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Food safety in informal markets

Hazard assessment for food in East African Community countries

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Cover: Open-air vegetable market in Bujumbura, Burundi (Photo credit: Maureen Kuboka, 2023)

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Food safety in informal markets: Hazard assessment for food in East African Community countries

Abstract

Food-borne diseases result from consuming unsafe food. The burden of food-borne diseases is disproportionately high in Africa. Despite this, there has been a lack of empirical data on food safety and food-borne diseases. One challenge in food safety research in Africa has been the dominance of informal food markets. This thesis reports on the food safety status in informal markets in East African Community (EAC) countries, focusing on hazard levels, risk factors for contamination, stakeholder perceptions and effectiveness of a food safety intervention. A mixed methods approach was used. Firstly, a systematic review and meta-analysis were conducted across seven EAC countries. Of 4,134 initial records, 53 studies were included for review and analysis. Pooled prevalence estimates were 41% for *Escherichia coli* (*E. coli)* (95% CI: 34–52%), 12% for *Salmonella* spp. (95% CI: 12–27%), and 9% for *Campylobacter* spp. (95% CI: 7–32%). Secondly, 16 focus group discussions and 33 key informant interviews involving traders, consumers, and stakeholders in the food system were conducted in Burundi and Kenya. Consumers and traders were found to confuse food quality with food safety. Consequently, they relied on heuristic cues and physical assessment to guarantee food safety. Animal source foods were perceived as most likely to cause disease. Risky practices such as food adulteration, improper traditional processing, slaughter, and consumption of diseased or dead animals were reported. Thirdly, knowledge, attitude, and practice (KAP), alongside a prevalence survey, were conducted among 170 meat sellers in Kenya, categorised into treatment (n=59) and control (n=111). Additionally, 103 meat samples were collected in Burundi. Overall, meat contamination with *E. coli*, coliforms and *Salmonella* exceeded EAC standard limits. KAP survey revealed that higher practice scores were associated with reduced levels of *E. coli* and coliform in meat. Higher cleanliness scores and access to running water were associated with reduced odds of *Salmonella* contamination. The KAP and hazard prevalence results showed no significant difference between treatment and control groups. Our study reveals high contamination levels in foods, and that consumers are at risk of pathogenic infections through risky behaviours and unhygienic handling. These findings can inform effective risk communication and strategic interventions aimed at reducing the risk of foodborne diseases.

Keywords: (Risk, foodborne diseases, food markets, food security, Africa)

Livsmedelssäkerhet på informella marknader: Riskbedömning för livsmedel i länder i Östafrikanska gemenskapen

Abstract

Konsumtion av kontaminerad mat kan leda till livsmedelsburna sjukdomar, och bördan av livsmedelsburna sjukdomar är oproportionerligt hög i Afrika. Trots detta har det saknats empiriska data om livsmedelssäkerhet och livsmedelsburna infektioner. En bidragande faktor till både hög förekomst av livsmedelsburna sjukdomar och till brist på data kan vara dominansen av informella livsmedelsmarknader. Denna avhandling rapporterar om livsmedelssäkerheten på informella marknader i länderna i Östafrikanska gemenskapen (EAC), med fokus på prevalens av smittämnen och riskfaktorer för kontaminering, samt effektiviteten av interventioner och kunskap och åsikter hos olika aktörer. Flera olika metoder användes i studien. Först genomfördes en systematisk översikt och metaanalys i sju EAC-länder. Av 4134 identifierade artiklar inkluderades 53 studier för granskning och analys. Sammanslagen prevalensuppskattning var 41 % för *E. coli* (95 % konfidensintervall (KI): 34–52 %), 12 % för *Salmonella*-arter (95 % KI: 12–27 %) och 9 % för *Campylobakter*-arter (95 % KI: 7–32 %). Därefter genomfördes 16 fokusgruppsdiskussioner och 33 intervjuer med viktiga intressenter i livsmedelssystemet i Burundi och Kenya. Konsumenter och försäljare visade sig blanda ihop livsmedelskvalitet och livsmedelssäkerhet, och därför förlitade de sig på observationer och annan fysisk bedömning av livsmedlen för att avgöra om livsmedlen var säkra att konsumera. Animaliska livsmedel ansågs mest sannolika att orsaka sjukdom. Riskfyllda metoder som felaktig traditionell bearbetning, slakt och konsumtion av sjuka eller döda djur rapporterades. Sedan utvärderades kunskap, attityd och praktik (KAP), tillsammans med en prevalensundersökning bland 170 köttförsäljare i Kenya, kategoriserade i grupperna intervention (n=59) och kontroll (n=111). Praktiska rutiner, tillsammans med rengöring och sanitet samt tillgång till rinnande vatten, kopplades till köttkontaminering med *E. coli*, totalantal koliforma bakterier och *Salmonella*. Resultaten från KAP och prevalensstudierna visade ingen signifikant skillnad mellan intervention och kontrollgrupperna. Vår studie visar höga föroreningsnivåer i kött och att konsumenter löper risk för patogena infektioner genom ohygienisk hantering och riskbeteenden. Dessa fynd ger grundläggande information för att kunna utforma effektiv riskkommunikation och strategiska insatser i syfte att minska riskerna för livsmedelsburna infektioner och förbättra folkhälsan.

