VALUE CHAIN MAPPING TO ASSESS GOVERNANCE CHALLENGES, FOOD SAFETY RISKS, AND *ESCHERICHIA COLI* GENETIC DIVERSITY ALONG THE DAIRY FOOD SYSTEM IN NAIROBI KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

I dedicate this Ph.D. to my loving husband Hon. Jessee Wanyeki and our sons MicHalifax Mwangi and MicCaleb Kimathi, my mam Sophia Kiambi and dad Japhet Kiambi.

Jessee Wanyeki, *"you believed in me and constantly reminded me of my talents and strengths. You have been extremely patient, supportive and a pillar of encouragement and prayers".*

MicHalifax, *"you have encouraged me and prayed for me all through. Thank you for your patience and support".*

MicCaleb, *"we gave each other encouragement as we 'did homework' in the evenings and over the weekends. That was very encouraging and I really loved your company on that dining table".*

My parents, *"thank you for the foundation you laid in my life and for believing in me and constantly praying for me. I treasure you my dear parents".*

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ABSTRACT

Food systems present complicated networks where production and distribution of food products can either be achieved through simple or complex value chains. Such system complexities present avenues for introduction, transmission and maintenance of food-borne pathogens and other food hazards. It follows that management of food safety require a holistic analysis of these networks, particularly to understand their structures and practices that influence the system's sustainability and resilience. The overarching objective of this study was to investigate the structure, governance and food safety challenges in the Nairobi dairy value chain (NDVC) with a hypothesis that rapid urbanization exerts pressure on interconnected complex food systems within rapidly growing urban areas, consequently impairing the quality of livestock sourced foods supplied to consumers. From January 2014 to January 2015, various data were gathered through conducting of 23 key informant interviews, 22 focus group discussions and collection of 290 milk samples from 144 nodes of the NDVC. Data collection methods and analysis included value chain mapping, investigation of governance structure and its influence on food safety, bacteriological sampling of cow milk for analysis of bacterial quality and genetic diversity of *Escherichia coli*. Content thematic analysis was utilized for qualitative data to identify the emerging themes that described patterns of operations, interactions of people, flow of commodities, governance themes, key challenges and their implication on food safety. Bacterial quality of milk was done by determination of total bacteria (TBC) and total coliform (TCC) counts which were described in the context of average values for colony forming units per milliliter (cfu/ml) of milk with reference to the East Africa Standards (EAS).

The acceptability of milk samples based on the EAS was analyzed by performing logistic regression analysis while the genetic diversity of *E. coli* was determined by GTG_5 fingerprinting method and dendrograms were generated to show relatedness of *E. coli* based on banding patterns from different bacterial isolates.

Results on mapping indicated that NDVC were vast and complex, comprising of seven chain profiles which were principally dominated by independent, yet highly interconnected small-scale operators. Each profile linked to other chain profiles hence forming the overall complex NDVC. Therefore, interventions on improvement need to consider these numerous inter-linked chain profiles to achieve the desired impact. Furthermore, interaction of actors was shown to be diverse through fragmented governance structures characterized with noncompliance to existing regulatory requirements. Hence, understanding of value chain governance would help decision-makers on potential areas that could improve efficiency and food safety along the dairy value chain. The mean values of cfu/ml for milk obtained at farm and collection centres was within acceptable EAS limits for TBC; However, TCC values at farm level were 3-times higher than lowest limits of EAS. When compared to the farm, acceptability of milk reduced downstream with milk from retail being less acceptable on TBC and TCC. Several practices with influence on bacterial quality of milk were identified: very muddy cowsheds, unconventional sources for animal feeds, use of spoilt milk for value added products, adulteration of milk, acceptance of low quality milk for processing and lack of cold chain. *E. coli* genetic diversity revealed a similarity matrix of between 50–70 % amongst isolates from the same region, signifying independent bacterial evolution or distinct milk contamination sources and not clonal spread of certain strains. In conclusion, the findings reflect diversity of people involved in the NDVC, their relationships and varied food safety practices which create opportunities for milk contamination.

Therefore, enhancing system's efficiency requires a holistic approach to policy interventions. A risk benefit analysis along the value chain nodes will be important to identify which particular nodes generates more benefits to value chain actors and level of risk around such nodes with regard to food safety.

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ABBREVIATIONS AND ACRONYMS

A.I – Artificial Insemination

A4NH – Agriculture for Nutrition and Health

AHA – Animal Health Assistant

AMR – Antimicrobial Resistance

ATM – Automatic Milk Machine

C.I – confidence Interval

CAP – Chapter

CFU – Colony Forming Unit

CFU/ML – Coliform Forming Unit per Millilitre

CGIAR – Consultative Group for International Agricultural Research

CIDP – County Integrated Development Plan

CMR – Centre for Microbiology Research

DALYs – Disability Adjusted Life Years

DLP – Directorate of Livestock Production

DNA – Deoxyribonucleic Acid

DTA – Dairy Traders Association

DVC – Dairy Value Chain

DVS – Directorate / Director of Veterinary Services

E. coli – Escherichia Coli

EAS – East Africa Standards

EMBA – Eosin Methylene Blue agar

ESEI – Environmental & Social Ecology of Human Infectious Diseases Initiative

EU – European Union

FAO – Food and Agriculture Organization of the United Nations

FAOSTAT – Food and Agriculture Organization Corporate Statistical Database

FGD – Focus Group Discussion

GDP – Gross Domestic Product

GOK – Government of Kenya

GPS – Global Positioning System

GTG5 – 5′-GTG GTG GTGGTG GTG-3′

GVC – Global Value Chains

HIV – Human Immunodeficiency Virus

IFAD – International Fund for Agricultural Development

ILRI – International Livestock Research Institute

IMViC – Indole, Methyl Red, Vogues Proskaeuer and Citrate

ISO – International Organization for Standards

KALRO – Kenya Agricultural Research Organization

KCC – Kenya Cooperative Creameries

KDB – Kenya Dairy Board

KEBS – Kenya Bureau of Standards

KEMRI – Kenya Medical Research Institute

KII – Key Informant Interview

KNBS – Kenya National Bureau of Statistics

LPO – Livestock Production Officer

MCCs – Milk Collection Centres

MHA – Muller Hinton agar

NDVC – Nairobi Dairy Value Chain

NKCC – New Kenya Cooperative Creameries

ODK – Open Data Kit

OIE – Office International des Epizooties

OR – Odds Ratio

PCR – Polymerase Chain Reaction

PFGE – Pulsed Field Gel Electrophoresis

Ph.D. – Doctor of philosophy

PHO – Public Health Officer

PHPT – Public Health, Pharmacology and Toxicology

PPT – Parts Per Trillion

SDP – Smallholder Dairy Project

SPCA – Standard Plate Count Agar

TBC – Total Bacteria Count

TCC – Total Coliform Count

USAID – United States Agency for International Development

UHT – Ultra Heat Treatment

UK – United Kingdom

UPGMA – Unweighted Pair Group Arithmetic Mean

USA – United States of America

USAID – United States Agency for International Development

VCA – Value Chain Analysis

VRBA – Violet Red Bile Agar

WHO – World Health Organization

CHAPTER 1: GENERAL INTRODUCTION

Dairy refers to milk and any food products prepared from milk like cream, cheese, butter, milk powder, fermented milk and yogurt. Dairy products are key to food security, livelihoods, resilience and nutrition to millions of people, ensuring that their diets provide necessary nutrients required for physical and cognitive development. Global demand for dairy products has rapidly grown over the past few decades. This has particularly been influenced by several factors including, increasing human population and therefore demand for more milk, fast economic growth resulting to increased purchasing power, rapid urbanization and increased desire for intake of animal source proteins especially within the developing countries (Herrero *et al.*, 2014).

The global dairy industry is comprised of numerous countries with unique production practices and consumer markets. In 2017, approximately 676 million tonnes of milk were produced across the world, with the highest share of the milk production coming from Europe (32.8%), Asia (30.2%) and Americas (27.3%). While, Africa countries only produced approximately 185 million tonnes of milk which represents about 5.2% of the total global share (FAOSTAT, 2017). Of this, Kenya's contribution to the Africa share was about 2.6% (4.8 million litres).

Herrero (2014) predicts that by 2030, demand for milk consumption in Sub-Saharan Africa will triple but the production will not rise to meet this demand. On the other hand, a combination of growth and migration will result to substantial increase in the urban population in Africa which is expected to rise from 35% of the total population in 2007 to a projected 51% by 2030 (U.N, 2007). Increased urbanization coupled with the predicted low milk supply will put pressure to the existing value chains and further trigger evolution of more chains which will complicate the already complex food system.

Food systems present some of the most complicated networks especially in the urban areas where production and distribution is through simple to complex value chains (Alarcon; *et al.,* 2017; Carron *et al.,* 2017; Foran *et al.,* 2014; Hueston and MacLeod, 2012). Such system complexities are excellent avenues for introduction and transmission of pathogens including food hazards among other food safety risks (Gereffi *et al.,* 2005; Gereffi and Lee, 2009). Food safety comprises the practices and conditions promoted across a food supply chain with the intention of ensuring food quality and preventing contamination and foodborne illness. World Health Organization (WHO) estimates that thirty one (31) out of the thirty two (32) diseases reported globally between 2007 and 2015, were caused by foodborne hazards (WHO, 2015), while other report estimate that more than one billion people come down with foodborne related diarrhoea annually (Mead *et al.*, 1999). Foodborne illnesses are common globally and are a problem not only to developing but also developed countries. For instance, in the United States of America (USA) alone, foodborne infections were estimated to cause approximately 48 to 76 million illnesses, 128,000 to 325,000 hospitalizations, and 3,000 to 5,000 deaths each year (Mead *et al.,* 1999; Scallan *et al.*, 2011). A study conducted in Italy to estimate burden of salmonella in foods, revealed a prevalence of 2.2% of 71,643 food samples tested, with highest contamination being observed in raw poultry products (9.9%), followed by processed meat (5.3%), raw pork (4.9%) and 0.1% for dairy products (Busani *et al.,* 2005). A coordinated food-sampling program designed to monitor microbiological quality and safety of specific ready-to-eat products in the United Kingdom (UK), revealed numerous food safety concerns with an overall unsatisfactory rate of 17% for aerobic colony counts (Meldrum *et al.,* 2005).

A national survey done by the Australian government in 2000, revealed that foodborne illnesses were responsible for about 100 outbreaks, some of them implicated to dairy products (Kirk *et al.*, 2010) while in France, about 60 foodborne outbreaks were implicated to milk and milk products (De Buyser *et al.*, 2001).

As well, there have been numerous food safety concerns in the food systems in developing countries, ranging from presence of zoonotic disease pathogens, antibiotic residues, antibiotic resistance, aflatoxins and chemicals like formalin, hydrogen peroxide and Melamine. Microbial contamination is labelled as one of the leading concerns in food systems in developing countries mainly due to inadequate and poorly developed food safety structures and policies (FAO, 2004). For instance, studies conducted in Tanzania and Ghana have demonstrated varying but high prevalence of bacteria in milk products (Lubote *et al.,* 2014; Parry-Hanson Kunadu *et al.,* 2018) and showing numerous genetic resistance diversity to various antibiotics (Parry-Hanson Kunadu *et al.,* 2018).

In some instances, chemicals have been used to adulterate milk especially in systems that are not robust enough to detect the vice. An example is the Chinese infant formula scandal that involved addition of Melamine into infant formula in 2008 (Pei *et al.,* 2011), that resulted to development of kidney stones and illness in almost 300,000 children and six infant deaths. Melamine due to its high nitrogen component was offered to farmers by some manufacturers who called it “protein powder” to artificially boost the apparent presence of protein in the infant formula, a deception for the milk quality inspectors (Fairclough, 2008).

Kenya, like other developing countries has not been exempted from the burden of food borne illnesses and presence of numerous hazards in milk. A study conducted to establish health hazards in milk under different marketing conditions found that up to 80% of samples did not meet national bacterial quality standards (Omore *et al.,* 2000). Furthermore, other studies have shown that for every 10,000 servings of unpasteurized milk consumed in Kenya, two to three cases of diarrheal diseases result from common toxin-producing bacterium like *E. coli* (Grace *et al.,* 2008).

In addition, high levels of aflatoxins M1 (Kang'ethe and Lang'a, 2009), antibiotic residues (Ondieki *et al.,* 2017), presence of antibiotic resistant bacteria (Ombui *et al.,* 2000) and zoonotic disease causing agents like *Brucella abortus* and *E. coli* 0157:H7 have been reported in both raw and pasteurized milk at farm and market level (Kang'ethe *et al.,* 2007, 2000).

According to a previous report, Nairobi relies majorly on milk supply chains that originate from outside the city and whose characteristics are not well-defined (Alarcon *et al.,* 2017). For instance, unpublished government livestock production annual report for 2012 indicated that milk production within Nairobi was about 39 million litres (GOK, 2012); against the required 388 million litres based on the estimated 125 litres per capita milk consumption in urban areas (SDP report, 2004) for the 3.1 million city residents then (KNBS, 2010). Currently Nairobi with a population of 4.5 million people (KNBS, 2019) and growing at annual rate of about 4% (Aubry *et al.,* 2010), means that more milk will be required thereby putting massive pressure on the existing milk value chains and possible evolution of new ones to satisfy the rising demand. These chains due to complexity of urban food systems may present avenues for introduction and transmission of disease pathogens and other food safety concerns.

There are many factors that may contribute to unsafe milk (Lubote *et al.,* 2014) and challenges of food safety in Africa are precipitated by poor food safety systems, lack of systematic surveillance, underdeveloped human resource and insufficient capacity to determine the magnitude of the problem (FAO, 2004). Considering the competing priorities and inadequate resources in these countries, designing and implementation of interventions to promote food safety requires a targeted risk based approach that focuses on value chain mapping to thoroughly understand the **'what'** (e.g. contamination practices, quality deficiencies, poor accessibility), the **'when'** (risk seasonality), the **'where'** (in which chains, chain nodes, areas it occurs), the **'who'** (who creates it and who is exposed), the **'how'** and the **'how much/many'** (e.g. how much contamination, how many people are exposed) (FAO, 2011a).

Value chain therefore, refers to the sequence of activities required to make a product or provide a service including inputs supply, through production practices, processing, distribution and final disposal of waste products (Kaplinsky and Morris, 2000a). Value chain mapping refers to analysis of people, products, chain profiles, spatial and temporal dimensions and connectivity within a value chain (Kaplinsky and Morris, 2000a). These elements are essential to understand dynamics of the system as well as assessment of the structural vulnerabilities (Alarcon; *et al.,* 2017; FAO, 2011a; Rushton, 2008) and provides the critical framework needed for full analysis of the food system (Kaplinsky and Morris, 2000a; Rich and Perry, 2011; Rushton, 2008).

A comprehensive understanding of the systems structure through value chain mapping and determining how the interactions interplay (governance) therefore is critical in identification of areas requiring interventions. Several authors argue that interactions of actors within the systems are not just random, but are organized somehow (Gereffi, 1994; Gereffi *et al.,* 2005; Kaplinsky and Morris, 2000a; Porter, 1998, 1980).

This brings about the concept of 'governance' that focuses on the structure of interactions and coordination mechanisms existing between actors (Kaplinsky and Morris, 2000b). Matters about who decides what is produced and what rules exist whether they are legislation, private standards or cultural norms (including incentives, agreements, and sanctions) are all explained by governance. An understanding of how such chains are organized and coordinated is important in determining the point of entry if anyone wants to bring any interventions that aims to improve or modify the chains (FAO, 2011a; Kaplinsky and Morris, 2000b).

This is because those involved at every level of the value chain need to see their importance and what they stand to ultimately gain to motivate optimal cooperation (Kaplinsky and Morris, 2000a). For example, Kenya milk marketing is dominated by small scale informal traders who control over 80% of all marketed milk (Leksmono *et al.*, 2006). Informal systems means that the enterprises are not registered or licensed to operate and as such are very difficult to regulate as well as problematic in monitoring food safety hazards and risks (Arzey, 2001; Grace *et al.,* 2010). Being aware of this, there have been attempts by the Kenya government to organize the dairy system by training and certification of informal traders through a program dubbed, "formalization of the informal sector" (Alonso *et al.,* 2018; Omore and Baker, 2009).

Although food safety benefits would be expected in such organized and well-regulated systems, the number of traders adopting training and certification have remained low, primarily due to high cost of acquiring multiple licenses from different government agencies (Alonso *et al.*, 2018). Such arrangement coupled with fragmented regulations have been reported to compromise efforts towards promoting food safety (Abebe *et al.,* 2017; Gereffi and Lee, 2009).

In other areas like, Lebanon, food safety issues have been described to be addressed by several legislative and regulatory decrees with overlapping functions (Abebe *et al.,* 2017) and the food safety laws are termed as fragmented and limited in scope and scale to cover all parts of the food supply chain (Abebe *et al.,* 2017; El-Jardali *et al.,* 2014). Without analyses of the governance to understand the reasons behind non-compliance in the chains, governments cannot achieve food control (Gereffi and Lee, 2009), and yet there is no one food regulation that is a one size fit all.

It is appreciated that urbanized environments are melting pots of activity as that they are all part and parcel of the often shared geographical, social, environmental and political contexts (UN-Habitat, 2014).

The degree of mixing and contact between human and livestock in the congested and sometimes poorly sanitized urban environments creates ecological niches with opportunities for pathogen transmission and some studies have linked urbanization to the risk of emerging infectious diseases (Knobler *et al.,* 2006; Smolinsky *et al.,* 2005). Approximately 60% of human pathogens (FAO, 2011a) and about 80% of novel pathogens have zoonotic origins (Woolhouse and Gowtage-Sequeria, 2005). Foodborne diseases are responsible for approximately 420,000 deaths per year (WHO, 2015). The processes leading to the emergence of novel pathogens or introduction and transmission of food safety hazards and other risks are like those resulting in exposure to and spread of known pathogens. It is appreciated that due to complexities of food chains, urbanization is likely to provide excellent platforms to expand the range of food-borne pathogens as well as to amplify health and economic impacts of a single contamination incident. From the public health perspective, studies linking value chain mapping, governance of chains and investigation of microbial genetics (Manel *et al.,* 2003) in relation to urban settings, are inadequate, yet this is important in developing and evaluating strategies that mitigate health concerns.

Molecular techniques have been developed to differentiate bacterial isolates, and molecular typing is frequently used to identify sources of contamination or infection and to determine routes of transmission and persistence of bacterial strains within various environments (Holderegger and Wagner, 2006). *E. coli* has frequently been used as a molecular marker for relatedness or diversity of bacteria in many studies because of its unique characteristics; it is zoonotic, exists in many hosts, in most environments, on food and in milk (Luo *et al.,* 2011). Certain *E. coli* strains like O157 have themselves emerged through different types of pathways to become very significant zoonotic public health problems (Armstrong *et al.,* 1996; Innocent *et al.,* 2005).

Theoretically, it would be expected that *E. coli* isolates from same cows for instance, and in the same farms and probably the areas supplied by these sources would be genetically similar. Low genetic diversity would indicate a dominant source of contamination (Gambero *et al.,* 2017), but some studies have documented significant genotypic and phenotypic diversity of *E, coli* within a common source (Houser *et al.,* 2008). This means, that designing of interventions should take into consideration dynamics within chains to prevent further contamination and to mitigate the health risks (Harwood *et al.,* 2000).

In this thesis, a combination of methods was utilized to understand Nairobi's dairy value chain in the perspective of food safety. Value chain mapping (Kaplinsky and Morris, 2000a) helped in gaining understanding of the people working in the system, the products and product flows including practices of the different people working in the system. Further, understanding of the governance helped unveil challenges in interaction of the actors and the subsequent food safety challenges.

A combination of value chain mapping with ecological characterization of the food system using bacteriology to understand milk quality and safety coupled with molecular analysis to determine the resultant patterns of *E. coli* diversity provides a novel analysis approach to inform targeted interventions in complex urban food systems.

1.1 Study hypothesis

Rapid urbanization within developing countries exert pressure on the interconnected complex food systems that compromises food safety and governance standards, thus the quality of livestock sourced foods supplied to consumers is impaired.

1.2 Problem statement

In 2012, milk production in Nairobi was approximately 39 million litres (GOK, 2012); against the required 388 million litres for the 3.1 million city residents then (KNBS, 2010). This was based on the estimated 125 litres per capita milk consumption for urban areas (SDP report, 2004). If the production remains constant (although its likely to go lower due to inadequate land to keep more cows and grow pasture), and the estimated per capita consumption does not change, it imply that by 2050, when the Nairobi population will have grown to about 14 million people (Aubry *et al.*, 2010), and, approximately 1.8 billion litres of milk will be required to feed the city dwellers. Similarly, Herrero, (2014), has predicted that demand for milk will triple in the next three decades. This means that almost all milk will be supplied through milk chains originating from production systems based outside the city either locally and / or internationally. This imply that, milk value chains between production and consumption will become even more complex, and further this will diversify the connectivity of health risks through the numerous chains.

Similarly, as human population are increasing per square area with urbanization, animals must also find a way of being accommodated, thus an increased human animal interaction. This increase in degree of mixing and contact between human and livestock in the congested and sometimes poorly sanitized urban environments creates ecological niches with opportunities for pathogen transmission and some studies have linked urbanization to the risk of emerging infectious diseases (Knobler *et al.,* 2006; Smolinsky *et al.,* 2005).

This rapid urbanization coupled with unmatched milk production with the predicted demand for dairy products has been argued to exert pressure to the existing value chains and may trigger mushrooming of additional chains to satisfy the rising demand for dairy products (Herrero *et al.*, 2014).

The complexities associated with complex urban food chains are therefore likely to provide excellent platforms to expand the range of food-borne pathogens as well as to amplify health and economic impacts of a single contamination incident (Foran *et al.,* 2014).

Regulation of food safety laws and monitoring of food risks is therefore critical in ensuring delivery of quality and safe products to the consumer (Gereffi *et al.,* 2005; Gereffi and Lee, 2009). However, there are enormous challenges in enforcing food safety laws due to inadequate capacities throughout the value chain including lack of training on food safety to the majority of value chain actors (FAO, 2004), and the prevailing weak governance systems characterized by fragmented rules with duplication of regulation efforts by multiple government agencies (Alonso *et al.,* 2018). This is further confounded by the inability to monitor food safety hazards along the dairy value chain since most of the milk is marketed through the informal channels (Leksmono *et al.,* 2006), which are difficult to regulate and monitor for the food risks (Arzey, 2001).

Adequate planning of risk management strategies must be cognizant of these shortcomings for effectiveness in food safety. Since priorities always compete in the resource strained countries like Kenya, there are established molecular modelling techniques that can be utilized to explore the most critical points where the greatest impact could be achieved with minimal resources. Such approaches include molecular mapping to understand sources and movement of contaminants along the value chains. For instance, modelling techniques using molecular marker organisms like *E.coli* (Holderegger and Wagner, 2006; Houser *et al.,* 2008; Luo *et al.,* 2011), would be beneficial to inform strategic designing of interventions to prevent further contamination and to mitigate health risks (Harwood *et al.*, 2000).

This study utilized a combination of value chain mapping with ecological characterization of food system using bacteriology to understand milk quality and safety coupled with molecular analysis to determine the resultant patterns of *E. coli* diversity to provide a novel approach for analysis of complex urban food systems to inform targeted interventions that improves quality of animal source foods and wellbeing of communities.

1.3 Justification

Debates on food safety continue to dominate the research agenda, particularly in the area of gathering information to inform policy. The Kenya government has been struggling to organize the dairy sector for ease of regulation, revenue collection and monitoring of food safety (Alonso *et al.,* 2018; Omore and Baker, 2009). Additional evidence that support such efforts are critical. In answering the set of research questions in this study, this thesis broadly contributes towards the efforts for holistic understanding of complex food systems in urban areas towards addressing food safety. The thesis demonstrates that analysis of complex systems can benefit from borrowing research methods from other disciplines.

Value chain mapping and analysis of governance (Kaplinsky and Morris, 2000a) emphasizes on the need to critically analyze each component of the value chain as each of them would present unique avenues for food safety concerns. This is particularly because distribution of risks are not uniform and is driven by certain factors, whether known or unknown (Smolinsky *et al.,* 2005). In the effort to enforce food safety policies and other regulations, governments ought to be aware of factors hindering compliance, rather than deploying a one size fit all approach.

Furthermore, this study would contribute to the body of knowledge on adoption of holistic analysis, particularly of complex food systems prior to making much inferences on interventions. Finally, the results are useful for researchers and scholars who work in the dairy value chains, and who could replicate similar studies under different study contexts. The thesis has identified key areas for future research which can be explored by researchers and scholars willing to advance the dairy value chains research under varying production systems.

1.4 Study objectives

To investigate food safety risks, governance challenges and *E. coli* diversity along the dairy food systems in a rapidly growing urban environment.

1.4.1 The specific objectives of this study included:

1. To map dairy production activities, the stakeholders and flow of dairy products in Nairobi
2. To evaluate governance challenges along the mapped dairy value chains and their implications to food safety
3. To determine bacteriological quality of milk and food safety risks along the mapped dairy value chain
4. To analyze *Escherichia coli* genetic diversity along the mapped dairy value chain

1.4.2 Research questions

1. What is the structure and organization of Nairobi's dairy value chain and how can this analysis benefit design and implementation of better food safety interventions?
2. Are there specific governance themes and challenges faced by actors along the Nairobi's dairy value chain that could be targeted to improve milk safety?
3. How does milk quality and food safety risks differ along the various nodes of the dairy value chain?
4. How can the available molecular modelling techniques benefit policy decision making in reducing food safety risks for vast and complex food system?

1.5 Organization of the thesis

This thesis is organized in eight (8) chapters. **Chapter 1** is a general introduction to the various concepts used in this study including, an introduction of dairy value chains, an overview of food safety, value chain mapping, governance and use of *E. coli* diversity in analysis of food safety. The chapter also provides study hypothesis, problem statement, and justification of the study as well as the study objectives and the research questions. **Chapter 2** comprises the review of literature that was guided by the four specific objectives of this study. The chapter takes an empirical review on structures and organization of the dairy value chains, review on food system governance and challenges faced by actors along food value chains, review on milk quality and food safety risks along the dairy value chains and finally a review on integration of molecular modelling techniques for the benefit of policy decision on food systems. **Chapter 3** presents the materials and methods and provides details on the study area, methods for data collection, procedures for milk sampling and processing in the laboratory as well as approach for data analysis. **Chapter 4** describes results for the value chain mapping.

Chapter 5 describes governance themes and challenges faced by the value chain actors. The description further looks at food safety concerns that are related to these governance themes and challenges. **Chapter 6** presents analysis of milk quality and safety in the Nairobi's complex dairy value chain. **Chapter 7** describes analysis of *Escherichia coli* diversity. **Chapter 8** is the general discussion section that summarizes key findings of the study. The chapter concludes by highlighting key recommendations and future areas for research.

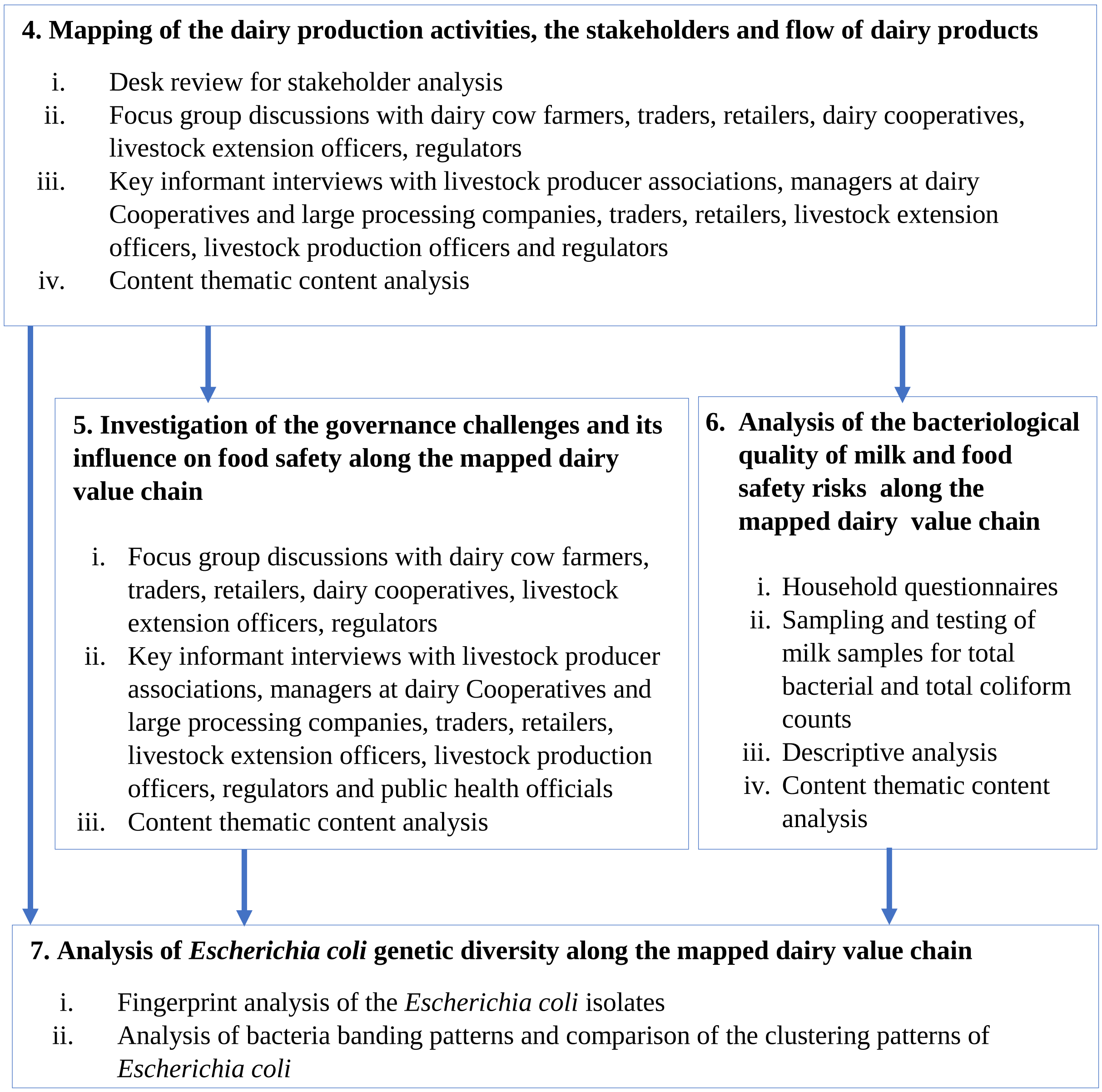


Figure 1: Conceptual framework for the Ph.D. study showing objectives for the various Chapters of the thesis and methods used for data collection and analysis

Source: Drawn by the author

CHAPTER 2: LITERATURE REVIEW

Introduction

Chapter 2 presents background information on structures of the dairy value chains, a review of the governance and challenges faced by actors along dairy value chains, an evaluation of milk quality and food safety risks along the dairy value chains and finally a review on integration of molecular modelling techniques for the benefit policy decision on food systems.

2.1 Empirical review on structures and organization of the dairy value chains

Value chain refers to the **sequence of activities** required to make a product or provide a service (Porter, 1985). A dairy value chain therefore is a collection of activities that are performed to design, produce, market, deliver and support its products (or services) from inception to final disposal of waste products (Kaplinsky and Morris, 2000b). In order to identify sources of competitive advantage in a value chain, various economists recommend a systematic examination of all activities involved at every level (FAO, 2011a; Kaplinsky and Morris, 2000b; Porter, 1985). Reports from analysis of various dairy value chains reveal six main segments/ structures of the dairy value chain (Achchuthan and Kajananthan, 2012; Khoi, 2013; Lowe and Gereffi, 2009; Nguyen *et al.*, 2016; USAID, 2008). These include the segment on inputs supply, production activities, milk collection/bulking, processing/value addition, marketing/distribution and consumption.

2.2 Inputs supply in dairy value chains

Inputs refers to the main products and services a dairy farmer requires to run the dairy operation. These include the dairy stock, feeds, water, animal health services, and breeding services like artificial insemination (A.I), credit facilities and milking equipment among other services. Feeding of dairy cows accounts for the largest cost of production and this differs between the different production systems and from country to another based on the available raw materials (Covaleski, 2005). For example, according to the mentioned FAO 2014 report that mapped global animal feeding systems, found that feeding of dairy cows in the developed countries was adapted for large-scale high yielding cows that were majorly confined. This is supported by a different study conducted in USA that found feeding of the cows to rely majorly on alfalfa hay, grain/corn silage, and soybean meal which were grown in large scale farms and supplied by several contracted local providers (Gereffi and Lee, 2009). On the other hand, feeding of dairy cows in the developing countries is designed to support smaller herd sizes that are generally low yielders, mainly on locally produced roughage (Covaleski, 2005).

Studies conducted in several developing countries reveal an over reliance on rain-fed pastures which commonly include natural grass, grown grass, legumes, crop residues, cereals and oilseed by-products (Khoi, 2013; Maleko *et al.,* 2018; Nguyen *et al.,* 2016; Sangeda and Maleko, 2018). These are often supplemented with commercial concentrates. That applies to Kenya (Nangole *et al.,* 2010; Rao, 2019) and with feeding costs contributing up to 80% of the total production costs under intensive production systems (Tegemeo, 2016; Wambugu *et al.,* 2011).

Due to the numerous challenges in obtaining sufficient feeds throughout the year, some farmers result to sourcing for pastures/ fodder by the roadsides and gathering of market left-overs among other unconventional animal feed sources (Alarcon *et al.,* 2017; Nangole *et al.,* 2010; Rao, 2019; Takiya *et al.*, 2019). While cows can convert feeds unpalatable and unfitting for humans into high-quality, protein-rich products (Matte *et al.,* 2012; Tedeschi *et al.,* 2015), unconventionally sourced animal feeds may result to presence of undesirable contaminants in milk. For instance, presence of heavy metals (Harlia *et al.,* 2018; Muhib *et al.,* 2016; Pilarczyk *et al.,* 2013) and antibiotic resistance bacteria in the environment (Van Boeckel *et al.,* 2019, 2017, 2015) may present opportunities for introduction of such contaminats in milk and the subsequent consequences in human health. Furthermore, other contaminats like aflatoxins in animal feeds have also been found to contaminate milk. For instance, a study conducted in Kenya revealed that up to 86% of feed samples from farmers, 81% from feed millers and 87% from agrovet shops tested positive for aflatoxin B1 (Kang'ethe and Lang'a, 2009). The same study found that aflatoxin M1 was present in about 72% of milk from small-scale farmers and 99% of the pasteurized marketed milk samples. As well, several other studies have shown occurrence of aflatoxins in animal feeds, thus posing significant public health risks (Binder *et al.,* 2007; Rodrigues *et al.,* 2011; Sirma *et al.,* 2019).

Animal health, breeding and extension services are other key inputs in dairy production serving as source of information on animal health, nutrition and productivity (Lowe and Gereffi, 2009). In some countries, these services are mainly offered through a network of private veterinarians (Lowe and Gereffi, 2009), dairy cooperatives (Armagan *et al.,* 2009; Faysse and Simon, 2015; ILRI, 2018; Staal *et al.,* 2001) or extension agents who are either working privately or contracted by the local government (Auma *et al.,* 2017; Chema and Gathuma, 2004; K'Oloo *et al.,* 2015; Nguyen *et al.,* 2016).

In some instances and mostly in developing countries, self-treatment and use of unqualified personnel for management of diseases in dairy cows is common, driven by several factors among them insufficient government support in provision of the animal health services, high cost of seeking veterinary services, presence of active informal service providers, direct marketing of medicines to the farmers and the ease of obtaining these drugs without prescriptions (Auma *et al.*, 2017; Chauhan *et al.*, 2018, 2016; Chema and Gathuma, 2004).

According to World Organization for Animal Health (*OIE*), most countries do not have sufficient veterinary services (Forman *et al.*, 2012; Weaver *et al.*, 2012) including Kenya (*OIE*, 2011). For example, even in the most advanced countries like the USA, the government veterinarians are reported to be scarce due to the high fragmentation of animal health sector with public and corporate sector veterinarians accounting for only 16% of the total veterinarians in the country (Lowe and Gereffi, 2009). In Kenya, breeding, extension and health services are mainly offered by the private sector and to some extent the government (Auma *et al.*, 2017; Chema and Gathuma, 2004; Ilukor, 2017; K'Oloo *et al.*, 2015). However, self-administration of medicines is also common with medicines obtained from agrovets by farmers or other unqualified people (Alarcon *et al.*, 2017; Auma *et al.*, 2017; Ilukor, 2017). Insufficient provision of animal health and extension services may result to inadequacies towards mitigating of animal disease risks including zoonotic diseases (Forman *et al.*, 2012; Woodford, 2004).

2.3 Milk production and dairy value chains

Production includes all activities that are required to convert inputs of products or services into semi-finished or finished goods (Porter, 1985). The farmer is the primary producer in the dairy value chain who carries out various animal husbandry activities such as feeding and undertaking various disease control measures. The global dairy herd is comprised of approximately 809,812,895 heads of animals producing about 843,035,455 tons of milk (FAOSTAT, 2018). Cows represent 32.7% of global dairy herd, followed by sheep (31.0%), goats (26.7%), buffalos (8.6%) and camels (1.0%). The same data show that in 2018, the whole fresh milk from cows accounted for 81% of the total global production followed by buffaloes (15.1%), goat (2.2%), sheep (1.3%) and camel (0.4%).

The global milk production is mainly through small-scale producers but some countries have a well-developed large scale production especially for cows (Lowe and Gereffi, 2009; Midgley, 2016; Werncke *et al.,* 2016). In the USA for example, a study conducted in 2012 to describe the dairy value chain showed that about 49% of the farms had at least 1,000 cows (MacDonald and Newton, 2014). In these large enterprises, milk production and value addition (pasteurization) was described to take place within the farms (Lowe and Gereffi, 2009). In Brazil, the third largest milk producer in the world (FAOSTAT, 2018) is also described to have relatively large herds (an average of 23.1 milking cows) per farm (Werncke *et al.,* 2016). However, in general, milk production is dominated by small- scale production in many countries including India which is the second largest (after USA) producer of milk globally (FAOSTAT, 2018). A study conducted in Pakistan to assess milk production in a peri-urban set up revealed that production was dominated by small-scale farms with an average of four cows per farm (Jalil *et al.,* 2009).

In Vietnam, producers were described to keep an average of 3-10 dairy cows per farm (Nguyen *et al.,* 2016), while in Bosnia and Turkey, about 95% of the dairy farms kept 8-10 cows (Nikolic *et al.,* 2013). In Montenegrin, Europe, of the total cattle population, 98% of the dairy farms were described to keep an average of three cows (Markovic and Dries, 2013).

In Kenya milk production is mainly by small-scale producers who account for more than 80% of all milk producers (SDP report, 2004; Staal *et al.,* 2003), keeping one to five cows producing an average of 6-20 litres of milk per day (Auma *et al.,* 2017; FAO, 2011b; H. Muriuki *et al.,* 2003).

With the numerous small-scale producers arises several food safety challenges due to the uniqueness of production and milk handling practices (Lemma *et al.,* 2018; Paraffin *et al.,* 2018; Ruegg, 2003). Among the common challenges and concerns at farms include lack of adequate information on proper herd management (Henson *et al.,* 2005; King *et al.,* 2017; Lemma *et al.,* 2018), high disease burden at farm level (Donkor *et al.,* 2007; Grace *et al.,* 2008; Kang'ethe *et al.,* 2008a; Paraffin *et al.,* 2018) and thus reduced quality of milk, high contamination due to poor hygiene standards (Donkor *et al.,* 2007; Kang'ethe *et al.,* 2005; Kivaria *et al.,* 2006; Swai and Schoonman, 2011), and high burden of antimicrobial resistance bacteria (Landers *et al.,* 2012; Van Boeckel *et al.,* 2019) among others.

2.4 Milk collection and bulking

Milk bulking involves assembly of milk from the numerous producers at a central point for ease of collection, processing or marketing (Sayin *et al.,* 2011). This is mainly achieved through establishment of milk collection centres (MCCs), also referred to as milk sheds by farmers, thus serve as bridges between producers and agribusiness (IFAD, 2010).

In most cases, the MCCs are specific points or sheds that facilitates ‘line collection’ of milk from producers with a tank (mainly of processors) that passes through the villages collecting milk at specific time of the day (Nguyen *et al.,* 2016; Sayin *et al.,* 2011).

Numerous benefits have been linked to farmers’ affiliation to MCCs. A study conducted in Egypt to assess the evolution of MCCs found that their establishment resulted in increased milk prices and improved milk hygiene (Daburon *et al.,* 2016). This was particularly due to the aspect of training and cooling systems that were introduced. In Turkey, a study conducted to understand the incentives towards farmer’s affiliation to MCCs cited the available opportunities that resulted to diversification of marketing channels, thus increasing their resilience (Sayin *et al.,* 2011). This meant that farmers had an additional outlet of their milk while still selling through their traditional outlets. Other benefits included the availed capacity to improve the dairy enterprise (Achchuthan and Kajananthan, 2012). In most cases, establishment of MCCs is based on proximity of farmers to each other, but also the component of trust is key to sustain the good relationships and to enable farmers’ access to information and informal credits through social connections (Nguyen *et al.,* 2016).

Despite these benefits, MCCs face some challenges among them poor road network which results to increased costs of milk collection (Auma *et al.,* 2017; Faysse and Simon, 2015; Nguyen *et al.,* 2016; Sayin *et al.,* 2011), inability to cope with quality requirements mainly due to lack of equipment (e.g. cold chain), lack of / inadequate training on milk handling (Auma *et al.,* 2017; Faysse and Simon, 2015; Sayin *et al.,* 2011), and presence of numerous intermediaries between farmers and MCCs, thus inability to maintain good milk quality, (Demirbaş *et al.,* 2009).

