dairy vendors in Kenya. *Global Food Security, 18*(August), 86–92. https://doi.org/10.1016/j.gfs.2018.08.006.

Arimi, S. M., Koroti, E., Kang'ethe, E. K., Omore, A. O., & 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), 1–8. https://doi.org/10.1016/j.actatropica.2005.05.012.

Baltenweck, I., & Staal, S. (2007). Beyond one-size-fits-all: Differentiating market access measures for commodity systems in the Kenyan highlands. *Journal of Agricultural Economics, 58*(3), 536–548. https://doi.org/10.1111/j.1477-9552.2007.00129.x.

Baltenweck, I., Staal, S. J., Owango, M. O., Muriuki, H. G., Lukuyu, B., Gichungu, G., Kenyanjui, M., Njubi, D., Tanner, J., & Thorpe, W. (1998). *Intensification and competitiveness of smallholder dairy production systems in the greater Nairobi milk- shed*.

Bebe, B. O., Lee, J. Van Der, Kilelu, C. W., van der Lee, J., & Kilelu, C. W. (2018). *Milk retailing Innovation in Kenya and consumers Perceptions of safety (No. 010; 3R Kenya project practice brief)*.

Bosire, C. K., Lannerstad, M., de Leeuw, J., Krol, M. S., Ogutu, J. O., Ochungo, P. A., & 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. *The Science of the Total Environment, 579*, 786–796. https://doi.org/10.1016/j.scitotenv.2016.11.027.

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

Chen, B., Lewis, M. J., & Grandison, A. S. (2014). Effect of seasonal variation on the composition and properties of raw milk destined for processing in the UK. *Food Chemistry, 158*, 216–223. https://doi.org/10.1016/j.foodchem.2014.02.118.

Chepkoech, B. (2010). Milk quality control and regulation in dairy Production : A case of dairy producers in kikuyu division , kabete district, central province - Kenya. In *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*.

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*. Milano: Università Degli Studi di.

Deti, H., Hymete, A., Bekhit, A. A., Mohamed, A. M. I., & Bekhit, A. E.-D. A. (2014). Persistent organochlorine pesticides residues in cow and goat milk collected from different regions of Ethiopia. *Chemosphere, 106*, 70–74. https://doi.org/10.1016/j.chemosphere.2014.02.012.

Duncan, A. J., Teufel, N., Mekonnen, K., Singh, V. K., Bitew, A., & Gebremedhin, B. (2013). Dairy intensification in developing countries: Effects of market quality on farm-level feeding and breeding practices. *Animal, 7*(12), 2054–2062. https://doi.org/10.1017/S1751731113001602.

GOK, (Government of Kenya). (2012). *Dairy Industry Act : Cap 336*.

Janssen, E., & Swinnen, J. (2019). Technology adoption and value chains in developing countries: Evidence from dairy in India. *Food Policy, 83*(August 2017), 327–336. https://doi.org/10.1016/j.foodpol.2017.08.005.

Kabui, K. K., Arimi, S. M., Kang'ethe, E. K., Omore, A., Makokha, S., Nduhiu, G., Mainga, A. O., & 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*(1), 44–47.

Kamwine, M., Orikiriza, P., Taseera, K., Iramiot, J. S., Ojuka, P., Ikiriza, S., Atwebembeire, J., Otieno, D., Tweshengyereze, S., Mwanga-Amumpaire, J., Bazira, J., & Boum, Y. (2017). Prevalence of antibodies to Brucella species in commercial raw bovine milk in Southwestern Uganda. *BMC Research Notes, 10*(1), 1–5. https://doi.org/10.1186/s13104-017-2537-5.

Kang'ethe, E. K., Aboge, G. O., Arimi, S. M., Kanja, L. W., Omore, A. O., & McDermott, J. J. (2005). Investigation of the risk of consuming marketed milk with antimicrobial residues in Kenya. *Food Control, 16*(4), 349–355. https://doi.org/10.1016/j.foodcont.2004.03.015.

Kirino, Y., Kohei, M., Delia, G., & 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. https://doi.org/10.18697/ajfand.75.ILRI05, 03.

Koyi, N. P., & 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. https://doi.org/10.9790/2380-1006024556, 06.

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

Lindahl, J. F., Deka, R. P., Asse, R., Lapar, L., & 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*(1), 1555444. https://doi.org/10.1080/20008686.2018.1555444.

McDermott, J. J., & Arimi, S. M. (2002). Brucellosis in sub-Saharan Africa: Epidemiology, control and impact. *Veterinary Microbiology, 90*(1–4), 111–134. https://doi.org/10.1016/S0378-1135(02)00249-3.