Nyckelord: (Risk, livsmedelsburna infektioner, livsmedelsmarknader, livsmedelssäkerhet, Afrika)

La sécurité alimentaire dans les marchés informels : Évaluation des risques alimentaires dans les pays de la Communauté d'Afrique de l'Est

Résumé

Les maladies d'origine alimentaire résultent de la consommation d'aliments non sur. Le fardeau des maladies d'origine alimentaire est disproportionnellement élevé en Afrique. Malgré cela, il a existé un manque des données empiriques sur la sécurité alimentaire et les maladies d'origine alimentaire. Un des facteurs contributifs a été la domination des marchés alimentaires informels. Cette thèse rend compte de l'état de la sécurité alimentaire sur les marchés informels des pays de la Communauté d'Afrique de l'Est (EAC), en se focalisant sur les niveaux de dangerosité, les facteurs de risque de contamination, les perceptions des parties prenantes et l'efficacité d'une intervention en matière de sécurité alimentaire. Une approche mixte a été utilisée. Premièrement, une revue systématique et une méta-analyse ont été menées dans sept pays de la EAC. Sur 4 134 dossiers initiaux, 53 études ont été incluses pour examen et analyse. Les estimations de prévalence combinées étaient de 41 % pour *E. coli* (IC 95 %: 34–52 %), 12 % pour *Salmonella spp.* (IC 95 %: 12–27 %) et 9 % pour *Campylobacter spp.* (IC 95 %: 7–32 %). Deuxièmement, 16 discussions de *focus group* et 33 entretiens avec des informateurs clés impliquant des parties prenantes du système alimentaire ont été menés au Burundi et au Kenya. Consommateurs et commerçants confondaient qualité alimentaire et sécurité alimentaire. Par conséquent, ils s'appuyaient sur des indices heuristiques et des évaluations physiques pour garantir la sécurité alimentaire. Les aliments d'origine animale étaient perçus comme les plus susceptibles de provoquer des maladies. Des pratiques à risque telles que l'adultération alimentaire, un traitement traditionnel inapproprié, l'abattage et la consommation d'animaux malades ou morts ont été signalées. Troisièmement, connaissances, attitudes et pratiques (KAP), ainsi qu'une enquête sur la prévalence, ont été menées auprès de 170 vendeurs de viande au Kenya, classés en traitement (n=59) et témoins (n=111). De plus, 103 échantillons de viande ont été prélevés au Burundi. Globalement, la contamination de la viande par *E. coli*, coliformes et *Salmonella* a dépassé les limites standard de la EAC. L'enquête KAP a révélé que des scores de pratique plus élevés étaient associés à des niveaux réduits *E. coli* et coliformes dans la viande. Des scores de propreté plus élevés et un accès à l'eau potable étaient associés à une réduction des risques de contamination par *Salmonella*. Les résultats de la KAP et de la prévalence des risques n'ont mis en évidence aucune différence significative entre les groupes traités et témoins. Notre étude révèle des niveaux élevés de contamination dans les aliments, et que les consommateurs sont exposés à des infections pathogènes en raison de comportements à risque et d'une manipulation insalubre. Ces résultats peuvent éclairer une communication efficace des risques et des interventions stratégiques visant à réduire le risque de maladies d'origine alimentaire.

Mots-clés:(Risque, maladies d'origine alimentaire, marchés alimentaires, sécurité alimentaire, Afrique)

Dedication

To the memory of my late father, Mr Benjamin Kuboka, whose sacrifice and support were invaluable throughout my education.

I come as one, but I stand as ten thousand − Maya Angelou.