2.5 Dairy cooperatives

Dairy cooperatives, also referred to as dairy hubs are entities that are collectively owned or managed by farmers for milk bulking and/or chilling and from which farmers may gain access to other services they need for milk production (Mutinda *et al.,* 2015). Dairy cooperatives often receive milk directly from farmers and/or from several MCCs for further bulking and cooling before processing it or further transporting it to large processing companies. Dairy cooperatives are formal entities that are normally registered with regulatory authorities and usually have a constitution governing its membership and operations (Daburon *et al.,* 2016; Khoi, 2013; Kilelu *et al.,* 2019; Mutinda *et al.,* 2015; Ngeno, 2018; Nikolic *et al.,* 2013). The various benefits of farmers affiliating to the dairy cooperatives include improved access to inputs (feeds, A.I and animal health services, extension services), credits, markets and various services (Kilelu *et al.*, 2011; Mutinda *et al.*, 2015; Omondi *et al.*, 2017; C. Rademaker *et al.*, 2016). Studies conducted in Kenya show that shorter distances with less travel time encourage affiliation to the dairy cooperatives (Ngeno, 2018). In addition, some studied show that the more wealthier farmers are more likely to affiliate to cooperatives because they may be able and willing to bear more risks and may have preferential access to inputs and credit than their counterparts (Kassie *et al.,* 2009; Ngeno, 2018; Rao and Qaim, 2011). Some of the challenges faced by dairy cooperatives include high cost of milk collection from the many MCCs and intermediaries (Khoi, 2013; Nguyen *et al.*, 2016; Nikolic *et al.*, 2013) and lack of information to improve on milk quality (Armagan *et al.*, 2009).

2.6 Milk processing/ value addition

Milk processing involves the process of value addition to the raw milk to produce various dairy products like pasteurized liquid milk, milk powders, skimmed milk powder, ultra-heat treated milk, butter, cheese, yoghurt, fermented milk among others (FAO, 2016). There are several factors that influence the final composition of milk products including animal genetics, breed type, environmental factors, nutrition, stages of lactation and parity (Jenkins and McGuire, 2006). Upon reception of milk at the processing plant, there are several tests that are routinely done to ensure that the final products are safe for human consumption. Ideally, the various tests (Burke *et al.*, 2018) as guided by ISO standards catalog ISO/TC34/SC5 (ISO, 2018) are conducted in various milk and milk products.

Milk processing is mainly done within designated milk processing factories in many countries, but this can also be done at farm level or at the dairy cooperatives as is the case in most developed countries (Lowe and Gereffi, 2009). Such investments are majorly driven by several factors including the changing consumer demand patterns, prices, tastes and preferences, health, wellness, safety, experience and social impact (Deloitte, 2015). In most developing countries milk is processed by small-scale processors and this varies from country to another depending on local tastes, market demand, dietary habits and culinary traditions.

In Kenya, a few studies show that most milk is sold unprocessed with only 20% getting to processors (Leksmono *et al.*, 2006; Njarui *et al.*, 2010; Omore *et al.*, 2004). A study conducted in one of the high producing zones in Kenya showed that most cooperatives bulked and sold a huge proportion of milk raw to consumers (Njarui *et al.*, 2010).

Some of the main challenges faced by processors is poor infrastructure. The processors have to move from one collection centre to another picking small quantities of milk which increases the cost of transportation coupled with other inefficiencies in the dairy value chain which results in significantly high price of processed dairy products compared to those obtained from the informal value chain (TechnoServe Kenya, 2008). In addition, the processors have to deal with stiff competition from the informal sector and numerous costly licensing requirements (Abebe *et al.,* 2017; Alonso *et al.,* 2018; Nguyen *et al.,* 2016; Omore and Baker, 2009). Furthermore, the processors have to deal with poor utilization of the processing capacity due to insufficient milk supplied. For example, a study conducted in Montenegrin (in Europe), showed that only 15% of raw milk reaches the processors (Markovic and Dries, 2013). The study indicated that of the 85% of the milk that remains at farm, most of it was used to make various value added products like cheese, yoghurt and other products) while only a small proportion was sold as fluid milk. This is similar to the Kenya dairy value chain where about only 14% of milk is processed but different in that most of the milk that remains at farms is sold as fluid raw (Omore *et al.,* 2004).

2.7 Milk distribution and marketing

Milk transportation from farms is normally a responsibility of the farmer and in most developing countries, this is normally done on foot, bicycle, donkeys or vehicles (Daburon *et al.,* 2016; Demirbaş *et al.,* 2009; Omore *et al.,* 2004; Wambugu *et al.,* 2011). For the large dairy cooperatives and processors, milk from producers is usually transported by privately owned vehicles (mainly tankers) and/ hired vehicles (IFAD, 2013; Khoi, 2013; Lowe and Gereffi, 2009; Paludetti *et al.,* 2019). In most developing countries, milk is sold through both formal and informal distribution channels (Nguyen *et al.,* 2016; Nikolic *et al.,* 2013; Omore *et al.,* 2004).

The formal channels are usually those recognized through licensing by the relevant authorities and may include wholesalers, distributors, licensed retailers like milk bars and restaurants, while the informal chains are characterized by lack of licensing and thus limited regulation. These include roadside milk vendors, hawkers and some traders (Khoi, 2013; Omore *et al.*, 2004). Countries producing large volumes of milk through intensified production systems sell their milk mainly through the formal channels. For example, in the USA, a study conducted in 2009 to assess the US dairy value chain found that the top five dairy cooperatives distributed about 50% of the USA milk and about 49% of this milk was sold through supermarkets (Lowe and Gereffi, 2009). A study in South Africa, one of the African countries producing milk through intensive systems, sells over 95% of the milk via formal channels (Midgley, 2016).

In Kenya, for milk to reach the diverse milk consumers, over 80% of milk is marketed through informal channels (Auma *et al.*, 2017; FAO, 2011b; Leksmono *et al.*, 2006; H. Muriuki *et al.*, 2003). Farmers in low production areas are reported to be more likely to sell milk directly to consumers while those in high production areas are more likely to form longer milk distribution chains (Auma *et al.*, 2017).

2.8 Empirical review on food system governance and challenges faced by actors along food value chains

System governance is one of the central areas of value chain analysis, which aims at understanding the inter-linkages and inter-dependencies of activities and people operating in the chains (Kaplinsky and Morris, 2000b). This implies that interactions of actors within any systems are not just random, but are organized somehow, and with decisions at various levels that have upstream or downstream consequences on the food system (Gereffi, 1994; Gereffi *et al.*, 2005; Kaplinsky and Morris, 2000b; Porter, 1998, 1980).

Matters about what is produced, what rules exist and who sets the rules whether they are legislation, private standards or cultural norms are all explained by governance. Three major factors that influence governance include: (1) “the complexity of information or knowledge required to sustain a transaction” (‘complexity of transactions’); (2) the ability to codify and efficiently transmit this information (‘ability to codify transactions’); and (3) the capacity of suppliers to meet the requirements for the transactions (‘capabilities in the supply-based’) (Gereffi *et al.,* 2005). This therefore relates to the type of coordination existing in the chain (level of coordination asymmetry), but also to the issues of power asymmetry (dominance), it’s associated behavioural response and the operational barriers and benefits generated (Gereffi *et al.,* 2005). For example, a study conducted in Turkey showed that dominance of an actor in the system influenced how most of the milk was marketed in the country (Nguyen *et al.,* 2016). In this study, 32 out of 44 milk collection points sold all their milk which was said to represent 85% of the districts outputs to one major company. The relationship was said to be influenced by numerous incentives that farmers received from the company which included access to credit facilities, provision of equipment and trainings among others. However, the pricing and terms of payment (bonuses, penalties, quality and standards) were all decided by the company without any consultations with farmers. This is also seen in other study conducted in Turkey where some private companies were said to develop captive relationships with farmers by drawing short term contracts and threaten to switch sourcing of milk if any of the suppliers did not comply (Nikolic *et al.,* 2013). In order to encourage quality milk production, some companies have a policy for penalties and bonuses where milk payments are done on quality attributes (Nguyen *et al.,* 2016).

Effective coordination in the chain is essential to facilitate identification and use of dynamic opportunities that can improve efficiency and reduce risks (Kaplinsky and Morris, 2000b). For example, a study conducted in Lebanon to determine the effect of governance structures on food safety management found that there were differences in how food safety was managed by various producers (Abebe *et al.,* 2017). The food safety management systems were described to be applied only by few large-scale processors who focused more on large farms. This probably underscores the major governance challenges in that system whose regulatory systems were described as fragmented, limited in scope and scale to cover food safety and with overlapping functions between the multiple government agencies (El-Jardali *et al.*, 2014). Another study conducted in Vietnam found that the relationships between farmers and milk collection points were mainly driven by proximity to milk collection centres located by roadsides for the large processing companies(Nguyen *et al.*, 2016). The study established that societal connections were very influential in milk marketing such that social proximity was found to reduce uncertainties related to price, quality and quantity, and enabled access to informal credit, information and knowledge. This was particularly beneficial for farmers who were organized in hubs/groups, a model that was perceived to particularly benefit small-scale producers.

Other studies conducted to assess governance challenges influencing the dairy sector in various countries identified numerous structural vulnerabilities that were linked to low milk productivity, poor road network and fragmentation of producers who were dispersed in various places (Markovic and Dries, 2013; Nguyen *et al.,* 2016; Nikolic *et al.,* 2013). Consequently, this was said to increase the cost of milk collection and thus reduced profitability to both processors and producers.

As a result, processors have a reduced incentive to investing in appropriate milk management systems like cold chain, ultra-heat milk treatment and provision of organized extension services. Consequently, such loopholes present opportunities for unscrupulous groups into the farms to entice producers on quick wins. For instance, in 2008, there was a Chinese scandal that involved addition of melamine into the infant milk formula resulting to kidney stones and illness in almost 300,000 children and six infant deaths in several countries (Pei *et al.,* 2011). A detailed investigation found that melamine due to its high nitrogen component was offered to farmers by some manufacturers who called it "protein powder" to artificially boost the apparent presence of protein in the infant formula, a deception for the milk quality inspectors (Fairclough, 2008).

In Kenya, over 80% of milk flows through informal chains (Leksmono *et al.,* 2006; H. Muriuki *et al.,* 2003), and these are difficult to regulate and to monitor food safety risks and other hazards. In 2009, the government attempted to organize the informal sector through a program dubbed, "*formalization of the informal sector*" (Omore and Baker, 2009), and this was particularly fought by the formal system who were demanding that government should shield them against the traders (informal system), who were viewed as unfair competitors. The program entailed training on milk handling practices and business development modules, followed with certification of the traders by the Kenya Dairy Board (KDB). The trained and certified traders were expected to adhere to all the rules set by the KDB including selling of milk inside appropriate premises as well as payment of taxes, and acquiring of the various licences and permits (KDB, 2020) as a way of complying to the government rules and regulations. A follow up study among the previously trained informal traders and aiming at understanding the incentives and challenges for operating in the informal dairy sector found that several traders were faced with numerous challenges that hindered participating in more trainings as well as obstructed compliance (Alonso *et al.,* 2018).

Among the challenges were high cost of training by the business development service providers, prohibitive costs related to acquiring multiple and costly licenses to operate formally as well as ambiguous regulations which were described as unclear especially for those entering the business.

Kenya's dairy sector is regulated by the Dairy Industry Act Cap. 336 (GoK, 2012a). A few examples of provisions from this Act that support food control and safety include:

- The Board (KDB) shall not issue a certificate of registration and shall not register any person pursuant to this regulation unless the premises, plant, equipment, machinery, facility or structure which is the subject of the application fulfils the documentation, structural, construction, hygienic, environmental or any other requirements of these regulations and any other relevant legislations
- The Board may cancel a registration and revoke the certificate issued thereof if the holder of the certificate:
  - combines dairy produce operations with business that is considered incompatible with the dairy produce by the Board
  - has, in connection with his operations or structure, an employee who is suffering from any contagious or infectious disease certified by a medical practitioner and no remedial action has been taken at all or satisfactorily, or
  - has substantially violated any of the hygiene and safety measures required under the Act, or any other written law, or if the facility, premises, equipment, machinery or structure is not in a good state of repair.

In addition to the Dairy Industry Act, there are several other laws that have provisions for food control and safety. These include Public Health Act Cap. 242 (GoK, 2012b), Veterinary Surgeons and Veterinary Para-professionals Act No. 29 of 2011 (GoK, 2012c), Animal diseases Act Cap. 364 (GoK, 2012d) and Food Drugs & Chemical Substances Act Cap. 254 (GoK, 2012e). It is evident therefore that the current formal regulation framework has adequate provisions for promoting food safety. Apart from the laws, there are other instruments that implement the laws and some of those related to dairy industry include: the dairy master plan (MALF, 2010), Sessional Paper no. 5 of 2013 on the national dairy development policy (MALF, 2013) and other sector specific strategic plans towards development of agriculture, livestock and health among others. Moreover, there exists several standards developed by the Kenya Bureau of Standards (KEBS) to guide on minimum food quality and safety requirements (KEBS, 2020) as well as availability of privately driven internal quality management processes like ISO 22000 in large dairy cooperatives and processing companies.

Among the key challenges that hinder adequate implementation of these laws and other policy instruments include poor harmonization of various regulations, high costs of compliance (Alonso *et al.,* 2018; Omore and Baker, 2009), insufficient capacities including scarce personnel and laboratory facilities and lack of consumer awareness programmes which would be key in creating demand for quality and safe products (FAO, 2004). Without analyses of the governance to understand the reasons behind noncompliance in the chains, governments cannot achieve food control (Gereffi and Lee, 2009), and yet there is no one food regulation that is a one size fit all.

2.9 Empirical review on milk quality and food safety risks along the dairy value chains

Food safety comprises the practices and conditions promoted across a food supply chain with the intention of ensuring food quality and preventing contamination and foodborne illness. Food safety is one of the major public health concerns affecting competitiveness of most dairy value chains in most countries (Gereffi *et al.,* 2005; Gereffi and Lee, 2009). World Health Organization (WHO) estimates that each year globally, unsafe food results to more than 600 million cases of foodborne illnesses and 420,000 deaths (WHO, 2015). Approximately 30% of those deaths occur amongst children under 5 years of age, while about 33 million healthy daily adjusted life years (DALYs) are lost.

It is appreciated that urbanized environments are melting pots of activity as that they are all part and parcel of the often shared geographical, social, environmental and political contexts (UN-Habitat, 2014). The degree of mixing and contact between human and livestock in the congested and sometimes poorly sanitized urban environments creates ecological niches with opportunities for pathogen transmission and some studies have linked urbanization to the risk of emerging infectious diseases (Knobler *et al.*, 2006; Smolinsky *et al.,* 2005). Approximately 60% of human pathogens (FAO, 2011a) and about 80% of novel pathogens have zoonotic origins (Woolhouse and Gowtage-Sequeria, 2005). Foodborne diseases are a problem in both the developed and developing countries. In the USA alone, foodborne infections were estimated to cause approximately 48 to 76 million illnesses, 128,000 to 325,000 hospitalizations, and 3,000 to 5,000 deaths each year (Mead *et al.,* 1999; Scallan *et al.,* 2011). According to Mead, most of the illnesses (62 million), hospitalizations (265,000) and deaths (3,200) in the USA resulted from food contamination with unknown pathogens, while Salmonella, Listeria, and Toxoplasma constituted 75% of all cases caused by the known microorganisms (Mead *et al.,* 1999).

Apart from the US, other developed countries have reported foodborne related health concerns. In Italy for instance, routine testing for *Salmonella enterica* and *Listeria monocytogenes* on various animal sourced foods for two years detected in 2.2% of 71,643 food samples examined (Busani *et al.,* 2005). This, however, was thought to be an underestimation of the true food situation as the samples were few and not representative of the general population since were only meant for official food controls. The highest contamination with the *Salmonella enterica* were observed in raw poultry products (9.9%), followed by processed meat (5.3%), raw pork (4.9%) and 0.1% for dairy products. On serotyping, the report further indicates that about 50% of the bacteria isolates were like those that were commonly isolated in humans confirming the possibility of zoonotic potential.

A coordinated nine-year food-sampling program designed to monitor microbiological quality and safety of specific ready-to-eat products in the United Kingdom (UK), revealed numerous food safety concerns with an overall unsatisfactory rate of 17% for aerobic colony counts, 1.6% for *Escherichia coli* (*E. coli*), and 0.5% for Listeria species (Meldrum *et al.,* 2005). Furthermore, a review of food borne diseases attributed to consumption of milk in England for a four year period (1992-1996) found that out of the 600 people that got ill upon consumption of raw milk, 45 were admitted in the hospital (Djuretic *et al.,* 1997). Of these, Salmonella species were responsible for 11 outbreaks, while the rest was from Campylobacter species (5), Vero cytotoxin producing *Escherichia coli* O157 (3) and *Cryptosporidium parvum* (1 outbreak). In a national survey done by the Australian government to monitor foodborne diseases, established that foodborne illnesses were responsible for about 100 outbreaks, some of them implicated to dairy products (Kirk *et al.*, 2010).

Another study estimating proportion of diseases due to milk and milk products among food-borne diseases caused by Salmonella species, *Staphylococcus aureus, Listeria monocytogenes*, and pathogenic *E. coli* in France and other seven developed countries revealed that milk and milk products were implicated in 1-5% of the total bacterial disease outbreaks (De Buyser *et al.,* 2001). Further the report states that of the 60 milk related outbreaks investigated, various bacteria were responsible with salmonella species resulted to highest number of outbreaks (29 outbreaks) while the rest resulted from *Listeria monocytogenes* (10 outbreaks) pathogenic *E. coli* (11 outbreaks) and *Staphylococcus* for 10 outbreaks.

In the developing countries, there have been numerous food safety concerns ranging from presence of zoonotic bacteria, antibiotic residues, antibiotic resistance and aflatoxins among other chemicals like formalin, hydrogen peroxide and Melamine. Microbial contamination is labelled as one of the leading concerns in food systems in developing countries mainly due to inadequate and poorly developed food safety structures and policies (FAO, 2004). A study conducted to estimate the occurrence of *Salmonella species* and *E. coli* in milk value chain in Tanzania reported a prevalence of 37.33% for Salmonella species and 90.67% for *E. coli* (Lubote *et al.*, 2014). The study established that the prevalence of these micro-organisms was highest in milk sold by the street vendors (43.75%), while the lowest prevalence was in milk collected directly at the dairy farms (33.33%). The mean values of the total coliforms per millilitre (cfu/ml) indicated that milk deteriorated as it exited the farm through the various nodes of market nodes of the value chain (vendors and shops). Individual interviews conducted during the study revealed that poor animal husbandry, poor hygienic practices, lack of refrigeration and less awareness of the zoonotic pathogens were strongly associated with the prevalence of the micro-organisms.

A study conducted in Ghana to determine milk quality and characterize antimicrobial resistance (AMR) of Salmonella species in informally traded fresh milk reported a high bacterial load and numerous genetic resistance diversity to various antibiotics (Parry-Hanson Kunadu *et al.,* 2018). *E. coli* O157:H7 and *Staphylococcus aureus* were found to be present in 34.3% and 12.9% of dairy products respectively and with no significant differences in overall bacterial quality between raw and heat-treated milk.

Several other studies in Africa have reported diverse range of bacteria in raw milk including *Escherichia coli, Staphylococcus aureus, Pseudomonas, Bacillus,* and *Corynebacterium* species, some of which are zoonotic and can result to humans infections (Millogo *et al.,* 2010; Tryness *et al.,* 2011). Studies on the informally marketed raw milk have shown presence of wide range of micro-organisms particularly those of the *Enterobacteriaceae* family, an indication of poor hygiene (Donkor *et al.,* 2007; Kang'ethe *et al.,* 2005; Kivaria *et al.,* 2006; E. S. Swai and Schoonman, 2011). Furthermore, some highly pathogenic micro-organisms like *Mycobacterium species* have also been reported (Donkor *et al.,* 2007). It has also not been uncommon to have bacterial growth in pasteurized and ultra-heat treated milk (Ibanga *et al.,* 2014; Roesel and Grace, 2014), which could be an indication of system failure in terms of ensuring high quality of milk that arrives at processing plants or faulty pasteurization processes.

Apart from bacterial related problems, another example touching on compromised food system and resulting to serious public health outcome is the 2008 China scandal where infant formula was contaminated with melamine (Pei *et al.,* 2011). Melamine due to its high nitrogen content was meant to artificially boost the apparent presence of protein in the infant formula, a deception for the milk quality inspectors. As a result, this adulteration resulted to kidney stones and illness in almost 300,000 children and six infant deaths.

Further probing into the case revealed several loopholes in the China's dairy value chain where some manufacturers were reported to have offered a new version of protein powder (melamine) though it wasn't labelled so until it caused the numerous health problems to the infants (Fairclough, 2008).

Kenya, like other developing countries has a relatively huge burden of foodborne diseases. A study conducted to establish health hazards in milk under different marketing conditions found that up to 80% of samples did not meet national bacterial quality standards and 16% of the traded milk contained antibiotic residues (Omore *et al.,* 2000). The report noted that higher bacterial counts increased along the value chain as the milk left the farms through long distances to the markets and especially the chains supplying the urban areas. Other studies have shown that for every 10,000 servings of unpasteurized milk consumed in Kenya, two to three cases of diarrheal diseases result from common toxin-producing bacterium like *E. coli* (Grace *et al.,* 2008). In addition, this study reported presence of zoonotic disease-causing agents like *Brucella abortus* antibodies in pasteurised milk (25%) and raw milk (2-5%), while *E. coli* 0157:H7 was detected in 1% of the tested milk samples. Other studies have shown a 4% and 5% prevalence of antibodies to brucellosis in milk obtained from farms and from pooled samples at market level respectively (Kang'ethe *et al.,* 2007, 2000). Apart from bacteria, aflatoxin is another food safety concern that has been reported in the Kenya dairy value chain (Kang'ethe and Lang'a, 2009). The study by Kang'ethe established that 72% of milk from small scale dairy farmers, 84% from large and medium scale farmers and 99% of the pasteurized marketed milk were contaminated with aflatoxin M1. Aflatoxin M1 is a serious public health threat has been associated with liver cancer in humans and is excreted from cow udder following ingestion of feeds that are contaminated with aflatoxin M1 (Sirma *et al.,* 2019).

Other public health concerns cited from the Kenya dairy value chain is high levels of antibiotic residues in milk (Ondieki *et al.*, 2017) and presence of antibiotic resistant bacteria (Ombui *et al.*, 2000).

Specific studies conducted along Nairobi's dairy value chain also reveal important food safety concerns. A survey conducted to establish the occurrence of Aflatoxin M1 in the informally traded milk in Nairobi established that overall, 55% and 6% of the samples exceeded the maximum allowable levels by European Union of 50 parts per trillion (ppt) and the USA Food and Drug Administration (500ppt) respectively (Kirino *et al.,* 2016). The highest levels of Aflatoxin M1 were detected in milk that was directly sourced from farms and that sold at the kiosks and milk bars. Other food safety concerns identified were presence of antibodies to brucellosis in about 1% of the tested milk samples (Kang'ethe *et al.*, 2007); antibiotic resistant bacteria in milk and meat (Ombui *et al.,* 2000), antibiotic residues (Ekuttan *et al.,* 2007; Kang'ethe *et al.,* 2005; Shitandi.A, 2004), and presence of pathogenic *Escherichia coli* in marketed milk (Kang'ethe; *et al.,* 2007).

All these studies point to some level of weaknesses in food systems, and therefore food safety is not guaranteed. Challenges of food safety especially in developing countries are precipitated by poor food safety systems, lack of systematic surveillance, underdeveloped human resource and insufficient capacity to determine the burden of the food safety problem to inform policy and interventions (FAO, 2004). Furthermore, over 90% population in the developing countries rely on foods traded through informal markets which are characterized by non to minimal regulation, poor surveillance of public health hazards, desire to make profits whatever that takes, including adulteration of the products among others (Roesel and Grace, 2014). Such and other related deficiencies in the structural organization of food systems makes them difficult to thrive.

According to FAO and WHO (FAO, 2004), some factors that need to be considered in order to support food safety efforts, include enhanced political commitment to deal with foodborne problems, establishment of adequate interdisciplinary collaborations and strengthening of food surveillance systems to generate adequate data for informing policies and interventions. Considering the competing priorities and inadequate resources in these developing countries, designing and implementation of interventions to promote food safety requires a targeted risk based approach that focuses on value chain mapping to thoroughly understand the critical areas of intervention that would require minimum inputs, yet generating maximum impacts (FAO, 2011a).

2.10 Empirical review on integration of molecular modelling techniques for the benefit of policy decision on food systems

Emergence and transmission of public health threats including diseases has been described as dynamic and complex (Fineberg and Wilson, 2010). Such complexities have been associated with several drivers including spill over from wildlife (Plowright *et al.,* 2011; Wood *et al.,* 2012), globalization (Jones *et al.,* 2008), climate change (Colwell *et al.,* 1998), urbanization (Fineberg and Wilson, 2010; Smolinsky *et al.,* 2005), adaptation of micro-organisms (Morse, 1995), increased travel (Wilson, 1995) and many others. The intention of anybody dealing with food safety or disease control is basically to minimize the risk to a level that is non-significant since zero-risk is neither practical nor achievable (King *et al.*, 2006). This is because some factors that influence distribution of risk are unknown and even those known are not evenly distributed. Such factors are particularly propagated by the complex system linkages associated with social, ecological, environmental dynamics and economic factors (Wood *et al.*, 2012). Historically, approaches dealing with disease threats are mainly reactive, meaning that activities transpire during or after an outbreak (Smolinsky *et al.,* 2005).

However, contemporary research suggests that more comprehensive approaches of combating health threats would involve a forecasting approach (Davis *et al.,* 2004; Keeling *et al.,* 2001), or prediction of broad patterns in pathogen evolution or actually defining the underlying causes of emergence (FAO, 2011a; Taylor *et al.,* 2001). For this purpose, molecular techniques have proven to be useful tools.

For instance, molecular techniques have proved to be powerful in informing decision making during outbreak investigations and response (Dallman *et al.,* 2015; Underwood *et al.,* 2013). In 2009, an outbreak of entero-hemorrhagic *Escherichia coli* (EHEC) was reported in the United Kingdom among 93 visitors who had petted animals on an open farm (HPA, 2010; Underwood *et al.,* 2013). Phylogeny based on whole-genome sequencing and epidemiological data linked the outbreak to gross contamination of the environment which possibly was passed on from the positive animals, due to similarity of the gene sequences. This discovery resulted to a temporary ban of animal petting in the open animal farm until the outbreak was under control. A different study conducted in Canada to investigate a national-wide outbreak associated with *Listeria monocytogenes* from ready to eat meat, discovered three distinct, but highly related strains (Gilmour *et al.,* 2010). Of significant importance in this outbreak was discovery of two isolates that harbored a 50 kilo base pairs putative mobile genomic island encoding translocation and efflux functions. These parameters had not been discovered before and probably that is why the outbreak became large compared to previous outbreaks. This analysis confirmed the relevance of utilization of molecular technologies during high priority public health events and paved way for improved laboratory analysis of Listeria monocytogenes.

Advanced molecular diagnostic techniques have further been underscored in another study that reported an outbreak of diarrhea in a nursery school and whose cause was difficult to establish through ordinary serotyping (Dallman *et al.*, 2015). Genome sequencing of faecal samples rapidly confirmed that isolates of Shiga toxin-producing *Escherichia coli* (STEC) O26:H11 were associated with the outbreak. The bacteria were shown to be distinct from those analysed and demonstrating a linkage at the molecular level sharing a common source. This finding resulted to a change in the testing paradigm and prompted a review of the existing methods that were available for detection and typing of non-O157 STEC during outbreaks and in routine surveillance. Other studies have underscored the utility of molecular techniques in situations where conventional methods are unable to provide a conclusive diagnosis (Harris *et al.*, 2010; Lewis *et al.*, 2010).

Molecular techniques have also been utilized to detect emerging pathogens and thus becomes useful in prevention of introduction and spread of such micro-organisms. For example, the large outbreak in Germany in 2011 was described to be unique as the aetiology was discovered to be a combination of genomic features containing characteristics of pathotypes Entero-Aggregative (EAEC) and Entero-Hemorrhagic (EHEC) *E. coli*. The resultant strain was a new pathotype which was termed Entero-Aggregative-Hemorrhagic *E. coli*, EAHEC, (Brzuszkiewicz *et al.*, 2011). This finding as well as similar results from other studies supported a review of standards or legislations to prevent escalation of similar outbreaks (Honish *et al.*, 2005; Keene *et al.*, 1997). For example, in Canada, it was shown that that despite having met regulated microbiological and aging requirements, a certain type of cheese (unpasteurized *gouda* cheese) was implicated to human infections with *E. coli* O157:H7 (Honish *et al.*, 2005).

This resulted to a review of the federal legislation prohibiting preparation of that cheese from raw milk. Other studies have supported a molecular relationship between outbreaks in humans with animals and environment (Clermont *et al.,* 2011; HPA, 2010; Keene *et al.,* 1997; Underwood *et al.,* 2013) and the measures have been aimed at disconnecting the source from humans.

As seen in most of these studies described here, *E. coli* is an excellent molecular marker for relatedness or diversity of bacteria in many studies because of its unique characteristics; it is zoonotic, exists in many hosts, in most environments, on food and in milk (Luo *et al.,* 2011). Certain *E. coli* strains like O157 have themselves emerged through different types of pathways to become very significant zoonotic public health problems (Armstrong *et al.,* 1996; Innocent *et al.,* 2005). About 50% of *E. coli* population might reside in secondary habitats (Savageau, 1983) where they replicate to establish distinct stable strains that are different from the original host-adapted populations (Byappanahalli *et al.,* 2007, 2006; Walk *et al.,* 2007). Soil is particularly of significant importance in promoting environmental selection pressure which enriches the locally adapted genotypes that may contribute to the genomic diversity which may potentially transmit stress tolerant strains to new hosts through food or water (Bergholz *et al.,* 2011). The resultant heterogeneity therefore can serve as markers for microbial movement (Feng *et al.,* 2003). This is important in understanding critical points of disease emergence (or food safety) and transmission to understand the linkages between the source of pathogen and the route of transmission. In this regard, several studies have demonstrated the utility of molecular techniques like landscape genetic analysis to understand how *E.coli* deposition in soil changes extra-host population, by creating various genetically diverse *E.coli* strains (Byappanahalli *et al.,* 2006; Fremaux *et al.,* 2008; Texier *et al.,* 2008).

Risks of environmental contamination of milk with *E.coli* have previously been documented, linked to unhygienic practices like milking with uncleaned hands, unwashed cow udders at milking as well as poor milk post-harvest handling practices (Shija, 2013; Sserunjogi and Grimaud, 2007). Nevertheless, some studies have linked the presence of pathogenic *E.coli* strains in milk to infected cows, especially those with mastitis or contamination of their immediate environments (Cobbold and Desmarchelier, 2000; Gonggrijp *et al.,* 2016; Kuhnert *et al.,* 2005; Vicente *et al.,* 2005).

Food safety is of paramount significance particularly in urban areas where food systems are characterized by complex, interdependent and interlinked food chains, which may present excellent opportunities for introduction and transmission of pathogens (Alarcon; *et al.,* 2017; Carron *et al.,* 2017; Foran *et al.,* 2014; Muloi *et al.,* 2018). Such public health threats may arise at farm level (Busani *et al.,* 2005; Parry-Hanson Kunadu *et al.,* 2018) or as the products move through the interconnected value chains.

In the current study, analysis of *E. coli* genetic diversity has been utilized to explore the patterns of these micro-organisms (regardless of their importance in pathogenicity) at various nodes of the Nairobi's dairy value chain. This is because whenever *E. coli* is exposed to a certain environment outside its natural host, it adapts to its new environment due to selection pressure (Byappanahalli *et al.,* 2007, 2006; Ishii and Sadowsky, 2008; Walk *et al.,* 2007). The level of selective pressure is important in identification of host sources of the bacteria (Ibekwe *et al.,* 2011; Zexun *et al.,* 2005). Probable source (s) of these bacteria is achieved via comparison of fingerprints which involves phenotypic and genotypic profiles of the *E.coli* isolates with reference to the fingerprints of *E.coli* isolated from known environments (Mohapatra *et al.,* 2007).

Genotypic characterization aims at detection of specific genetic variations of the organism/ host using molecular techniques such as Pulsed field gel electrophoresis (PFGE) or repetitive palindromic DNA sequences, Rep PCR, (Sheludchenko, 2011; Zulkifli *et al.*, 2009) while phenotypic profiling distinguishes host specific biochemical properties such as building profiles for antibiotic resistance (Anderson *et al.*, 2006; Stefanowicz, 2006). Such analytical molecular techniques would help to understand the flow of *E. coli* and further deepens understanding of the relationships of these bacteria at various nodes of the milk value chains. An understanding of the correct source of contaminants and avenues for transmission is critical in maintaining the integrity of food as well as execution of better management practices to prevent transmission and emergence of food borne diseases (FAO, 2011a).

The studies presented in this chapter have developed much scientific knowledge about dairy systems, including their structures, governance and challenges that affect food safety and utilization of molecular techniques for policy interventions. However, there are numerous gaps in that most of these studies present only a portion of information on particular theme, while lacking a detailed holistic analysis of the system to link the various themes (structure of the dairy system, governance issues, food safety and identification of critical points for interventions). Such a holistic analysis that is lacking in these studies is necessary to inform strategies for enhancing the dairy systems. Therefore the aim of this study was to link all these components of the dairy value chain (Nairobi) to explore the prevailing structure (types of people and organizations involved, types of dairy products flowing in the system), examination of governance and challenges that would influence the food safety in the Nairobi dairy value chain, analysis of bacterial quality and *E. coli* genetic diversity to determine the stability of the system as well as identify the critical points requiring improvement).

2.11 Summary of the chapter

The Chapter has provided background information on the structures of dairy value chains, governance and challenges experienced by the value chain actors that influence food safety. In addition, the literature has covered a background on utilization of molecular techniques to inform policy decisions. The next chapter (3) describes the general materials and methods used to undertake this study.

CHAPTER 3: GENERAL MATERIALS AND METHODS

Introduction

The materials and methods chapter provides information on the study area, study population, approaches that were used for samples and data collection and analysis. The flow diagram in chapter 1 (Figure 1) outlined the relationship between the various objectives of the study and the methods that were used for field data collection and analysis.

3.1 Study area

The study was conducted in Nairobi, the capital city of Kenya. Nairobi is the most populated of the 47 counties (national administrative boundaries), and is inhabited by a cosmopolitan population constituting about 9.2 % of the total national human population of 47 million people. The urban area, which occupy 696.1 km^2 of land, lies between longitudes 36^o 45' East and latitudes 1^o 18' South and an altitude of 1,798 metres above sea level. The temperatures ranges between 10^0 C to 29^0 C while a bi-modal rainfall pattern is experienced with a mean of approximately 786.5 mm per annum.

The human population in Nairobi has grown by 45% from 3.1 million people in 2009 (KNBS, 2010) to 4.4 million in 2019 (KNBS, 2019). This imply an average increase of 130,000 people per year translating to an annual growth rate of 4.1%. The forecasted population growth is commensurate with previous prediction for population growth within urban areas in Africa which was projected at approximately 4% (Aubry *et al.*, 2010). The estimated human population density in the city is 6,000 people per square kilometre. Based on the current population, Nairobi is predicted to have a total human population of about 10.3 million by the year 2050. This rapid population growth is expected to create a lot of pressure on the production and supply of more food for the city dwellers.

Subsequently, this increased pressure may trigger evolution of more complex food chains which present challenges with opportunities for compromised food safety standards.

According to government livestock production annual report, Nairobi holds an average of 35,800 head of cattle, which is about 0.2 % of the national cattle population (GOK, 2012). This translates to a relatively smaller cattle to human population density of 0.008. During the same years, the average annual milk production was estimated at about 39 million litres which were obtained from all the nine sub counties of Nairobi. Figure 2 shows the numbers of dairy cows and milk produced in Nairobi, while the administrative boundaries of the nine sub counties: Westlands, Kasarani, Lang'ata, Embakasi, Starehe, Njiru, Makadara, Kamukunji and Dagoretti are shown in Figure 3. Lang'ata Sub County raises the highest number of dairy cow herds with over 11,000 head of cows, but, Kasarani has the largest volume of milk production (approximately 14 million litres) from about eight thousand head of dairy cows. Based on this data, it imply that milk producers in Nairobi produces only 10 % of the milk required by the urban population, which is also supported by a recent publication that estimated a deficit in milk supply to Nairobi at about 75 - 90 % (Alarcon *et al.*, 2017).

If the milk production remain the same (although its likely to go lower due to inadequate land to keep more head of cows and to grow pasture); and the estimated per capita consumption of milk does not change from 125 kg per person per year, then by 2050 when the human population in Nairobi will have grown to about 10.3 million people, then approximately 1.3 billion litres of milk will be required to meet the annual milk demand for the city. This means that almost all the milk (97%) will be supplied through milk chains originating from production systems based outside of the city either locally and / or internationally.

Similarly, as human population density is increasing per square area from increased urbanization, animal rearing could still be accommodated given the cultural orientation of communities that favours livestock keeping, consequently an increased human animal interaction which would present significant health risks to people who are part of these connected systems. This rapid urbanization coupled with unmatched milk production with the predicted rise in future demand for dairy products will exert pressure to existing value chains and trigger mushrooming of additional chains to satisfy the rising demand for milk products. The complexities associated with urban food chains are therefore likely to provide excellent platforms to expand the range of food-borne pathogens as well as to amplify health and economic impacts of a single contamination incident (Foran *et al.*, 2014). This study employed a cross-sectional study design. The cross-sectional design relates to the fact that sample collection and stakeholders were visited once, and not followed over time.

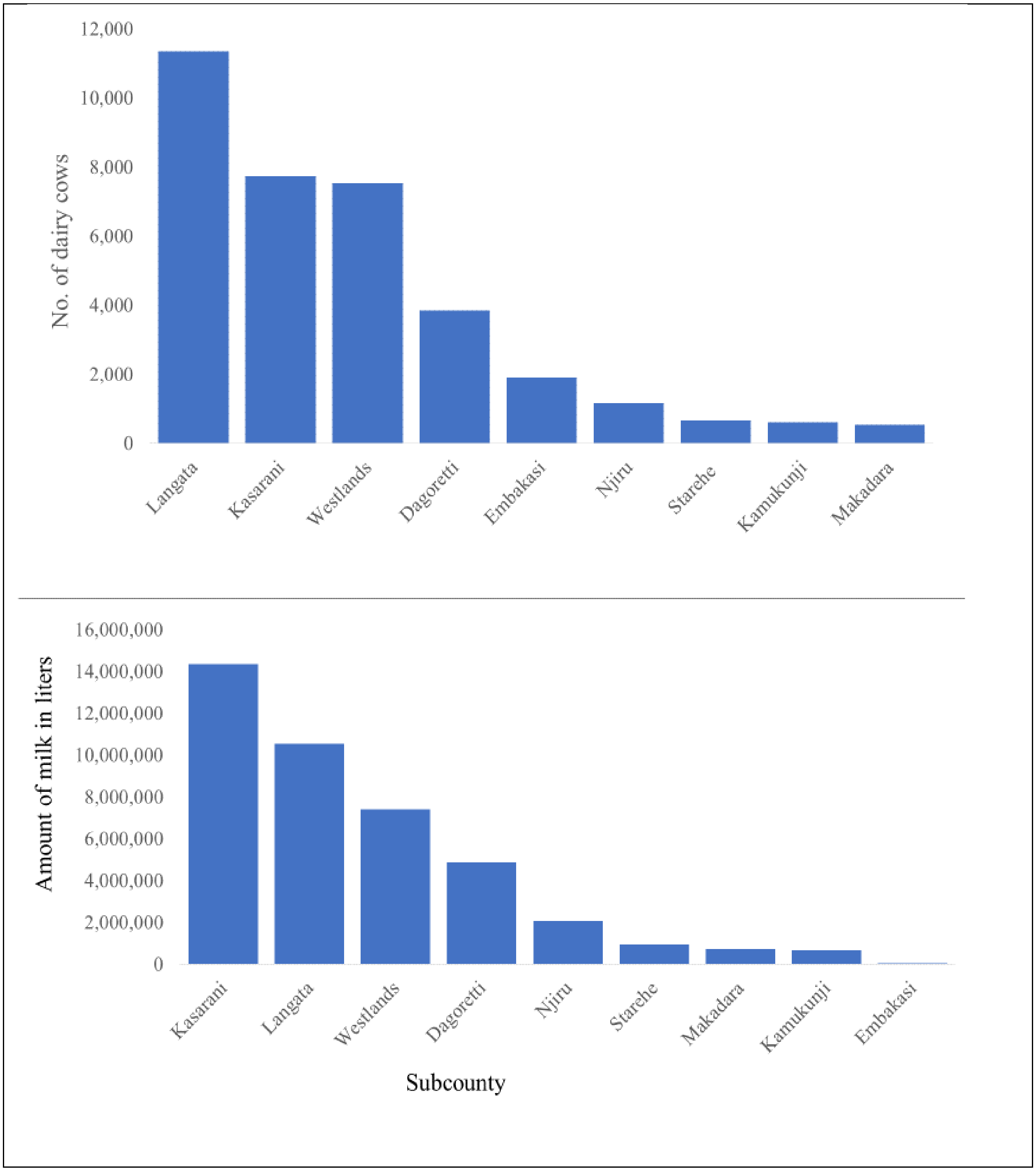


Figure 2: Number of dairy cows reared in Nairobi, and amount of milk produced per year

Source (GOK, 2012)

3.2 Selection of study locations

This study was part of a larger project which was based at the International Livestock Research Institute (ILRI) titled Epidemiology, Ecology and Socio-Economics of Disease Emergence in Nairobi (shortened as Urban Zoo) and is available online at https://www.ilri.org/research/projects/epidemiology-ecology-and-socio-economics-disease-emergence-nairobi-urban-zoo. The overall objective of the Urban Zoo project was to understand mechanisms leading to introduction of pathogens to urban populations through livestock commodity value chains, and their subsequent spread. The current thesis investigated the dairy value chains supplying milk products to Nairobi City. The Urban Zoo project collected biological samples from 33 sub locations within Nairobi. These sub locations were selected through a process of random allocation with an aid of a computer programme. The selection of sampling sites for the current study, involved a process whereby the 33 sub locations were entered in a Microsoft excel worksheet (http://www.wikihow.com/Create-a-Random-Sample-in-Excel) to facilitate random selection of one sub-location from a peri-urban area and another from an informal settlement to represent milk chains in the two different settings.