Migose, S. A., Bebe, B. O., de Boer, I. J. M., & Oosting, S. J. (2018). Influence of distance to urban markets on smallholder dairy farming systems in Kenya. *Tropical Animal Health and Production, 50*(7), 1417–1426. https://doi.org/10.1007/s11250-018-1575-x.

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

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

Nato, S. M., Matofari, J. W., Bebe, B. O., & Huelsebusch, C. (2018). Effect of predisposing factors on microbial loads in camel milk along the pastoral dairy value chain in Kenya. *Pastoralism, 8*(1). https://doi.org/10.1186/s13570-018-0123-7.

Ndambi, A., Njiru, R., van Knippenberg, C., Van Der Lee, J., Kilelu, C., & Ngigi, M. (2018). *Private and public costs and benefits of implementing a quality-based milk payment system in Kenya (No. 001; 3R Kenya Project Research Brief)*.

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., & Breiman, R. F. (2010). Risk factors for severe rift valley fever infection in Kenya, 2007 *The American Journal of Tropical Medicine and Hygiene, 83*(2_Suppl), 14–21. https://doi.org/10.4269/ajtmh.2010.09-0293.

Nyarugwe, S. P., Linnemann, A., Nyanga, L. K., Fogliano, V., & 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. https://doi.org/10.1016/j.foodcont.2017.07.038.

Nyokabi, S., Birner, R., Bett, B., Isuyi, L., Grace, D., Güttler, D., & 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*(3), 509–518. https://doi.org/10.1007/s11250-017-1460-z.

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

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

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

Ondieki, G. K., Ombui, J. N., Obonyo, M., Gura, Z., Githuku, J., Orinde, A. B., & 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*(Supp 1), 5. https://doi.org/10.11604/pamj.supp.2017.28.1.9279.

Orregård, M. (2013). Quality analysis of raw milk along the value chain of the informal milk market in Kiambu County , Kenya. *Master Thesis, 55*. ISSN: 1101–8151.

Orwa, J. D., Matofari, J. W., Muliro, P. S., & Lamuka, P. (2017). Assessment of sulphonamides and tetracyclines antibiotic residue contaminants in rural and peri urban dairy value chains in Kenya. *International Journal of Flow Control, 4*(1), 1–11. https://doi.org/10.1186/s40550-017-0050-1.

Roesel, K., & Grace, D. (2014). Food safety and informal markets: Animal products in sub-Saharan Africa. In K. Roesel, & D. Grace (Eds.), *Food safety and informal markets: Animal products in sub-saharan Africa* (1st ed.). Routledge.

Schwendel, B. H., Wester, T. J., Morel, P. C. H., Tavendale, M. H., Deadman, C., Shadbolt, N. M., & Otter, D. E. (2015). Invited review: Organic and conventionally produced milk-An evaluation of factors influencing milk composition. *Journal of Dairy Science, 98*(2), 721–746. https://doi.org/10.3168/jds.2014-8389.

Shitandi, A., & Sternesjö, Å. (2004). Factors contributing to the occurrence of antimicrobial drug residues in Kenyan milk. *Journal of Food Protection, 67*(2), 399–402. https://doi.org/10.4315/0362-028X-67.2.399.

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

Van der Lee, J., Klerkx, L., Bebe, B. O., Mengistu, A., & Oosting, S. (2018). Intensification and upgrading dynamics in emerging dairy clusters in the East African highlands. *Sustainability, 10*(11). https://doi.org/10.3390/su10114324.

Van der Lee, J., Oosting, S., & 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* (p. I). Harper Adams University. International Farming Systems Association, 12-15 July 2016.

Wambugu, S., Kirimi, L., & Opiyo, J. (2011). Productivity trends and performance of dairy farming in Kenya. In *Tegemeo Institute of agricultural policy and development* (p. 4). Tegemeo Institute Working Papers, 2011.

Wanjala, G. W., Mathooko, F. M., Kutima, P. M., & 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 Development, 17*, 11518–11532. https://doi.org/10.18697/ajfand.77.15320, 01.

Wanjala, G. W., Mathooko, F. M., Kutima, P. M., & Mathara, J. M. (2018). Prevalence of adulteration and inhibitory substances in raw and pasteurized milk marketed in Nairobi region. *Asian Food Science Journal, 3*(2), 1–8. https://doi.org/10.9734/AFSJ/2018/42382.

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 (Issue November)*. University of Nairobi.