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List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Maureen Kuboka, Ianetta Mutie, Karin Artursson, Johanna F. Lindahl, Gunnar Carlsson, Florence Mutua & Delia Grace (2026). Prevalence of *Escherichia coli*, *Campylobacter* and *Salmonella* spp. in the East African Community: A Systematic Literature Review and Meta-Analysis. (*Food Microbiology doi:org:10.1016/j.fm.2025.105004*)

II. Maureen Kuboka, Delia Grace, Karin Artursson, Johanna Lindahl, Gunnar Carlsson & Florence Mutua (2024). Food safety in informal public markets in Kenya: perceptions of stakeholders in the food chain. (*Frontiers in Sustainable Food Systems doi:10.3389/fsufs.2024.1411318*)

III. Maureen Kuboka, Karin Artursson, Linnet Ochieng, Florence Mutua, Delia Grace, and Johanna F. Lindahl. Knowledge, Attitudes and Practices of Meat Sellers in Nairobi and Risk Factors Associated with Microbial Hazards (Manuscript s*ubmitted for publication).*

IV. Maureen Kuboka, Florence Mutua, Delia Grace, Johanna F. Lindahl and Karin Artursson (other co-authors to be confirmed). Food safety in Burundi: a mixed methods study. (*Draft manuscript*)

Paper I and II are reproduced with the permission of the publisher and published open access.

The contribution of Maureen Kuboka to the papers included in this thesis was as follows:

I. **MK** was involved in the conceptualisation and coordination of study activities. Developed the study protocol with input from the supervisors. Involved in the screening of articles as one of the two independent reviewers. Oversaw data extraction exercise and performed statistical analysis with support from supervisors. **MK** is the main writer of the manuscript and revised it after feedback from co-authors and journal reviewers.

II. **MK** was involved in the conceptualisation, planning and coordination of study activities. Developed data collection tools, with support from the supervisors. Led the data collection team. Performed qualitative analysis of the texts with support from a qualitative data specialist. **MK** is the main writer of the manuscript revised it after feedback from co-authors and journal reviewers.

III. **MK** was involved in the conceptualisation, planning and coordination of study activities. Revised data collection tools (which were adapted from a previous study), with support from the supervisors. Led the data collection team. Performed lab analysis with the support of a research assistant. Performed statistical analysis with support from the supervisors. **MK** is the main writer of the manuscript and revised it after feedback from co-authors and journal reviewers.

IV. **MK** was involved in conceptualisation, planning and coordination of study activities, with support from supervisors and partners in Burundi. Led the data collection team. Performed lab analysis with the support of a research assistant. Performed qualitative and statistical analysis with support from the supervisors. **MK** is the main writer of the manuscript and revised it after feedback from co-author.

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Abbreviations

AIC	Akaike information criterion
AfCFTA	Africa continental free trade area
ASF	Animal source foods
ASTM	American Society for Testing and Materials
CAC	Codex Alimentarius Commission
CTT	Classical test theory
DALY	Disability Adjusted Life Years
DRC	Democratic Republic of Congo
EAC	East African Community
EAEC	Enteroaggressive *E. coli*
EC	European Commission
EHEC	Enterohaemorragic *E. coli*
EIEC	Enteroinvasive *E. coli*
EPEC	Enteropathogenic *E. coli*
EU	European Union
FBD	Foodborne diseases
FAO	Food and Agriculture Authority of the United Nation
FDA	Food and Drug Authority of the United States
GAIN	Global Alliance for Improved Nutrition
ICC	Item characteristic curve
ILRI	International Livestock Research Institute
IRT	Item response theory
KAP	Knowledge, attitude and practice
LMIC	Low- and middle-income country

ODK	Open data kit
OR	Odds Ratio
PP	Percentage point
RTE	Ready-to-Eat
SSA	Sub-Saharan Africa
SLR	Systematic Literature Review
STEC	Shiga-toxin-producing *E. coli*
TBC	Total bacteria count
WHO	World Health Organisation
WOAH	World Organisation of Animal Health
UNEP	United Nations Environmental Programme

1. Introduction

1.1 Food safety globally

Food safety is the assurance that food will not cause harm to consumers when it is prepared and eaten as intended (FAO & WHO, 2023). Foodborne hazards are harmful agents that are either naturally present in food or contaminate it at any stage in the value chain, making the food unsafe. These hazards can be microbiological, chemical, or physical (Barlow et al., 2015). Consuming unsafe food can result in serious consequences, including illness and death (Bisht et al., 2021; ECDC and EFSA, 2023). Ensuring food safety is crucial for public health, food security, and the social and economic well-being of individuals and nations.

In 2015, the World Health Organisation (WHO) identified 31 hazards associated with foodborne diseases worldwide. Diarrheal disease agents were the leading causes of these illnesses, with Norovirus, *Campylobacter* spp., *Salmonella* spp., and pathogenic *E. coli* topping the list. Additionally, *Taenia solium*, *Vibrio cholerae*, Hepatitis A, and aflatoxin have significantly contributed to the overall FBD burden (WHO, 2015).