For data collection, interviews with key people were conducted in eight of the nine sub counties (see figure 3). For the milk sampling, two locations were selected based on selection of the larger project to which the current study was linked. The selected locations for bacteriological sampling were Uthiru and Korogocho. Uthiru location (located partly within Dagoretti Sub County and the other areas are within Kabete location) was selected to represent a peri-urban area where dairy farming practises were common. The other livestock kept in the area included poultry, pigs, beef, sheep and goats.

On the other hand, Korogocho which is one of the largest informal settlement neighbourhoods in Nairobi, besides Kibera, Mathare and Mukuru kwa Njenga has a human population of 200,000 within an area of 1.5 square kilometres (KNBS, 2010). It is one of the locations in Kasarani Sub-county of Nairobi County. Although relatively small, Korogocho sub location is divided to seven villages (Kisumu Ndogo, Korogocho A, Korogocho B, Grogan A, Grogan B, Getathuru and Highridge). Livestock keeping is not a major activity within informal settlements although a few households keeps dairy cows, pigs, poultry, sheep and goats (Gathuthi *et al.*, 2010).

The study units involved were farmers of dairy cows, feed manufacturers, livestock extension officers, public health officers, personnel working with milk bulking and processing companies, traders, retailers, and the regulators (Kenya Dairy Board and the city council of Nairobi). The Directorate of Veterinary Services (DVS) provided a letter introducing the research team to various people and organizations within the selected study areas after which booking of appointments commenced through phone calls, emails or physical visits to their offices.

Selection of key informants was done through consultations with senior management at the Kenya Dairy Board (KDB), Public Health office at the DVS and the officer in charge of dairy section at the Directorate of Livestock Production (DLP). These people helped towards development of a comprehensive list of stakeholders and provision of their contact information. Furthermore, consultations were done with other researchers who had previously worked on dairy value chain studies to improve on stakeholder analysis. These included United States Agency for International Development (USAID) dairy value chain competitiveness programme, ILRI and the Kenya Agricultural and Livestock Research Organization (KALRO).

The various people selected for key informant interviews included managers and top leadership of various organizations including an animal feed manufacturing company, dairy cooperatives, dairy traders association, large milk processing companies, KDB, DVS, DLP, livestock production officers (LPOs) and public health officials (PHOs). At the end of each interview, the key informants were requested to suggest other person (s) in the same or different organization (s) who could be asked further questions especially when there were information gaps. They also suggested other companies or sectors that were viewed to play an important role in the system through a snowballing interview process.

Selection of participants for focus group discussions (FGDs) was facilitated by government Animal Health Assistants (AHAs) within the veterinary office at the sub counties selected for the study. However, this was in exception of the FGD with KDB licensing officers which was organized by the KDB head office and the FGDs organized in Kibera which were facilitated by a community mobilizer (a famous person involved in most of health related mobilization activities at the community). A guidance on selection of participants was given to the AHAs/ community mobilizer such that for each group there was adequate gender representation, wider geographical coverage of the people (so that all participants did not come from one village), as well as participant's understanding of the dairy systems in the area. Each group of participants was selected based on their specific type of business/ enterprise as described by the stakeholder analysis. The various FGDs that were conducted included dairy cow farmers (urban and peri-urban), dairy cooperatives, traders associated with dairy traders association (DTA) and traders not affiliated to DTA, retailers, LPOs, PHOs, KDB officers in charge of licensing and the city council of Nairobi).

Selection of units for milk sampling was based on a snowballing approach (Glen, 2014). The first step was to visit the chief of the area (sub location) who helped with information on the administrative boundaries of the area and assisted in listing of categories and numbers of the various nodes of the milk chains in the area. These included farms, milk bars, shops/kiosks, supermarkets, restaurants, roadside vendors, automated milk machines, milk collection centres, and dairy cooperatives and if there were mobile traders seen in the area. A dairy farm was used as the starting point for sampling upon obtaining consent from the owner (see appendix A- the data collection consent form). From the first farm, snowballing approach was used to select the next nearest farm within the same village and the procedure was repeated up to a maximum of four farms within one single area in a village. This was considered as cluster one. Then the team moved about 200 - 300m (about every 50m in Korogocho since it's a smaller area) from the first cluster to another within the same village and the procedure was repeated. This was done throughout the village until the teams got to where sampling started and then moved to the next village where the process repeated (as in cluster one). If there were any other different nodes (collection centres, retailers) between the farms (neighborhoods) or between the clusters within the villages or between one village and the next, they were recruited to the study.

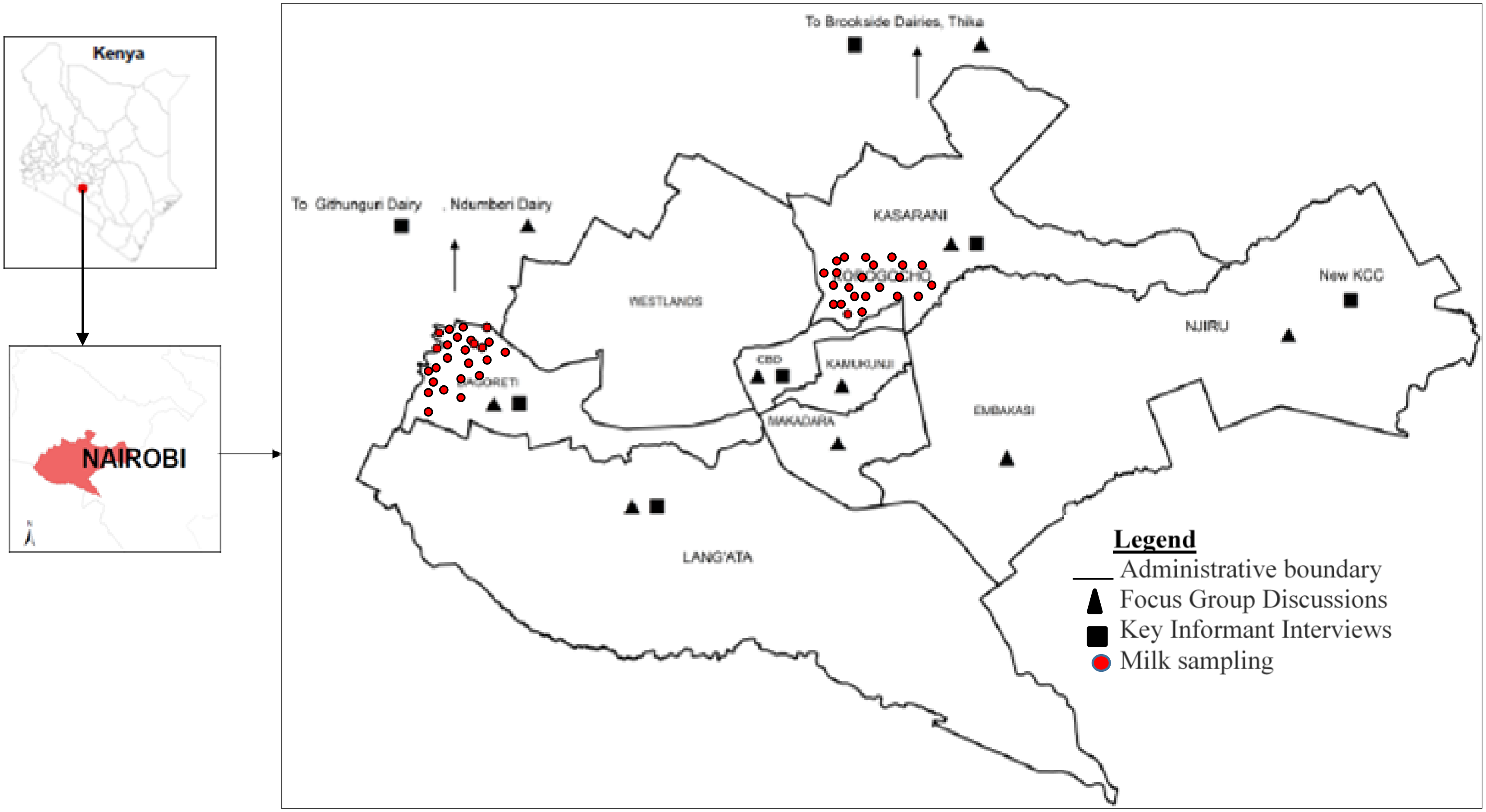


Figure 3: Map of Nairobi County showing areas where data collection and sampling were done

3.3 Methods for data collection

From January 2014 to January 2015, various data were gathered through conducting of 23 key informant interviews (involving 35 people), twenty two focus group discussions (FGDs) involving 116 people and collection of 290 milk samples from 144 nodes along the Nairobi dairy value chain. Data collection methods and analysis employed for this study included value chain mapping, investigation of governance structure and its influence on food safety, bacteriological sampling of cow milk for analysis of bacterial quality and genetic diversity of *Escherichia coli (E.coli)* along nodes of the milk value chain. Prior to the engagement of participants involved in key informant interviews and FGDs, a written consent was sought and obtained from every participant. The consenting process also included obtaining permission to record voice (s) or video documentation of the interview. This helped the research team to concentrate on listening to the interviewee (s) and for ease of transcribing later. However, there were also two research assistants who recorded the discussions on notebooks. Flip charts were utilized to draw the various interactions and flows of products as discussions were progressing. Each FGD comprised of 6-12 participants and interview sessions lasted for approximately 2-3 hours. The preferred language (s) for discussions was agreed upon before commencing with interviews. In each FGD, a local person who understood the local language (s) was identified to clarify words or statements unclear to the group. Most sessions were conducted in Kiswahili language. Participants were allowed to brainstorm on each question until there was consensus on the issue under discussion. The interviews were guided by checklists of open-ended questions administered by the author (see appendices B, C and D).

Value chain mapping involved conducting of key informant interviews and FGDs to collect data about people involved in chain activities, products, chain profiles, spatial and temporal dimensions and to understand the connectivity of events within the value chain. Informed by the stakeholder analysis, the key people and organizations involved in the dairy value chain were identified to determine the processes for data collection. In each key informant interview and FGD, data were gathered on type of enterprise being operated by each of the participants, different stakeholders who they interacted with and modalities of engagement, type of livestock and livestock products kept/traded, source of farm inputs (for farmers), source of milk and milk products (for traders, retailers, dairy cooperatives, large processing companies), description of how different products flow through the chains including characteristics in milk sourcing and selling, and practices in waste management.

Similarly, data on investigation of governance structure and its influence on food safety was achieved during value chain mapping. The specific data was on types of interactions among the value chain stakeholders, their challenges and the potential impacts of those interactions and challenges on food safety. These type of data collected included type of interactions with buyers/sellers/associations/government. Participants were asked to describe their affiliations or lack of affiliations to any associations or power groups; describe how a deal was made and types of agreements made (e.g. written contract, verbal agreement, daily payment or monthly payment plan etc.); list the types of incentives for dealing with people or organizations; list the types of agreements, rules and regulations they had to follow (legislative, private standards, cultural norms etc.); list the types of sanctions/penalties experienced for not adhering to such agreements; describing the challenges they faced within their interactions; and explain how their perceptions and practices influenced milk quality and safety.

Probing was used to collect data on practices at production, trading, collection/bulking, processing and transportation as well as influence of regulation and private standards.

Bacteriological sampling of cow milk was done at the farms, milk bars, shops/kiosks, supermarkets, restaurants, roadside vendors, automated milk machines and milk collection centers. The different types of milk sampled included raw, pasteurized liquid milk, Ultra Heat Treated, fermented and yoghurt. At the farm, the farmer was requested to milk about 50 mls directly into a sterile barcoded falcon tube but if the farmer was unable to milk for whatever reason, they were requested to give whatever remained from the last milking (even if it was pooled). To obtain about 50 mls of milk from the other nodes (retail and bulking centers), participants were requested to transfer directly into the sterile barcoded falcon tubes. However, if the milk was in packets or sealed bottles, the entire content was purchased. All milk samples were immediately placed in a cool box that was packed with ice packs and transported to the laboratory at the university of Nairobi department of Public Health Pharmacology and Toxicology within two to four hours of collection.

At the time of sampling, a pretested semi-structured questionnaire was administered by the author (appendix E). The questionnaire was piloted amongst a few value chain actors (dairy cow farmers and shops) within Uthiru sub location. The details of epidemiological data collected included:

- Area where the business/ farm is located (sub county, sub location, village)
- Type of node (farm, milk bar, shop/kiosk, supermarket, restaurant, roadside vendor, automated milk machine, milk collection center, dairy cooperative
- Sex of the interviewee

- Age of the interviewee in years
- Ownership status of the business or farm (owner, employee or relative)
- Source of milk (geographical location and type of node supplying)
- Type of milk supplier (own, farmer, trader, cooperative, distributor)
- Duration in minutes the milk had stayed before being sampled. This was calculated by subtracting time of the interview and time the milk was received at the node where sampling was done
- Volume of the product handled per day
- Buying and selling price of the product
- Number of milk pooled together in the sample
- Preservation method used if any
- Whether the cow was under any antibiotics treatment

3.4 Sample processing in the laboratory

Prior to sampling, an excel database was created in the laboratory's project password protected computer bearing all the fields for the variables that were collected during sampling. Additional fields were added for results on every test that was performed on the samples. Milk samples that were purchased in large quantities (packets and bottles) were aseptically aliquoted into sterile barcoded falcon tubes (the barcode was an exact pair of the temporary barcode that was placed on the packet or bottle). Immediately after, all samples were scanned into the excel database. Tests that required to be done immediately were carried out according to laboratory standard operating procedures and as explained in chapters 5, 6 and 7.

These included: culture and isolation for enumeration of total bacteria counts (TBC), total coliform count (TCC) and identification and purification of *E.coli* for analysis of its genetic diversity. The primary samples were then kept at -80^0 C for further testing.

Analysis of TBC and TCC was done at the department of Public Health Pharmacology and Toxicology the University of Nairobi. For each sample, analysis of TBC involved preparation of fourfold serial dilutions (10^{-1} to 10^{-4}) in sterile phosphate buffered water which was inoculated in standard plate count agar (SPCA) Oxoid at 32^0 C for 48 hours. Similarly, threefold dilutions (10^{-1} to 10^{-3}) were done for analysis of TCC. Coliforms were cultured in Violet Red Bile Agar (VRBA) Oxoid and incubated at 37^0 C for 24 hours. The plates were assessed for ease of counting the colonies so that SPCA plates with countable colonies between 25 and 250 colony forming units (CFU) per plate and VRBA plates with countable colonies between 15 to 150 CFU/plate were selected for enumeration. Colony counting was aided with use of a colony counter (CLC-570). After enumeration of coliforms for each sample, up to five (5) distinct colonies per plate were picked and plated on MacConkey Agar (Oxoid) and incubated at 37^0 C for 24 hours. To increase the chances of obtaining pure *E.coli* colonies, the purified discrete colonies from each plate of MacConkey was subjected to, Indole, Methyl Red, Vogues Proskaeuer and Citrate (IMViC) reactions. The plates were then stored in a refrigerator at +4^0C until the IMViC results were read. A positive reaction for Indole and Methyl Red combined with a negative reaction for Vogues Proskaeuer and Citrate (++--) indicated pure *E.coli* colonies. From the stored plates in the refrigerator, pure colonies of *E.coli* were then harvested for storage and another potion of the same sample used for DNA extraction and the subsequent PCR analysis. The pure colonies of *E.coli* were preserved in sterile skimmed milk at -80^0C.

Analysis of *E.coli* genetic diversity was done at the Centre for Microbiology Research (CMR) laboratory at the Kenya Medical Research Institute (KEMRI). The *E.coli* isolates that were previously stored in skimmed milk at the University of Nairobi were transported to CMR in a cool box. At CMR, isolates were revived (grown) in Tryptone soy agar, at 35^0 C overnight (see appendix F). The protocol for DNA extraction and finger print analysis is explained in chapter 7. Using a wire loop, three to five colonies were suspended in 1000 µl of sterile distilled water. The bacteria were lysed by boiling at 110^0 C for 10 minutes in a water bath. The lysate was centrifuged at 15,000 revolutions per minute (rpm) for five minutes. The supernatant was then used directly as the template for PCR analysis.

3.5 Data management and analysis

Content thematic analysis was employed for qualitative data obtained from the key informants and focus group discussions. The voice and video recordings were carefully listened to, to identify emerging themes that described an activity or a specific profile of the chain. In addition, data entry was complemented with use of more information collected in notebooks and on the flip charts that were created with participants during the interviews. Subsequently, word document templates were developed to facilitate a systematic organization of emerging themes to meaningful sections (such as type of suppliers, source of services, interactions with other stakeholders, flow of products and the associated deficiencies and vulnerabilities.). The initial process allowed to recognize major themes for the value chain mapping process which included, 1) identification of people and products, 2) profiling of people and products, 3) creation of flow diagrams (chain profiles) to describe the flows of people and products and 4) writing of narratives to further describe the emerging themes. Proportion estimates were indicated where available.

Whenever a disagreement was detected the source believed to be most reliable was used to clarify information. After the mapping process, thematic content analysis process was repeated to identify themes related to governance and food safety.

Analysis of TBC and TCC entailed a descriptive analysis that focused on determination of mean, median, minimum and maximum statistical measures. Further analysis involved logistic regression analysis which was conducted in Stata software to assess for acceptability of milk in reference to the East Africa Standards, 2017. Thematic analysis of qualitative data collected during the value chain mapping enabled description of key practices and challenges with potential linkage to food safety. Description of *E.coli* genetic diversity was based on explanation of bacterial relatedness observed on the dendrograms generated through fingerprinting techniques.

3.6 Summary of the chapter

The chapter has presented details of the study area with indicators that show how important it is to understand dairy value chains in Nairobi, since over 90% of milk is supplied from chains emanating from outside the city. Furthermore, the different methods that were used for data collection and analysis were outlined. The use of different approaches for data collection and analysis was important for analysis of the complex urban food systems to inform targeted interventions. The next chapter presents mapping of these dairy value chains supplying Nairobi city. The chapter will describe the structure and organization of the dairy value chain in Nairobi as the necessary first step in understanding the vast food system. This value chain mapping lays the framework on which the other result chapters will be overlaid.

CHAPTER 4: VALUE CHAIN MAPPING OF THE DAIRY VALUE CHAINS SUPPLYING NAIROBI CITY

Introduction

The chapter will explore value chain mapping through collection of mainly qualitative data through focus group discussions and key informant interviews to describe the various actors and products flowing through the dairy value chain in Nairobi. Details about selection of study areas and study population has been covered in chapter three.

Global demand for dairy products has gained prominence over the past few decades due to population growth and increase in per capita income in developing countries (Herrero *et al.*, 2014), coupled with alteration of the global supply that has been influenced by significant changes in husbandry, genetics and nutrition linked to new processing and marketing systems. By 2050, it is estimated that in sub-Saharan Africa milk demand will triple with the greatest increases in East Africa (Herrero *et al.*, 2014). However, milk supply across the region is not predicted to match the estimated demand. An in-depth consideration of milk value chains to identify strengths and weaknesses of the existing systems to estimate how they will respond to the shortfall in supply is critical.

In 2012, Kenya, the country with the highest per capita milk consumption in Africa (SDP report, 2004), produced approximately 4.8 billion litres of milk (FAOSTAT, 2012); 75% was obtained from cows, 18.8% camels, 5.4% goats and 0.7% from sheep. The dairy sector is one of the largest agricultural segments of the country contributing about 4% of the national Gross Domestic Product (GDP) and 14% of the agricultural GDP (KDB, 2014).

The industry which was initially under the government monopoly through the Kenya Cooperative Creameries (KCC) has rapidly evolved following its liberalization and decontrol of prices in the 1990s (Leksmono *et al.*, 2006). This resulted in an explosion of informal dairy markets while generating many opportunities for private processors (Muriuki *et al.*, 2003). Growing at an annual rate of about 5 to 7%, the sector is a source of livelihood to approximately 1.8 million small-scale producers who account for over 80% of the country's milk producers (KDB, 2014). The marketing channels are mainly driven by the informal sector which is responsible for over 80% of all marketed milk (Leksmono *et al.*, 2006). This translates to over 40,000 employment opportunities which are approximately 70% of personnel working in the dairy industry in Kenya (FAO, 2011b).

Government annual reports on milk production indicate that milk production within Nairobi accounted for approximately 39 million litres per year (unpublished government milk production data, 2012). Conversely, milk intake is estimated to be highest in the urban centres at 125 litres per capita (SDP report, 2004). This implies that Nairobi, with a population of about 3.1 million people (KNBS, 2010) consumed approximately 388 million litres of milk in 2009 or approximately 10% of the country's production. Thus, over 90% of milk consumed in Nairobi is supplied through value chains linked to production outside the city. Understanding the structure and functionality of such milk chains is essential.

A few studies have attempted to describe the structure of the country's dairy value chain (Baltenweck *et al.*, 1998; I. Rademaker *et al.*, 2016; Staal *et al.*, 2001; TechnoServe Kenya, 2008). However, the methodologies used have been on general flows rather than a comprehensive description of each of the specific segments of the dairy value chain, which is critical in understanding the overall dairy system.

This chapter utilizes the '**Mapping'** component which is one of the four critical steps in conducting a value chain analysis (VCA) (FAO, 2011a; Kaplinsky and Morris, 2000a). Mapping involves a systematic analysis of the people involved and products flow along the value chain taking into consideration input supply, production, processing, distribution and marketing activities of a specific product or service (Kaplinsky and Morris, 2000a). It provides a visual depiction of the basic structure and a framework to guide systematic chain analysis and other important areas such as food safety and pathogen flows (Alarcon; *et al.,* 2017).

4.1 Materials and methods

Four research questions guided the mapping process of the Nairobi's dairy value chain: 1) Who are the people (and organisations) involved in the Nairobi's dairy value chain? 2) What is the structure of the milk production and milk flow into the city? 3) What is the overall structure of the Nairobi's dairy value chain?

4.2 Mapping of stakeholders and flow of products

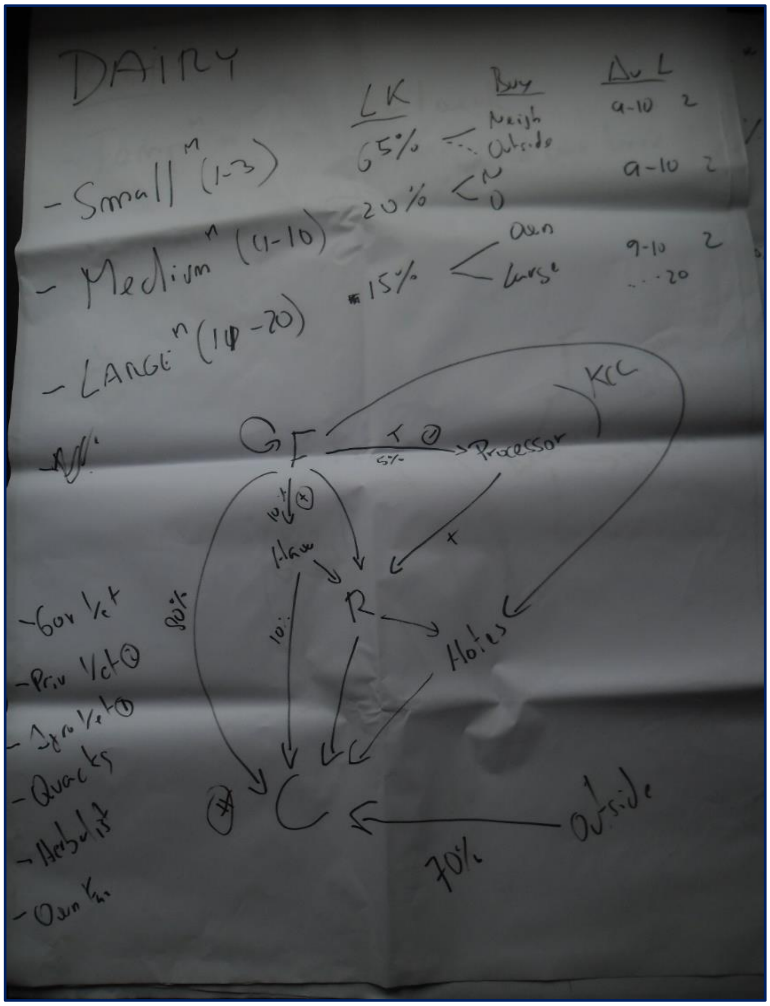
Data were collected using a combination of two methods: (1) the use of open ended questions (e.g. what are the different type of traders existing in the markets?); and (2) the creation of flowcharts with participants until a consensus on the type of people, products, locations, flows, and quantities, was reached (see example on how flow charts were drawn in figure 4). When using open questions prompts were used to further explore and clarify the activities and people, products and flows profiles. Flowcharts created with the participants were also used as a basis for formulating the open questions. Where possible, the participants were asked to agree on proportions of people, livestock and products within a particular chain; otherwise, they were asked to agree on the main pattern.

In the focus group discussions participants were asked to:

1. Briefly describe their business and operations
2. Identify and describe their interaction with other stakeholders. Special emphasis was placed on understanding and differentiating the diversity of suppliers, buyers and transporters of their animals or products
3. Identify and describe the type of animals, products and value adding activities associated to each type of people in the chain
4. Identify the routes, places, areas and seasonal differences of their interactions with the different stakeholders
5. Indicate the main patterns of chain flows and people existing and, when possible, to agree on the proportion of people or flow of products within a particular chain in a given market

Similar questions were asked to each of the key informants but additionally describing their interaction with the government and other stakeholders, role in influencing the chain, products description including their flows. Secondary data supplemented data obtained on dairy cow keeping and milk production in the city. In addition, the key informants' were asked to:

1. Describe the different types of dairy products they were dealing with and the types of operations involved with these suppliers
2. Describe the value addition activities they were involved in, their distribution and the type of buyers associated with each
3. Provide estimates and the proportion of flow of animals and products in the different chains
4. Describe seasonal and time patterns of the flows



The figure shows how the LPO's described the chain in Kasarani. The arrows indicate the flow of milk from farmers all through to consumers

Figure 4: Example of flow chart filled during FGD with Livestock Production Officers in Kasarani

4.3 Data entry and analysis

The voice and video recordings were carefully listened to and all the information was transcribed into pre-formatted templates; which were word documents systematically organized to enter qualitative data in distinct sections based on the emerging themes. Data entry was complemented with data collected in notebooks and on the flip charts created with participants during the FGDs and KIIs.

Thematic qualitative analysis was performed to identify the emerging themes that describe patterns of operations, interactions of people and flow of commodities, inputs or the end disposal of waste. Using these emerging themes and the flowcharts obtained in each FGD and KIIs, advance flowchart (maps) were created to represent the structure of the different chains existing in the dairy value chain. These maps or flow-diagrams are referred here as ‘Chain profiles’. Each chain profile describes in detail a specific segment of the dairy food system. For the purposes of clarity, some of the information such as feeding, watering of livestock, animal health, breeding services, regulation and licensing was omitted from the flowcharts but then explained in the narrative.

Data validation was achieved by ensuring proper representation of the participants following stakeholder analysis. Information gathered through FGDs was triangulated during KIIs. When discrepancies were detected, additional consultations were done with other experts working or conducting research in the dairy value chain.

4.4 Results

A total for 20 FGDs with 105 people and 23 KIIs with 35 participants were conducted (table 1).

Table 1: Summary of the people and organizations that were interviewed

Chain node/Functions	**People working in the chains**	**Activity**	**No. of FGDs** (No. of people)	**No. of KIs** (No. of people)
Input supply	Feed manufacturers	Feed production, feed distribution, advisory on dairy cow feeding	-	1 (3)
Production	Dairy cow farmers in urban informal settlements (Kibera)	Milk production, selling of milk	1 (10)	-
	Dairy cow farmers in peri-urban areas (Dagoretti and Kikuyu)	Milk production, selling of milk	2 (14)	-
	Small scale Dairy Farmers Association	Offer advice to producers (production, breeding), linking producers to markets	-	1 (3)
	Kenya Livestock Producers Association	Create learning opportunities for producers through exhibitions, linking producers to financiers and markets	-	1 (2)
	Dairy Cooperatives (medium and large scale)	Milk assembly, bulking, cooling and transport of raw milk, extension services and inputs, offer credit facilities, and soft loans to producers	1 (7)	1 (1)
Milk collection and selling	Traders affiliated to the Dairy Trader Association	Extension and inputs, milk assembly, bulking and transport of raw milk, lobbying for policies	-	3 (3)
	Traders not affiliated to the Dairy Trader Association	Milk assembly, bulking and transport of raw milk	3 (19)	-

		Milk assembly, bulking, cooling and transport of raw milk, extension services and inputs, offer credit facilities, and soft loans to producers	1 (7)	1 (1)
Processing	Two largest milk processing companies based in Nairobi (Interviews done with managers of the companies)	Extension services, milk assembly, bulking, cooling and transport of raw milk, milk processing, value addition and distribution of processed milk products	-	6 (8)
Retailing	Supermarkets, traders, milk bars, restaurants, automated milk machines (ATM), roadside vendors, shops and kiosks	Processed and raw milk outlets, direct milk sales to consumers	2 (13)	2(2)
People supporting and influencing the chains	Kenya Dairy Board	Set standards, inspect and license dairy enterprises, regulate dairy industry and facilitate trade	2(8)	2(4)
	Directorate of Veterinary Services (head office)	Disease control, extension services to producers, facilitate trade	-	2(2)
	Directorate of Livestock Production (head office)	Extension services to producers	-	1(2)
Service providers/ Influencers	Livestock production officers (at sub-county level)	Provision of extension services (e.g. advice on animal management, housing, etc.)	7 (21)	-
	City council of Nairobi	License businesses	1 (6)	-
	Non-Governmental Organizations and Donor partners (Technoserve, USAID)	Extension services, strengthening producer groups / cooperatives	-	2(4)
Total			**20 (105)**	**23 (35)**

4.5 Mapping of stakeholders

Seven chain profiles (or system segments) were identified forming the overall Nairobi's dairy value chain (Figure 5). These include: farming systems in urban informal and peri-urban areas (Figure 6); chain profiles for traders affiliated to Dairy Traders Association (DTA) and non DTA (Figure 10); medium and large dairy cooperatives (Figure 14); and the chain profile for large processing companies (Figure 15). Each of the chain profiles links to other chain profiles thus forming the overall complex dairy value chain.

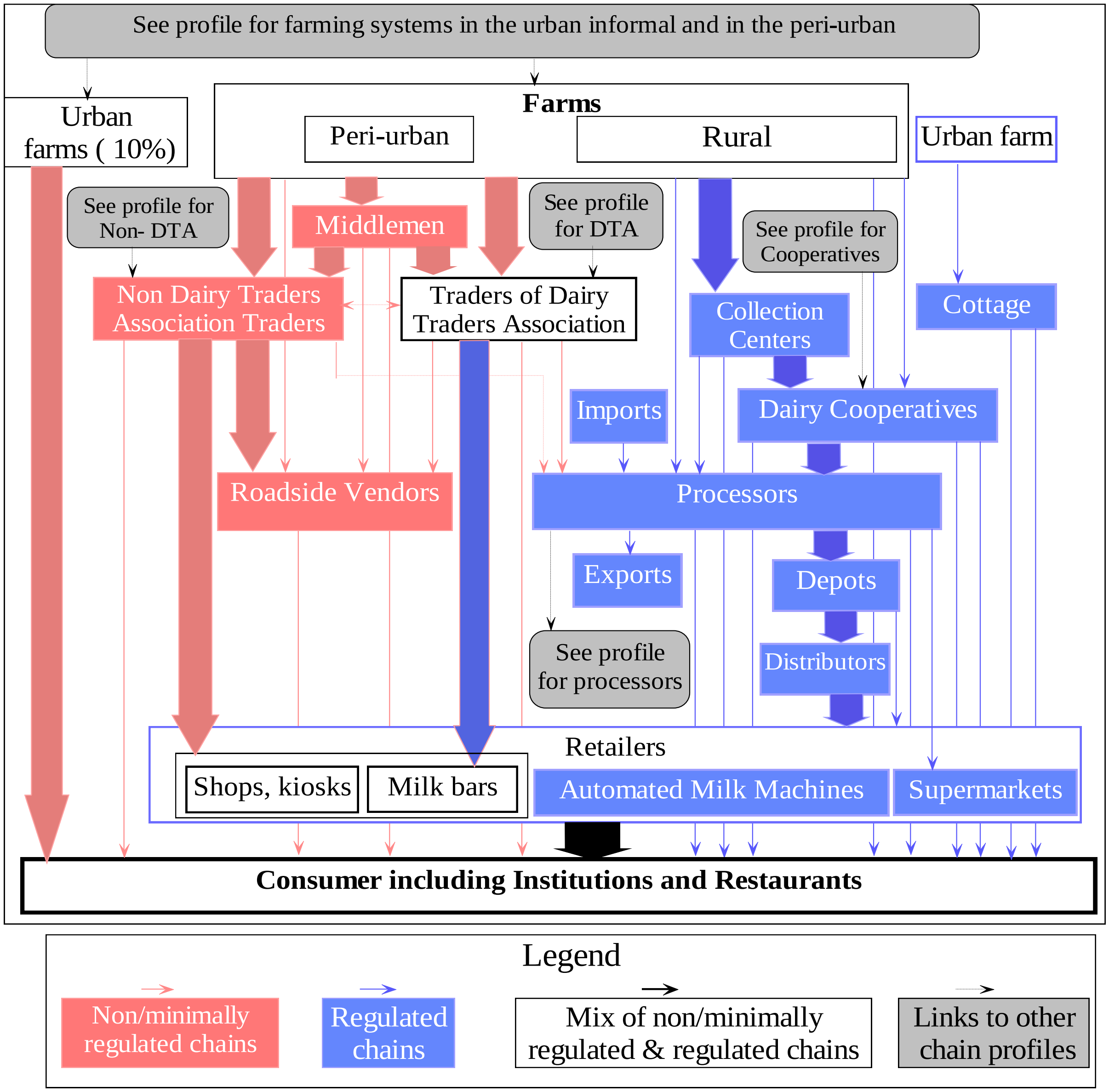


Figure 5: Flow diagram indicating the overall structure of the dairy food system operating in Nairobi.

The figure identifies the major chain segments (or chain profiles) composing the dairy system, and which are then provide in full detail in the other figures. This figure differentiate between the non or minimally regulated chains (informal – in red) and the regulated chains (formal – in blue).

Interviews with the government officers revealed that the dairy value chain is comprised of formal and informal chains. Formal chains described as those operated by dairy enterprises that were fully or partially effectively regulated through inspection and licensing. Such chains included dairy cooperatives, milk processing companies, some milk bars, some of the traders within DTA, some shops and one cottage (a type of node where milk is produced, processed, branded and packaged at the farm, mainly for high-class users and large hotels). Informal chains were described as those operated by dairy enterprises that evaded regulation and engaged in minimal value addition activities. Such chains included the roadside vendors, some of the DTA traders, non-DTA traders, some milk bars, some shops and kiosks. Successful operations of the informal enterprises, and particularly with traders, activities were reported to be performed during the night or very early in the morning, away from the official working hours of KDB inspectors.

Detail assessment of each of the segments demonstrates numerous linkages between the formal and informal chains through buying and selling activities resulting to a thoroughly interlinked system. This is well demonstrated in the specific chain profiles described later in this article.

4.6 Chain profiles for the farming systems in the urban informal settlements and at the peri-urban areas of Nairobi

The chain profiles for the two farming systems are shown in figure 6.

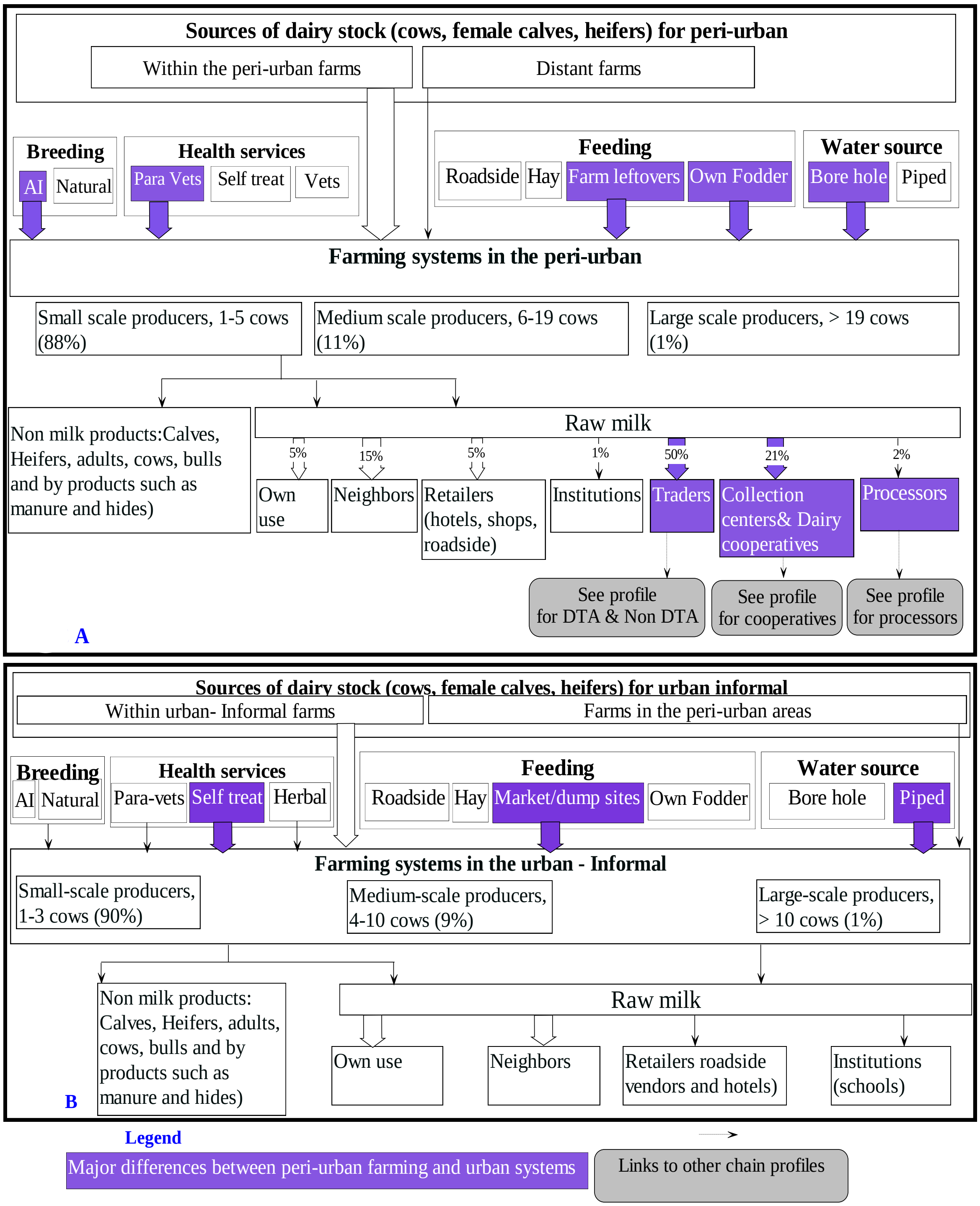


Figure 6: Chain profiles for (A) peri-urban and (B) urban farming systems

Footnote: Profile **(A)** represents farming system in the peri-urban areas. It shows that majority of farms in the peri-urban areas have between 1-5 cows; rely on artificial insemination (AI) for breeding, para-veterinarians for animal health services; and their feeding is mainly from farm leftovers and own grown fodder, while water for livestock is mainly drawn from boreholes. Milk selling from these farms is mainly through traders, milking collection centres, diary cooperatives or directly to the large processing companies. Profile **(B)** shows farming systems in the urban informal areas. It shows that over 90% of dairy farming systems in the urban informal areas have between 1-3 cows; AI and natural breeding are almost equally utilized; their sick animals are treated by owners without consultation of veterinarians or para-veterinarians; and livestock feeds are mainly obtained from the markets and dumping sites, while water is obtained from taps connected by the city council. Milk selling from these farms is mainly for own consumption or is sold to neighbours.

4.6.1 Dairy herd and livestock keepers

FGDs with livestock production officers estimated approximately 38,000 dairy cow keepers in six of the seven sub-counties of Nairobi County, predominantly in a smallholder setup. Small-scale production in the urban informal was defined as those keeping 1-3 cows (90% of the dairy cow keepers), while in the peri-urban they kept 1-5 cows (88%). Medium-scale farmers kept 4-10 cows (8%) in the urban informal and 6-19 cows (11%) in the peri-urban while large-scale farmers kept more than 10 cows (1%) in the urban informal and more than 19 cows in the peri-urban (1%). The large scale and some of the medium-scale farmers were either schools, company farms or individuals who focused on dairy as a commercial enterprise. The small-scale and some of the medium-scale farmers kept dairy cows not only for subsistence but also as a source of prestige and financial security.

Farmers in the urban informal settlements and majority of peri-urban farmers operated independently. However, some farmers in the peri-urban areas were affiliated to self-help groups, livestock producer associations and the dairy cooperative societies. Affiliation to groups was done with the aim of increasing milk production, increasing their bargaining power, creating new avenues for selling milk, as well as to benefit from credit facilities on animal feeds, household items, school fees and organized animal health extension and breeding services.