Globally, unsafe food causes an estimated 600 million illnesses and 420,000 deaths each year. Additionally, over one million illnesses annually result from chemicals, primarily heavy metals (Gibb et al., 2019). The burden of foodborne diseases (FBD) is particularly severe in low-and middle-income countries (WHO, 2015).

1.1.1 Global food safety policy and regulation

Food safety policies and regulations are established to ensure consumer protection and promote fair trade through harmonised standards (CAC, n.d.). The United Nations (UN), through the joint efforts of the World Health Organisation (WHO) and the Food and Agriculture Organisation (FAO), holds the mandate for global food safety policy and regulation (FAO, 2023; WHO, 2022).

The FAO and WHO work with member countries by providing scientific evidence and strengthening their capacity to deliver safe food for all. A key responsibility is to support the integration of food safety into national policies and assist in establishing infrastructure that minimises food safety risks. By using the FAO/WHO Food Control System Assessment Tool, countries can monitor and evaluate the performance of their food control systems, thereby promoting continuous improvement (FAO, 2023; WHO, 2022).

Additionally, the FAO and WHO ensure the implementation of active surveillance and response systems within countries to monitor and address foodborne disease events. Through the International Food Safety Authorities Network (INFOSAN), FAO and WHO facilitate information sharing among countries to prevent, manage, and respond to food safety incidents (Savelli et al., 2019).

The Codex Alimentarius Commission (CAC), jointly established by the FAO and WHO as the standard-setting body, serves as the international reference for food safety, aiming to protect consumer health and promote fair trade (CAC, n.d.). The FAO and WHO participate in the CAC by providing recommendations based on independent scientific evidence regarding food safety risks, ensuring that standards align with public health considerations.

The UN quadripartite, comprising the FAO, WHO, the World Organisation for Animal Health (WOAH, formerly OIE), and the UN Environment Programme (UNEP), formed a collaboration in 2022 under a joint One Health plan of action. For food safety interests, this initiative aims to ensure the protection of public health and sustainability throughout the agri-food supply system (FAO et al., 2022).

1.1.2 Regional food safety control and legislation

In developed countries, food safety governance is structured with distinct laws and oversight bodies responsible for surveillance, control, and management of food safety priorities. For example, the general food law created by the European Commission (EC) sets out principles for food safety, consumer protection, and trade within the EU. The Commission also established the European Food Safety Authority (EFSA), which provides

oversight and independent scientific advice on matters related to food safety (FAO & WHO, 2002).

In the United States, the primary law governing food is the Federal Food, Drug, and Cosmetic Act (FDCA). The main agencies responsible for food safety regulation, inspection, and surveillance are the Food and Drug Administration (FDA) and the USDA Food Safety and Inspection Service (FSIS) (Lam & Patel, 2023).

In Southeast Asia, the ASEAN-Food Safety Regulatory Framework was developed to guide food safety authorities on priority activities for ensuring food safety and consumer protection (Lin, 2018). The African Food Safety Authority was recently established by the African Union in 2025, to provide oversight for the regional harmonisation of food safety legislation and promote intra-regional trade (African Union, 2025).

1.2 Burden of FBD in Africa

The burden of disease is measured in Disability Adjusted Life Years (DALYs), which represent years of life lost due to illness or disability and premature death. One DALY equates to one year of life lost (Devleesschauwer et al., 2014).

The African population bears the greatest burden of FBD, estimated at 1,200 DALYs per 100,000 population, with children disproportionately affected. For instance, of the 59,000 global deaths due to non-typhoidal *Salmonella*, 32,000 were in Africa. The overall FBD burden in Africa translates to 91 million cases and 142,000 deaths annually (WHO, 2015). The loss in productivity is estimated at USD 20 billion, with an additional USD 3.5 billion spent on treatment costs (Jaffee et al., 2019).

In Kenya, the FBD burden, based on estimates from five of 47 counties, is extrapolated to be 1,140 DALYs per 100,000 population, mainly due to diarrhoeal diseases. This represents 1% of the annual GDP loss (Hoffman & Baral, 2019). In Rwanda, FBD burden from the consumption of milk and dairy products contaminated with five bacterial agents was estimated at 3,870 DALYs and resulted in 55 deaths in 2010 (Sapp et al., 2023).