4.6.2 Sourcing of the dairy stock

Long calving intervals, sometimes more than three years, characterised dairy cows in both urban informal and peri-urban areas. Farmers retained a female calf in the herd unless there was lack of space or an urgent need to sell. Replacement stock were directly bought from neighbourhoods and rarely through brokers.

In the absence of neighbourhood sources or of the need to upgrade to increase milk yields, the urban informal dairy keepers sourced their dairy stock from the peri-urban farmers, primarily through brokers. Heifers were rarely purchased from the livestock Agricultural Showgrounds during livestock exhibitions or from rural areas. Although perceived to be more productive, these sources were alleged to be expensive and posed transportation challenges.

Word of mouth in the villages were described as the main source of information for identifying buyers for animals. Farmers from both systems preferred to purchase adult dairy cows in their sixth to seventh month of pregnancy or lactating animals as milk is their main source income. Some farmers reported to book a calf from a neighbour’s in-calf cow, but with the condition to purchase it only if the calf was a female. Transportation of replacements was mainly by trekking when these were sourced from neighbourhoods or by vehicles when sourced from long distances.

4.6.3 Housing of dairy stock

Both the urban informal and peri-urban farmers described their farming systems as zero grazing. The housing facilities were mainly constructed adjacent to the farmers' main residential house because of insecurities associated with theft of livestock but also due to land scarcity. In some instances particularly in the urban informal, the cowsheds were said (and observed by researchers) to share the same roof with the owners, and only partitioned by a wall.

Figure 7: Cow in a milking parlor at Korogocho. Note the very muddy cow shed

Figure 8: Cows at a shed in Korogocho area. Note the very muddy cow shed

4.6.4 Feeding and watering of dairy stock

Livestock were described to be mainly stall fed on Napier grass (*Pennisetum purpureum*), garden leftovers after harvesting, local grass (*Pennisetum clandestinum*), hay and kitchen leftovers. FGD with dairy cow farmers in the peri-urban areas identified own grown fodder and garden leftovers (maize stocks and banana stems) as the most common livestock feed in the peri-urban while the farmers in the urban informal mainly utilized leftovers from markets and garbage from dumping sites (FGD dairy cow farmers in urban informal). Market leftovers were particularly fetched from the roadside vendors who routinely sell roasted maize, vegetables, fruits and green groceries. A small fee was said to be paid to the roadside vendors and the some cartels comprised of homeless (street) children who usually operated by the dumpsites to facilitate such collection of these leftovers.

During dry seasons with fodder scarcity, some livestock owners purchased hay or cut pastures available by the roadsides. In addition, urban informal farmers reported to cut grass along the leaking sewer lines (which was viewed as very green and healthy). Due to its high cost, farmers reported that hay was rarely fed alone, but usually mixed with any other available feeds. Almost all farmers reported to use commercial dairy meal, maize germ or bran during milking. Sweepings from poultry houses were also reported to be mixed with commercial feeds supposedly to increase milk production (FGD with farmers peri-urban).

Water provision for the dairy stock within urban informal settlements was mainly from piped water supplied by the city council, although sometimes waste water derived from washing clothes or utensils was reported to be used. On the other hand, FGD with farmers in the peri-urban areas reported use of water mainly from boreholes within the neighbourhoods and sometimes from piped water, shallow wells and stored rain water.

Figure 9: Cows being fed on market leftover in Korogocho area (left) and tethered to feed on grass at homestead at Uthiru area (right)

4.6.5 Breeding services

Artificial insemination (AI) and natural breeding methods were reported to be utilized by both farming systems, but with the former more commonly used than the latter. Although farmers reported their preference for AI due to perceived benefits of increased milk yields, they described natural breeding method as the most successful. They considered AI as a trial and error method whose success would probably occur after three or more trials or no success at all. Farmers in the urban informal settlements reported that the AI providers would sometimes inseminate three days after the cows had shown heat while in other instances they would inseminate a cow twice (morning and evening) apparently to increase the chances of conception. It was common practice in both farming systems for farmers to opt for natural breeding following such frustrations from AI. Some of the farmers within the FGD with urban informal reported that they did not attempt AI at all due to previous frustrations or from the experiences they see from the neighbours. For the peri-urban farmers affiliated to dairy cooperatives, AI services were reported to be pre-organized by the dairy cooperative so that farmers did not have to pay cash upon service. According to interviews with dairy cooperatives, large processing milk companies and with farmers in the peri-urban, recovery of such AI related costs were obtained from the monies accrued on the milk deliveries at the end of the month. However, some of the farmers from peri-urban still had experienced low conception rates of their cows attributing this to perceived low quality semen. Some of the semen used in the peri-urban was reported to be sourced from United States of America (USA) and Netherlands which was perceived to be of higher quality but majority of the farmers used locally produced semen from the Kenya Animal Genetics Resource Centre (KAGRC). Although reportedly expensive, few farmers in the peri-urban reported to use sexed semen from KAGRC and from Worldwide Sires (a limited company) to maximize the chances of getting female calves.

4.6.6 Provision of animal health services

FGD with farmers in the urban informal described that treatment of their dairy stock was mainly decided and implemented by the farmer, family member or neighbours who were perceived to have animal disease knowledge and experience in their treatment, and without consultation with animal health professionals. Farmers reported that drugs were purchased from Agrovets (retailing shops for agricultural chemicals and veterinary medicines) or used herbal medicines obtained from the neighbourhood. Some medium and large-scale farmers occasionally utilized para-veterinarians (those with certificate or diploma training on animal health) in treatment of their livestock according to LPOs, while others it was the farmers who selected their own treatment (as with small farms). Farmers explained that veterinarians (those with Bachelors' Degree in Veterinary Medicine) and other livestock extension officers (government staff) were never contacted, principally because they were unknown to farmers. In addition, farmers explained that they were not willing to seek government veterinary services because rumours in the neighbourhood indicated that keeping livestock in the city was illegal. Farmers therefore perceived that discovery of their enterprises by government officials would result to their arrest and confiscation of their livestock.

On the other hand, farmers in the peri-urban areas reported to obtain animal health services principally from para-veterinarians, but with some degree of services obtained from veterinarians and own treatment following purchase of drugs from Agrovets. Farmers in the peri-urban also expressed their misery in finding veterinarians whom they termed as very difficult to find and were mainly consulted as the last resort, primarily to solve difficult problems such as repeated treatment failures, disease outbreak situations or to determine the cause of death when caused by unknown aetiologies. Farmers affiliated to the dairy cooperatives reported that services were commonly obtained from animal health care specialists contracted by the cooperatives although some of these farmers sought for the services privately at their own cost to avoid monthly deductions associated with this arrangement.

For both production systems, the main information source on animal health were reported to be the Agrovet shops, people in annual livestock agricultural shows, the local radio, television and also other farmers, mainly through word of mouth.

4.6.7 Marketing of milk from the urban informal and peri-urban farming systems

Fresh milk was identified as the most important commodity derived from these farming systems. Other products included calves, heifers, bulls, fermented milk and to a lesser extent yoghurt. In both systems, milk was mainly for subsistence use and a source of quick cash through farm gate sales. Farmers explained that the type of agreement between themselves and buyers was purely based on trust and verbal agreement on quantities of milk sold, time for collection, prices and modalities of payment (whether cash, payments in advance or paying after consumption of the milk). However, written agreements prevailed for milk deliveries for peri-urban farmers affiliated to dairy cooperatives.

Over 99% of the milk produced in the informal urban systems was sold raw at farm gate with less than 1% delivered to local schools and restaurants. Farmers in the peri-urban reported that farm gate sales accounted for more than 50% of their milk to traders, 15% to neighbours and 5% to retailers. Approximately 30% of their milk was sold through milk collection centres or dairy cooperatives (21%) or directly to the large dairy processing companies (2%). Collection centres were described as specific points or simple sheds located by the roadsides or points under specific trees with or without any structure where farmers deliver milk at a specific time for collection by the dairy cooperative or large processing companies. They were reported to be organized by farmers in those particular localities.

Milk from farms was mainly packaged into recycled plastic containers (soda, water, or beer bottles for smaller volumes and five-litre or twenty-litre plastic containers for larger milk volumes). Those delivering to the collection centres, dairy cooperatives and processing companies were required to use legally recommended aluminium cans.

When distances were within the neighbourhoods, milk transportation was mainly done by foot but longer distances particularly in the peri-urban areas involved use of donkeys, vehicles (private and public), motorcycles or motorbikes.

4.7 Chain profiles for traders affiliated to Dairy Traders Association and Traders not affiliated to Dairy Traders Association

Government officials approximated to 30,000 the number of milk traders operating in the country, which then they broadly were categorized into DTA and non-DTA traders. DTA traders form about 20% of the traders in the country and comprise 30% of farmers-traders, 60% of traders-only and 10% trader-transporters. To register with DTA, traders were required to pay registration fee and an annual retention fee. Additionally, though not completely mandatory, traders were required to undergo training by specific KDB accredited business development service providers on milk handling, hygiene, bookkeeping, business ethics and value addition ($20 per course). Once trained, the traders obtained an identification card bearing the DTA and Kenya Dairy Board logos as an identification of legalized traders and hence shielding them from arrests by KDB for illegal milk trading. According to the officials, DTA traders were perceived to provide better quality milk than non-DTA traders. However, the officials estimated that only 45% of their members had gone through the training because traders did not find much benefit in paying for the training since it was still possible to run milk business without it.

The non-DTA traders (characterised by non-recognition by KDB and DTA) represent the majority of milk traders in the country. Their involvement in milk trading was described as “not planned” and of low initial capital investment.

The chain profiles for DTA and non-DTA traders are shown in figure 10 below.

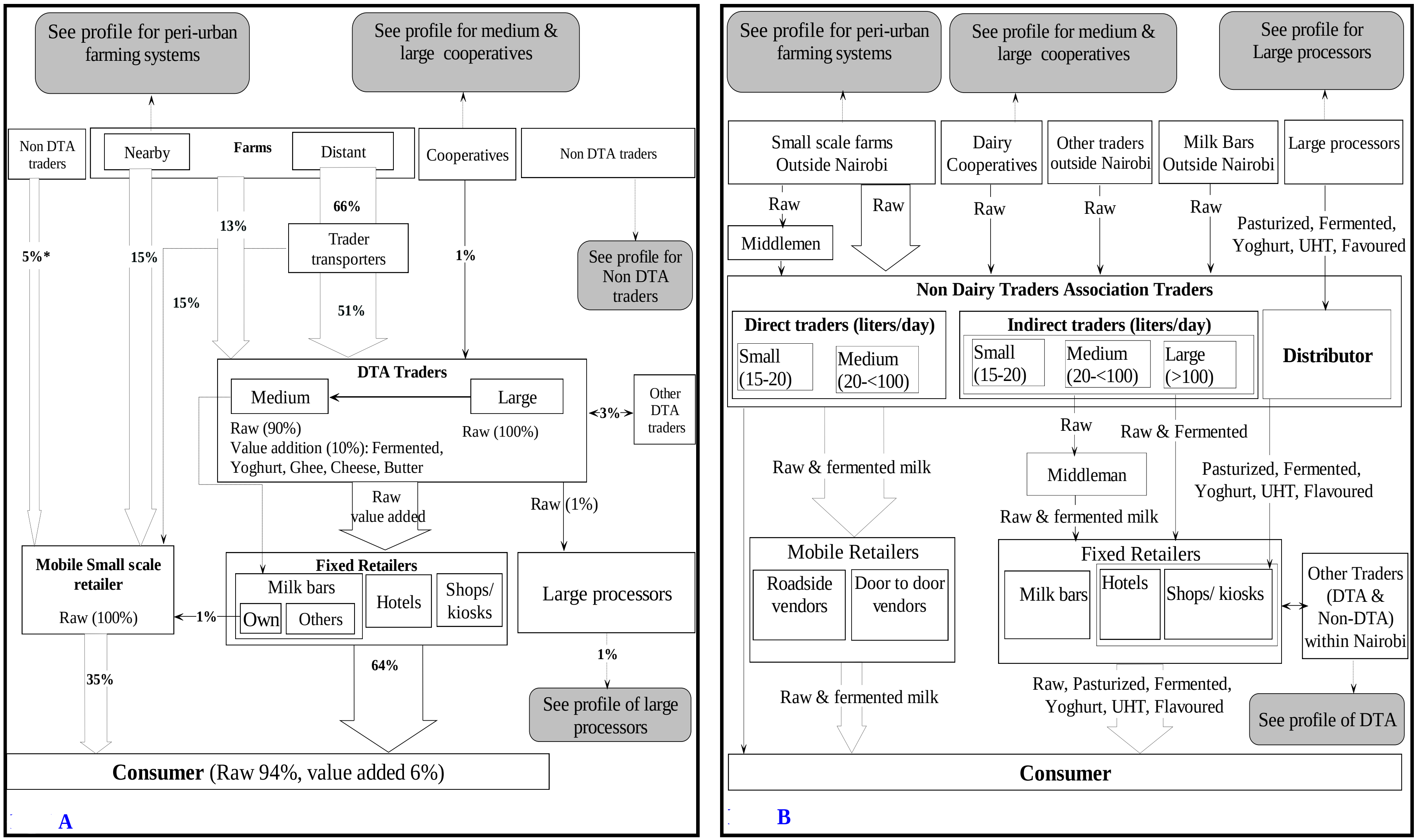


Figure 10: Chain profile for (A) traders that are part of the Dairy Traders Association (DTA Traders) and (B) for traders not belonging to the Dairy Traders Association (Non-DTA trader).

Footnote: In the left figure (A), the percentages indicate the quantity of milk traded by DTA traders and mobile small scale retailers.

4.7.1 Milk Sourcing by DTA and non-DTA traders

There were no major differences between milk sourcing practices by the DTA and non-DTA traders except that a few of the non-DTA traders principally dealt with processed branded products such as pasteurized milk, UHT, yoghurt, fermented milk, cheese, ghee and butter. Sourcing of these products was through an organized system and dependent on supply from processing companies.

Overall, it was established that both types of traders obtained raw milk from the same geographical areas and their milk sourcing practices were similar. Almost all the milk handled by the traders was reported to originate directly from farms (mainly small-scale farmers keeping 1-5 cows), and rarely from other sources. Sourcing from dairy cooperatives or from other traders was principally done only to address any deficit in milk volumes for their specific clients.

Approximately 60% of all milk traded in Nairobi by DTA traders was reported to originate from distant farms while large volumes flowed from peri-urban farms outside Nairobi through non-DTA traders. The rest of the milk was believed to originate from farms located in far rural areas of the country. Payments were reported to be done in advance, on cash, weekly or monthly depending on the agreement between the trader and the farmer (s). When agents were involved, monies were channelled to the farmers through them. In this case, the traders, did not interact with the farmers directly.

The main mode of milk transportation by both types of traders was described to be by foot when moving over short distances but mainly by sticking 20-litre plastic containers under passengers' seats in the public vehicles for longer distances. Some of the medium and large-scale traders, however, were reported to sometimes use their private vans, bicycles or motorcycles to transport milk.

4.7.2 Milk selling by Traders in Dairy Traders Association and non-Dairy Traders Association

Both DTA and non-DTA traders sold their products mostly to private consumers and retailers (milk bars, restaurants, shops and kiosks). Sometimes, but rarely, some of the milk was said to be sold to large processing companies or to other traders. It was estimated that approximately 90% of all the milk was sold raw except for the few non-DTA traders dealing with processed branded products. About 30% of medium scale DTA traders were believed to own milk bars (figure 11, a milk bar at Uthiru area) and carried out value addition activities on 10% of their milk to produce yoghurt, fermented milk, cheese and butter.

Note the walls made up of old sacks and the multiple unclean equipment on the floor (contrary to premises set up requirement by the Kenya Dairy Board. At the time of study, the refrigerator was not in working condition but milk was stored inside

Figure 11: Milk bar at Uthiru.

No geographical restrictions were reported on where traders are allowed to sell their milk, except with the legal licensing requirement from KDB which only a few traders complied with. However, it was mentioned that traders had clientele who were somewhat "permanently" engaged with them through verbal agreements. Figures 12 (kiosk) and 13 (roadside vendor) show some milk outlets by retailers.

Mobile retailers were described as those traders or retailers without permanent premises. They sold milk by moving from door to door or sold at certain points along the roadsides. For non-DTA traders, milk flowing through mobile retailers was estimated to be considerably high compared to the flow of milk through fixed retailers. Medium and the large-scale non-DTA traders reported that once they have delivered milk to their main clients (fixed retailers), they sold their remaining milk as roadside vendors. Some large-scale traders were also reported to transport large quantities of milk from far in their vans to sell to passers-by.

Whether from DTA or non-DTA, spoilt milk was never discarded. This was mainly sold as fermented milk at a small price or was converted to yoghurt by addition flavours and food colours to fermented milk.

Figure 12: Raw milk displayed for sale in a kiosk at Uthiru, Dagoretti.

Note the open drainage system passing in front of the kiosk and lack of cold chain on the displayed raw milk.

Figure 13: Raw milk displayed by the roadside in Korogocho, Kasarani.

Note the open sewer draining into the open drainage system and lack of cold chain on the displayed raw milk.

4.8 Chain profile for the dairy cooperatives

Dairy cooperatives were described as the organizations formed by several farmers who get together to organize corporate bulking (sometimes cooling), value addition activities, distribution and selling of their milk products. Dairy cooperatives were reported to be located in the peri-urban areas with none existing in the urban or in Nairobi informal settlements since almost all milk produced by these farms was reported to be sold through farm gate sales. Key informant interviews with dairy cooperatives managers classified these cooperatives into three types, small, medium and large based on the amount of milk handled per day. They were estimated to handle 10,000, 25,000 and 200,000 litres per day respectively.

The chain profiles for the medium and the large dairy cooperatives are shown in figure 14.

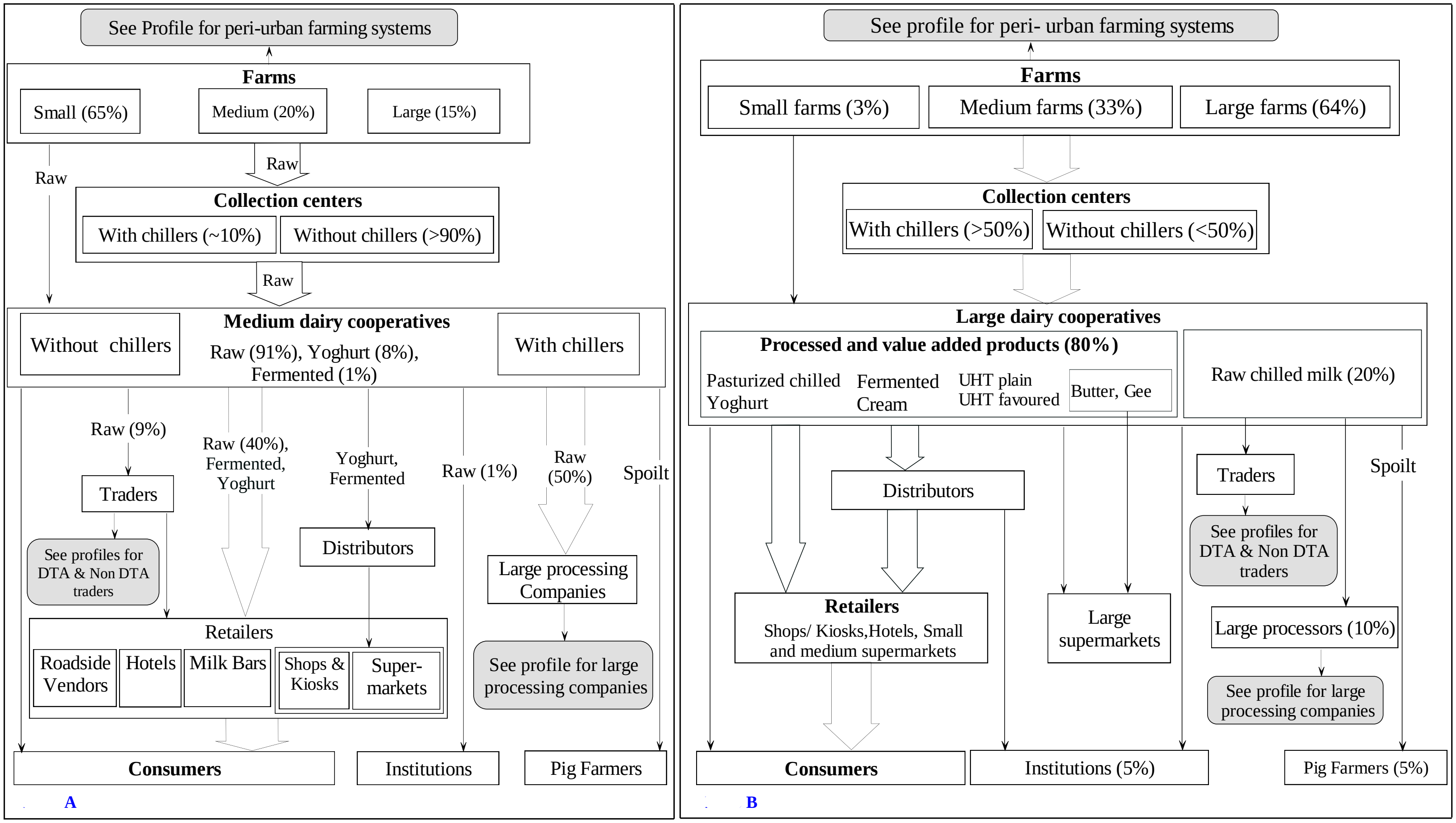


Figure 14: Chain profiles for the medium (A) and the large dairy cooperatives (B).

Footnote: The chain profile **(A)** shows that medium size cooperative get most of their milk from small scale peri-urban farms and sell it as raw to retailers and large processing companies. On the other hand, profile **(B)**, large size cooperative get their milk form medium and large peri-urban farms and sell most of it to retailer either directly or through distributors.

4.8.1 Sourcing of milk by the dairy cooperatives

Generally, milk was reported to be obtained from within the peri-urban farms (Figure 14). Although in some scenarios farmers approached the cooperatives for enrolment through formation of milk collection centres. Over 64% of members belonging to the large-scale dairy cooperatives were large-scale farmers keeping more than 19 dairy cows and producing an average of 15-25 litres per day while the medium-scale cooperatives membership constituted of approximately 65% of small-scale farmers (2-5 dairy cows) and 20% medium-scale farmers (6-10 dairy cows).

However, whatever scale of the cooperative, milk was directly sold by the farmers to the cooperative but mostly through milk collection centres. Most (>90%) of the collection centres under the medium scale cooperatives were reported to lack chilling facilities while more than 50% of those operated by large cooperatives were reported to have chillers.

Farmers reported that milk transportation to collection centres involved a variety of transport modes, including by foot, donkeys, bicycles, motorbikes and private or public vehicles. Transportation from the collection centres to the cooperatives was reported to be organized by the cooperatives, but its cost was transferred to farmers in form of revenue deduction from their monthly sales. Payment of milk deliveries was described to be paid by the cooperative at the end of the month into the farmer’s bank account.

4.8.2 Selling of milk by the dairy cooperatives

Large cooperatives estimated 80% of all their milk was processed to produce pasteurized, UHT milk, yoghurt, fermented, cheese, butter, ghee, cream and long life flavoured milk. These were sold mainly through distributors to retailers or directly to consumers. The remaining 20% was sold raw, but chilled, to other processors (mainly large processing companies), institutions like schools and rarely to traders.

Medium-scale cooperatives sold approximately 91% of their milk as raw to retailers, traders and private consumers. Fermented milk and yoghurt were sold from approximately 8% and 1% of their milk respectively. Rejected milk at the cooperative (or collection centre), was normally taken back by the farmer, who then sells it to private consumers and neighbours at a lower price. In some instances, especially if milk spoils after receiving it from the farmers, the cooperative reported to be offered or to be sold at lower prices to pig farmers.

4.9 Chain profile for the large processing companies

Large processing companies, figure 15, were reported to be receiving approximately 400,000 to 500,000 litres per day, the actual names of the companies withheld.

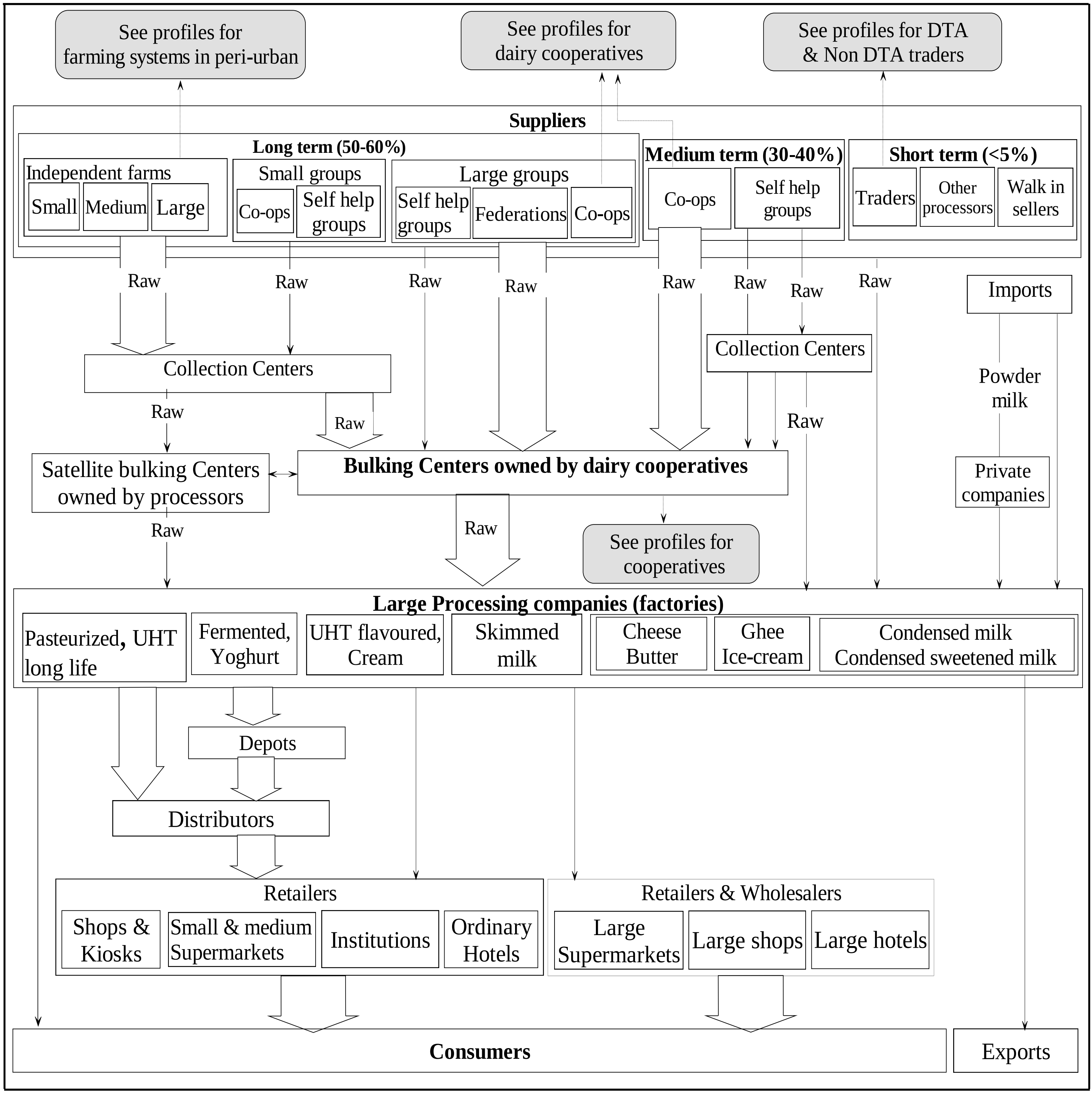


Figure 15: Chain profile for large milk processing companies.

Footnote: The chain profile for large processing companies shows that milk is mainly sourced directly from farmers through collection centres and bulking centres (dairy cooperatives). All milk products emanating from such systems is processed into value added products and sold to retailers through distributors.

4.9.1 Milk sourcing by the large processing companies

Milk procurement by both companies revealed similarities in various aspects, such as the strategic milk collection arrangements throughout the milk-producing areas in the country. Milk sourcing for large processing companies was said to mainly depend on contractual arrangements with suppliers, either on a long, medium or short term. About 50- 60% of the milk suppliers were contracted on a long-term basis, with yearly renewable contracts. The long-term suppliers enjoyed a pre-established pay per litre throughout the year irrespective of any unforeseen negative externalities, yearly bonuses, first priority during glut period, regular extension and A.I services, credit facilities and prompt payments at the end of the month. Majority of the long-term suppliers are large individual farmers (>19 cows) and farmers' groups (cooperatives, collection centres, self-help groups) of which about 89% comprised of small-scale farmers (1-5 cows).

Medium and short-term suppliers constituted 30% to 40% of the suppliers. They enjoy some of the benefits availed to the long-term suppliers but considered second and third priority for medium and short-term respectively. Contracts for medium and short-term suppliers lasted about six and three months, respectively. They constituted of small and medium dairy cooperatives, self-help groups and other processors who were unable to finish their raw milk.

Non-contracted suppliers represented 5% of these companies milk supply. They sold milk to large processors when they have no other place to sell especially during wet seasons when there is milk surplus due to overproduction. Some of the non-contracted suppliers include some individual farmers, milk traders, some self-help groups; walk-in sellers and other milk processors. In the case of unavailability of funds to pay suppliers at the end of the month, this category of suppliers is paid last (sometimes payments done after two or three months).

Due to high competition of the scarce milk at the farm level especially during the dry seasons (with traders and other processing companies), the large processing companies have arrangement with specific dairy cooperatives who supply them with milk at specific times of the day accounting for more than 60% of the milk handled by the processors.

Although no specific people are contracted to deliver milk for specific value-added products, milk from pastoral communities was said to be best for cheese and butter production due to its high butterfat and solids-non-fat characteristics. One company also mentioned of importation of powder milk which was mainly reconstituted and sold as liquid pasteurized milk particularly during the dry seasons when milk production was low.

4.9.2 Milk marketing by the large processing companies

Large processing companies carry out value addition in all of their milk to sell various value-added products. Milk distribution from the factory is done by the companies directly to depots where wholesalers (distributors) collect from although some of them were reported to collect the products directly from the companies. Distributors were described as traders with special arrangements with the large processing companies so that after making down payment to the company, they are able to collect the company's products and distribute them mainly to retailers (shops, restaurants and supermarkets). Some of the distributors were said to be stationed within the premises of the large processing company.

4.10 Discussion

The objective of this study was to understand the structure of the dairy value chain in Nairobi utilizing the Mapping component of the VCA (Hellin and Meijer, 2006; Kaplinsky and Morris, 2000a). Available literature on the Nairobi or Kenya dairy value chain studies can be traced back in the1990s (Baltenweck *et al.*, 1998; Gitau *et al.*, 1994). These studies broadly analysed the production node of the dairy value chain in the context of market access and agro-ecological zones. Other studies that followed, broadened the analysis scope to include more chain segments and a broader contextual analysis (IFAD, 2012; Staal *et al.*, 2001; USAID, 2008). Presently, VCA has been adopted for analysis of animal disease risks(FAO, 2011a), policy analysis (Kaitibie *et al.*, 2010; Leksmono *et al.*, 2006; H. Muriuki *et al.*, 2003; Salasya *et al.*, 2006; Schmitz, 2005) and production (Devendra, 2001; Salami *et al.*, 2010) for strategic decision making. The study presented here shows a detail analysis of the structure of the different chains in the dairy system supplying Nairobi, which has not been fully described before. The results provide an analytical framework to conduct a full dairy value chain analysis and allow effective investigation of food safety risks and policy interventions.

Our findings indicate that Nairobi's dairy value chain is vast, with profound complexities explained by the tightly or loosely interwoven chains. For example, direct or indirect linkages were shown to exist between small-scale and large-scale enterprises as well as between informal and formal chains. While such networks provide business opportunities for all the stakeholders involved, the distinctive flows and interactions provide opportunities for further interrogation to understand food safety and food security issues. This type of examination would be dependent on a detailed understanding of every specific chain considering that each of the chain profiles and their segments have different food safety risks practices, perceptions and controls.

Likewise, the numerous inter-linkages identified throughout the system means that interventions and policies supporting some chains may have an impact on other chains which are important to be considered; thus enhancing realization of benefits from the entire value chain. For example, if any policy intervention targets improvement of milk bacterial quality, assessment of the various nodes of the value chain (production, bulking, processing and marketing) would inform on the areas of vulnerabilities that would require what type of intervention. If at production level the milk is contaminated beyond the maximum bacterial counts, it means the milk that reaches the processor would require prolonged pasteurization procedures which would impact on the profits that probably the processor may not be willing to incur unless the consumer would be willing to pay for an additional cost. It is important to note that a significant proportion of the low-income population of Nairobi depends on informal supply chains. Careful consideration needs to be taken when making changes in these chains, as, if negative, they may reduce access to milk to vulnerable households and increase their risk of malnutrition. The results from this study provides therefore a practical framework that can be used to analyse the weaknesses and opportunities of the chains and overall dairy system, and to generate suitable policy interventions. Policymakers when planning any development or mitigation measures in the value chains, would require to critically evaluate impact in each of the system segments or chain profiles. The importance of this has been underscored in other studies (Alarcon; et al., 2017; FAO, 2011a) and has also been increasingly utilized to inform critical policy changes (Leksmono *et al.*, 2006).

The result on the people and products revealed the complexity of interaction between people and products flows. The chains were principally made up of discrete individual entities (producers, retailers, traders) that were mainly small scale in nature.

This probably follows the country's dependence on smallholders that is seen along the entire value chain (KDB, 2014). For example, the largest proportion of suppliers for large processing companies comprised of smallholders who had come together to form milk collection centres, dairy cooperatives or self-help groups and were not purely individual large-scale producers. This indicates the important role played by the small-scale producers in the overall national supply and their contribution to the complexity of the chains. Therefore, stakeholders should be cognizant of this while formulating any chain development and upgrade strategies.

The vast inter-linkages between the formal and informal chains observed in this study indicated that there were no obvious boundaries for operations, but that all chains were demand driven. For example, milk from some informal chains was shown to flow into the formal chains. Viewed from a food safety perspective, this study hypothesises that the food safety concerns in the informal chains would "spill-over" to the formal chains as suggested by some studies (Leksmono *et al.*, 2006; Roesel and Grace, 2014). The authors argue the importance of enhancing health education to both systems. However, this cannot be effectively achieved without understanding the entry points into the systems.

The results on production systems in the urban and peri-urban shows important inefficiencies of the system and thus the inability to adequately supply the city's population. The production in both systems exhibited limited access to quality animal health services, ineffective breeding services, and inadequate feeding requirements as well as constrained housing owing to limited land. Although urban farming has gained prominence in the recent past, seen as a pathway to food security to the rapidly growing populations in cities (Lee-Smith, 2010), the underlying inefficiencies prohibit realization of such intentions.

The population of Nairobi is projected to double by 2050 (Aubry *et al.,* 2010); while demand for milk may triple by the same time (Herrero *et al.*, 2014). This means that the city will be expected to produce more than 30 times the current production, which stands at 39 million litres per year (unpublished data, 2012). Hence, deliberate enhancement of the supply chains emanating from outside the city will be critical. While there is need to enhance milk production to meet the current and the anticipated demand for dairy products, it is evident that opportunities for expanding production particularly in the city and peri-urban areas are limited owing to the prevailing system inefficiencies (Musa and Achola, 2015; Southall, 2005). Additionally, the small-scale production in the city is more of subsistence driven rather than business oriented. Therefore, the producers are not able to attract supportive services (extension, veterinary, breeding and business development) effectively. Consequently, productivity remains low. It has been shown that organized groups are more likely to benefit from such services due to their enhanced social capital (Acharya *et al.*, 2010). This was also observed in the current study where producers affiliated to dairy cooperatives accessed such services, farm and domestic inputs on credit. With the widening margin between milk production and demand in the city, alternative supply sources are inevitable.

The readily sought alternative by the traders was the peri-urban and other distant farms from the rural areas. Currently, these alternative sources (peri-urban and rural areas) may appear to have enough milk to supply into the city. However, with the anticipated urbanization in rural Africa (U.N, 2007) and the noticeable growth of major cities in Kenya following devolution of development through County system of governance (Kenya Government, 2010), the current supply may not be adequate to satisfy the anticipated demand. Instead, the peri-urban and the rural areas will concentrate on supplying the cities that would be coming up in their areas.

This will further be confounded by the seasonality pattern for milk production in the country which is principally smallholder relying on rain-fed pastures (KDB, 2014). The system may have to rely in an increase of larger and more complex chains coming from outside the city. Understanding the current structure and functionality of the dairy system is critical for policymakers in charge of planning and regulating the sector.

The current structure of the dairy value chain will have to change in order to meet the anticipated rising demand. The policy interventions will need to address not only strategies for increasing production (more farms), but also that the system has to become more resilient to externalities and efficient now and in the long run to particularly enhance milk production per cow, improve cold chains, promote value addition activities and support marketing channels to prevent losses.

Additionally, the structure for sourcing and transportation of milk by traders, which was reported to sometimes occur from over 200 kilometres from the city, may not guarantee freshness and hygiene due to lack of cold chain and use of appropriate milk containers. It has also been observed that a new trend of supply into the African cities may arise from the regions perceived to have efficient supply chains and higher hygienic standards. European Union (EU) for example, abolished the quota system of milk production in 2015, encouraging maximised milk output that may end up in surplus; which may find its way into these cities hence further complicating survival of the local dairy enterprises, particularly of small-scale stakeholders. The recent acquisition of 40% shares from Kenya's leading dairy processor by a major European firm is an early indicator of such penetration of the international dairy enterprises into the African dairy markets (Food Business Africa, 2015).

There have been attempts to organize the informal milk trading through formation of DTA by the government. Although this was meant to streamline milk marketing in the informal systems, this study established that traders affiliated to DTA have continued to operate at individual capacities and with similar practices to the non-DTA traders. It appears doubtful that the major objective was achieved. It seem that traders have no perceived benefits for joining the DTA as seen from the low membership and their unwillingness to participate in the business development training organized by the association. It is possible that even those traders who had joined DTA may have utilized this platform to legitimize their businesses rather than embracing the principle focus. The commodity group trading models, such as associations or cooperatives, are intended to facilitate product assembly, lobby for prices, and seek markets among others. These have particularly been successful in the rural/high milk production areas (I. Rademaker *et al.*, 2016). However, promotion of dairy associations/ dairy cooperatives in the areas such as Nairobi city where there is ready market and the consumers are willing to pay for the milk may be difficult to thrive as evidenced by the low membership in the DTA. Additionally, platforms like dairy cooperatives become unpopular due to their inability to pay better prices and on timely manner as seen in the informal system which pays higher premiums on cash at delivery (FAO, 2011b; TechnoServe Kenya, 2008). The attempt to formalize the traders in order to enhance food safety (Leksmono *et al.*, 2006), appears not to have achieved the desired objective because the dynamics between the formalized traders (DTA) and the non-DTA appeared to be similar. Therefore, this study has detailed specific structural differences and similarities in both systems thus providing a base for further analysis and exploration of other suitable options.

4.11 Summary of the chapter

The Chapter has presented the structure (people and their interactions, the products and products flow) of the dairy system operating in Nairobi. This was a necessary first step of mapping the system which lays a framework (backbone) to overlay other segments of value chain analysis including governance, barriers to entry, system upgrading and distribution of benefits as well as food safety risks and risk profiles for emerging zoonotic diseases. The results show the interdependency of the stakeholders involved in the inter-linked dairy chain profiles. As such, these results demonstrated the need for a holistic approach and well defined policy interventions that should target every segment of the value chain in order to enhance the system's efficiency and food safety.

The next chapter describes the governance of Nairobi's dairy value chain which overlays on the mapped framework, with the aims to understand how various stakeholder interactions and challenges were experienced by value chain actors linked to food safety.

CHAPTER 5: INVESTIGATION OF THE GOVERNANCE STRUCTURE OF NAIROBI DAIRY VALUE CHAIN AND ITS INFLUENCE ON FOOD SAFETY

Introduction

The chapter will present the governance structure and challenges faced by the various value chain actors. Details about selection of study areas and study population has been covered in chapter three.

By 2050, demand for milk consumption will triple in Africa and particularly in East Africa driven by population growth, increasing urbanization and improved purchasing power due to economic growth (Herrero *et al.,* 2014). Kenya is one of the countries in Africa with high milk consumption estimated to be between 50 and 100 litres of milk per person annually (Bosire *et al.*, 2017). The significance and prominence of the Kenya dairy sector is exemplified by its nutritional importance (Dominguez-Salas *et al.,* 2016), its 3.5% contribution to the total gross domestic product (H. Muriuki *et al.*, 2003), its economic value estimated at 230 million US dollars (Kaitibie *et al.,* 2010) and creation of numerous job opportunities. The Food and Agriculture Organization of the United Nations (FAO) estimates that for every 1,000 litres of milk handled daily, about 841,000 full-time jobs are created at farm level and 15,000 jobs at processing level (FAO, 2011b). Further, the sector is a source of livelihood to more than 2.6 million people representing 80% of small-scale producers (KDB, 2014) and benefiting more than 80% of the people involved in informal milk trading (Leksmono *et al.,* 2006).

The dairy value chains supplying Nairobi are characterized by fragmented structures, which resulted from liberalization of the dairy sector in the 1990s (Leksmono *et al.,* 2006). Average milk consumption by city dwellers is generally high with poor households consuming approximately one litre of milk per week (Cornelsen *et al.,* 2016; James and Palmer, 2015). Rearing of dairy cows is not a major activity within Nairobi and over 90% of milk consumed in the city is supplied through value chains linked to production outside the city (Alarcon *et al.,* 2017). As a result, Nairobi's dairy value chain is characterized by complex interactions between a vast number of small-scale actors who mainly operate independently but are highly interconnected (as decribed in chapter 4). Seven chain profiles (or system segments) constitute most of Nairobi's dairy value chain. These chain profiles include: i) farming systems in urban informal settlement areas, ii) farming systems in peri-urban areas, iii) traders affiliated to the Dairy Traders Association (DTA), iv) traders not-affiliated to the DTA, v) medium-size dairy cooperatives, vi) large dairy cooperatives and vii) large processing companies. Each of the chain profiles links to another, thus forming the overall complex dairy food system. With increasing population growth, rapid urbanization coupled with unmatched demand and supply, the Nairobi dairy system will continue to evolve putting pressure on the existing value chains and triggering evolution of new chains, further complicating the already complex food system.

Several studies conducted in Kenya show the occurrence of various foodborne illnesses and presence of numerous hazards in milk. A study conducted to establish health hazards in milk under different marketing conditions found that up to 80% of samples did not meet the national bacterial quality standards (Omore *et al.,* 2000). Furthermore, another study reported that for every 10,000 servings of unpasteurized milk consumed in Kenya, two to three cases of diarrheal disease result from common toxin-producing bacterium like *Escherichia coli* (Grace *et al.,* 2008).

In addition, high levels of aflatoxins M1 (Kagera *et al.,* 2019; Kang'ethe and Lang'a, 2009; Kuboka *et al.*, 2019), antibiotic residues (Ondieki *et al.,* 2017), antibiotic resistant bacteria (Ombui *et al.,* 2000) and zoonotic disease causing agents like *Brucella abortus* and *Escherichia coli* 0157:H7 have been reported in both raw and pasteurized milk at farm and market levels (Kang'ethe *et al.,* 2007, 2000).

Efficient food safety control is strongly linked to the way food chains are organized and governed. The concept of governance describes the structure of interactions, power and coordination mechanisms existing between actors (Kaplinsky and Morris, 2000b). Several authors argue that interactions of actors within the systems are not just random, but are somehow organized (Gereffi, 1994; Gereffi *et al.,* 2005; Kaplinsky and Morris, 2000a; Porter, 1998, 1980). Matters about who decides what is produced, why particular stakeholders interact, what type of rules exist (whether these are legislation, private standards or cultural norms), how these are enforced and codified (includes incentives, agreements and sanctions) and who are the rule makers in the system are all explained by value chain governance.

An understanding of how such chains are organized and coordinated is important in determining the point of entry to bring interventions that aim to improve or modify the chains (FAO, 2011a; Kaplinsky and Morris, 2000b). This is further emphasized by Michael Porter's concept on enhancing competitiveness for business models that aims at identifying the points of greatest force that would result in the greatest competitive advantage (Porter, 1985). This is because those involved at every level of the value chain need to see their importance and what they stand to ultimately gain to motivate optimal cooperation (Kaplinsky and Morris, 2000a). For example, Kenya milk trading is dominated by small-scale informal traders who control over 80% of all marketed milk (Leksmono *et al.,* 2006).

Informal systems are defined as enterprises that are not registered or licensed to operate and therefore are very difficult to regulate and monitor food safety hazards and risks (Arzey, 2001; Grace *et al.*, 2010). Being aware of this, there have been attempts by the Kenyan government to organize the dairy system by training and certification of informal traders through a program dubbed, "formalization of the informal sector" (Alonso *et al.*, 2018; Omore and Baker, 2009). Although food safety benefits are expected in such organized and well-regulated systems, a study documented by Kiambi *et al* (2018) established that trained and certified traders affiliated to the DTA continued to operate with similar practices as the non-trained traders who were not affiliated to the DTA. In addition, the study reported that the number of traders adopting training and certification remained low, primarily due to the high cost of acquiring multiple licenses from different government agencies (Alonso *et al.*, 2018). Such arrangements coupled with fragmented regulations have been reported to compromise efforts towards promoting food safety (Abebe *et al.*, 2017; Gereffi and Lee, 2009).

In Lebanon, for example, food safety issues have been described to be addressed by several legislative and regulatory decrees with overlapping functions (Abebe *et al.*, 2017) and the food safety laws are termed as fragmented and limited in scope and scale to cover all parts of the food supply chain (Abebe *et al.*, 2017; El-Jardali *et al.*, 2014). Another study conducted in Vietnam found that relationships between farmers and milk collection points were mainly driven by proximity to milk collection centres located by roadsides for the large processing companies. The study found that societal connections were very influential in milk marketing such that social proximity was found to reduce uncertainties related to price, quality and quantity, and enabled access to informal credit, information and knowledge (Nguyen *et al.*, 2016).

This was particularly beneficial for farmers who were organized in hubs/groups, a model that was perceived to particularly benefit small-scale producers.

In Kenya, a study implemented to support dairy smallholder commercialization found that although farmers were best suited to coordinate themselves horizontally (with other farmers), they were not necessarily best positioned to enhance vertical coordination (with other stakeholders) as they lacked such capacities (Kilelu *et al.,* 2019). Farmers were observed to struggle with dilemmas such as inclusion, loyalty, trust and imbalanced power relations both amongst farmers and with other value chain actors. These studies suggest that successful coordination and governance of agri-food chains requires other intermediary arrangements that build on alliances between farmer organizations and other public or private organizations (Kilelu *et al.,* 2019). However, such coordination is not always effective, especially in complex food systems and with multiple regulatory agents. These studies therefore generate important information on how analysis of governance enhances coordination to improve the robustness of a food system, but they lack the holistic analysis approach in respect to food safety.

5.1 Materials and methods

Three research questions were examined: i) What are the governance challenges experienced by different actors in the chains? ii) What are the main governance factors that explain stakeholders' interactions and chain behaviour? and iii) What are the food safety implications that can be derived from the challenges and governance factors identified? From the mapping activity (chapter 4), data was collected in FGDs and KIIs for analysis for the governance and challenges experienced by value chain actors. In each FGD, participants were asked to describe:

1) Their enterprise and operations. For example, for dairy farmers, efforts were made to understand farm management practices (feeding, breeding, animal health services, selling of milk); traders were asked to describe patterns for milk sourcing, products they deal with, value addition and selling patterns, among others.
2) Their interactions. For each of the interactions mentioned (with buyers/sellers/associations/government) participants were asked to:
   a. Describe their affiliations or lack of affiliations to any associations or power groups (participants were prompted to give reasons for being or not being in such groups)
   b. Describe how a deal is made and the types of agreements made (e.g. written contract, verbal agreement etc.)
   c. List the types of incentives for dealing with the said people or organizations
   d. List the types of agreements, rules and regulations they had to follow (legislative, private standards etc.)
   e. List the types of sanctions/penalties experienced for not adhering to such agreements
   f. Describe the challenges they faced within interactions.
3) Explain how their perceptions and practices influenced milk quality and safety. Probing was used to understand:
   a. Practices at production, collection/bulking, processing and transportation
   b. Influence of regulation and private standards.

A similar approach was used for each of the key informants but with the addition of describing their role in influencing the chain. Some examples of the questionnaires used for this study are provided in the supplementary material.

Thematic qualitative analysis was performed to identify emerging themes that provided an understanding of a challenge incurred by value chain stakeholders, a governance factor or an associated food safety factor. Themes were categorized by type of stakeholder: urban (informal settlement) and peri-urban farmers, DTA trader, non-DTA trader, retailers, dairy cooperatives, large processing companies and the different types of public regulators (as established in chapter 4).

A theme was considered a challenge when it represented a barrier to entry or upgrade, or for efficient or safe completion of an activity. A theme was considered related to governance if it involved interaction of stakeholders, structural organization of power groups, chain dominance, rule setting and/or following (private standards, legislation or other norms), types of agreements and rule enforcement (including sanctions and penalties). Themes that could be categorized as both a challenge and related to governance were placed in the governance section (e.g. a power group imposing a barrier to a stakeholder). Food safety implications were then derived from participants' explanations of how governance and challenges impact food safety behaviour, or through authors' deductions on resulting themes.

5.2 Results

5.2.1 Dairy farmers

5.2.1.1 Farmers' challenges

Seven challenges were identified among all groups (Table 4). All farmer groups described problems with artificial insemination (AI) services that often failed due to untimely heat detection by famers or unskilled A.I providers, increasing the need for repeat insemination. These A.I providers were perceived to be money driven rather than by professionalism. Animal feeds was also a challenge reported in the three groups, as often they were insufficiently available, costly and of low quality, particularly the commercially acquired hay and concentrates. Some farmers had to use unorthodox sourcing of feeds, such as leftovers from markets or dumpsites, and green pastures growing by sewer lines (farmers in informal settlement areas) and by the roadside (peri-urban farmers). Diminishing land size necessary for cultivation of fodder and extension of herds was listed as the main reason for these issues, with land size changes driven by growing urbanization and property developments like real estates. This poor reproduction efficiency and high cost of inputs were stated as the reasons for a perceived lack of profits, which was worsened by their frustration in accessing credit and loan facilities to boost their dairy enterprises. Farmers reported mostly to rely on other farmers to access any information related to dairy farming. Farmers in informal settlements reported that they mostly rely on unqualified persons and self-treatment of their livestock.

Figure 16: Photo of participants during a focus group discussions with dairy farmers in Dagoretti

Figure 17: Photo of participants during a focus group discussions with dairy farmers in Kikuyu

Table 2: Challenges reported by farmers in Dagoretti and Kikuyu (peri-urban areas) and Kibera (urban informal settlement area)

	Peri-urban		**Informal settlement**	**Potential key food safety Implications (*authors' view)**
	Dagoretti	**Kikuyu**	**Kibera**	
Losses associated with poor heat detection and repeat inseminations due to unskilled AI providers	✓	✓	✓	*Poor efficiency implies less profits and reduced capacity to upgrade farm
High cost and low-quality feeds	✓	✓	✓	Possible use of contaminated feeds, increased vulnerability to diseases
Low production, high cost of inputs and difficult to make profits	✓	✓	✓	*Lack of capacity to upgrade farm and improve food safety management
Competition for animal feed, but not for milk market	✓	✓	✓	*Possible use of contaminated feeds, increased vulnerability to diseases
Lack of training on food safety and insufficient extension services	✓	✓	✓	*Reduced capacity to control foodborne zoonosis and implement good practices. Scarcity of extension services and high cost of private animal health services results in the use of untrained and unqualified persons for management of animal diseases
Unable to access training offered by dairy coops as only for members	✓	✓		*Food safety information is dependent upon farm-to-farm knowledge transfer, which may not be informed by best practices
Difficult to access loans (capital, medicine, AI and feed)	✓	✓	✓	*Lack of capacity to upgrade farm to improve food safety management
Diminishing land for dairy (real estate development)	✓	✓	✓	*Potential for increased transmission of disease and contamination of products
Lack of enough milk for value addition	✓			
Animal diseases e.g. mastitis, East Coast Fever, helminthiasis, pneumonia in calves		✓		*Possible contamination and transmission of foodborne and zoonotic diseases
Expensive and ineffective treatments			✓	*Reduced capacity to control foodborne zoonosis
Feeling of being prohibited access to training and animal health services (lack of business legitimacy)			✓	*Reduced capacity to control foodborne zoonosis and implement good practices
Difficult to find and keep workers (farming perceived as rural jobs)	✓		✓	*May reduce motivation of workers to follow good practices

5.2.1.2 Governance themes associated with dairy farmers and implications for food safety

The governance themes identified by farmers and their implications for food safety are presented in Table 5. Several themes pointed to a general self-reliance by farmers due to insufficient access to government support and lack of capacity to receive training due to lack of associations in informal settlement areas or low membership in dairy cooperatives in peri-urban areas. Farmers said there was a ready milk market and therefore felt no need for associations, while others mentioned that the incentives for dairy cooperative affiliation was to access credit facilities or services (animal feeds, AI and health services, soft loans). Whereas farmers affiliated to dairy cooperatives received some training and extensions services, those in informal settlement areas reported fear of sanctions (arrest, jail, confiscation of livestock) for keeping livestock in the city which was seen as being outlawed; this explained why they could not attend any training organized by government. It was perceived that farmers' preferred selling milk to hawkers or traders (rather than cooperatives) for quick cash and better prices and that it was easy to switch traders who refused to compromise on milk quality (adulteration). Furthermore, farmers reported a lack of contracts with traders. While farmers did not perceive that milk was controlled by any power group, feed price was however seen to be controlled by just a few companies, which increases the cost of production and the need to access alternative informal low-quality feeds.

Table 3: Governance themes identified by farmers, traders and retailers along the Nairobi dairy value chain

Node	**Governance themes**	**Food safety implications (*author's view)**
Farmers	Lack of farmers' associations (urban informal area); low membership to cooperatives in peri-urban areas (All farmers) Farmers learn from each other, rare interaction with government (Farmers, cooperatives, LPOs) Prefer selling to hawkers - better price and pay cash on delivery (Farmers in peri urban) Lack of formal contracts but operates on trust (All farmers, traders, retailers) Low cost of switching to other hawkers (easy to switch traders) (Farmers in peri urban) Women more involved at production, but men decide on selling of cows (Farmers in peri urban) Consumer preference to buy milk directly from farmers (All farmers) Few feed companies control feed prices (Dairy cooperatives) Financial pressure not to dispose of milk during treatment for disease (All farmers) Farmers are responsible for maintenance of some milk collection centres (Farmers in peri urban)	*Lack of associations and fear of government prevents access to food safety training *Low cost of switching to hawkers and ready market implies traders have low power to sanction farmers based on food safety and increased risk of unsafe milk sold *Control of feed prices by few companies generates lack of access to quality feeds for some farmers, who then shift to informal sources with low quality. This may lead to cross-contamination and disease vulnerability *Pressure to avoid financial losses nudges some farmers to not observe withdrawal period or to dispose of unsuitable milk
Traders and retailers	Do not see added value for training since they can still make profits (DTA and non-DTA traders) Difficulty to adhere to KDB rules and DTA code of ethics (DTA traders and retailers) Target low income people because they demand cheaper prices (DTA traders and retailers) Unable to sell to institutions - law restrict selling of raw milk (DTA and non-DTA traders) Exorbitant pasteurization fee by the large processing companies (DTA traders) Easy to start business, if not paying licence (DTA, non-DTA traders and retailers) Unlicensed businesses located far from main roads to escape regulation (non-DTA traders) Lack of contract and operates on trust (DTA and non-DTA traders) Farmers decide on mode of payment by traders (DTA, non-DTA traders and retailers) Negative perception of traders by large processing companies (DTA and non-DTA traders) Women dominate dairy business in informal settlements (non-DTA traders) Area chiefs resolve disputes of rejected milk (non-DTA traders) Non-DTA have strong social networks for milk selling and support in crisis (non-DTA traders) Prefer to sell raw to avoid extra cost and sell at cheaper prices (DTA and non-DTA traders) New hawkers work under existing hawkers to gain trust (DTA and non-DTA traders) Pressure of rejecting milk due to lack of supply (DTA, non-DTA traders and retailers)	*Traders not part of DTA do not have access to food safety training provided by the association *Traders not willing to pay for training- lack of incentives *Lack of access to pasteurization services reverts to selling of raw milk to consumers *Trained traders can profit from value addition knowledge and avoid use of unsuitable milk *Cost of multiple licenses incentivizes operation without medical certificate and avoidance of food safety regulations *Lack of food safety control of milk during transportation (based on trust) *The pressure to avoid financial losses nudges traders to convert spoiled milked into fermented milk or yoghurt *Large processing companies provide traders with hydrogen peroxide to conserve milk during long distance transportation without cold chain. This reduces incentive for traders and farmers to observe hygienic practices

Footnote: In table 5, the people in brackets is the type of stakeholder who said that in the interview

5.2.2 Traders and retailers

5.2.2.1 Challenges associated with traders and retailers

The list of challenges reported by DTA, non-DTA and retailers are shown in Table 6. A common theme for all groups was the perceived inability to obtain the multiple, costly and cumbersome licences required by KDB and city council. For example, Table 5 shows the basic requirements necessary to operate a retail milk bar. Besides stringent specifications for premises (tiled walls, cemented floors, running water etc.), approximately Kenya shillings 18,100-42,200 (USD 180 - 420) is required to purchase licences/permits for milk retailing at a milk bar. This amount is excluding daily cess (type of revenue that is paid to KDB on every litre of milk handled per month). Apart from a few DTA traders who operate with a few licences, most of the traders and retailers reported operating without any required licences. Consequently, corruption and harassment of non-DTA and retailers were cited as a big challenge. For example, non-DTA traders reported that during the wet season, city council officers poured their milk out and arraigned the trader in a court of law where they were fined or jailed. During the dry season, traders reported that the officers would confiscate their milk and did not arraign them in court.

Figure 18: Photo of the author during a Key informant interview with Dairy Traders Association

Non-DTA traders and retailers reported challenges in sourcing milk from multiple farmers due to low productivity per farm, hence they lost valuable business time roaming from farm to another. Additionally, non-DTA traders complained of KDB’s demand for aluminium containers for milk transportation which they described as being heavy, difficult to carry in public service vehicles and associated with losses due to spillage. Consequently, they reported use of non-food grade plastic containers. While some traders reported cleaning the containers with hot water and soap, they said some traders used other preservation methods like addition of formalin and hydrogen peroxide to minimize spoilage while transporting milk over long distances without a cold chain.

For DTA members, the main challenge mentioned relates to the extremely low membership in their association, which deflates their efforts to negotiate for better regulation and marketing terms. They were also unable to sell to institutions because the law prohibits sale of unpasteurized milk to consumers, yet the cost of setting up pasteurization units was unaffordable. Their attempt to obtain pasteurization services at a small fee by the large processing companies was futile; they cited unending fights between large processors and DTA who were seen to compete unfairly, since they were perceived to require less capital and smaller business running costs than large processors.

Table 4: Challenges associated with dairy traders and retailers

	DTA	Non-DTA	Retailers	Food safety implications (*authors' view)
Must source milk from many farms because of low production per farm		✓	✓	*Reduced capacity to establish contract and, hence, food safety agreements with suppliers
Competition for sourcing, not for selling milk	✓	✓		*Reduced power to establish private standards on food safety
Aluminium containers unsuitable because they are heavy, cause spillage and difficult to carry		✓		Use of plastic containers that are difficult to clean
High cost of business development training before entry into DTA	✓			*Reduced food safety knowledge and good practice by non-DTA
Too many rules and multiple licences required by KDB and city council	✓	✓	✓	*Increase of illegal business difficult to regulate and enforce
High business rent and standards in high-end market	✓			*Increased use of food safety practices in high-end markets
Lack of access to institutions (since they sell raw milk)	✓			*Milk safety control by institutions
Lack of capital to establish pasteurization unit	✓			Selling of raw milk
Lack of access to pasteurization services (from processors)	✓			Selling of raw milk
Lack of capital to buy food grade containers recommended by KDB	✓			Use of plastic containers that are difficult to clean
Harassment by city council/KDB due to lack of licences and medical certificate		✓	✓	*Reduced cooperation to follow food safety practices
Corruption from city council (they bribe often to continue with trading)		✓	✓	*Reduced incentive to implement food safety practices
Insecurity because they operate very early hours (from 2 am)		✓		*Escape regulation

Emerging threat of milk vending machines (consumers prefer buying from these machines)		✓	*Perception of increased food safety and quality in milk vending machines
Lack of training and knowledge		✓	*Reduced food safety knowledge and good practices
Low membership in DTA (only 2,203 of the total 56,446 traders are active members; of the active members, 40% are in Nairobi)	✓		*Reduced use of training and power to improve standards in the system

Table 5: Requirements for operating a retail milk bar

	Description	Source	Cost (*K Sh.)	Valid
Application fee	Application fees to KDB	KDB	600	One off
Recommendation letter	From KDB-certified milk supplier	Supplier	No charge	
KDB licence	Certify milk business by the KDB	KDB	2500	1 year
Business medical certificate	Certifies premise as a food kiosk	City council	5,000	1 year
Single business permit	To be allowed to trade in the city	City council	5,000-5,500	1 year
Medical check-up employees	Medical check-up of employee before award of medical certificate	Government health facility	400-1,000	1 year
Fire extinguisher inspection fee	To verify fire extinguisher has been installed at the business facility	City council	1,000	1 year
Carriage (permit)	Transport/movement permit	KDB	1,600	1 year
Garbage collection fee	City council garbage collection	City council	2,000- 25,000	1 year
**Cess fee	Per litre of milk traded	KDB	0.4/litre	Monthly
Total			**18,100-42,200 per year (excluding cess)**	

*Kenya shilling 100, approximately USD 1. **Cess fee is a type of tax levied by the KDB for every litre of milk traded (source http://www.kdb.go.ke/licensing-procedures/)

5.2.2.2 Governance themes associated with dairy traders and retailers and implications on food safety

Governance themes identified by traders and retailers are provided in Table 5. Registration with DTA requires traders to pay a certain fee and undergo training by specific KDB-accredited business development service providers on milk handling, hygiene, bookkeeping, business ethics and value addition. The majority of traders were not affiliated with DTA, which was reported to be due to unwillingness to pay for this training citing its high cost, the ability to sell and make profits without the training, the perception that farmers and consumers did not require traders be trained to buy/sell milk, the difficulties in adhering to rules set by DTA and KDB (high milk standards and multiple licences) and lack of protection by government from unfair competition with untrained non-DTA traders. This was perceived as a reduction in the capacity to negotiate or influence the chain. For instance, traders perceived that the access to institutions and high-end markets was also hindered by the large processing companies, who quoted exorbitant charges for pasteurization services. This was seen as an ability to rapidly influence milk prices in the market. This generates a negative perception of traders for these companies. On the other hand, non-DTA traders and retailers reported it was easy to start a milk business, but it required one to be strategic to evade licences and regulation. They reported the existence of strong social networks that supported them in milk sourcing and selling, and to bail out when arrested.

All the groups reported that they targeted low-income consumers and low incentive to reject unsuitable milk due to insufficient supply and added value to spoiled milk (fermented or yoghurt). Traders reported that some large processing companies provided farmers and traders with hydrogen peroxide (in tablet form) to add into milk to prevent spoilage during long distance transport when they had no cold chain facilities.

5.2.3 Dairy cooperatives and large processing companies

5.2.3.1 Challenges associated with dairy cooperatives and large processing companies

Challenges associated with dairy cooperatives and large processing companies are provided in Table 8. Lack of coolers was reported as a big challenge by cooperatives due to high cost of installation and maintenance. This was reiterated by the large processors who in addition cited low milk volumes in the country as a major disincentive for such investments. Cooperatives and large processors reiterated their frustration regarding frequent milk rejections which they complained promotes unfair competition especially with the informal sector. Despite internal guidelines regarding milk quality, sometimes they were forced by circumstances to accept milk of lower quality. This was attributed to low farm production of milk which led to increased competition with the informal sector, who were perceived to not care much about milk quality. It was reported that there were no policies for management or disposal of the rejected or spoiled milk, other than giving it back to the supplier. Rejected milk was therefore reported to be sold for pigs (cooperatives and large processors) or converted to home-made yoghurt or sold as *'mala'* (traditionally fermented milk) by farmers, traders and retailers. Additionally, cooperatives and large processors echoed their frustrations with lack of adequate infrastructure citing the poor road network in production areas and lack of physical sheds for milk collection (milk collected by roadsides). Apart from the high cost linked to milk collection from many farmers/collection centres, breakdown of vehicles and thereby delayed delivery of milk to destinations was identified as a major challenge associated with high levels of milk contamination and spoilage.

Table 6: Challenges associated with dairy cooperatives and large processing companies.

	Dairy cooperatives	Large processing companies	Food safety implications (*authors' view)
Farmers reluctant to learn from free training	✓		*Reduced knowledge and good practices
Farm owners not attending training (they send attendants)	✓		*Lack of knowledge transfer to the person who has power to enforce
Production losses due to poor heat detection by farmers	✓		*Poor efficiency implies less profits and reduced capacity to upgrade business
Low milk supply in dry seasons	✓	✓	*Poor efficiency implies less profits and reduced capacity to upgrade business
Lack of breeding expertise by extension officers	✓		*Poor efficiency implies less profits and reduced capacity to upgrade business
Low number of active members with most selling to traders because they pay cash	✓		*Use of less regulated channels
Lack of enough coolers at bulking centres	✓		*Risk of milk spoilage
Low milk volumes to warrant installation of coolers or key infrastructure	✓	✓	*Lack of cold chain increases risk of milk spoilage
High milk rejection from small-scale farmers	✓		*High volumes of rejected milk increases pressure to recirculate
High cost and poor quality of inputs discourage productivity	✓	✓	*Poor efficiency implies less profits and reduced capacity to upgrade business
High cost of multiple licences	✓	✓	*Increase of illegal business difficult to regulate and enforce
Over taxation and double payment of cess		✓	*Increase of illegal business difficult to regulate and enforce
Poor roads and public infrastructure	✓	✓	*Increased risk of milk spoilage
High prevalence of animal diseases	✓	✓	*Risk of milk contamination
Struggle to reject unsuitable milk (low supply, competitors)	✓	✓	*Risk of unsafe milk entering the food chain
Lack of procedures for management of rejected milk	✓	✓	*Risk of unsafe milk entering the food chain
Shortage of staff to provide extension services	✓		*Reduced food safety knowledge and good practices

Operating at half capacity due to unstable markets and machine maintenance challenges	✓	
Lack of enforcement of standards across the value chain	✓	*Reduced incentives to follow food safety practices

5.2.3.2 Governance themes associated with dairy cooperatives and large processing companies and implications on food safety

Table 9 displays the governance themes associated with dairy cooperatives and large processing companies. Both groups suggested that a milk trading environment exists that displays unfair competition. They reported that: i) the government failed to regulate the informal sector while overregulating the formal chains (cooperatives and processors), ii) the KDB had started formalizing traders through training and registration (DTA), iii) they lacked support in infrastructure development associated with high costs of milk collection from farms, iv) with devolved system of governance, several counties (subnational) were setting up dairy plants (further reducing milk that they received from rural areas), v) inability to compete with traders on pricing since traders had minimal operating costs and vi) it was a struggle to reject milk since it would be accepted elsewhere (lack of policies for management of rejected milk). This unfair competition was believed to generate a lack of effective monitoring and reduced the incentive to comply with food safety regulations along the value chains. Several positive incentives were mentioned that may influence farmers to join and supply the dairy cooperatives and large processing companies. These were financial, through improved access to credit or better payment, and technical, through provision of services (e.g. animal health) or access to training. On the other hand, sanctions were in place to reduce milk rejections (especially through bad practices, such as milk adulteration) and to incentivize farmers to avoid selling milk to independent traders. This contrasted with the perception that dairy cooperatives are unwilling to pay for milk quality, reducing the incentive for farmers to improve.

Table 7: Governance themes identified by dairy cooperatives and large processing companies.

Governance themes from dairy cooperatives and large processing companies	**Food safety implications** (*authors' view)
Unfair competition – Failure to regulate traders and overregulation of formal chains (large processing companies) – Licensing of traders (formalization of informal sector) (large processing companies) – Inability to compete with traders on pricing and cost of production (large processing companies) – Lack of support on infrastructure development (large processing companies and dairy cooperatives) – It is a struggle to reject milk (large processing companies and dairy cooperatives) – Devolution system of governance seen as threat with most counties installing processing plants (large processing companies) Positive incentives – Credit access to feed, AI and animal health services and household items (but feed more expensive) (dairy cooperatives) – Cooperatives provide loans at lower interest rate to members (dairy cooperatives) – Provide internal training to members only (dairy cooperatives) – Bonus provided on amount of milk delivered and profits (large processing companies and dairy cooperatives) – Cooperatives test milk samples from farms with recurrent spoilage events (large dairy cooperatives) – Long-term suppliers paid first by processing companies in times of financial crisis (large processing companies) – Large processing companies assure a constant price to long-term suppliers (large processing companies) – Large processing companies pay based on volume band system (large processing companies) – Large processing companies recommend farmers to financial institutions for loans (large processing companies) Sanctions – Farmers are forbidden to sell milk to hawkers or adulterate milk, and incur heavy sanctions if discovered (large dairy cooperatives) – Milk rejections are sanctions though loss of bonuses (large processing companies and dairy cooperatives) – Farmers and traders bear the cost of milk rejections (including termination of contracts) (large processing companies) Others – Cooperatives not willing to pay for quality (large dairy cooperatives) – High private standards (need to follow a lot of internal rules) (large processing companies) – Feel that government should develop a national protocol for the use/ disposal of rejected milk so that it doesn't flow back to consumers (large processing companies) – Payment to suppliers done monthly post-delivery (large processing companies and dairy cooperatives)	Cooperatives provided access to food safety training to farmers Lack of clear protocol nudges farmers to resell rejected milk Private standards implemented to ensure hygiene (e.g. use of adequate aluminium containers, ISO certified, HACCP procedures) Organoleptic tests done at collection centres and microbiological analysis at processing centres to ensure quality control Control mechanism to diagnose cases of recurrent spoilage Incentive to reduce rejections though loss of bonuses Access to cheaper loans may incentivize food safety upgrade of farms Cooperatives provide access to private veterinarians and other animal health services *Hawkers are more likely to receive unsuitable milk from farmers Processing companies feel that the greatest challenges to the quality of milk comes from small and medium suppliers *Long distance vehicles with lack of cooling system may be more susceptible to milk spoilage/adulteration Monitoring storage post-marketing ensures minimal spoilage and overstocking of milk by retailers

- Farmers registered in cooperatives without written contract (dairy cooperatives)
- Large processing companies test milk delivered by cooperatives (large processing companies)
- Offer AI service to non-members, but paid in cash but members are deducted from milk sales at the end of the month (dairy cooperatives)
- Members must own a cow (s) to be allowed as a member, to avoid recruiting hawkers (dairy cooperatives)
- There is lack of control or monitoring of milk during transit (large processing companies)
- Provide training to extension agents to ensure quality (large processing companies)
- Large processing companies have written contract with most suppliers (large processing companies)
- Large processing companies monitor storage by some clients post-marketing (large processing companies)

Footnote: In table 9, the people in brackets is the type of stakeholder who said that in the interview

5.2.3 Government officers

These include the KDB, PHOs, LPOs and city council officers. The role of KDB is regulation of the dairy sector through enforcement of the Dairy Industry Act CAP 366. The board is responsible for inspection and licensing of milk handling premises and surveillance on quality and safety of milk and milk products along the dairy value chain. The Nairobi city council is responsible for licensing of businesses. They provide single business permits, business medical certificates, employees' medical certificates, inspect installation of fire extinguishers at business premises and facilitate garbage collection. The responsibility of PHOs was reported to be food and sanitary inspection of premises, offering of medical certificates and enforcing public health-related laws like Public Health Act, CAP 242, Drugs and Chemical Substance Act, CAP 254, Meat Control Act, CAP 354 and regulation of food related city by-laws. The responsibility of LPOs was reported to be advising farmers on production through extension, monitoring of disease outbreak rumours, advice on appropriate housing structures and dimensions for livestock, dissemination of information, creating linkages with markets, organizing farmer field days and training of farmers.

5.2.3.1 Challenges associated with government officers

Challenges reported by KDB, PHOs, LPOs, and city council officers are reported in Table 8. Hawkers (mobile traders) were described as the most difficult people to control and regulate; and they were perceived to adulterate milk through addition of margarine (to deceive consumers on high butter fat content), water (to increase volumes), antibiotics (for preservation) and flour (to deceive consumer on milk thickness). Hawkers were also perceived to ignore milk hygiene since their lower milk prices compel consumers to buy from them.

Another challenge reported was the lack of medical certificates, which was attributed to the high cost and frequency of obtaining them. For example, it was reported that a medical certificate is required to be renewed every six months. Officers felt that some retailers were not comfortable with the lack of clarity on the type of test needed to obtain the medical certificate, with many of them fearing being tested for HIV status. Inadequate water supply was also cited as a major problem. It was said that those people without water rarely mopped their premises and instead only swept their floors. Furthermore, the origin of water used for cleaning utensils was of questionable quality since it was supplied by cart pullers. Inadequate water problems were further complicated by poor infrastructure (semi-permanent buildings in area), especially in the informal settlement areas which were located near open sewage trenches. Another challenge was related to lack of cold storage facilities; which was due to power breakdowns in supermarkets in informal and peri-urban areas.

Lack of an adequate workforce was reported as a significant hindrance to effective performance by the dairy system. For example, it was reported that there were very few government officers employed to serve at various levels of the system from production (few extension services by LPOs) and there was an inadequate number of staff to effectively undertake monitoring, regulation and enforcement (KDB, PHOs, city council).

Table 8: Challenges associated with government officers

	KDB	PHOs	City council officers	LPOs	Food safety implications (*authors' view)
Milk hawkers pose biggest challenge to control	✓	✓	✓		Escape regulation and monitoring of food safety hazards
Lack of licences and medical certificates	✓	✓	✓		Increase of illegal business difficult to regulate and enforce
Inadequate water supply	✓	✓	✓		*Risk of unsuitable food safety practices
Lack of cold storage facilities	✓	✓	✓		*Lack of cold chain increases risk of milk spoilage
Long distance transportation without cold chain	✓	✓	✓		*Lack of cold chain increases risk of milk spoilage
Inadequate staff to enforce regulations	✓	✓	✓	✓	Reduced efficiency to monitor and enforce food safety regulations
Lack of office vehicles to facilitate licence issuing; employees must walk to premises			✓		*Poor efficiency implies reduced capacity to regulate the system
Inappropriate milk handling (non-food grade containers)	✓	✓		✓	*Risk of milk contamination and spoilage
Cost of food-grade containers four times higher than plastic container	✓				*Risk of milk spoilage
Lack of access to essential amenities (toilets, difficult to clean floors, poor waste disposal, poor drainage systems), poor personal hygiene		✓		✓	*High risk of milk contamination
Inappropriate housing for animals (cow sheds connected to main houses)			✓	✓	*High risk of milk contamination
Lack of knowledge (retailers)		✓			*Risk of unsafe milk entering the food chain
Conflicting hours of operation (hawkers, traders, roadside vendors operate very early or late (when government facilities have closed)	✓	✓	✓		*Risk of unsafe milk entering the food chain
High cost of getting into premises is prohibitive for hawkers and roadside vendors			✓		*Increase of unregulated chains which are difficult to monitor and regulate

Lengthy process of sanctioning which takes 1-3 months		✓			Reduced incentive to enforce compliance
Compliance issues within lower socio-economic strata	✓		✓		*Risk of unsafe milk being sold
Sick animals which do not respond to antibiotic treatment are sold to butchers or traders				✓	*Risk of unsafe milk being sold
Farmers not observing antibiotic withdrawal period				✓	*Risk of unsafe milk being sold

5.2.3.2 Governance themes associated with governance officers and their implication on food safety

Table 9 reports governance themes identified by KDB, PHOs, LPOs and city council officers. Lack of premises by mobile traders and retailers made monitoring, regulation, training and application of sanctions difficult. Due to this, the city council deployed a team of field officers to collect daily cess and to identify retailers/traders operating illegally without a premise, as required by law. Political interference was cited as a big challenge in enforcement of laws. Attempts to close uncompliant businesses met with interference by politicians who want to be seen as the voice of people (city council, PHOs).

Table 9: Governance themes identified by government officers

Governance themes	KDB	City council	PHOs	LPOs	Food safety implications (*authors' view)
Failure of traders and retailers to obtain licenses	✓	✓			*Sale of milk by unlicensed traders and retailers means milk escapes regulation and monitoring for food safety risks
Hawkers lack of permanent milk trading premises makes it difficult to apply sanctions	✓	✓			*Increase of illegal business difficult to regulate and enforce
Specialized team from city council regulates roadside vendors and hawkers with semi-permanent infrastructure (e.g. cess collection)		✓			*City council's collection of revenue from unlicensed traders and retailers escalates further sales of milk that is not monitored by KDB for food safety risks
Political interference (politicians prevent closure of noncompliant businesses)		✓	✓		*Encourages unregulated chains which are difficult to monitor and regulate
Fragmented licensing (same city council, different offices handle various licences that traders are required to obtain)	✓				*Increase of illegal business difficult to regulate and enforce
Traders and retailers in semi-permanent structures do not have licences but pay daily cess	✓	✓			*Increase of illegal business difficult to regulate and enforce
Conflict of interest; it is illegal to sell milk without premises and licences, but revenue is still collected from illegally operating businesses like hawkers and roadside vendors		✓			*Encourages unregulated chains which are difficult to monitor and regulate
Retailers not willing to obtain licences due to high cost and their perceived lack of value due to inadequate services like fluctuating electricity and poor roads	✓	✓			*Increase of illegal business difficult to regulate and enforce
Livestock keeping is illegal in the city and farmers (in city) cannot be licensed		✓		✓	*Prevents farmers from seeking services from government
Retailers in high-income areas do not have a problem with compliance (90%)		✓			
Provision of training on food handling to retailers	✓	✓	✓		
Uncompliant retailers/traders (licensing) are given a 14-day notice to comply, otherwise arrested and taken to court (to scare the rest), or may have their businesses closed or milk confiscated		✓	✓		

5.3 Discussion

This study investigated governance and challenges associated with food safety in the complex dairy value chain of Kenya's largest urban setting. The value chain framework previously developed by Kiambi *et al.* (2018) was utilized to overlay governance and challenges themes to facilitate interpretation and clarity of results. It is agreed that complex food systems require strategic analytical approaches to determine critical points for intervention and several studies have described how such analysis can be achieved (Alarcon; *et al.,* 2017; FAO, 2011a; Muloi *et al.,* 2018; Onono *et al.,* 2018). It is important to note that the food safety concerns identified in this study represent stakeholders' views and authors' inference of the results. The extent to which these concerns can cause high levels of food safety hazards requires further validation, especially through risk assessment and microbiological procedures. A detailed analysis of these risks was beyond the scope of this study, as this study was focused on understanding the role of governance in the creation of risks. It is clear, however, that tackling the complex governance structure in the milk system, and in particular the many interactions between parallel value chains, has several downstream impacts on potential disease risks and the subsequent food-borne disease burden in human consumers.

At production, farmers reported a general lack of or inadequate support by the public and private sectors. This is characterized by insufficient training and extension services coupled with lack of incentives in the system. Farmers felt there was a lack of an enabling environment to promote dairy enterprises, in particular when faced with a high prevalence of animal diseases, high cost and low-quality animal feeds, diminishing land for expansion of dairy (blooming of real estate) and the lack of credit and loan facilities. This perhaps reflects the national image of the dairy industry post liberalization in 1991 (MALF, 2013, 2010; I. Rademaker *et al.,* 2016).

Government divestiture of the Kenya Cream Creameries which resulted in privatization of services such A.I, tick control and veterinary clinical services caused a general decline in performance of the dairy sector (MALF, 2013). Food safety implications associated with these challenges are related to widespread lack of extension services and training, suggesting that milk production practices and attention to food safety is dependent upon the source of information (whether good or bad). Various studies have explored diseases and other public health hazards in milk (Grace *et al.,* 2008; Kang'ethe; *et al.*, 2007; Kang'ethe and Lang'a, 2009; Ombui *et al.,* 2000; Omore *et al.,* 2000, 2002a; Ondieki *et al.,* 2017). A detailed analysis of these risks is beyond the scope of this study, but several of the hazards identified in those studies stem from the governance issues discussed in the present work. It is clear that tackling the complex governance structure in the milk system, and in particular the many interactions between parallel value chains, has several downstream impacts on disease risk and the subsequent food-borne disease burden in human consumers.

The main challenges and governance issues associated with traders and retailers were harassment by KDB, city council and PHOs for lack of required licences and permits due to the associated costs and cumbersomeness of obtaining them. While the laws, policies, licenses, permits and standards are meant to streamline coordination and bring order along the value chain, this has not been the case for Nairobi's dairy value chain. These findings are consistent with previous analyses that cited inappropriate regulations as a major factor constraining development of enterprises particularly in developing countries (Alonso *et al.,* 2018; Pfeffermann, 2001). In an attempt to organize informal milk trading in Kenya, KDB established a training and certification model that enabled formalization of the informal traders (Roesel and Grace, 2014).

However, the mode of operation for the certified traders was like those of uncertified traders, raising speculations that traders were seeking to legitimize their businesses rather than improve how they conducted business (Kiambi *et al.,* 2018). Traders escape harassment from regulators when they have a certificate, but they continue with their original practices. Furthermore, Alonso *et al.* (2018) found that there were no differences in bacterial quality of milk sourced from trained and untrained traders, and hence highlighted the interlinkage in the system and the difficulties in applying incentives to increase milk quality. This may also explain the numerous food safety problems identified at the retail nodes in the current study. Among those mentioned were sale of raw milk to consumers, adulteration (addition of water or other substances like margarine and flour), value addition of spoiled milk to be sold at cheaper prices and the addition of hydrogen peroxide or formalin to preserve the milk for long distance transportation without a cold chain. In addition, the findings indicate that farmers could easily switch traders/retailers who questioned the quality of their milk, implying that there is low power to sanction farmers based on food safety, thus increasing the risk for unsuitable milk to enter the distribution chain. To ensure monitoring of food safety hazards in a complex system like Nairobi, the relevant sector requires an understanding of critical areas that require minimum interventions to achieve maximum impact. Proper incentives and rewards may be critical to enable effective transformation of the sectors. For example, the sector may need to invest in educating consumers who will then demand quality milk. Publicly subsidizing various inputs may also provide incentives to ensure milk quality. Training alone is not adequate as shown by Alonso *et al.* (2018), but increasing both the demand for a safe product and the earning potential of the value chain actors based on the quality of their product will provide incentives to follow food safety regulations.

Policymakers must also take into consideration that the informal sector employs about 80% of the people working in the dairy sector; thus many people depend on the informal dairy sector for their livelihoods and it is a path to reduce poverty, hunger and malnutrition (Salasya *et al.,* 2006).