The economic burden due to FBD is estimated at USD 391 million in Burkina Faso and USD 793 million in Ethiopia, equivalent to 3.0% and 0.9% of gross national income, respectively (van Wagenberg & Havelaar, 2023). Despite the FBD burden being highest in Africa (WHO, 2015), poor surveillance systems and under-reporting have resulted in limited reports on the occurrence of FBD events (Grace, 2017; Sosah & Donkor, 2025). Additionally, in most FBD cases, it has been challenging to establish the source of infection. In the absence of surveillance reports and empirical evidence, expert elicitation has been relied upon, which has associated most FBD events with animal-derived sources and products consumed raw, although processed products have also been linked to FBD (Sapp et al., 2022).

1.2.1 Food safety regulation in Africa

The role of the African Union

The African Union recently launched the African Food Safety Agency (AFSA) to harmonise food safety policies across the continent, aiming to promote trade under the African Continental Free Trade Area (AfCFTA). As this is yet to be operationalised, traditional oversight by national authorities is in place. These government agencies formulate regulations based on the Codex Alimentarius, often resulting in variations across countries that can hinder trade. Additionally, countries rely on regional regulations, such as those of the East African Community (EAC) (FAO, 2023; Kang'ethe et al., 2020).

1.3 Food safety and regulation in EAC

The EAC is a regional bloc in Africa, made up of eight partner states: namely, Burundi, Democratic Republic of the Congo (DRC), Kenya, Rwanda, Somalia, South Sudan, Tanzania (United Republic of Tanzania), and Uganda. The regional bloc was established in 1999, with the core objectives of strengthening political, social and economic ties, and the establishment of a common market for trade of goods and services (East African Community, 2002).

Agricultural products are the top-most traded goods across EAC, with animal source foods (ASF) ranking third, including dairy products, honey and eggs. Additionally, the trade of live animals and meat has been rapidly increasing at a rate of 13% from 2017 to 2022 (Chatham House Resource Trade Database, 2022). Despite this, harmonised policies across countries are lacking; instead, each partner state applies its own regulations established by the national food control authority. In the EAC Secretariat, food safety is overseen by the Technical Working Group (TWG) on medicines and food safety, which is nested within the health program, with a focus on disease surveillance, epidemic prevention and control. The TWG is currently working on a draft food safety and quality policy (EAC, 2025).

1.3.1 Food supply and food safety regulations in Burundi

Burundi is a country in EAC which has a total population of 14.4 million, with over 85% living in rural areas and depending on agriculture for food and livelihoods (FAO, 2015). Poverty levels are high, with about 70% of the population living on less than USD 3 per day (World Bank, 2025). The hunger index is provisionally estimated at > 40 due to a lack of data, compared to a global average of 18, thus considered alarming (GHI, 2025). Poverty and food insecurity have been identified as drivers of poor diets, which can further exacerbate foodborne infections (Stehl et al., 2025).

Several policies are in place regarding agriculture, food security and nutrition in the country; however, these do not directly address food safety. Various technical regulations, including laws, decrees, and ministerial ordinances, govern the safety of animal-derived foods, as listed in Table 1. Responsibility for food safety is divided among different ministries: agriculture, health, and trade, which can create loopholes in the execution of mandates (Niragira et al., 2020).

Research on food safety has been limited; consequently, there is a lack of understanding of the extent of food safety challenges and the burden of foodborne disease. Only a few studies are available on milk quality and aflatoxins (Iribagiza et al., 2024a; Iribagiza et al., 2024b; Udomkun et al., 2018). In addition, recent studies have reported the endemicity of foodborne parasites (Minani et al., 2022; Minani et al., 2024). The levels of pathogens

in foods and exposure pathways that can lead to public health risks are understudied.

Table 1: Technical regulations on food safety control of animal source foods in Burundi

Technical regulation	Ministry in charge	Purpose
Law No. 1/28 of 24 December 2009	Ministry of Environment, Agriculture and Livestock	Ensure the health of domestic, wild and aquaculture animals, and bees
Ministerial Ordinance No. 710/652 of 3 April 2019	Ministry of Environment, Agriculture and Livestock	Sets the conditions and procedures for the health inspection of animals and food products of animal origin
Ministerial Ordinance No. 710/653 of 3 April 2019	Ministry of Environment, Agriculture and Livestock	Examination of slaughter animals and veterinary health inspection of meat and meat products
Ministerial Ordinance No. 710/654 of 3 April 2019	Ministry of Environment, Agriculture and Livestock	Govern slaughterhouses and slaughter areas
Law No. 1/17 of 30 November 2016	Ministry of Environment, Agriculture and Livestock	Organisation of fisheries and aquaculture
Decree-Law No. 1/16 of 17 May 1982	Ministry of Public Health and Acquired Immunodeficiency Syndrome (AIDS) Control	Establish the public health code

Modified from: Niragira et al., (2020).