At the dairy cooperative and large processing company level, the main challenges influencing food safety were the low milk quality (adulteration, lack of cold chain and lack of withdrawal following administration of medicines) and lack of policies for management of milk that has been rejected at reception with the rejects being resold to competitors (traders). The quality of milk reaching the processing unit defines the final quality of processed milk. Yet there are weak support services to farmers which contributes to hygienic milk production and handling. Considering that farmers are just a small proportion of the country's small scale producers, it is not surprising that such challenges are major reasons for the lack of milk quality differentiation between formal and informal systems (Alonso *et al.,* 2018; Roesel and Grace, 2014; Salasya *et al.,* 2006). Strict standards are not enough to ensure that high-quality milk is supplied to cooperatives and large processing companies. Farmers and distributors require capital to produce and deliver a quality product. Farmers also require access to affordable veterinary care, and both farmers and distributors require infrastructure such as adequate roads.

Dairy cooperatives and processing companies report that they accept milk that should be rejected because of a lack of clear policy regarding management of rejected product. These entities reported that if milk is rejected by them, it flows back into the food chain through their competitors; as a result, they opted to accept it and assumed that it would be diluted when mixed with other good milk. If such milk were coloured differently, or disposed of at reception, it may incentivize the formal systems to adhere to quality control measures and enhance compliance with food safety regulations.

The current study has established that lack of compliance to rules and regulations was common as seen by the reluctance of various actors to obtain licences and permits. Ideally, business licences and permits are mainly used for purposes of taxation, but they also help the government monitor and regulate businesses that may affect public safety. This study has identified the fragmented, costly and complex regulatory system as a barrier to compliance and to formalization of milk enterprises. This agrees with other studies (Alonso *et al.,* 2018; Pfeffermann, 2001). Often, lack of coherence in policy and practice (fragmented system) results in one arm of the government doing something that is contrary to the other arm of the same government. For example, although it was illegal and strongly prohibited by KDB to hawk or trade milk in open (without premises), the city council organized a team that collected revenue from these businesses and charged a daily fee (not necessarily a licence or permit). Other studies agree that lack of integrated regulatory functions is a problem in the dairy sector globally but local authorities drive the required changes based on their identified challenges (Gereffi *et al.,* 2005; Orden and Roberts, 2007). For example, Gereffi (2005) argues that when demand and supply are fragmented, there is a higher likelihood of having no or limited public standards that cover only basic food safety aspects (Gereffi *et al.*, 2005). Such systems are characterized by less developed private quality and social and environmental standards. Hence, as it is, the Nairobi dairy system will be difficult to organize until licensing is integrated and costs reduced. If most people continue to run businesses informally, the few numbers of regulators will continue to be overwhelmed with non-compliant people. But once the system is organized, it means the stakeholders will be known and it will be possible to provide systematized training, monitor food safety hazards and enforce the law.

While food safety concerns arise from both formal and informal systems (Alonso *et al.,* 2018; Roesel and Grace, 2014), and considering the tight interactions among actors in both systems (Kiambi *et al.,* 2018), the government should find a common ground to holistically address food safety challenges. Sound policy reforms have been shown to have widespread economic benefits (Alonso *et al.*, 2018; Pfeffermann, 2001; Salasya *et al.*, 2006). For example, the Nairobi dairy value chain is vast and formal chains are somewhat integrated with informal chains (Kiambi *et al.*, 2018). So, emphasis on criminalizing and penalizing actors in the informal chains without addressing factors that hinder formalization directly impacts on possible gains that are desired by the system, like food safety and food security. Consequently, even the formal chains may not function optimally, as seen in their struggle to reject any milk. In this study, it was reported that sometimes dairy cooperatives and large processing companies received milk that should be rejected. They argued that considering milk is scarce and there is always a ready milk market, if the formal systems rejected such milk, the supplier will always find another outlet and that milk will get into the food chain through other channels and thus the formal systems will be the losers.

Unfair competition was reported as another governance issue driving compromised food safety, particularly by large processing companies and dairy cooperatives (formal sector). These actors cited a lack of protection by KDB from the informal sector who were said to trade freely with minimal costs and without licenses, and yet they dominated the milk market. The frustration in regulation of the informal sector was described from the aspect of KDB's attempt to formalize the informal sector (Leksmono *et al.*, 2006). This is also seen in the current study where city council officials charge a daily fee for the noncompliant traders and retailers (hawkers or selling outside a premise which is against the law). However, the central question is what food safety value is added with more flexible regulation and increased compliance?

More studies are needed to fully understand this relationship, particularly in systems where the milk structure is vast and liberalized like in Nairobi. Consumers are always looking for value in whatever commodity or services they seek. In the Nairobi milk system, it seems the government is not adding value through regulation, seen by the enormous number of people trading without licences. These actors felt like regulation was an extra burden that increased operational costs without increasing profit potential. As a result, out of the 56,446 traders in the country, only 2,203 were active in DTA (879 in Nairobi). Therefore, large amounts of milk was flowing through the informal milk marketing channels as demonstrated in other studies (FAO, 2011b). However, other researchers argue that regulation enhances food safety, but this is possible only in systems where government regulation incentivizes product quality linked to increased profit potential and the infrastructure supports business development (Gereffi *et al.*, 2005). Otherwise, if regulation does not offer any added value to both producers and consumers, consumers will continue to obtain milk from informal sources. Consumer will need to push for quality for effective transformation, but with a rapidly increasing population (especially poor people), quality may not necessarily be the priority.

In the current study, various sanctions were mentioned to enforce regulation. These included negative sanctions like rejections of poor-quality milk from farmers and suppliers, deregistration of members from cooperatives for breaking agreements, prosecution of defiant traders and positive incentives such as payment of bonuses. But why is it that milk safety is not improved with the prevailing sanctions? According to Kaplinsky and Morris (Kaplinsky and Morris, 2000b), the power to govern requires the capacity to sanction behaviour directed against transgressions (the “stick”) and a reward system for conformance (the “carrot”).

Considering our results, we argue that there is a clear need to organize milk marketing in the city to enhance adequate governing. Incentives must consider the fragmented governance system (KDB, city council, public health offices), milk scarcity and high demand, which leads to ease of selling mild that has been rejected elsewhere. As it is currently, incentives may not be strong enough to counter illegal practices and the benefits for not complying are higher than the losses that come with being caught up by the law.

Policy implications

There are challenges in achieving food safety goals within the current formal regulation framework which has enough provisions for promoting food safety (Dairy Industry Act, Public health ACT, Legal Notice No.209 of 2011 Veterinary and Paraprofessionals ACT). However, compliance to various rules and regulations is hindered by the complex procedures for acquiring the multiple licences and milk trading permits which are also expensive. At the same time, there appears to be added advantage for most traders who do not comply with official rules and regulations since they are able to successfully compete at milk sourcing and marketing while they evade regulation.

Our analysis highlights the importance of understanding governance to improve food safety. There have been previous attempts aimed at organizing the dairy sector through formalization of the informal sector among other efforts to improve food safety (Omore and Baker, 2009). In Kenya, formalization involves obtaining several licences and permits (see example in Table 5), a premise that must comply with specific hygienic and operational requirements (KDB, 2020), milk handling in aluminium/food grade containers and observing cold chain compliance. We argue that while all these measures could serve to safeguard food safety, the impacts could be anti-poor, and pro-big business not favouring most of the small-scale actors who form the vast and complex Nairobi dairy value chain.

Formalization of the dairy value chain needs to be adaptive to the requirements of the poorest producers and other actors. The government needs to be cognizant of the different actors in terms of scale and capacity so that regulation considers and develops tailored interventions which could be regulated and charged accordingly (there should not be a one size fits all).

Formalization of the informal sector would require re-alignment of the fees and licences in the system. Rather than each regulatory body raising revenues through small-scale charges imposed on every actor (e.g. the daily cess fees which should be charged to transporters only, but which is charged to all actors), charges could be more centralized through an income tax-based system or other centralized form of revenue generation. No doubt this would require some realignment of government institutions and their mandates; in developing economies, some level of political buy-in would no doubt be required for this. Realigning the sector would also impact the public health and veterinary inspection systems relevant to dairy farming and marketing. Much of the time, these inspections are the basis for ad hoc fees. A key policy question to be addressed is how to improve regulation without resulting in a ballooning ad hoc inspection system. There may be innovative ways to involve the private sector and/or self-regulation by farmers and, in particular, farmers groups, in this process. Training in best practice for all value chain actors would be an essential component of this.

Some studies have emphasized the value of organized milk trading systems as a means of improving food safety and governance (Alonso *et al.,* 2018; Omore and Baker, 2009). However, we clearly show that subscription to these groups remains very low (Kiambi *et al.,* 2018) and that membership is usually motivated by a desire to legitimize existing practice rather than adopt improved practices. The problematic nature of informally constituted groups is that their trade undermines the value proposition of larger scale players in the system, and they are therefore seen as threatening to the formal sector business model.

If these groups are to expand their footprint, some mechanism to ensure that they are operating in a fair market is required.

5.4 Summary of the chapter

The Chapter has presented the governance structure and challenges faced by various actors in the Nairobi's dairy value chain. The chapter has highlighted the implications of various challenges and governance issues on food safety. It has shown that just as the Nairobi's dairy system is fragmented and interdependent (as shown in chapter 4), so is the diversity of actors' relationships, and food safety implementation approaches and practices. Governance themes were related to weak relationships between government and various stakeholders, unfair competition in the system and the high cost of multiple licences through complex procedures. These were some of the key drivers triggering noncompliance to official rules and regulations thus triggering of food safety themes that included inadequate training and extension services; inadequate access to cold chain facilities, adulteration and low milk quality delivered to dairy cooperatives and large processors, and lack of food safety training. The range of issues highlighted are based on stakeholders' perceptions and reflects the complexity of the relationships between them. Many of the governance themes demonstrate the linkages that are both beneficial and confrontational between the formal and informal sectors, and between industry and regulatory authorities, with possible direct food safety consequences. Findings obtained provide indications to decision-makers of potential governance areas that could help improve efficiency and food safety along the dairy value chain. The next chapter will present results of bacteria quality and food safety risks along the mapped dairy value chain.

CHAPTER 6: BACTERIOLOGICAL QUALITY OF MILK AND FOOD SAFETY RISKS ALONG THE MAPPED DAIRY VALUE CHAIN

Introduction

The chapter will present results on the total bacteria count (TBC) and total coliform count (TCC) as indicators of system stability/ robustness in terms of food safety. Details about selection of study areas and study population has been covered in chapter three.

The global dairy industry, comprised of approximately 265 million cows, has continued to grow over the past decade with milk production increasing from 590 million tons in 2009 to 683 million tons in 2018 (FAOSTAT, 2018). Of this, Kenya produced approximately 3.8 million tons which represented about 10.8% and 0.6% of the Africa and global shares respectively. While comparatively small, the dairy sector is significant to Kenyan livelihoods, both nutritionally and economically (Muriuki *et al.,* 2003). The sector is one of the largest agricultural segments of the country contributing about 4% of the national Gross Domestic Product (GDP) and 14% of the agricultural GDP (KDB, 2014). Exponential growth of the dairy sector is expected with the predicted rise in demand for milk and other milk products influenced by growth in population, rapid urbanization and desire for intake of livestock source foods (Herrero *et al.,* 2014). For example, Herrero (2014) predicts a triple increase in milk demand in the Sub-Saharan Africa by 2050, while the Food and Agriculture Organization of the United Nations (FAO) forecasts a 175% rise in milk demand for the Kenyans between 2010 and 2050 (FAO, 2017).

According to the national livestock production report of 2012, Nairobi, one of the fastest growing urban cities in Africa (Aubry *et al.*, 2010) produced approximately 39 million litres of milk (GOK, 2012).

This was against the required 388 million litres based on the estimated 125 L per capita milk consumption in urban areas (SDP report, 2004) for the 3.1 million city residents then (KNBS, 2010). Furthermore, based on this per capita consumption and the projected 4% growth rate of the city (Aubry *et al.*, 2010), it means that by 2050, there will be approximately 10.3 million residents in Nairobi and these will require about 1.8 million tonnes of milk. It follows that more than 97% of milk consumed in the city will be sourced from production systems that are based outside the city. Currently, the proportion of milk that comes from outside Nairobi accounts for about 75-90% (Alarcon *et al.*, 2017). The characteristics of those milk chains supplying Nairobi have been described as highly complex and made up of multiple small-scale value chain actors who are highly interconnected and interdependent (as shown in chapter 4).

Achieving food safety in such complex food systems is a challenge particularly because milk production is primarily by small-scale farmers and marketing channels are dominated by informal systems (FAO, 2011b; Omore *et al.*, 1999; Roesel and Grace, 2014). The rising milk demand (FAO, 2017; Herrero *et al.*, 2014) coupled with unmatched production (Herrero *et al.*, 2014), complex interactions between value chain actors (as shown in chapter 4) and compromised governance of the Nairobi dairy system (as shown in chapter 5) will put massive pressure on the existing milk value chains with possible evolution of new ones to satisfy the rising demand. Complexities associated with urban food chains could provide excellent platforms to expand the range of food-borne pathogens as well as to amplify health and economic impacts of a single contamination incident (Foran *et al.*, 2014). On the other hand, the degree of mixing and contact between human and livestock in the urban environments has been shown to create ecological niches with opportunities for pathogen transmission and some studies have linked urbanization to the risk of emerging infectious diseases (Knobler *et al.*, 2006; Smolinsky *et al.*, 2005).

There are many factors that may contribute to unsafe milk (Lubote *et al.*, 2014) and challenges of food safety in Africa are precipitated by poor food safety systems, lack of systematic surveillance, underdeveloped human resource and insufficient capacity to determine the magnitude of the problem (FAO, 2004). Considering the uneven distribution of hazards/risks (FAO, 2011a), the competing priorities and inadequate resources in these countries, designing and implementation of interventions to promote food safety requires a targeted risk based approach that focuses on value chain analysis (Kaplinsky and Morris, 2000a). This involves a thorough understand the **'what'** (e.g. contamination practices, quality deficiencies, poor accessibility), the **'when'** (risk seasonality), the **'where'** (in which chains, chain nodes, areas it occurs), the **'who'** (who creates it and who is exposed), the **'how'** and the **'how much/many'** (e.g. how much contamination, how many people are exposed) (FAO, 2011a). Several studies have mapped various value chains within the food systems in Nairobi: namely beef, sheep and goat value chain (Alarcon; *et al.*, 2017); camel milk value chain (Muloi *et al.*, 2018), livestock keeping in the city (Alarcon; *et al.*, 2017); Nairobi dairy value chain (Kiambi *et al.*, 2018), the poultry value chain (Carron *et al.*, 2017), the pork value chain (Murungi *et al*, in Prep) and the governance issues (Kiambi *et al.*, 2020b). These studies provide the critical frameworks needed for full analysis of the food system and to guide development of necessary interventions along the value chains. In addition, such detailed scrutiny of the systems helps to understand dynamics therein including assessment of any structural vulnerabilities (Alarcon; *et al.*, 2017; FAO, 2011a; Rushton, 2008).

Bacteriological characteristics of milk would help to determine the quality of milk flowing through the various nodes of the value chains. This is because bacteriological quality depends on various factors among them health status of the animal (Cobbold and Desmarchelier, 2000; Donkor *et al.,* 2007; Gonggrijp *et al.,* 2016; Millogo *et al.,* 2010; Tryness *et al.,* 2011) as well as practices in milk handling and storage (Kuhnert *et al.,* 2005; Shija, 2013; Vicente *et al.,* 2005). Some studies on raw milk have demonstrated presence of wide range of micro-organisms in marketed milk associated with poor hygiene standards (Donkor *et al.,* 2007; Kang'ethe *et al.,* 2005; Kivaria *et al.,* 2006; Swai and Schoonman, 2011), or possible infection of cows at farms as shown by presence of zoonotic pathogens like *Mycobacterium species* (Donkor *et al.,* 2007), *Brucella abortus* and *E. coli* 0157:H7 (Grace *et al.,* 2008; Kang'ethe *et al.,* 2008a). Other hazards identified in raw milk at market level include presence aflatoxins (Kang'ethe and Lang'a, 2009; Sirma *et al.,* 2019), antibiotic residues (Ondieki *et al.,* 2017) and antibiotic resistant bacteria (Ombui *et al.,* 2000). On the other hand, although pasteurized milk is expected to have minimal hazards, some studies have found excessive levels of bacteria in processed milk (Ibanga *et al.,* 2014; Roesel and Grace, 2014) which may indicate a system failure in terms of ensuring high quality of milk that arrives at processing or faulty pasteurization processes (Black, 1996). In addition, compromised regulatory standards and procedures at pre and post marketing may also influence the quality of processed milk as shown in the studies conducted in China on the infant formula that was adulterated with melamine (Fairclough, 2008; Pei *et al.,* 2011).

Investigation of bacterial load, specifically analysis of TBC and TCC, has widely been used as indicators to determine sanitary quality of milk (Wanjala *et al.,* 2017). TBC in milk reflects the total number of bacteria that can grow to form countable colonies on standard methods agar when incubated aerobically at 32°C for 48 hours (Christen *et al.,* 1992).

Milk stored at ambient temperatures with poor hygienic standards would favour bacterial growth and multiplication leading to its deterioration (OConnell *et al.,* 2016; Sarkar, 2015). On the other hand, coliform bacteria are present in the environment and in the faeces of all warm-blooded animals and humans (Feng *et al.,* 2003; Jayarao and Henning, 2001; Oliver *et al.,* 2005). Therefore, while it is possible that infected cows could shed the bacteria in milk (Abebe *et al.,* 2016; Hogan and Smith, 2003; Larry *et al.,* 2010), detection of coliforms in milk indicate possible contamination with the bacteria from the cow environment including udder, milking utensils, water or the handler (Bonfoh *et al.*, 2003).

6.1 Materials and methods

Most of the qualitative data used in this chapter was collected during the mapping of the dairy value chain (chapter 4). Methods for qualitative data collection and analysis, selection of areas and nodes for milk sampling as well as milk sampling processes are explained in chapter 3.

6.1.1 Determination of Total Bacteria Counts (TBC)

Samples were prepared according to protocol described by (Christen *et al.,* 1992). For each sample, tenfold serial dilutions (10^{-1} to 10^{-4}) were prepared in sterile phosphate buffered diluent (0.0425g of potassium dihydrogen phosphate per litre of distilled water), pH 7.2. Enumeration of Total Bacteria Counts (TBC) was done using sterile standard plate count agar (SPCA); (APHA; Oxoid®) that was prepared according to the manufacturer's instructions. One millilitre of the undiluted milk sample and each of the four serial dilutions were aseptically pipetted into a separate sterile pre-labelled disposable 90-mm diameter petri dishes on which freshly prepared agar was poured. The mixture (sample plus media) were gently but thoroughly mixed by whirling to ensure even distribution of the sample into the culture medium.

The content was left to solidify at room temperature and the plates incubated at 32°C for 48 hours after which, assessment of the countable colony forming units (CFU) between 25 and 250 per plate were selected for enumeration (see figure 19).

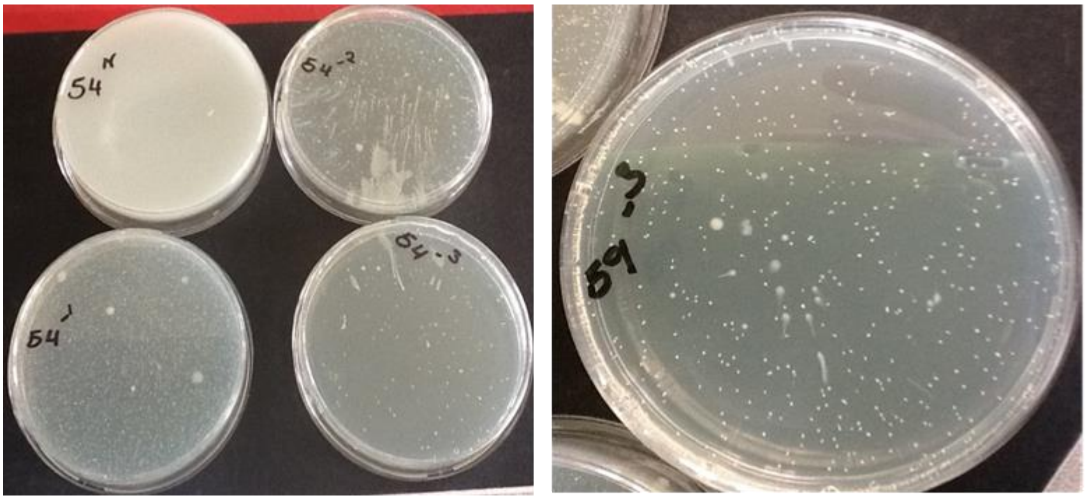


Figure 19: Bacteria growth on Standard Plate Count Agar for enumeration of total bacteria count.

6.1.2 Determination of total coliform counts (TCC)

Sample preparation was carried out similarly as those for TBC and only the first three serial dilutions were used. For enumeration of TCC, milk samples were cultured in Violet Red Bile Agar (VRBA) Oxoid® guided by the manufacturer's instructions. Culture and isolation was carried out as described elsewhere (Christen *et al.*, 1992). Incubation for coliforms was done for 24 hours at 37°C for growth. Plates with discrete 15 to 150 CFUs were selected for counting (see figure 20). For both TBC and TCC, colony counting was aided by the colony counter (CLC-570).

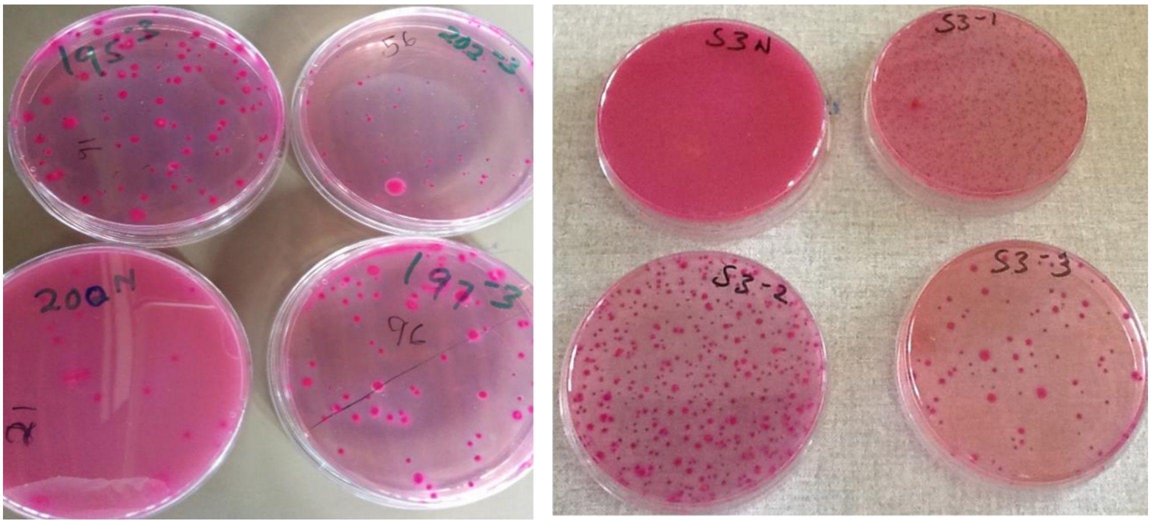


Figure 20: Bacteria growth on Violet Red Bile Agar for enumeration of total coliform counts.

6.1.3 Data analysis and presentation of results

Results are presented in a format that combines both qualitative and quantitative data. This approach was used given qualitative results often explain quantitative trends and vice versa.

6.1.3.1 Food safety practices

The voice and video recordings were carefully listened to and all the information was collated into pre-formatted templates (i.e. Word documents organized to enter qualitative data in distinct sections based on predefined categories related to food safety concerns). Data entry was complemented with data collected in notebooks. The first step in analysis was to collate data in pre-formatted word documents which allowed for systematic organization of the emerging food safety themes. The second stage of analysis entailed thorough reading of templates and organization of the data in distinct sections based on the emerging food safety themes which were categorized as challenges. These included a category on what was the practice (s) that was of food safety concern, who said it (during the interview), where the practice (s) was mentioned to occur and why the practice was said to occur. To comprehensively explore the factors that may impact the food quality and safety, the qualitative analysis contextualized main practices that were mentioned at milk production, bulking centres, processing, transportation and retailing.

6.1.3.2 Analysis of Total bacterial counts and Total Coliform Counts

Data cleaning, coding and analysis were done in Stata 16 (StataCorp, 2019). Descriptive statistics measures including mean, median, minimum and maximum were used to present the values for TBC and TCC. However, for TBC, the nodes that had less than three samples were excluded from the analysis due to impracticability of analysis of means and medians from only one or two samples. These included samples from milk vending machines (2 pasteurized), traders (2 raw), homemade yoghurt from milk bars (2) and homemade fermented milk (2 samples) and yoghurt from restaurants (2 samples). Interpretation of results for TBC and TCC was referenced to the limits specified in the East Africa Standards (EAS) developed in 2017 (KDB, 2017). These are provided in table 1.

6.1.3.3 Statistical analysis

Logistic regression analysis was performed to detect any significant differences on milk TBC and TCC between various nodes and milk types. Two binary outcome variables were used as an indicator of whether the sample was acceptable or not based on the levels according to the EAS standards (KDB, 2017) for TBC and TCC. The logistic regression models were then run to assess difference in the outcomes variables (1) per node (two models); (2) per milk type (two models); and (3) per node type, but only considering raw milk samples (two models). Model coefficients are reported at odds ratios where coefficients above 1 indicate an increase in odds and coefficients below 1 indicate a decrease in odds. Due to the clustered nature of the data, (i.e., milk samples clustered in nodes), the variance-covariance matrix corresponding to the parameter estimates was specified using a clustered sandwich estimator ((i.e., vce (cluster) command in Stata). This estimator allowed to account for intragroup correlation for the estimation of standard errors. Model specification was performed in Stata 16.1(StataCorp, 2019).

Table 10: East African Standards (2017) referenced in interpretation of Total Bacterial and Total Coliform Counts

Interpretation for Total Bacteria Count

Standard	Milk type	Microbiological quality limits	Source
EAS 67	Raw cow milk		https://archive.org/details/eas.67.2006
	Grade I	$< 2x10^5$	
	Grade II	$>2x10^5 – 1x10^6$	
	Grade III	$>1x10^6 – 2x10^6$	
EAS 69	Pasteurized milk	$3x10^4$	https://archive.org/details/eas.69.2006
EAS 33	Yoghurt & fermented milk	0*	https://archive.org/details/eas.33.2006
EAS 27	UHT	10	https://archive.org/details/eas.27.2006

Interpretation for Total Coliform Count

Standard	Milk type	Maximum total coliform count per ml	Source
EAS 67	Raw cow milk		https://archive.org/details/eas.67.2006
	Very good	$0 – 1x10^3$	
	Good	$1x10^3 – 5x10^4$	
EAS 69	Pasteurized milk	10	https://archive.org/details/eas.69.2006
EAS 33	Yoghurt & fermented milk	0	https://archive.org/details/eas.33.2006
EAS 27	UHT	0	https://archive.org/details/eas.27.2006

*total plate count includes yeast and moulds which have a limit of 10 for *E. coli, Salmonella spp.* and *Staphylococcus aureus*

6.2 Results

6.2.1 Characteristics of participants and milk sampling indices

One hundred and fourty four (144) people were interviewed during milk sampling. Of these, 56.9% (N=82) were females. The ages of participipnats ranged from 18 to 86 years with a median age of 39.5 years. The mode was 45 years. Most of the respondents (≈85%) reported to own the enterprise, while the rest were either employees (≈12%) or relatives (≈3%). For those who kept cows (farmers), majority of them (≈84%) reared between 2-3 milking cows, followed by those keeping 6-9 cows (≈13%). Only a small proportion of farmers (≈3%) kept 10-13 milking cows. In terms of volumes of milk handled per day, majority of the respondents (≈59%) reported to handle between 0.5-20 litres of milk, followed by 21-100 litres (≈34%) while only a small proportion (≈7%) handled more than 100 litres per day.

Two hundred and ninety (290) cow milk samples were collected from the various nodes represented by the respondents. These included farms (N=63), milk collection centres (N=5), kiosks (N=37), milk bars (N=17), roadside vendors (N=14), restaurants (N=3), mobile traders (N=2), milk vending machines (N=2) and from a supermarket (N=1). The different types of samples collected included raw milk (N=203), home-made fermented milk (N=12), home-made yoghurt (N=3), pasteurized milk (N=35), Ultra Heat Treated milk (N=13), processed yoghurt (N=13) and processed fermented milk (N=11).

The majority (≈44%) of the milk from which these samples were obtained was described to have come from within Nairobi county, while the rest was sourced from areas located in other counties including Murang'a county (≈1.7%), Nyandarua county (≈1.4%) and Nyeri county (≈0.3%). About 0.3% of the respondents reported that they did not know where the milk had been sourced from. Delivery of milk from the various sources was reported to be mainly (≈88%) direct (own cows or own transport).

The rest reported to have milk delivered by traders (≈9%), dairy cooperatives (≈3%) and a small proportion (≈0.5%) by processors (processed products). Information regarding recent use of antibiotics in cows from which the samples were obtained was not known by 50% of the respondents, while the rest of the participants said that antibiotics had not been used in the cows for about two weeks prior to the sampling.

6.2.2 Results on total bacterial (TBC)

Table 13 displays the means, median, minimum and maximum parameters for TBC of different types of milk at different nodes of the dairy value chain. Milk at production nodes (farms and collections centres) was generally good and within the acceptable EAS limits. At farm, milk had a mean of $3.5x10^5$ cfu/ml, at grade II of EAS (greater than $2x10^5 - 1x10^6$) while that of collection centres was within the limits, at grade III of EAS ($1x10^6 - 2x10^6$) at $1.4x10^6$. This shows that the mean values for milk at farm was better in terms of TBC than that at collection centres. Further, bacterial quality of milk deteriorated at retail level (restaurants, milk bars, roadside vendors and shops/kiosks). Compared with raw milk at farm which had mean of $3.5x10^5$ cfu/ml, all other liquid milk from most nodes (except pasteurized and UHT) had much higher mean values. For example, cfu/ml mean value at milk collection centres was four times more than EAS limits for farm, 11.4 times (restaurants), 12.3 times (milk bars), 22.6 times (roadside vendors) and 9.4 times in milk collected from shops/kiosks. Mean values for processed (pasteurized and UHT) products were within the EAS limits and were 0.1 lesser than mean values for milk at farm. When compering the mean values of milk samples that had values with unacceptable EAS standards, milk from roadside vendors was the worst in terms of TBC, followed by milk bars, restaurants, shops/kiosks and collection centres in that order.

Table 11: Total bacterial count (TBC) in milk sampled from various nodes of the Nairobi's dairy value chain.

The table shows mean, median, minimum and maximum values for colony forming units per millilitre for TBC in different milk types. In red font are the TBC values that exceeded East Africa Standards 2017.

Variable	**Node type**											
	Farms	Collection centres	Restaurants	Milk bars		Roadside vendors	Shops/ Kiosks		Shops/ supermarket			
Sample type	Raw (N= 107)	Raw (N=12)	Raw (N=6)	Raw (N=6)	Homemade fermented milk (N=8)	Raw (N=14)	Raw (N=27)	Homemade fermented milk (N=3)	UHT (N=13)	Pasteurized (N=33)	Fermented processed milk (N=11)	Processed yoghurt (N=12)
Mean	$3.5x10^{5}$	$1.4x10^{6}$	$4.0X10^{6}$	$4.3x10^{6}$	$5.2x10^{6}$	$7.9x10^{6}$	$3.3x10^{6}$	$3.9x10^{6}$	$3.5x10^{3}$	$3.1x10^{4}$	$5.0x10^{3}$	$4.5x10^{4}$
Median	$3.3x10^{4}$	$5.0x10^{5}$	$3.4x10^{6}$	$2.5x10^{6}$	$3.5x10^{6}$	$3.5x10^{6}$	$1.0x10^{6}$	$6.9x10^{5}$	0	0	$1.2x10^{3}$	$3.3x10^{1}$
Minimum	**0**	$1.9x10^{3}$	$1.6x10^{5}$	**0**	$1.2x10^{4}$	$4.6x10^{3}$	$1.7x10^{2}$	$1.2x10^{4}$	0	0	0	0
Maximum	$6.2x10^{6}$	$9.2x10^{6}$	$8.8x10^{6}$	$1.1x10^{7}$	$2.2x10^{7}$	$3.1x10^{7}$	$2.1x10^{7}$	$1.1x10^{7}$	$4.6x10^{4}$	$6.3x10^{4}$	$3.8x10^{5}$	$8.2x10^{5}$

6.2.3 Results on total coliform counts (TCC)

Table 14 displays the mean, median, minimum and maximum parameters for TCC of different types of milk at various nodes of the value chain. Except for raw milk from collection centres and pasteurized milk products, the mean values for all the other milk samples exceeded the acceptable EAS limits for TCC. When liquid milk samples were compared with what is considered as of "good" TCC by EAS ($1x10^3$ – $5x10^4$), milk from farms was three times higher indicating unacceptable contamination of milk which should not be sold to consumers. Milk from roadside vendors was 13 times poorer than the EAS limits, 8.2 times (milk bars), 3.2 times (shops/kiosks) and 1.6 times (restaurants). Hence the worst milk in terms of TCC when compared to EAS was from roadside vendors, milk bars, shops/kiosks, farms and restaurants in that order.

Table 12: Total coliform counts (TCC) in milk sampled from various nodes of the Nairobi's dairy value chain.

The table shows mean, median, minimum and maximum values for colony forming units per millilitre for TCC in different milk types. In red font are the TCC values that exceeded East Africa Standards 2017.

Variable	**Node type**											
	Farms	Collection centres	Restaurants	Milk bars		Roadside vendors	Shops/ Kiosks		Shops/ supermarket			
Sample type	Raw (N=(107)	Raw (N=12)	Raw (N=6)	Raw (N=6)	Homemade fermented milk (N=8)	Raw (N=14)	Raw (N=27)	Homemade fermented milk (N=3)	UHT (N=13)	Pasteurized (N=33)	Fermented processed milk (N=11)	Processed yoghurt (N=12)
Mean	1.5x10^{5}	2.6x10^{4}	7.8x10^{4}	4.1x10^{5}	2.0x10^{5}	6.5x10^{5}	1.6x10^{5}	2.8x10^{5}	0	2.1x10^{1}	0.3x10^{1}	9.6x10^{2}
Median	0.2x10^{1}	4.0x10^{3}	4.7x10^{4}	3.5x10^{5}	5.0x10^{4}	2.6x10^{5}	6.1x10^{4}	2.6x10^{3}	0	0	0	0
Minimum	**0**	8.7x10^{1}	4.1x10^{3}	**0**	0.3x10^{1}	1.1x10^{3}	0.1x10^{1}	0	0	0	0	0
Maximum	6.5x10^{5}	1.x10^{5}	2.0x10^{4}	9.8x10^{5}	2.0x10^{6}	3.0x10^{6}	1.6x10^{6}	8.4x10^{5}	0	4.1x10^{2}	2.7x10^{1}	5.6x10^{4}

6.2.4 Logistic regression analysis

For analysis based on the type of the nodes, the reference node type was the farm so that coefficients represent significant differences between a farm and a node type. For the TBC, results show that the odds that milk samples from milk bars and restaurants were acceptable were 98% less than the odds of samples collected at the farm being acceptable. Similarly, the odds that samples from roadside vendors, shops/ kiosks and supermarkets were acceptable were 97%, 93% and 89% respectively less than samples collected at the farm (table 15). There was not a significant difference between the odds of milk from collection centres being TBC acceptable and those from farms being acceptable. For TCC, model results indicated that that the odds that milk samples from milk collection centres were acceptable was 82% less than the odds of samples collected at the farm, while that of milk from milk bars and restaurants were 97% and 94% respectively less than farm samples. Similarly, the odds that samples from roadside vendors and shops/ kiosks were acceptable were 98% and 88% respectively less than samples collected at the farm. There was not a significant difference between the odds of milk from supermarkets being TCC acceptable and those from farms being acceptable.

Table 13: Logistic regression analysis for total bacterial and total coliform counts by the node type where milk sample was obtained.

All type of milk samples considered in this analysis. (Farm use as baseline category for the model)

Node type	TBC levels acceptable OR (95% CI)	TCC levels acceptable OR (95% CI)
Collection centres	0.30 (0.06 - 1.47)	0.18*** (0.05 - 0.65)
Milk bars	0.02*** (0.01 - 0.10)	0.03*** (0.01 - 0.10)
Restaurants	0.02*** (0.00 - 0.08)	0.06*** (0.02 - 0.19)
Roadside vendors	0.03*** (0.01 - 0.16)	0.02*** (0.00 - 0.08)
Shops/ kiosks	0.07*** (0.02 - 0.23)	0.12*** (0.04 - 0.36)
Supermarkets	0.11*** (0.03 - 0.35)	0.53 (0.21 - 1.39)
Constant	16.83*** (5.32 - 53.25)	16.83*** (6.48 - 43.73)
Observations	287	287

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Analysis comparing TBC in raw milk at the various nodes of the value chain showed that the odds that milk samples from restaurants and roadside vendors were acceptable was 97% less than the odds of samples collected at the farm being acceptable. Similarly, the odds that samples from milk bars and shops/kiosks were acceptable were 96% and 94% lower, respectively, compared to farm. For TCC, results showed that the odds that milk was acceptable from the various nodes were all lower than the odds of acceptability for farm samples, including 82% lower for collection centres samples, 88% lower for restaurant samples, 98% lower for road side vendor samples, 96% lower for milk bar samples, and 95% lower for shops/ kiosks samples (table 16).

Table 14: Logistic regression analysis for total bacterial and total coliform counts comparing raw milk samples from various nodes of the value chain.

(Note: no raw milk samples obtained from supermarket). Farm used as baseline category for the model.

Node type	TBC levels acceptable OR (95% CI)	TCC levels acceptable OR (95% CI)
Collection centres	0.30	0.18***
	(0.06 - 1.47)	(0.05 - 0.65)
Restaurants	0.03***	0.12**
	(0.01 - 0.11)	(0.01 - 0.94)
Roadside vendors	0.03***	0.02***
	(0.01 - 0.16)	(0.00 - 0.08)
Milk bars	0.04***	0.04***
	(0.01 - 0.19)	(0.01 - 0.18)
Shops/ kiosks	0.06***	0.05***
	(0.01 - 0.22)	(0.02 - 0.16)
Constant	16.83***	16.83***
	(5.32 - 53.26)	(6.48 - 43.74)
Observations	201	201

Robust 95% CI in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For analysis based on the type of milk, the reference was raw milk (table 17). There were few significant differences in the odds of TBC and TCC acceptability across milk types. For TBC, the odds that home-made milk (yoghurt and fermented) and processed (yoghurt and fermented) were acceptable was 97% and 90% lower, respectively, than raw milk. Results on analysis of TCC showed that only home-made (yoghurt and fermented) had lower odds (94%) than raw milk in being acceptable.

Table 15: Logistic regression analysis for total bacterial and total coliform counts by the milk type.

Raw milk used as baseline category for the model.

Milk type	TBC levels acceptable OR (95% CI)	TCC levels acceptable OR (95% CI)
Home-made (yoghurt and fermented)	0.03***	0.06***
	(0.00 - 0.21)	(0.01 - 0.28)
Processed (yoghurt and fermented)	0.10***	1.15
	(0.02 - 0.50)	(0.58 - 2.28)
Long life	0.82	
	(0.41 - 1.65)	
Pasteurized	1.51	1.92
	(0.62 - 3.69)	(0.77 - 4.75)
Constant	2.74***	2.61***
	(1.86 - 4.03)	(1.81 - 3.76)
Observations	290	277

Robust 95% CI in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.2.5 Practices that may influence food safety along the Nairobi dairy value chain

There were several practices that were mentioned during key informant interviews and FGDs that could possibly influence food safety (table 18). At production, such factors were related to keeping cows in very muddy cowsheds, obtaining animal feed from dumpsites and market leftovers, obtaining feeds by the roadsides, treatment of the cows by unqualified personnel coupled with compromise on withdrawal periods following treatment, resale of milk that has been rejected from dairy cooperatives or allowing it to ferment further (and taken as fermented milk) and addition of water to increase the volume of milk.

At the bulking centres, the FGD and KII with dairy cooperatives and some large processors reported that they sometimes, especially during milk scarcity, accepted milk that should be rejected. They argued that rejection of milk at such periods of scarcity and in the midst of the liberalized dairy sector would set their competitors at an undue advantage of selling what they rejected. One of the managers at the bulking centres argued that the bad milk would be neutralized (unacceptable contents wil be diluted) by good milk. He said, "*since not every farmer will have bad milk or will have used antibiotics at the farm, the good milk will neutralize the bad milk and overall all the milk will be fairly good. So we don't reject all that need to rejected except when it is grossly curdled or dirty. Our competititors who don't care about quality, especially the informal traders will be waiting for it and they will sell it since milk market is ever ready* ". Milk cooling and basic screening tests were said to be lacking at most collection centres with screening relying on organoleptic tests. On disposal of milk that had been rejected at the bulking centres, dairy cooperatives and large processors reported that suppliers were sent back with such milk, which they reported that some of it was returned back to the the food chain.

At retail, milk adulteration through addition of water was reported to be a frequent occurrence at retail aiming at increasing volumes of milk.This was reported to occur mainly during during dry seasons when milk production was low. According to the traders and retailers, the practice was mentioned to occur at the farm level, traders (those selling milk to retailers), retailers including roadside vendors, milk bars, restaurants and at the shops/ kiosks. Another food safety challenge mentioned at retail was lack of colling facilities during transportation and at the sale points. Raw milk that spoilt either at transit or at sale point was said to be sold either as fresh liquid milk at a lower price than the raw milk, or was converted into yoghurt or fermented milk.

Fermented milk was basically prepared by letting the raw milk that had curdled to stay for a few more days in a container to ferment more, while preparation of yoghurt entailed addition of flavours and colour to the raw fermented curdled milk. Finally, there was a glaring gap at regulation and enforcement of the food safety practices in the value chain as several businesses (traders and retailers) were reported and observed to be operated without the necessary government permits and licenses.