1.3.2 Food supply and food safety regulations in Kenya

Kenya has a population of approximately 47 million, with about 30% of people living below the poverty line (Kenya National Bureau of Satistics, 2023). Most of the low-income earners rely on informal markets for food and nutrition (Muunda et al., 2023; Tschirley et al., 2004; van der Lans et al., 2012). Informal markets are therefore common in Kenya and include open-air markets, small shops, kiosks, and eateries.

Table 2 displays the market share of various retail outlets for fresh produce. Fresh vegetables, fruits and fish are obtained from open-air markets and kiosks, while meat and milk are mainly sold in shops and kiosks (Koech et al., 2024; Muunda et al., 2023; van der Lans et al., 2012). In addition, supermarkets are emerging, supplying about 20% of fresh foods, and expanding with rising incomes and the growing middle class (Neven & Reardon, 2004; Tschirley et al., 2004).

Table 2: Percentage market share of retail outlets by income quantiles for fresh produce in Nairobi, Kenya

Income quantile	Super-market chains	Mini markets	Green-grocer shops	Open-air markets	Kiosks	Hawkers
1-lowest	0.0	0.1	0.0	64.7	41.5	3.6
2	0.0	0.0	0.0	60.6	34.4	3.7
3	0.4	0.7	0.0	60.7	36.4	1.8
4	1.7	0.1	0.0	59.5	38.0	0.4
5-highest	13.7	0.4	1.7	47.8	32.6	2.4

Source:(van der Lans et al., 2012)

The main laws on food safety are the Food and Drug Act of 1978, revised in 2023, and the Public Health Act of 1921, revised in 2002. Additionally, various other laws and regulations govern food safety. Table 3 summarises the regulations enacted to promote the safety of ASF. Despite a well-established legal framework, there are gaps in enforcement, resulting in a weak control system. Furthermore, most of these regulations are outdated and have not addressed emerging issues such as the expanding informal food sector.

The national food policy of 2021 acknowledges the scale and importance of the informal food sector; however, specific guidelines relevant to the sector are missing from the policy (The National Food Safety Policy, 2021). Similar to Burundi, food safety regulation is delegated to various departments within the ministries of agriculture, health, and trade. The multiplicity of agencies makes regulation and control complex, as it leads to duplication of roles and responsibilities, which can result in some areas being overlooked.

Efforts to establish an overarching body to coordinate food safety activities have not yet been successful (Kang'ethe et al., 2020; Oloo, 2019).

An effective national food safety control system can be divided into four pillars, including legal frameworks, surveillance and control, evidence and communication (Kwoba et al., 2023). Kenya seems to have a functional legal framework, but lacks in surveillance, evidence and communication (Kang'ethe et al., 2020 ; Oloo, 2019). Risk-based studies that generate evidence to drive investment in food safety surveillance and control systems are warranted.

Table 3: Technical regulations on food safety control of animal source foods in Kenya

Technical regulation	**Ministry in charge**	**Purpose**
Public Health Act, Cap 242	Ministry of Health	• To make provision for securing and maintaining health • Handle matters related to food (anything other than water and drugs intended for food preparation)
Food, Drugs and Chemical Substance Act, Cap 254	Ministry of Health	• To make provision for the prevention of adulteration of food, drugs and chemical substances • Prohibit the sale of food that is unfit for human consumption (unwholesome, adulterated, poisonous, harmful) or food not of the nature and quality demanded
Animal Diseases Act, Cap 364	Ministry of Agriculture, Livestock and Fisheries	• Isolate infected animals intended for slaughter • Bury or destroy carcasses • Slaughter and dispose of carcasses from animals declared infected, with compensation • Examine animals, carcasses, meat and animal products for evidence of notifiable diseases
Standards Act, Cap 496	Ministry of Investment, Trade and Industry	• Promote standardisation and provide for testing of products • Examine, test and sample of commodities • Inspect processes and manufacturing premises