Table 16: Key practices mentioned by stakeholders as influencing food safety along the Dairy value chain in Nairobi, Kenya.

Practice (s)	Who said	Where is the practice done	Why the practice was said to be done
➢ Poor drainage, muddy cowsheds	All FGDs with farmers	Farms	- inadequate land for expansion - lack of capital to build good sheds with drainage
➢ Animal feeds sourced from dumping sites, sewer lines, market leftovers, roadsides	FGD with farmers in the urban informal area	Farms	- feed scarcity especially in dry seasons - pasture from sewer lines is ever green and available
➢ Mixing of sweepings from poultry houses with dairy commercial feeds	Farmers (Both FGDs in peri-urban area)	Farms	- perceived to increase milk production
➢ Self-treatment or use of untrained personnel for management of animal diseases	All FGDs with farmers, FGDs with LPOs	Farms	- inadequate money to engage professionals - unaware on where the animal health professionals were - fear of being arrested for keeping livestock which is perceived outlaw (urban informal area)
➢ Failure to observe withdrawal periods following use of antibiotics in milking cows	All FGDs with farmers, FGDs with LPOs	Farms	- economic losses with milk disposal - lack of knowledge on withdrawal
➢ Adulteration of milk through addition of water	All FGDs with farmers, KII with DTA, FGDs with non-DTA traders and with trailers	Farms, by traders, roadside vendors, milk bars and shops/ kiosks	- to increase milk volumes especially in dry seasons when milk production is low
➢ Adulteration of milk by adding substances like hydrogen peroxide, formalin, caustic soda, egg yolk, margarine, sugar, wheat flour	KII with DTA & FGD with non-DTA traders, FGD with trailers	By traders	- hydrogen peroxide and formalin as preservatives caustic soda, egg yolk, margarine, sugar and wheat flour to increase milk density
➢ Conversion of raw milk that has "accidentally" curdled to home-made "fermented milk" or "yoghurt" or selling it at cheaper price	All FGDs with farmers, KII with DTA, FGDs with non-DTA traders and with trailers	By traders, farmers, milk bars, shops/kiosks, restaurants	- believe that curdled milk is not spoilt milk. One farmer said, "*unboiled milk that curdles is very good for eating ugali*". Ugali is a type of meal made of ground corn.
➢ Re-sale of milk that has been rejected at the milk bulking sites	All FGDs with farmers, KII with DTA & FGD with non-DTA traders	By farmers, traders, milk bars, shops/ kiosks, restaurants	- disposing milk is a loss (economic related factors) - there is always a ready market for such milk
➢ Occasionally, accepted milk that should be rejected	FGD and KII with dairy cooperatives, KII -large processing companies	Milk collection centres, dairy cooperatives, large processors	- milk is scarce and there is a ready milk market - if they rejected, the milk would be sold to competitors
➢ Most milk collection centres located by roadsides and without sheds and lack of coolers	KIIs with dairy cooperative and large processing companies, FGDs with dairy cooperatives	Milk collection centres, dairy cooperatives, traders, milk bars, shops	- low milk volumes do not warrant investment on construction of sheds - high cost of running cooling systems
➢ Storage of milk in non-food grade plastic containers	FGD with non-DTA traders, KII – DTA traders, FGD – retailers, KII (KDB, PHOs)	By traders, milk bars, shops/ kiosks, restaurants	- plastic containers were affordable - they were easy to transport - have minimal spillage

FGD = Focus group discussions, KII = Key informant interviews, DTA = Dairy Traders Association, KDB = Kenya Dairy Board, PHOs = Public Health Officers, LPOs = Livestock Production Officers

6.3 Discussion

By 2050, demand for milk consumption will triple in Sub-Sharan Africa (Herrero *et al.,* 2014) while in Kenya, consumption has been projected to rise by 175% from 2010 to 2050 (FAO, 2017). The current population in Nairobi (KNBS, 2019), coupled with high per capita milk consumption (SDP report, 2004) that is unmatched with production has resulted to most of its milk being sourced from production systems that are based outside the city (Alarcon *et al.*, 2017; Kiambi *et al.*, 2018). The situation is expected to worsen with the projected population growth (Aubry *et al.,* 2010) and increased demand for milk by the city dwellers (FAO, 2017). Food chains associated with urban food systems are complex are thus likely to provide excellent platforms to expand the range of food-borne pathogens (Foran *et al.,* 2014; Knobler *et al.,* 2006; Smolinsky *et al.,* 2005).

The current study utilized the previously developed framework of the Nairobi's dairy value chain (Kiambi *et al.,* 2018) to investigate milk quality and safety in the complex food system to identify food safety challenges. The mapped framework demonstrated the vastness and complexity of Nairobi's dairy value chain with multiple interaction between various actors and nodes of the value chain. Based on those complex interactions, the study concluded that a holistic approach would be required to address any interventions and policy decisions. This is approach has been supported by other studies (Alarcon; *et al.,* 2017; Carron *et al.,* 2017; FAO, 2011a; Muloi *et al.,* 2018).

The current study found that TBC levels at production nodes (farms and collections centres) were generally good and within the acceptable limits of the EAS for TBC, but TCC limits were higher (than EAS) at the farms. This agrees with several other studies that have demonstrated good bacterial quality of milk at farm levels (Millogo *et al.,* 2010; OConnell *et al.*, 2016; Paludetti *et al.,* 2019; Stulova *et al.*, 2010).

However, this could be compromised by other factors like health status of the animal (Cobbold and Desmarchelier, 2000; Donkor *et al.*, 2007; Gonggrijp *et al.*, 2016; Millogo *et al.*, 2010; Tryness *et al.*, 2011) and practices related to milk handling and storage practices (Kuhnert *et al.*, 2005; Shija, 2013; Vicente *et al.*, 2005). Apart from TBC and TCC, which only serve as an indicator of the robustness of the system in the current study, some of the practices reported (and observed by the researchers) at the farms warrants further investigation to inform broader interventions. For example, availability of animal feeds was reported to be a challenge and sometimes farmers fed cows from feeds sourced from dumping sites, leaking sewer lines, market left-overs and those obtained by the roadsides. Such unconventional feed sources may present opportunities for introduction of heavy metals and the subsequent public health concers (Harlia *et al.*, 2018; Muhib *et al.*, 2016; Pilarczyk *et al.*, 2013). In addition, sweepings from poultry houses were reported to be mixed with dairy commercial concentrate feeds as this was percieved to increase milk production. This practice may result to introduction and transmission of antimicrobial resistance (AMR) as several studies have demonstrated high levels of AMR in poulrty and poultry environments (Van Boeckel *et al.*, 2019, 2017, 2015).

We noted that bacterial quality of milk deteriorated at retail level. For example, the logistic regression analysis for TBC showed that the odds that milk samples from retailers were acceptable was less than the odds of samples collected at the farm as follows: 98% (milk bars), 98% (restaurants), 93% (shops/kiosks), 97% (roadside vendors) and 89% supermarkets. For TCC, model results indicated that that the odds that milk samples from milk collection centres were acceptable was 82% less than the odds of samples collected at the farm, while that of milk from milk bars and restaurants were 97% and 94% respectively less than farm samples.

Similarly, the odds that samples from roadside vendors and shops/ kiosks were acceptable were 98% and 88% respectively less than samples collected at the farm. Our results agree with findings from other studies that show such bacterial deterioration of milk as it flows from farms through the retailing system (Donkor *et al.,* 2007; Millogo *et al.,* 2010; Parry-Hanson Kunadu *et al.,* 2018; Swai and Schoonman, 2011). Such deterioration may be influenced by among other factors, heavy bacterial load at source (Paludetti *et al.,* 2019; Stulova *et al.,* 2010), adulteration (Panahzadeh *et al.,* 2016), flow of milk over longer distances without cold chain or poor handling practices at transportation and storage. In the current study, there are some reported practices that may contribute to increased bacterial count in milk at retail level. For example, milk was stored in plastic (non-food grade) containers and cold chain was deficient as reported in various KIIs and FGDs (see table 7). Traders and retailers in Nairobi reported to depend on local agents based at the farms to source for milk on their behalf, which was then bulked into 20L plastic containers and transported while stack under passengers' seats in public vehicles (FGDs with non-DTA traders and retailers, KII with DTA traders). Despite the law requiring milk transportation to be done in cold chain and by licenced vehicles (transport permit issued by KDB), the traders and retailers indicated that it was expensive to travel to farms daily to source for milk as well as to own or hire a vehicle to transport their milk. Probably, that's the reason some traders were mentioned to use unorthodox methods for preservation of milk like addition of hydrogen peroxide and formalin. Addition of formalin and hydrogen peroxide have been mentioned as a way of increasing the shelf life of milk in the absence of cold chain (Panahzadeh *et al.,* 2016). Apart from the ethical aspect, researchers have reported that artificial preservatives such as addition of such chemicals could result to serious health problems including cancer (Lisanti *et al.,* 2011; WHO, 2006).

If the raw milk spoilt, this was reported as "*accidentally curdled*", it was reported to be converted into fermented milk (allowed to ferment for several more days) or yoghurt (addition of flavour and colours onto the fermented milk). This probably explains the high TBC and TCC in home-made fermented milk and home-made yoghurt. On regression analysis, our results indicated that the odds that home-made milk (yoghurt and fermented) and processed (yoghurt and fermented) were acceptable for TBC was 97% and 90% lower, respectively, than raw milk, while for TCC, home-made (yoghurt and fermented) had lower odds (94%) than raw milk. While most Kenyans normally boil milk before consumption (Omore *et al.*, 2000, 2002b), it is important to note that these products (home-made fermented and yoghurt) were made from raw milk that had gone bad. Consequently, these could pose significant public health threats if the raw milk was sourced from cows infected by any zoonotic diseases. For example, consumption of raw milk has been associated with brucellosis in humans (Kiambi *et al.*, 2020a).

The logistic regression analysis of the processed milk products were generally within the acceptable limits for TBC and TCC. This agrees with other studies that show the utility of pasteurization and ultra heat treatment which significantly reduce bacterial load in milk (Baur *et al.,* 2015; Elizondo-Salazar *et al.,* 2010; Novoa and Restrepo, 2007). However, other studies have shown significant levels of bacteria in pasteurized milk (Alonso *et al.,* 2018; Grace, 2017; Grace *et al.,* 2012; Ibanga *et al.,* 2014; Roesel and Grace, 2014). This happens with poor quality of raw milk (Millogo *et al.*, 2010; OConnell *et al.,* 2016; Paludetti *et al.,* 2019; Stulova *et al.,* 2010), when there is a breakdown in pasteurization process (Black, 1996), or factors related to post processing handling. In our curent study, assessment of maximum values for colony forming units for TBC and TCC showed that there were some processed milk products that were highly contaminated (refer to table 13 and 14 in the results section).

These included pasteurized milk ($4.1x10^2$), processed fermented milk ($2.7x10^1$) and processed yoghurt ($5.6x10^4$). Some practices elucidated during FGDs and KIIs with the dairy cooperatives and large processing companies and that may contribute to high bacterail load in processed milk could be linked to lack of cold chain at the collection centres and acceptance of milk that should be rejected. It was explained that accepting such milk was mainly because the commodity was scarce and their failure to collect it would result to benefiting their competitors (mainly traders) who were perceived as not to care about quality. Unfair competition among value chain actors has been identified as one major factor that hinders achieving optimal food safety in the Nairobi dairy value chain (Alonso *et al.*, 2018; Kiambi *et al.*, 2020b). Other factors that were mentioned in the current study incuded lack of training on hygiene across the value chain, selling of milk through hawking from place to place or by the roadside, selling of milk in unlicensed premises (hence such milk is not monitored by the regualatory authorities. Therefore, addressing food safety requires concerted efforts of every actor in the value chain. Some strategies that have been deployed to improve milk safety elsewhere include improvement of infrastructures at farms and at collection, enhanced information on production, improved frequency of milk collection to reduce build-up of bacterial in milk (Reguillo *et al.*, 2018; Smigic *et al.*, 2012). Undoubtedly, heightened training and extension services would facilitate good production and milk handling practices.

6.4 Summary of the chapter

This study has provided a detailed analysis of food quality and safety challenges in Nairobi's complex dairy value chain. Descriptive analysis of the mean values for TBC and TCC show that milk was relatively good at farm level and for processed products, but these parameters deteriorated at retail level.

Logistic regression analysis showed that the odds that milk samples from retail (milk bars, restaurants, shops/kiosks, roadside vendors and traders) were less acceptable than the odds of samples collected at the farm for TBC and TCC. Likewise, the odds that raw milk samples from retail (milk bars, restaurants, shops/kiosks, roadside vendors and traders) were acceptable was less than the odds of raw samples collected at the farm being acceptable for TBC and TCC. For analysis based on the type of milk, with raw milk as the reference, few significant differences in the odds of TBC and TCC acceptability across milk types. Several practices with possible influence on food safety were mentioned. The next chapter will describe *E. coli* genetic diversity to identify points for milk contamination along the dairy value chain and thus identify points that could be targeted for improvement of milk safety.

CHAPTER 7: ANALYSIS OF *ESCHERICHIA COLI* GENETIC DIVERSITY ALONG THE MAPPED DAIRY VALUE CHAIN

Introduction

The chapter will present results on analysis of *E. coli* genetic diversity to identify critical points (nodes) where milk contamination as a marker for areas with possibility of introduction and transmission of pathogens through milk to humans. Details about selection of study areas and study population has been covered in chapter three.

Milk consumption is popular across the globe due to many nutritional values such as proteins, calcium, vitamin B12, iodine and magnesium (Suttle, 2010). In addition, demand for milk and other milk products are expected to grow in the Sub-Saharan Africa influenced by the rise in population, urbanization and increased preference for animal source foods (Herrero *et al.,* 2014). The FAO predicts that demand for milk in Kenya will increase by 175%, rising gradually from 4,839,000 tons (2010) to 7,513,000 tons (2030) and 13,298,000 tons in 2050 (FAO, 2017). However, this predicted demand will be unmatched with production (Herrero *et al.,* 2014). It follows that numerous value chains may evolve to support milk supply into the country and therefore understanding the structures and functionality of the milk systems is critical in addressing targeted food safety interventions (Alarcon *et al.,* 2017; Kiambi *et al.,* 2020b, 2018; Muloi *et al.,* 2018).

Food systems present some of the most complicated networks especially in the urban areas where production and distribution is via simple to complex value chains (Alarcon *et al.,* 2017; Carron *et al.,* 2017; Foran *et al.,* 2014; Hueston and MacLeod, 2012).

Such system complexities are excellent avenues for introduction and transmission of pathogens including food hazards among other food safety risks (Gereffi *et al.*, 2005; Gereffi and Lee, 2009; Pei *et al.,* 2011). Milk, particularly due to the high nutritional content makes it an ideal medium for growth of bacterial contaminants (Pal *et al.,* 2016) among other food safety hazards (Ibanga *et al.,* 2014; Ondieki *et al.*, 2017; Sirma *et al.,* 2019).World Health Organization (WHO) estimates that 31 of the 32 diseases reported globally between 2007 and 2015, were caused by food borne hazards (WHO, 2015).

Microbial food contamination is one of the leading concerns in food systems in developing countries mainly due to inadequate and poorly developed food safety structures and policies (Aung and Chang, 2014; FAO, 2004). Studies conducted in Kenya show that milk may be contaminated with bacteria at different levels of the value chain and some of the bacteria may be of zoonotic importance. For example, presence of bacteria like *Mycobacterium bovis* in cattle may represent a potential risk to humans infection through consumption of unpasteurized milk (Gathogo *et al.,* 2012; Kang'ethe *et al.,* 2008b). As well, some studies have identified *Brucella abortus* and *Escherichia coli* (*E. coli*) O157:H7 in marketed milk which indicates a weakness in diseases management at farms (Grace *et al.,* 2008; Kang'ethe *et al.,* 2008a). Furthermore, high prevalence of brucellosis in humans has previously been linked to consumption of raw milk (Kiambi *et al.,* 2020a; Njeru *et al.,* 2016; Osoro *et al.,* 2015).

The processes involved in the introduction and transmission of diseases (or food safety hazards) in humans, animals and environment are complex (Wood *et al.,* 2012). This is mainly due to the numerous interlinkages of the food networks and linkages involved from production through processing, marketing and disposal of waste products, with each step providing opportunities for risks (Foran *et al.,* 2014).

A guideline developed by FAO on animal diseases risk management amplifies the need to thoroughly understand the livestock value chains in the context of operations and decision making by stakeholders to enhance effective and targeted interventions (FAO, 2011).

Among the many bacterial contaminants in raw and processed milk, *E. coli* is the most common (Ali and Abdelgadir, 2011). *E. coli* is a gram negative rod-shaped, facultative anaerobic, coliform bacterium of the family *Enterobacteriaciae* and is commonly found in the lower intestines of warm-blooded animals where they leave as harmless normal gut microbiota (Kaper *et al.*, 2004; Tenaillon *et al.*, 2010). However, some serotypes can cause serious food poisoning in their hosts and occasionally are responsible for food contamination incidences that have prompted product recalls in the developed economies (Vogt and Dippold, 2005). Boiling of raw milk is known to kill most bacterial contaminants, but, the heat resistant toxins such as enterotoxins can still be harmful to the final consumers (Nørrung *et al.*, 2009).

About 50% of *E. coli* population reside in secondary habitats like soil, plant surfaces, ground water and other environments allowing for opportunity to colonize new hosts also referred to as extra-hosts (Collins *et al.*, 2005; Savageau, 1983). Here, they can replicate to establish distinct stable strains that are different from the original host-adapted populations (Byappanahalli *et al.*, 2007, 2006; Walk *et al.*, 2007). Contaminated soil is particularly of significant importance in promoting environmental selection pressure which enriches the locally adapted genotypes that may contribute to the genomic diversity which may potentially transmit stress tolerant strains to new hosts through food or water (Bergholz *et al.*, 2011). As well, the high degree of genome plasticity, which results from gene losses and gains, through horizontal transfer (Rasko *et al.*, 2008; Touchon *et al.*, 2009).

The resultant heterogeneity in these organisms makes it possible for *E. coli* to reside in many environments (Luo *et al.,* 2011) and therefore the organism can serve as a marker for microbial movement (Feng *et al.,* 2003; Jayarao and Henning, 2001; Oliver *et al.,* 2005). This phenomenon is important in understanding critical points of disease emergence (or food safety) and transmission as well as understanding the linkages between the sources of pathogen and the route of their transmission. In this regard, several studies have demonstrated utility of molecular techniques like landscape genetic analysis to understand how *E. coli* deposition in soil changes extra host populations, by creating various genetically diverse *E. coli* strains (Byappanahalli *et al.,* 2006; Fremaux *et al.,* 2008; Texier *et al.,* 2008). The potential risks for environmental contamination of milk with *E. coli* have previously been documented, and these are linked to unhygienic practices like milking dairy cows with dirty hands, unwashed cow udders at point of milking as well as poor post-harvest handling practices of milk and its products (Shija, 2013; Sserunjogi and Grimaud, 2007).

In Nairobi, milk is marketed through a complex framework that is comprised of small-scale individuals, who may be perceived to work independently, but previous research show that these actors are highly connected and interdependent (Kiambi *et al.,* 2020b, 2018). Therefore, introduction of food safety hazards may happen at any point of the value chain but there is insufficient information to demonstrate such points which may serve as critical control points if well analysed. Repeated sequences in bacterial genomes such as Enterobacterial repetitive consensus sequences (ERIC) and the GTGGTGGTGGTGGTG (GTG_5) can be useful in conducting such analysis particularly to investigate the clonal variability of the bacterial isolates (Švec *et al.,* 2010).

Although these techniques have a low resolution as compared to whole genome sequencing and work best in related bacterial species, the methods can be exploited to asses genetic diversity in a group of similar bacterial species (McLellan, 2004). This can help track the flow of microorganisms. According to FAO, an understanding of the correct source of contaminants and avenues for transmission is critical in maintaining the integrity of food systems including in execution of better management practices to prevent spread and emergence of diseases (FAO, 2011).

7.1 Materials and methods

7.1.1 Selection of study units

Selection of study area is described in chapter three. In chapter six, the methods for data collection and sampling for analysis of total coliforms (TCC) from which *E. coli* isolates for this chapter are drawn has been documented. In brief, 290 cow milk samples were collected from 63 farms, five milk collection centres, 37 kiosks, 17 milk bars, 14 roadside vendors, three restaurants, two milk vending milk machines, two mobile traders and one supermarket. The types of samples obtained included raw milk (N=203), home-made fermented milk (N=12), home-made yoghurt (N=3), pasteurized milk (N=35), Ultra Heat Treated milk (N=13), processed yoghurt (N=13) and processed fermented milk (N=11). The samples were collected from two locations, Uthiru (Dagoretti and Kabete sub locations) and Kasarani location. Uthiru location is a peri-urban area in Nairobi and dairy farming was a common practice. On the other hand, Korogocho is one of the largest informal settlement neighbourhoods (slum) of Nairobi and livestock keeping is not a major activity although some people keep a few dairy cows, pigs, poultry, sheep and goats (Gathuthi *et al.*, 2010).

Milk sampling commenced early in the mornings and ended by 10am. At the farm, the farmer was requested to milk about 50mls directly into the sterile barcoded falcon tube but if the farmer was unable to milk for whatever reason, they were requested to give whatever remained from the last milking (even if it was pooled). To obtain about 50mls of milk from the other nodes (retail and bulking centers), participants were requested to transfer directly into the sterile barcoded falcon tubes. However, if the milk was in packets or sealed bottles, the entire content was purchased. All milk samples were immediately placed in a cool box that was packed with ice packs and transported to University of Nairobi (UoN), Microbiology laboratory within two to four hours of collection. At the UoN, various tests including enumeration of total coliforms and isolation of *E. coli*.

7.1.2 Isolation of *Escherichia coli*

For each milk sample, pre-enrichment was done in 0.1% sterile peptone water by incubating a 10-fold dilution of the sample for 24 hours at 37^0C. A primary culture was then obtained by transferring, about 5µL (loopful) of each dilution using a sterile wire loop on MacConkey Oxoid™ agar and incubation done at 37°C for 24 hours to get distinct colonies. This was followed by purification process which entailed sub-culturing of four pink, dry and pin-point (rounded colonies) on MacConkey Oxoid™ agar and incubating at 37°C for 24 hours (secondary culture). A single characteristic colony from each sub-culture plate was emulsified into an Eppendorf containing 0.5ml sterile normal saline for running of various biochemical tests. Biochemical tests included Indole test, Methyl red test, Voges-Proskauer test and Citrate utilization test (IMVIC) as described elsewhere (Hafeez and Aslanzadeh, 2018).

Biochemical identification of *E. coli* was based on the IMVIC results as follows: Indole positive (+), methyl red positive (+), vogues Proscar negative (-) and utilization of citrate negative (-). Pure *E. coli* isolates from the secondary purification were then cultured onto nutrient agar Oxoid™ at 37^0C. The isolates were then stocked in sterile skimmed milk and gradually frozen at -20^0C to -40^0C and finally -80^0C for future analysis. The processes involved with PCR analysis were conducted at the Centre for Microbiology Research at the Kenya Medical Research Institute (KEMRI).

7.1.3 Selection of isolates for fingerprinting

Two hundred and sixty eight (268) *E. coli* isolates were successfully revived from the stocked cultures. All the isolate unique identifiers for the 268 isolates were entered into Microsoft excel worksheet (http://www.wikihow.com/Create-a-Random-Sample-in-Excel) to facilitate random selection of isolates that could be conveniently analysed. The total number of isolates that were entered into the Gelcompar®2 software for analysis impacted on the legibility (with clarity of the clusters reducing with inputting very many samples. Therefore, a total of 107 isolates were selected. The first set comprised of 46 isolates that was based on milk type, sampling points and sampling regions to represent a broad overview of the diversity in the three areas of study. Similarly, from each of the three areas, isolates from farms were picked to represent patterns for diversity at farm level. These included 13 isolates that were recovered from Kasarani farms, 21 from Dagoretti and 27 isolates from Kabete farms.

7.1.4 Reviving of *E. coli* isolates and extraction of DNA

The stored colonies were revived by picking a loopful of them and inoculating at 37^0C for 24 hours in Eosin Methylene Blue agar (EMBA) which was prepared according to the manufacturer's instructions and stored at 40^0C until use. The colonies with the characteristic green metallic sheen growth were picked using a sterile wire loop and streaked on Muller Hinton agar (MHA) and incubated 24 hours at 37^0C. The colonies were then harvested for DNA extraction and remainder were stored in skimmed milk at -80^0C for future use.

The boiling method of DNA extraction was used in this study (Dashti *et al.*, 2009). Revived pure *E. coli* colonies on MHA plate were emulsified in 1mL distilled DNase/RNase-free water and boiling done at 95°C for 15 minutes to achieve bacterial cell lyses. Separation of bacterial nucleic material was done by centrifuging the boiled content at 140000 Xg for 5 minutes. Supernatant containing the extracted DNA was transferred in a sterile Eppendorf tube and stored at -20°C.

7.1.5 Finger printing

The polymerase chain reaction (PCR) method was to amplify that target repetitive extragenic palindrome sequence present in bacterial DNA (McLellan, 2004). The GTG_5 (5′-GTG GTG GTGGTG GTG-3′) single primer was used in the PCR amplification of target DNA (Mohapatra *et al.*, 2007). The reactions were done using PuReTaq™ Ready-To Go™ PCR beads (GE Healthcare, Bukinghamsire UK) following the manufacturer's instructions. Thermo-cycling steps included: initial denaturation at 95°C for two minutes, annealing at 40°C for one minute, a short extension step at 65°C for eight minutes and then a final extension at 65°C for eight minutes. Staining of the DNA loaded in agarose gel was done using SYBR™ green stain.

Gel electrophoresis was performed at 80 Volts in 1× Tris acetate EDTA (TAE) buffer for one hour to separate the amplifies genomic fragments.

7.1.6 Data analysis and interpretation of Dendrogram

Fingerprint analysis was done using the Gelcompar®2 software version 6.6 BioNumerics software available online at (https://download.appliedmaths.com/sites/default/files/download/bn_quickguide_0.pdf). Digital images were entered into Gelcompar®2 software and edited to grey scale for ease of bands definition. The banding patterns of analyzed *E. coli* isolates using the Pearson coefficient method that is based on similarity score among isolates. Dendrogram was constructed using the unweighted pair group arithmetic mean (UPGMA) (Christianson *et al.*, 2012). Dendrogram analysis was based on clustering patterns of isolates from the various locations, farms, shops and milk vending machines sampled. Isolates that clustered tightly with a similarity matrix of >80% were strongly considered genetically related (McLellan, 2004).

7.2 Results

Dendrogram generated from the 46 *E. coli* isolates derived three main groups of the bacteria designated as G.1, G.2 and G.3 (**Figure 21)**. Further, the three groups subdivided into six clusters, designated as A, B, C, D, E, F and G for ease of analysis and distinction. None of the bacterial clusters and consecutive sub-clusters had 100% similarity as presented in the generated dendrogram (**Figure 21)**. A big proportion of bacterial isolates from the same region clustered together, with cluster B dominated with bacterial isolates from Kabete region while cluster D, F, G had bacterial isolates predominantly from milk samples obtained from Kasarani.

However, 2 clusters that were depicted as A and C had isolates of *E. coli* from milk sampled from Dagoretti region that potentially indicates a common origin or source of contamination. Cluster E had the most diverse isolates recovered from milk samples obtained from Kabete, Kasarani and Dagoretti regions. In exception of a single sub-cluster consisting of 2 isolates from the same farm in Kasarani region, there was no indication of clustering based on similar farms, milk bars, milk vending machines, roadside milk vendors or one sold at the shops. In summary, the diversity in most clusters as presented in this dendrogram is a great indication of independent evolution rather than clonal spread of a specific *E. coli* strain.

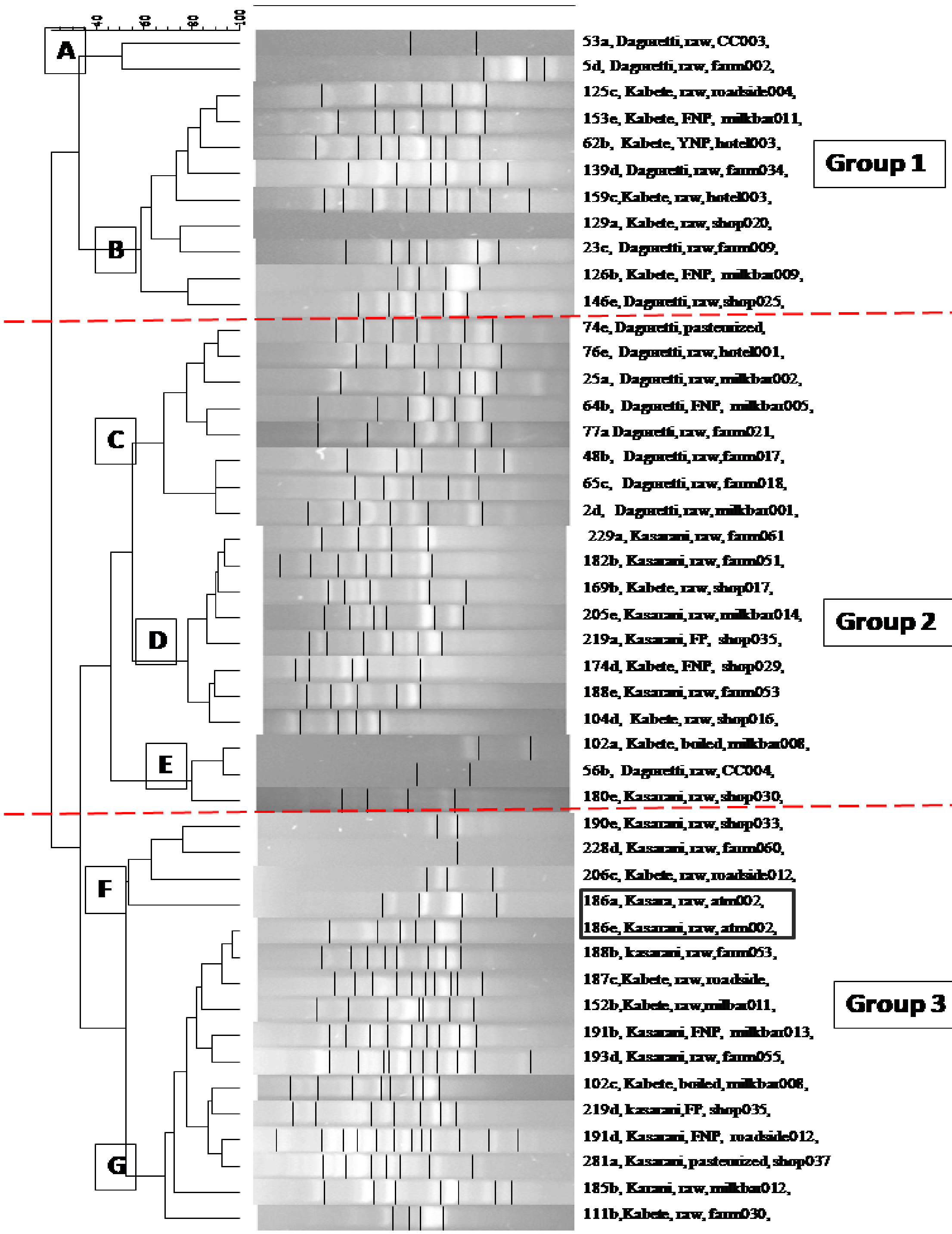


Figure 21: Dendrogram presenting a set of 46 diverse *Escherichia coli* isolates from milk samples collected in Nairobi (Kasarani, Dagoretti and Kabete) in Kenya.

Footnote: Samples of fermented non-packed (FNP), fermented packed (FP), pasteurized and raw milk sold at the milk vending machine (ATM), roadside, hotel and shops collected and analyzed to assess diversity of *Escherichia coli* contaminants. FNP represents home-made fermented milk and FP is processed fermented milk. The first column on the metadata section of the dendrogram represents unique identification code of the isolates.

Similar results were noted in a dendrogram generated from 13 isolates from milk sampled in Kasarani area. Isolates for raw milk samples within the same farm did not cluster together therefore signaling a variation in genetic diversity **(Figure 22)**.

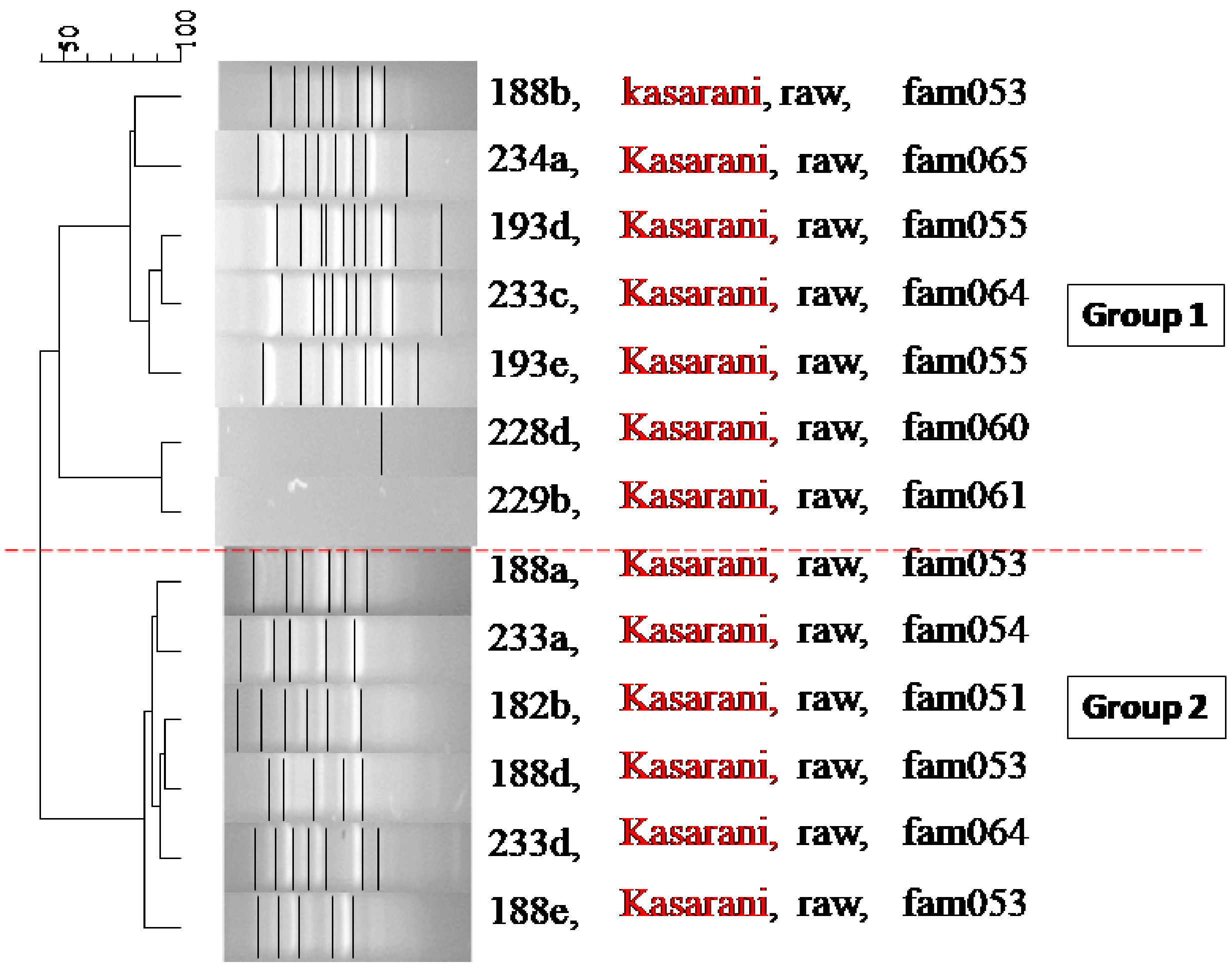


Figure 22: Dendrogram generated from selected *Escherichia coli* isolates from raw milk samples collected in various farms in Kasarani area.

Footnote: Isolates from the same farm were given the same identification number then letter a-e added for the different isolates. Fingerprint analysis of the 13 *E. coli* isolates from milk samples collected in 9 farms in Kasarani, Nairobi showed two major groups of clusters.

E.coli isolates from raw milk samples across Kabete clustered in four (4) major groups that had similarities of ≥50% **(Figure 23)**. Tight clustering with 100% similarity was noted between two (2) isolates in the first group that strongly suggested clonal spread. Further, the analysis showed that most *E. coli* isolates from raw milk within the same farm in Kabete (**farm039**) belonged to distinct clonal groups and therefore no indication of possible milk cross-contamination, (**Figure 23)**. There was also a big indication that same milk within a farm in Kabete were contaminated with distinct strains of *E. coli* as suggested by distinct clustering of isolates from same sample (**139a, 139d, 139e**).

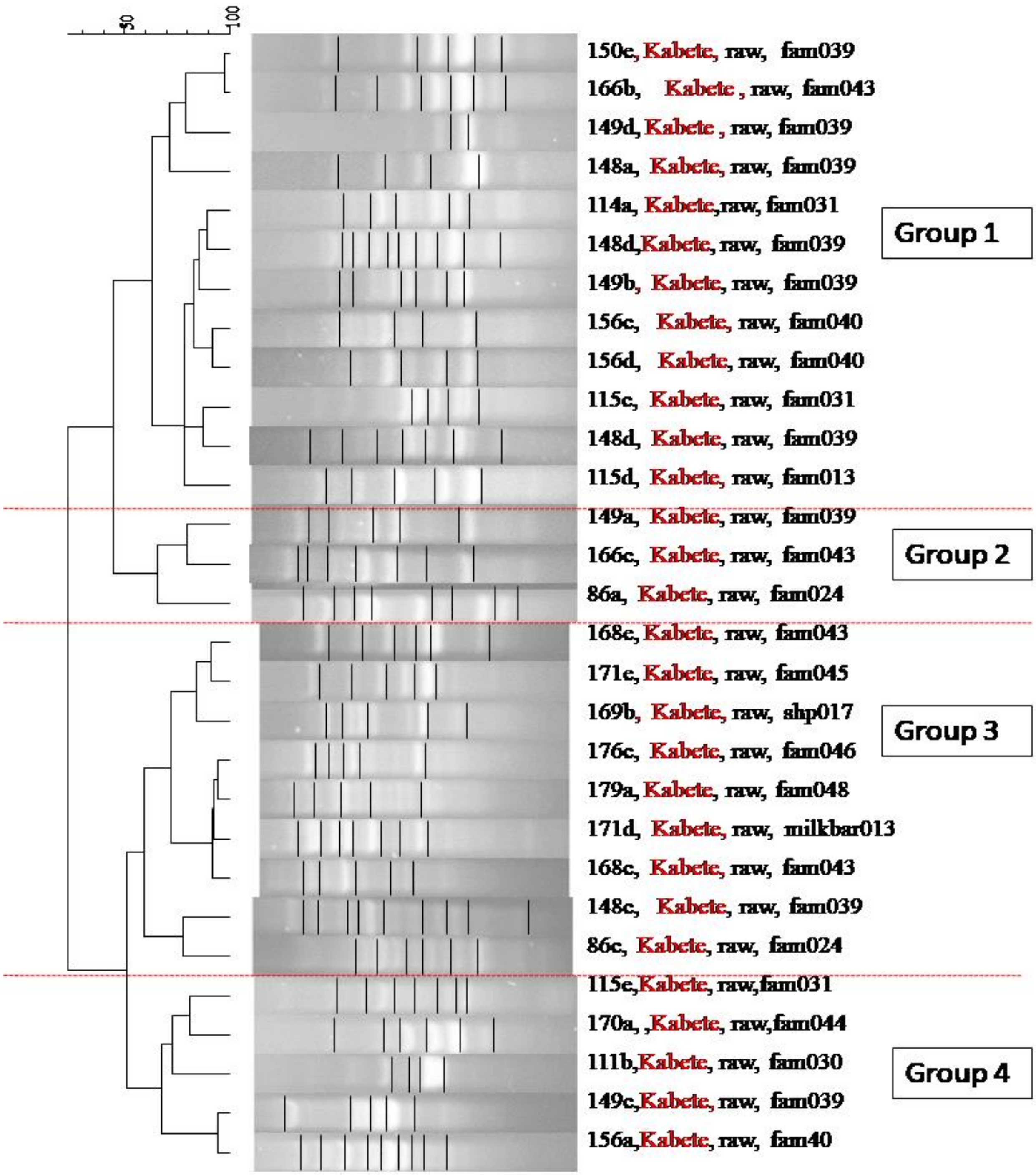


Figure 23: Dendrogram generated from selected *Escherichia coli* isolates from raw milk samples collected in various farms in Kabete area.

Footnote: Raw milk samples from 11 farms in Kabete area, Kenya were collected and analyzed to establish the genetic diversity of *Escherichia coli* isolates. A dendrogram based on banding patterns of 29 *Escherichia coli* showed four major groups of isolates clustering. The dendrogram showed no major indication of clustering of the isolates from same farm in Kabete.

There was a big indication that same milk within a farm in Dagoretti were contaminated with distinct strains of *E. coli* as suggested by distinct clustering of isolates from same samples (**Figure 4)**. This dendrogram however showed some little indication of clonal relatedness where a set of 2 pair of isolates from the same farms clustered tightly with a similarity score of ≥80% [**(38a & 38e), (40b & 40c)]**.

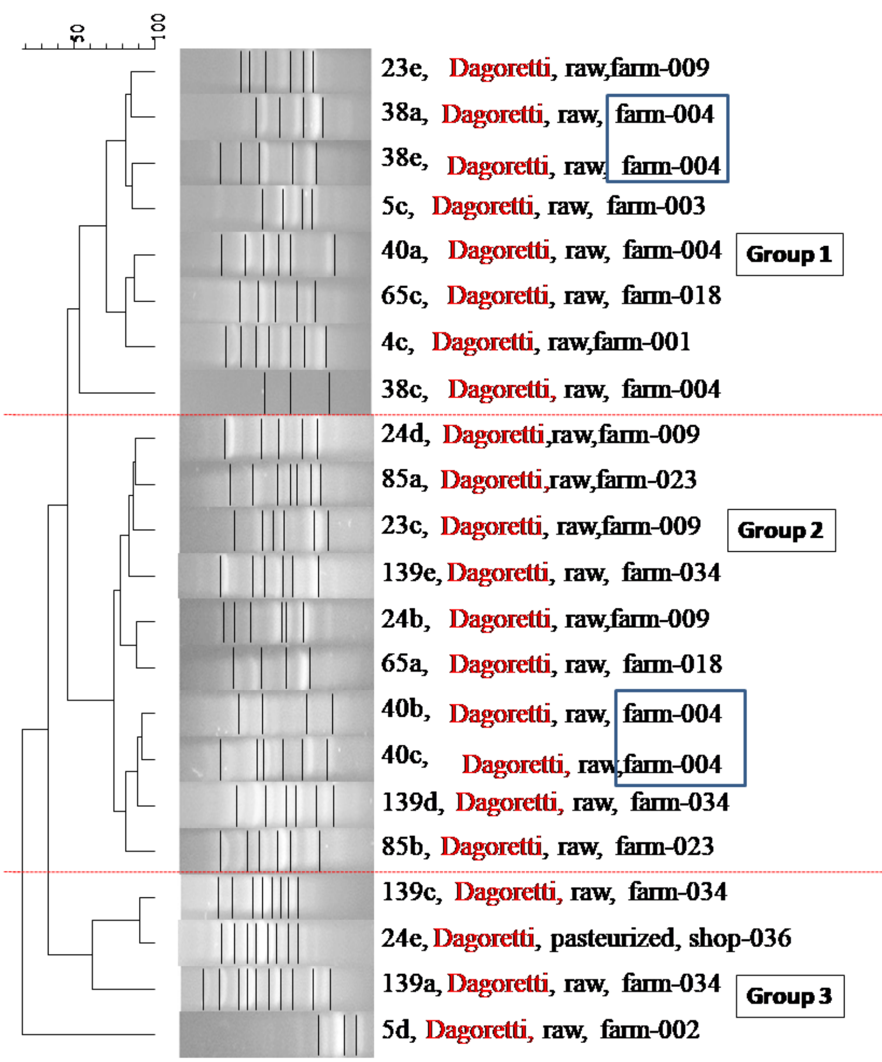


Figure 24: Dendrogram generated from selected *Escherichia coli* isolates from raw milk samples collected in various farms in Dagoretti area.

Footnote: The 22 *Escherichia coli* analyzed clustered in three major clusters (depicted as group 1, 2, 3) on the dendrogram.

7.3 Discussion

Emergence and transmission of foodborne pathogens is dynamic and complex (Fineberg and Wilson, 2010) associated with several drivers resulting from urbanization and adaptation of micro-organisms among other factors (Fineberg and Wilson, 2010; Smolinsky *et al.*, 2005). These factors are normally propagated by the complex system linkages associated with social, ecological, environmental dynamics and economic factors (King *et al.*, 2006; Wood *et al.*, 2012). Historically, approaches dealing with disease threats are mainly reactive, meaning that activities transpire during or after an outbreak (Smolinsky *et al.*, 2005). However, contemporary research suggests that more comprehensive approaches of combating health threats would involve a forecasting approach (Davis *et al.*, 2004; Keeling *et al.*, 2001), or prediction of broad patterns in pathogen evolution or actually defining the underlying causes of emergence (FAO, 2011a; Taylor *et al.*, 2001). For this purpose, molecular techniques have proven to be useful toolsin informing decision-making during outbreak investigations and response (Dallman *et al.*, 2015; Underwood *et al.*, 2013), identification of the original source of infection (Clermont *et al.*, 2011; HPA, 2010; Keene *et al.*, 1997; Underwood *et al.*, 2013) as well as detecting emergence of new pathogens (Brzuszkiewicz *et al.*, 2011; Honish *et al.*, 2005; Keene *et al.*, 1997). Such benefits can be achieved through the application of affordable and available low-resolution fingerprinting methods that can help determine diversity and possible sources of microbial contaminants in the milk distribution chain.

Phylogeny analysis done in this study showed that most *E. coli* isolated from raw, pasteurized, fermented milk and yoghurt had little indication of genetic relatedness across the value chain nodes; farms, milk collection centres, milk bars, restaurants, roadside vendors, shops/kiosks supermarkets and milk vending machines.

The recovered bacterial isolates were therefore genetically diverse which infer distinct sources of contaminants along the value chain. *E. coli* isolates from milk samples collected in the same farm were also genetically diverse which also strongly indicate a wide range of contamination source even within the same farm. Due to its presence in many environments (Luo *et al.,* 2011), *E. coli* may contaminate milk from various sources during different stages of production, storage, transportation and processing, which could explain the genetic diversity of these bacteria in the various milk products. The presence of *E. coli* in raw milk is common and may be associated with the health status of the cows (Cobbold and Desmarchelier, 2000; Gonggrijp *et al.,* 2016; Kuhnert *et al.,* 2005; Vicente *et al.,* 2005) and the dairy cattle have also been identified as reservoirs for genotypically and phenotypically diverse *E. coli*(Houser *et al.,* 2008; Son *et al.,* 2009). Other sources of contamination of milk with *E coli* include the environment of the cow due to poor and unhygienic milk handling techniques like milking with unclean hands, dirty milking equipment and unwashed cow udders at milking(Kuhnert *et al.,* 2005; Shija, 2013; Vicente *et al.,* 2005)as well as prolonged storage of raw milk at ambient temperature (OConnell *et al.,* 2016; Sarkar, 2015). On the other hand, presence of *E coli* in pasteurized milk may indicate inadequate pasteurization process or contamination of the product post pasteurization (Black, 1996).

Milk distribution in Kenya is largely unregulated with more than 80% of the milk being sold by small-scale informal traders (Leksmono *et al.,* 2006). Informal systems means that the enterprises are not registered or licensed to operate and as such are very difficult to regulate as well as problematic in monitoring food safety hazards and risks (Arzey, 2001; Grace *et al.,* 2010). Cognizant of this, there have been attempts by the government to organize the sector through training and certification of informal traders (Alonso *et al.,* 2018; Omore and Baker, 2009).

However, a subsequent study found that compliance with formal rules geared towards promoting of food safety are hampered by the numerous challenges and governance issues in the dairy system (Kiambi *et al.,* 2020b). While the study by Kiambi (2020b) pointed the policy makers on the need to address the governance challenges, the current study adds extra evidence that milk is contaminated at various points of the milk value chain and thus emphasizes on the need to critically analyse the system prior to designing and implementation of any interventions. This is further underscored by the fact that the Nairobi dairy system is comprised of multiple value chain actors who are majorly small-scale in nature and are highly interlinked and interdependent (Kiambi *et al.,* 2018).

7.4 Summary of the chapter

This chapter has described the genetic diversity of *E. coli* at various nodes of the milk value chain. The study indicates that *Escherichia coli* isolates had little indication of genetic relatedness across the value chain nodes; farms, milk collection centres, milk bars, restaurants, roadside vendors, shops/kiosks supermarkets and milk vending machines. This therefore means that milk contamination happens at various points along the value chain nodes. Therefore, policy on control and prevention of milk-borne disease and infections should not only focus on activates at the farm level but the entire value chain. Deliberate measures should be put in place to ensure milk safety through the enforcement of hygiene measures and improved milk handling from production farm to the final consumers. The next chapter will describe the general discussion of the main findings discussed in this thesis.

CHAPTER 8: GENERAL DISCUSSIONS AND RECOMMENDATIONS

Discussion

The overarching objective of this study was to investigate the structure, governance and food safety challenges in the Nairobi dairy value chain (NDVC). The study hypothesized that rapid urbanization exerts pressure on the interconnected complex food systems, consequently the quality of livestock sourced foods supplied to consumers of dairy products is impaired. Data collection methods and analysis included value chain mapping (chapter 4), investigation of governance structure and its influence on food safety (chapter 5), bacteriological sampling of cow milk for analysis of bacterial quality (chapter 6) and genetic diversity of *Escherichia coli* as markers for the system's stability (chapter 7).

In chapter 4, the research question aimed at mapping of profiles for the dairy value chains supplying Nairobi to understand the structure of NDVC as a basis for subsequent analysis described in chapters 5, 6 and 7. The results on dairy value chain mapping showed that NDVC was vast, with profound complexities illuminated by the interdependency of stakeholders involved in the inter-linked dairy chain profiles. Furthermore, it was shown that the chains were principally made up of individual entities (producers, retailers, traders) that were principally dominated by small-scale operators. Consequently, the approach used in this analysis showed that if these dairy chain actors were evaluated at individual level, their significance would have appeared minimal, yet they form the entire dairy system and contributes to the complexity of system. Indeed, other studies conducted in Nairobi have described similar complexity of the livestock value chains that are predominantly characterized by small-scale actors for the red meat, broiler chicken and egg food systems (Alarcon *et al.,* 2017; Carron *et al.,* 2017; Onono *et al.,* 2018).

An understanding of these elements within the food system helps to identify any structural vulnerabilities and deficiencies that may compromise quality (Alarcon; *et al.*, 2017; FAO, 2011a; Rushton, 2008), in addition to providing the critical framework needed for full analysis of the food system (Kaplinsky and Morris, 2000a; Rich and Perry, 2011; Rushton, 2008). A guideline developed by FAO on animal diseases risk management amplifies the need to thoroughly understand the livestock value chains in the context of operations and decision making by stakeholders (FAO, 2011a). This is because networks and linkages involved from production through processing, marketing and disposal of waste products provides opportunities for disease risks (as well food safety risks). Those involved at every level of the value chain need to see their importance and understand what they eventually stand to gain in order to motivate optimal cooperation in the production and supply of safe foods (Kaplinsky and Morris, 2000a).

In chapter 5, the research question aimed to understand the governance and its influence on food safety along the mapped NDVC. The result show that just as NDVC is fragmented and interlinked with actors who are quite diverse in relationships, approaches and practices on food safety implementation. Similar to findings from other reports, the current study found that the relationship between government and various stakeholders were weak and were also characterized with non-compliance to official rules and regulations (Alonso *et al.,* 2018; Omore and Baker, 2009). Indeed, although there is firm establishment of the dairy value chain in the law according to the Dairy Industry Act (GoK, 2012a), the current study found that compliance was hindered by several factors including high costs of the multiple licenses and milk trading permits which were often obtained through cumbersome procedures. Other studies have also linked this noncompliance to legal rules in food systems to fragmented and costly licenses (Alonso *et al.,* 2018; Pfeffermann, 2001).

At the same time, there appeared to be added advantage for most dairy traders who did not comply with official rules and regulations since they were able to successfully compete at milk sourcing and marketing while they evaded regulation. The study also found a lack of coherence in policy and practice (fragmented systems in government); whereby, whatever KDB termed illegal according to the official practice by law (e.g. hawking or selling of milk outside a premise), the city council would appear to encourage through collection of revenue inform of a daily fee called cess. This may imply that these actors could thrive in the industry as long as they knew how to deal with different arms of government. This lack of integration of regulatory functions has been previously been reported as a challenge when addressing food safety (Gereffi *et al.*, 2005; Orden and Roberts, 2007). The study also revealed that another major driver for unsafe milk supplied to consumer was the element of unfair competition among actors as demonstrated by the way each of them is treated by the legal entities. While food safety concerns arose from both formal and informal systems (Alonso *et al.*, 2018; Roesel and Grace, 2014), and considering tight interactions among actors in both systems; there have been some efforts by the government to formalize the informal sector (Omore and Baker, 2009). The aim has been to effectively coordinate and regulate the sector considering that over 80% of milk is supplied through informal marketing channels (FAO, 2011b; H. Muriuki *et al.*, 2003). However, this has encountered severe antagonism by formal sector who accuse government of not offering the deserved protection for the sector. Their argument is based on the fact that formal systems incur higher costs to comply with regulations (premises, licenses, permits, cold chain etc.) as opposed to their competitors in the informal system whose costs are minimal and only comprise of the purchase of the milk container (s) and milk itself.

However, the actors in the informal system have argued that the rules are very tight and the costs to formalize are heavy and therefore acting as barriers for them to participate in the sector. Therefore emphasis on criminalizing and penalizing actors in the informal chains without addressing factors that hinder formalization directly impacts on possible gains that are desired by the system, like food safety and food security. This chapter therefore emphasises on the need to understand governance systems and how it impacts on food safety along the dairy value chains. The governance and challenges themes identified during this study therefore underscore on the need for holistic system analysis when developing food policies and other interventions aiming to improve system efficiency and food safety.

In chapter 6 the research question aimed at determining the total bacteria count (TBC) and total coliform count (TCC) as indicators for milk quality and food safety. The framework developed in chapter 4 provided information on prevailing nodes for bacteriological milk sampling. The various governance themes and challenges explained in chapter 5 provided indication on some of the factors that may influence the stakeholder interactions and practices thereof and thus the quality of milk flowing between the various nodes of the value chain. Analysis of TBC and TCC indicate that the bacteria occurred in all milk samples but at varying levels of acceptability based on the East Africa Standards (EAS). This variation was dependent on type of milk sample and type of node where milk was obtained. Raw milk sourced from farms and processed milk samples obtained from supermarket were shown to be within acceptable TBC and TCC limits compared to the other milk samples obtained from other nodes of the milk value chain.

This might be explained by some of factors that were identified in the system like keeping cows in very muddy cowsheds, unconventional animal feed sources, and value addition on spoilt raw milk, adulteration of milk, inadequate/lack of cold chain and acceptance of low-quality milk for processing. These results suggest that the Nairobi milk system is unstable and presents with various potential points for milk contamination along the interconnected complex milk distribution networks. Therefore any interventions to improve milk will need to focus on the issues presenting at specific nodes. Although milk in farms was relatively good, the current study (in chapter 1) and other studies (Alarcon *et al.*, 2017; GOK, 2012) have shown that only a small proportion of Nairobi residents have access to milk that is sourced directly from farms. Previous research indicate that more than 80% of milk consumed in Nairobi is supplied through informal chains with highly interlinked actors (Leksmono *et al.*, 2006), yet these are the nodes that are presenting low bacterial quality and consequently having the potential to obtain even more contaminants along the dairy value chain downstream. This is because, the milk that is retailed faces numerous challenges linked to poor milk storage and handling practices which would relate to lack of cold chain and unhygienic handling practices (Kuhnert *et al.*, 2005; Shija, 2013; Vicente *et al.*, 2005). The holistic analysis in this study reveals several factors that influence bacterial quality of milk and this could as well indicate the system's vulnerability to other shocks. Any interventions needs to be cognizant of the different actors in terms of scale and capacity to inform tailored interventions (there should not be a one size fits all).

In chapter 7 the research question aimed at determining the *E. coli* genetic diversity in milk sampled collected from several nodes of the NDVC. The *E. coli* isolates were obtained from the TCC analysis done in chapter 6. Results show that just like the TBC and TCC varied at various nodes, so is the genetic diversity of *E.coli*.

While *E. coli* is common in many environments, its diversity within the value chain is a good indicator of the system's stability and therefore may contribute to identifying the major sources of contamination and subsequent point to strategic areas of intervention. From the analysis of the isolates, three major clusters were identified based on bacterial banding patterns and a big proportion of the subsequent sub-clusters in these phylogenies revealed a similarity matrix of between 50-70% among isolates from the same region. Further analysis showed that most isolates from milk sampled within the same farm did not cluster which strongly suggest variation in recovered *E. coli* strains. Put together, these findings are an indication of independent bacterial evolution or distinct milk contamination sources and not as a result of clonal spread of certain strains. This distribution of *E.coli* genetic diversity (at farms, and the various node types and milk types) reveals how unstable the milk system that supply the city are. It is not obvious that the bacteria in milk sold as packet, yoghurt or fermented at different nodes is the same as the bacteria isolated from raw milk at the farms. This means that apart from spreading any existing pathogens at the farm level, the system is still vulnerable to contamination with points for possible introduction of new pathogens and other food related hazards along the chain. These could be driven by the current complex organization of the people (as described in chapter 4) and the diverse practices among the actors in the NDVC (as seen in chapter 5). Probably, that is why urbanization has been linked to emergence of new pathogens and diseases (Knobler *et al.,* 2006; Smolinsky *et al.,* 2005). This thesis therefore argues that policy on management of food safety (control diseases which are milk-borne) should not only focus on activities along a few nodes of the value chain but along the entire value chain to ensure milk safety that is supplied to consumers within the city.

8.1 Limitations of the study

There are some potential limitations in this study. First, is that data used for analysis of chapters four, five and part of six, were qualitative gathered through narrations, and quantitative data through proportional estimation from the FGDs and key informant interviews. Such data could be prone to selection and recall bias and thus may not be representative. However, a wide variety of people representing various segments of the value chain were interviewed while ensuring adequate triangulation to minimize errors. In addition, the types of questions asked during the interviews also allowed for free discussions without leading participants to any specific answers. It was key that during the FGDs consensus was reached, following rigorous logical discussions and results were also presented to other key informants in the system to assess for errors and to validate the results.

Second, the sample size for analysis of TCC and TBC was insufficient for testing of statistical significance. Sample collection was based on snowballing technique due to lack of information on types and location of various nodes. Therefore, the results cannot be used to make inferences about the populations (Glen, 2014). Nevertheless, the study used a combination of techniques to show vulnerable points within the dairy systems and providing some factors that would influence milk quality in such complex food networks like Nairobi. Furthermore, the results provide indications of potential risks that may occur in the system while showing areas that could be targeted for improvement of the systems and for future studies.

Lastly, although the dairy sector is of significant importance in the country, data collection and analysis concentrated on milk chains supplying Nairobi and therefore the results may not be generalizable to the entire country and other systems.

Nonetheless, engagement of the regulators and other stakeholders with a national-wide mandate on the dairy sector may reflect the country's situation and the methodology utilized for this study may be replicated to study the country's dairy industry.

8.2 Conclusion

This study identified numerous inter-linkages across the dairy chain profiles in Nairobi's complex food system, demonstrating significant interdependency among the stakeholders. The range of issues highlighted also reflect the diversity of people who live and work in the dairy system and the complexity of their relationships. The analysis of TCC, TBC and *E. coli* genetic diversity has demonstrated a lack of stability of the system indicating that milk contamination occurs at various points along the value chain. This confirms the hypothesis of this study that interconnected complex Nairobi dairy food system may present opportunities for introduction and transmission of food safety hazards and other public health hazards through livestock sourced foods that are supplied to consumers. Consequently, enhancing the system's efficiency require a holistic and system-wide approach to mitigate the risk of exposure to food-borne pathogens while policy interventions should consider every segment of the value chain to ensure food safety.

8.3 Recommendations for future research

- Further study to investigate the incentives that may drive prudent practices that promote food safety may be useful to inform designing further awareness, training or implementing other identified interventions.

- There is need for re-alignment of the coordination mechanisms along the NDVC which will include harmonization of fees and licences in the system. A cost benefit analysis would be important to provide empirical evidence on whether or not to centralize revenues through an income tax-based system or other centralized form of revenue generation. A key policy question to be addressed would be on how to improve regulation without resulting in a ballooning ad hoc inspection system currently in place.
- Exploration of innovative ways to involve the private sector and/or self-regulation by the value chain actors e.g. farmers and, in particular, farmers groups, traders associations, processors' associations etc.
- Determining statistical significance of various hazards and potential hazards identified by the study and relating them to their probable public health risks.
- Replication of the methodology applied in the study in other parts of the country (urban and rural) to provide a wider scope from analysis with evidence based data to inform designing of better interventions aimed at improving food safety in the entire country's dairy value chain.

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APPENDICES

Appendix A: Data Collection Consent Form

ID:

Type of business:

Area:

Project name: Epidemiology, ecology and socio-economics of disease emergence

<u>Current research: Mapping and understanding the livestock food chain in Nairobi</u>

Dear Ms, Mr,

We are a team of researchers working at the International Livestock Research Institute, Kenya in collaboration with the Liverpool University, Royal Veterinary College of London, State Department of Livestock Development and University of Nairobi. We are studying the food value chain related to livestock production in Nairobi. Our aim is to understand how the food system in Nairobi works, from animal production to consumers. For the dairy value chain, we need to investigate the processes involved in animal production, trade and sales until the milk reaches the consumer. We would like to know which way the animal and the milk travel; which people who are involved in this chain what challenges they face during their work and what they struggle with; and we want to assess what are the possible food risks in these chains. The objective of our work is to generate information that is geared to improve how the food systems works in order to provide opportunities for businesses, employment and to provide safe and affordable food to consumers. We hope that it will improve access to milk in the poorest areas of Nairobi resulting in improved nutrition of people.

We would very much appreciate your help and collaboration in this project. Your participation is very important for the success of this study. We believe the results of this project would be useful for you and we would be happy to communicate them once they are ready **(if so, please provide us with an e-mail address or telephone number that we can reach you later)**. We highlight that this work is being carried out by independent research workers at ILRI, which has a mandate to study all livestock-related issues. We do not represent any government body.

We would like to inform you that any personal data disclosed during this interview will remain confidential to the research team, and will only be used for the purposes of this project.

Your identity will remain anonymous in any reports or presentations. All the data collected will be analysed by the main researcher and any confidential data will be treated accordingly; coding of sensitive data will be conducted as necessary.

For research purpose, we also would like to take pictures of your establishment/business at the end of the interview. This will only be used for research purpose and may be presented at international conference or in publications. However, no personal name or specific location will be displayed with the picture. Nonetheless, pictures will only be taken with your permission. No picture will be taken if you do not want.

I would like to draw to your attention to the fact that any data that you provide to the researchers of this project could be published in form of scientific reports and/or in scientific papers; I may also use your words along with those of others to describe particular views or experiences relevant to the research. However, all personal data concerning you and your practice will be maintained anonymous at all times. Please note that signing of this form does not affect your right to stop this interview at any point.

"I consent that the information disclosed during the interview may be used for internal reports within the University of Liverpool, University of Nairobi, the International Livestock Research Institute and other project partners' institutions, and in documents that will be in the public domain such as external reports and published scientific research papers".

Signature/ Date:

Name/s:

Appendix B: Checklist for focus group discussion with dairy cow farmers

Date of interview: ___________________

The basic strategy will be to assess (1) the structure of the chains (i.e. origin and destination of dairy products and types of interactions with other people), (2) product differentiation characteristics, (3) the type of economic transactions, (4) seasonality effects, (5) the management of waste (milk leftovers), (6) the challenges, incentives and aspirations of the people working in the chain, (7) the governance (power-holder) of the chain (this include the rules: formal and informal), (9) the existence of associations and (10) behaviour towards food pathogen hazards identified during the discussion.

Strategy:

2 Facilitators (at least one that speak Swahili)

2 Person taking notes (at least one that speak Swahili)

Material use:

Flip chat

Marker pens

Camera

Note book

Strategy:

1. **Arrival of participants.**

At arrival each participant will be given a nametag, in order to facilitate discussion. Then the researchers will present themselves, the project and the purpose of a focus group. After this, the researcher will read the consent form to the group and will then ask the participants to sign it if they agree with the conditions.

The focus groups will continue with those participants that have agreed to the conditions of the focus group. Permission will also be asked for the use of a camera recorder. If permission is not obtained, then only annotations will be recorded.

Note to facilitator: If disease risk practices are identified, it is important to further explore them using prompts as: why? Tell me more what happened? How often does this occur?

2. **Self-introductions**
3. **Can you please describe to us what categories of farms there are in this area? (E.g. Large, medium, small)**. The researcher has to start drawing a map of the destination of the different products on the flip chart

    a. Where do you **buy/source your animals**?

    b. What **products do** you sell?

    c. What type of **markets do these products have**?

    d. Ask about interactions (see section 4)

    e. What are the **average prices** for the various value added products?

    f. Are the different **categories connected to different type of people** (sellers/buyers) or place? Why? Get proportions

    g. What **time of the year** do you normally sell your animals?

    - Do other people produce batches at different times? What type of people?
    - Is there a **seasonality effect** for these products?

    h. Please describe the process on how the animals **are moved and sold (or meat milk)**?

i. Who transport the animals? And how?

4. Interaction with sellers:

a. How do you know or find these persons?

b. How is the deal made? What are the terms?

c. What determines the prices? And how is the payment done?

d. Do you have any contract with them? Verbal or written? If so, for how long?

e. What are the reasons to work with them?

f. What are the conditions they require?

g. Is there a big company or group of people that take a big part of your business?

5. Interaction with buyers:

a. Where do you buy your animals?

b. What are the reasons to work with them?

c. How do you know or find these persons?

d. How is the deal made? What are the terms?

e. What determines the prices? And how is the payment done?

f. Do you have any contract with them? Verbal or written? If so, for how long?

g. What are the conditions they require?

h. What happens when you are not able to meet the conditions? Do you provide any sanctions to them?

i. Could you tell me about the main difficulties you normally have with them? Why?

j. Is there a big company or group of people that take a big part of your business?

6. Do you have any association? How does it work? If not, do you work as a group somehow?

a. What is the purpose of the association/ group?

b. How many people are in the association? What proportion of farmers are parts of it? Why some farms are not part of the association?

c. Are there people from outside? What is the structure?

Block 2 – Upgrading (20 - 30 min.)

Barriers to entry	Government
Challenges	Other people

7. **Tell me how you started your business as a dairy farmer? Is it different from how you will have to start today? In what way?**

a. What is the average capital to start a farm? (large, medium, small)

b. How do you obtain the capital needed?

c. What are the main challenges to obtain this capital?

d. What are the difficulties to start this business?

e. How do you **interact with the government?**

f. **What are the other challenges of being a dairy farmer? Why? (rank them)**

- What could be the solutions to these challenges?

- Challenges related to access or ownership of land?

8. Is there any **training available on livestock management**?

a. Who provides it?

b. And in animal health?

c. How useful are these trainings?

Block 3 – Food safety (30-40 min.)

List Animal health people	List Disease risks
List Food safety challenges …………………..	

9. Animal Health management:

a. How would you **know that your animal is sick**?

b. W**hat do you do** when you find your animal sick?

c. **When** would you use the different animal health managers (probe into qualified vets, animal health assistants, over the counter drugs, herbal etc.)?

d. What are the **main diseases** that affect your farm?

e. Tell me about **when last you had a sick animal**? Whom did you call?

f. What is the **mortality** rate of your dairy animals per year? Why? What are **the main causes**?

g. **What do you** when one of your animals dies? Why?

- How do you **dispose of the dead animals**? Why?

10. With whom do you interact for **waste** management?

- How do you **dispose of the manure** created by your animals? Why?
- What happen with other by-products when generated? With hides? With aborted fetuses? With placentas? Why?

11. Tell me in your opinion what are the **points where disease can get into your animals**?

a. **What do you do** about it?

b. What are the **main challenges to control** these points?

12. Tell me in your opinion what are the **food safety risks in a farm**?

a. **What do you do** about it?

b. What are the **main challenges to control** these points?

Block 4 – Aspirations and Upgrading (10 min)

List of Aspirations	List of Real changes

13. **What are your aspirations? Why?**

a. What are the obstacles to get there?

b. What are the main changes that you foresee for the future?

c. Would the facilities be improved? Why or why not?

d. Would the way of making deals or interacting with people improve? Why?

Thank you very much for participating in this focus group discussion.

END

Post-focus group data collection:

- Facilitator should record:
  - Type of language used by participant
  - Sex of participants
  - Any other important cultural data that arise.

Appendix C: Checklist for focus group discussion with milk retailers and traders

Date of interview: ___________________

The basic strategy will be to assess (1) the structure of the chains (i.e. origin and destination of dairy products and types of interactions with other people), (2) product differentiation characteristics, (3) the type of economic transactions, (4) seasonality effects, (5) the management of waste (milk leftovers), (6) the challenges, incentives and aspirations of the people working in the chain, (7) the governance (power-holder) of the chain (this include the rules: formal and informal), (9) the existence of associations and (10) behaviour towards food pathogen hazards identified during the discussion.

Strategy:

2 Facilitators (at least one that speak Swahili)

2 Person taking notes (at least one that speak Swahili)

Material use:

Flip chat

Marker pens

Camera

Note book

Strategy:

11. Arrival of participants.

At arrival each participant will be given a nametag, in order to facilitate discussion. Then the researchers will present themselves, the project and the purpose of a focus group. After this, the researcher will read the consent form to the group and will then ask the participants to sign it if they agree with the conditions.

The focus groups will continue with those participants that have agreed to the conditions of the focus group. Permission will also be asked for the use of a camera recorder. If permission is not obtained, then only annotations will be recorded.

Note to facilitator: If disease risk practices are identified, it is important to further explore them using prompts as: why? Tell me more what happened? How often does this occur?

Introductions

12. Brief introduction of participants. The researchers will ask them to explain briefly their **main occupation, how much milk** they **trade per** day.
13. What are the **requirements** for one to become a milk trader? Who sets the requirements? (find out how many have fulfilled the requirements)
14. What are the **general challenges** for being a milk trader? Why?
15. With whom and what type of people, do you **interact** with in your work? **(list)**

    a. Farmers (types of farms)

    b. Milk collection centers (actual name and location and contacts if possible)

    c. Milk chilling centers (actual name and location and contacts if possible)

    d. Cooperative societies (actual name and location and contacts if possible)

    e. Dairy Traders Association (if they are not members. Why not members?)

    f. Other milk traders (hawkers)

    g. Processing plants (which ones?)

    h. Other Associations/ groups (which ones?)

    i. Institutions (KDB, city council, other government)

    j. Milk bars

    k. Cottage industries

l. Hotels

m. Shops/ kiosks/ supermarkets

n. Road side vendors

o. Consumers

16. How do you interact with these persons? Why?
17. How do you know or find these persons? How is the deal made?
18. What are the conditions required to work with each type? Do the conditions refer to milk quality? Quantities? Risk practices?
19. What happens when you are not able to meet the conditions?
20. What determines the prices (quality, quantity)? Who sets the prices (seller, hawker, big companies)?
21. How is the payments done? Cash, weekly, monthly?
22. Do you have any contract with them? Verbal or written? If so, for how long?
23. What are the reasons to work with each type?
24. What are the main difficulties you normally have with the different people that you interact with? Which category is most troublesome? Why?
25. Is there a time in the year that you work more or less with them? Which ones? When?

Mapping and governance

26. What are the **different categories of milk traders** e.g. in terms of:
    a. **Volumes** of milk traded per day (large or small traders, how much milk?)
    b. **Type** of product they sell (raw milk, value added)
    c. **Distance** covered in source for milk (local, long distant traders)
    d. **Registration** status (registered traders, and non-registered traders)

e. Affiliation to **association** (DTA members, other associations etc).

Ask them where they belong and why?

27. Are there **gender differences** among the milk traders? Why?
28. Do you have any **association**? How does it work? If not, do you work as a group somehow?
    d. What is the purpose of the association?
    e. How many people are in the association? What proportion of milk traders are parts of it? Why some traders are not part of the association?

Buying

29. What **types of products** do you deal with?
30. Are there **organized systems** through which you buy your products? Please explain, or why not?
31. Where do you **buy/source your milk**? (Actual names of places). Why?
32. Please explain the **process of obtaining milk** from different sources
33. Do you buy from farmers directly? Collection centers? Cooperative societies? From other traders? Why?
34. Are there **other traders** who buy from other different places? Which type of traders? Which places? Why?
35. What are the different buying prices from each category? (farms, collection centers, cooperatives, other traders, etc)
36. Does the **source** of your products change with **seasonality**? Please explain
    a. What happens during **over production**? (Which months?)
    b. What happens during **scarcity**? (Which months?)

c. What happens during **normal/ average** production? (Which months?)

37. What are the **other sources** of your products? Which time of the year? Why?
38. What **challenges** do you face with **buying your products** with the different categories? Why?

Transportation

39. How do you **package** your milk for transportation? (type of containers) Why?
40. Is milk from **different sources mixed**? Please explain
41. Is there an **organized system** by which you transport your products? Please explain, or why not?
42. How do you **transport** your milk? (mode of transports) Why?
43. What **permits/ documents** must one have to transport milk? Who gives them? (Ask them if they have). Why not?
44. Are there **penalties** for not having those documents? What penalties? By who?
45. Are there **incentives** for correctly carrying out your business? What incentives? From who?
46. What **times of the day** do you transport milk? (at night, during the day, any time) Why?
47. **How long** does it take you to **reach your destination** from time you buy milk? (in hours)
48. What do you **do to prevent milk from going bad**? Why?
49. Are there **other traders** who have **different practices to prevent milk spoilage on the way**? Which ones? What do they do?
50. Do you have a **cooling system when milk is on transit**? Why not?
51. What are the **main difficulties** you have in transportation?

Selling

52. Is there an **organized way through which you sell** your products? Please explain, or why not?
53. What type of **markets/ clients** do you target? Why?
54. How **do you know or find these clients**? What are the **terms and conditions** for the deal?
55. What happens if one is not able to fulfill the terms and conditions?
56. Please describe the process on how the **milk is sold**? E.g. do you supply to a common point to many clients? Do you move from door to door? Do you stand at one point and sell all of it by yourself?
57. What are the **average prices** for the various value added products?
58. What determines the prices? How is the payment done?
59. Is there a big company or group of people that take a big part in your business? How?
60. What are the **main difficulties** you normally have with **buyers**? Why?

Waste management

61. How do you handle **milk that goes bad** before arriving or on arrival to your client?
62. What happens with the **milk that is not sold**? Why? Addition of preservatives? Chilling? What?

Challenges, incentives and upgrading

63. What are the **main challenges of being a milk trader**? (list and **rank**) Why?
    a. What are the **major costs of your** business? Why?
    b. How did you **start your business** as a milk trader? (Savings, loan, gifts?) Is it different from how you will have to start today? In what way?
    f. Is there any **training available on milk trading**? Who provides it?

11. **Who are your competitors?**

  a. Rank in terms of importance

  b. How do you interact with them?

  c. How do your competitors affect the market?

  d. What challenges do you face with your competitors?

  e. Is there any sanctions applied to unfair competition? Does it work?

64. In your opinion, **who call the shots** in the dairy/milk trading?

  a. How do you know that they are the ones to take notice of?

  b. Does everyone take notice of them? If not, who doesn't? Why not?

  c. Are there any consequences when not listening to them?

Food safety

65. What are the **main food safety problems** you see in:

  a. Milk sourcing and packaging?

  b. Milk transportation?

  c. Milk preservation methods?

  d. Milk storage?

  e. Milk containers types and cleaning?

  f. Personnel hygiene involved in milk trade?

  g. Personnel training?

  h. Management of spoilt milk?

  i. Management of excess milk?

  j. Management of milk during scarce periods? Any bad practices?

14. **What are your aspirations? Why?**

a. What are the obstacles to get there?

b. What are the main changes that you foresee for the future? Branding your products? Opening a milk bar? Milk dispenser?

c. Would the facilities be improved? Why or why not?

d. Would the way of making deals or interacting with people improve? Why?

The end

Post-focus group data collection:

- Facilitator should record:
    - Type of language used by participant
    - Sex of participants
    - Tribe represented by the participants
    - Any other important cultural data that arise.

Appendix D: Checklist for data collection from regulators, licensing authorities and other government officials

1. Date of interview: ______________________________________
2. Position of the interviewee: ______________________________
3. Organization / department: ________________________________
4. Please name the area you are in charge of? (stop at the appropriate level)
5. Please describe your day to day activities in your current role?
6. Main challenges?

Present the flipchart diagrams to validate the list of stakeholders

7. Where are the hawkers?
   a. Please explain what a hawker means?
   b. What a broker is?
   c. What a road-side vendor is?
8. What type **of surveillance** is done and where?
   a. How **much staff** is there to do the job?
   b. **Who regulates** the other ones?
   c. What are **the challenges** for doing the surveillance?
      i. Which chains present the highest challenges? Why?
      ii. How this challenges affects the food safety?
   d. How is **quality controlled**?
9. What are the food safety **challenges/risks** you experience with them? Why? (sanctions and motivations)
   i. Where this challenges are more frequent?
   ii. Why this risks exist?
   iii. In terms of **source** of products?
   iv. In terms of **cleaning** of **establishment**?

v. In terms of cleaning of **tools** like scooping jugs? **Water** used, water source?

vi. In terms of **infrastructure**/equipment like collecting point if inside a building or outside in open ground?

vii. In terms of **storage** of products like plastic vs aluminium containers?

viii. In terms of **transport** of products?

ix. In terms of **personel**? **Training** of personel? (prompt on how the training is done) (also prompt on what kind of training and continous profesional development the public health officer has)

x. In terms of **waste** management? **Leaftover** management? Milk **preservation** practices?

xi. Any other hazard identified?

xii. Does **seasonality affects** food safety? How? Why?

xiii. Does the type of settlement affects food safety? How? Why?

xiv. Do you have any challenges regualting **the big companies**? Why?

10. What are the main policy gaps in your opinion?
11. In your opinion, **who call the shots** in the market? Why?
12. How do you **coordinate with other ministries** in order to tackle challenges with licensing and challenges with safety of the dairy products?
13. What are the **changes that you can foresee** in the future concerning
    a. Dairy sector licensing system?
    b. And in terms of public health?
    c. Extension services?

Appendix E: Questionnaire administered during milk sampling

A. Questionnaire number________________________________
B. Date of interview: ____________________________________
C. Name of enumerator: _________________________________
D. Area the business/ farm is located
    a. Sub-county: ______________________
    b. Sub-location: _____________________
    c. Village___________________________
B. GPS readings of the business location
    a. E___________________
    b. S___________________
E. Type of node (record)____________________________________
F. What is the source of your milk, yoghurt, mala?
    a. Own farm
    b. Neighbors farm/ farms in neighborhood
    c. DTA trader (describe)______________________________
    d. Non DTA trader (describe)___________________________
    e. Farm in peri-urban(describe)__________________________
    f. Farm in the urban(describe)__________________________
    g. Milk collection center (name)________________________
    h. Dairy cooperative (name)____________________________
    i. Large processing company
    j. Other (specify)_____________________________________
G. Do you use different sources for your morning, mid-day and evening milk? Name other sources: Explain

H. Sample description

Non-processed products

Sample	Sample ID	Actual geographical area of sourcing	Actual time received/ time you prepared this product	Number of different sources pooled	Comments
Raw milk					
Boiled milk					
Fermented (home-made)					
Yoghurt (homemade)					
Milk from Automated milk machine					

Processed products

Sample	Sample ID	Company name	Time received/ prepared this product	Expiry date (read packet)	Comments
Fermented branded (processed) milk					
Yoghurt (processed) (branded)					
Pasteurized milk					
Long life (UHT)					

Appendix F: **Protocol for culture, isolation and purification of Escherichia coli**

Day 1: sample reception and processing

Milk sample reception by ensuring that they are in good condition and well labelled

Measure 5ml of the milk sample and transfer to 45ml of sterile buffered peptone water (BPW) for enrichment (Ratio of 1:9)

Incubate at 37^0c for 18- 24 hours

Day 2: Plating on MacConkey

Using a sterile loop pick a loop full (5ul) of the incubated sample and streak on the surface of well-prepared sterile MacConkey Agar i.e. Primary plating

Incubate at 37^0c for 24 hours

Day 3: Picking and purification suspected E. coli colonies

Select four pin point red or pink colonies from each primary plate and sub-culture on to the second MacConkey Agar plate for purification (secondary plating)

Incubate at 37^0C

Day 4: Biochemical testing

Pick purified single colonies and emulsify into an Eppendorf tube containing sterile normal saline for biochemical test

Run an IMVIC test to check if the colonies are *E. coli*

Temporarily refrigerate the isolates in Eppendorf tubes until you have the biochemical results

Incubate the IMVIC set up for 24-48 hrs

Day 5: *E. coli* confirmation

Read the IMVIC results where *E. coli* is Indole **positive**, methyl red (MR) **positive**, vogues Proscar (VP) **negative** and citrate **negative** i.e. ++--

Using the refrigerated isolates inoculate again on clean MacConkey agar

Incubate at 37^0C

Day 6: Culturing for storage

Pick red or pink colonies and streak onto the sterile nutrient Agar plates

Incubate at 37^0C

Day 7: Archival of *E. coli* isolates

Using sterile swabs stock the *E. coli* isolates into well-prepared sterile skimmed milk

Gradually archive into the freezers for further analysis i.e. -20^0C to -40^0C and finally -80^0C

Revival of *E. coli* isolates for DNA extraction

Day 1: Media preparation

Prepare the Eosin methylene blue Agar plates according to manufactures instruction

Incubate 2-3 plates randomly selected for sterility testing at 37^0c for 18-24hrs

Day 2: isolate revival

Remove the isolates direct from -80^0C freezers

Inoculate on the surface of the EMBA medium by scrapping on the surface of the freeze skimmed milk (this minimises contamination of the stored isolates

Incubate for 18-24 hrs at 37^0C

Day 3: Subculture on Muller Hinton medium

Pick single green metallic sheen colonies and inoculate on Muller Hinton medium

Incubate at 37^0C for 24 hrs

Day 4: Setting up for DNA extraction

Make an inoculum in 0.85% normal saline to make a McFarland standard of 0.5density

Swab the Muller Hinton (MH) plates with the prepared inoculum

Pick the remaining colonies on MH plates and emulsify in Eppendorf tubes containing sterile distilled water for DNA extraction

Perform fingerprinting

Appendix G: Similarity index report

VALUE CHAIN MAPPING TO ASSESS GOVERNANCE CHALLENGES, FOOD SAFETY RISKS, AND ESCHERICHIA COLI GENETIC DIVERSITY ALONG THE DAIRY FOOD SYSTEM IN NAIROBI KENYA

ORIGINALITY REPORT

13%	9%	6%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

2%

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