Fisheries and Management and Development Act of 2016	Ministry of Investment, Trade and Industry	• Conservation, management and development of fisheries and aquatic resources.
Meat Control Act, Cap 356 Meat Regulations No 10 of 2010	Ministry of Investment, Trade and Industry	• License, inspect and set standards for slaughterhouses and meat for local consumption and export • License and inspect slaughterhouses and premises where meat is processed for human consumption • License meat inspectors • Make regulations on import of meat and meat products, local slaughterhouse licensing and export slaughterhouse regulations • Ensure quality through setting of standards for processing meat products and additives; storage and transport of meat and meat products • Surveillance (sample meat products and food additives) • Control import and export of meat • Ensure meat is wholesome and fit for human consumption
Dairy Industry Act, Cap 336	Ministry of Agriculture, Livestock and Fisheries	• Improve efficiency of production, quality and marketing of dairy produce (milk, cream, butter, ghee, cheese and any other byproducts of milk) • Prescribe handling, transport and storage of dairy produce intended for consumption and the way produce shall be sold • Inspect dairy products to ensure they meet the quality standards • Surveillance (collect and test dairy)
Kenya Meat Commission Act, Cap 363	Ministry of Agriculture, Livestock and Fisheries	• Regulates purchase, slaughter stock (cattle, small stock, poultry), slaughter and market products, and ensure cold chain for slaughtered products • Establish and maintain abattoirs and cold storage for meat, meat products and eggs

Trade Description Act, Cap 505	Ministry of Investment, Trade and Industry	• Prohibit false trade descriptions • Prohibit false indications of price • Prohibit import of goods with false descriptions of origin • Inspect premises and seize and detain goods and documents
Cooperative Act, Cap 490	Ministry of Micro, Small and Medium Enterprises Development	• Run societies by keeping and auditing accounts (dairy cooperatives are governed under this Act)

Modified from: Kang'ethe et al., (2020).

1.4 Food safety in informal markets

Informal food markets are defined as non-modern, unregistered outlets where food is sold to consumers as raw or processed products. The informal food sector is heterogeneous and includes open-air markets in urban and peri-urban areas, small shops and kiosks, eateries and food service centres and micro and small processing cottages (Roesel & Grace, 2014).

Informal markets supply over 80% of food consumed in LMICs (Blackmore et al., 2020; Hannah et al., 2022; Tschirley et al., 2004) and act as a ready market for produce for smallholder farmers (Ferris et al., 2014). Due to the informality in structure, the sector often evades government control, taxation, social protection guidelines, labour laws, and employment benefits (Vanek et al., 2014).

1.4.1 Actors

Employment in the agricultural sector accounts for 57% of total employment in the population of Sub-Saharan Africa (SSA), while informal employment in non-agricultural work represents 66% of total employment (Vanek et al., 2014). Despite this significance, there is limited information on actual employment rates in the informal food production and distribution sector; therefore, it is unclear where employment in the informal food supply chain is reflected in the data above.

However, existing literature indicates that informal value chains provide numerous employment opportunities for individuals involved in production, processing, transportation, and market distribution as wholesalers and

retailers (Kiambi et al., 2018; Murungi et al., 2021; Nordhagen et al., 2023). Henson et al. (2023) argue that the number of retail vendors alone in mid-sized cities could be in the tens of thousands.

Food supplied to markets is predominantly produced by smallholder farmers (Dixon et al., 2001; Lowder et al., 2021), who own about two hectares of land in rural areas (Lowder et al., 2016) and often engage in crop cultivation alongside livestock keeping, fishery, or poultry farming. These farmers are considered the primary actors in the informal system. Within the supply chain, multiple levels of traders operate between producers and consumers, making the food chain longer and traceability systems challenging (Carron et al., 2017; Kiambi et al., 2020; Murungi et al., 2021; Nordhagen et al., 2023). In addition, informal value chains are characterised by middlemen, who act as intermediaries between different levels of traders (van der Lans et al., 2012).

Women and youth constitute a critical labour force in the informal food value chains, using them as a means of income generation and livelihood (Hall, 2017; Mugo & Kinyua, 2023; Raney et al., 2011). While underage children are sometimes involved in trading activities, this issue often goes undocumented for ethical reasons (Nordhagen et al., 2023). Some value chains, such as large animal meat, are more male-dominated (Murungi et al., 2021), while value chains such as poultry and milk sale are more female-dominated (Tangka et al., 2000; Tung, 2005).

Low-income earners and poor households are the main consumers in informal markets, as they use this channel to meet their nutritional needs at low expense (Tschirley et al., 2004; van der Lans et al., 2012). Other reasons why informal markets thrive are that they offer variety of fresh foods, are conveniently located, and provide friendly pricing as well as social ties (GAIN, 2022; Isanovic et al., 2023).

1.4.2 Governance, policies and food safety control

Informal value chains are characterised by numerous small players, which poses a challenge in food governance and control. In Kenya and other LMICs, food safety in domestic markets is managed at the local government level (The National Food Safety Policy, 2021). This decentralised approach is considered more suitable for governance as it enables closer administrative

support and service provision for local communities (Jafee et al., 2021). Local governments are mainly responsible for architectural planning of markets, providing sanitation services, conducting surveillance, and collecting levies. These markets are also overseen by market heads or market committees, who manage daily operations and maintain order (Davies et al., 2022; Henson et al., 2023).

However, a significant challenge is that municipal governments often lack the capacity to effectively implement food safety measures as set out in laws and policies. Limited public resources, competing priorities, and lack of data to support the urgency of food safety matters further hinder progress in food safety governance in local markets. This inadequacy exposes the public to health risks (Jafee et al., 2021).

One policy option presented by local governments is the formalisation of the sector through enforcement of regulations, registration, licensing or resettlement in new business areas (Henson et al., 2023). However, when this is done without the participation of the actors, it creates resistance and a disconnect between food control agencies and informal market actors (Grace et al., 2019; Resnick, 2019).

Young & Crush (2020) note that governance of informal value chains must occur in an enabling environment that supports the core players. They further observe that the success of policy and regulation in the informal sector depends on the inclusion and cooperation of informal actors, with a participatory approach adopted in decision-making and design of interventions.

Capacity building among the actors through the provision of training and technologies is also recommended as a more promising approach, which involves informal actors and improves knowledge and hygiene practices (Grace, 2023; Young & Crush, 2020). Additionally, reorganising actors into cooperatives as an initiative driven by the actors themselves and supported by the government and private sector, can enhance local government's ability to conduct surveillance, provide support more effectively, facilitate access to premium markets, and ensure product safety and quality (Kumar et al., 2013; Nyokabi et al., 2023).

1.4.3 Infrastructure

Infrastructure at informal markets is essential for preserving quality, reducing food loss and waste, and preventing health risks. This includes hygiene and sanitation infrastructure, slaughter facilities, and storage and transport facilities. However, these have often been found to be inadequate, missing, or poorly maintained (Henson et al., 2023).

Such infrastructural challenges hinder the provision of safe food in informal markets. For example, (Nyokabi et al., 2021) observed that milk in the informal chain was transported without cold-chain storage, which could accelerate its deterioration. In contrast, in more formal chains, milk cooling facilities were strategically located in rural areas where milk was aggregated to preserve its quality and shelf-life before being transported to processing plants. Additionally, lactometer and alcohol tests, along with other essential tests, were also conducted at milk reception centres to verify milk quality, which was not the case in informal chains.

In Kenya, the Meat Control Act provides guidelines for the control of slaughter activities and the sale of meat (The Meat Control Act, 1972). Ante-mortem and post-mortem examinations are conducted at the slaughterhouse to ensure that the meat is safe for consumption. However, some animals bypass these inspections due to a shortage of veterinary inspectors, who may be required to work across multiple facilities, leaving certain areas unattended (Cook et al., 2017; Otoigo et al., 2024). Poor transport facilities, road and transport networks, and a lack of specialised tools can also undermine surveillance efforts.

In the absence of testing and verification, informal actors tend to rely on sensory cues to assess food quality and safety (Bukachi et al., 2021), yet physical checks alone are insufficient to detect pathogenic contamination (Minani et al., 2024). Trained personnel, modern facilities, and rapid tests are essential to enhance surveillance activities, enabling the quick detection of foodborne risks and the implementation of appropriate prevention measures.

Additionally, access to a stable supply of clean water and electricity supports hygiene measures and proper food storage. Economic support through credit facilities can provide capital to invest in simple technologies

and equipment necessary for food safety, as well as enable actors to comply with other regulatory requirements (Young & Crush, 2020).

1.5 Application of risk assessment in informal markets

1.5.1 Risk assessment studies

Risk assessment is the gold standard in food safety research and has been used to identify, evaluate, and prioritise potential hazards to determine the likelihood and severity of harm. Risk assessment is a scientific process comprising four steps: hazard identification, hazard characterisation, exposure assessment, and risk characterisation. A hazard is not necessarily a risk; therefore, risk-based approaches, rather than hazard-based approaches, are applied in decision-making, establishing standards and guidelines to protect public health and facilitating trade (Barlow et al., 2015).

Despite its widespread application in the formal food supply chain, risk assessment has been little applied in informal food systems. This may be due to the complexity of these systems, which often involve non-linear flow of goods and people, with limited traceability (Grace et al., 2010). However, adaptive risk-based approaches can be applied in informal markets. One such approach is hazard analysis critical control point (HACCP) (Oloo et al., 2017; Zakhia & Program, 2002). Another is an integrated approach in research involving quantitative and qualitative methodologies to generate empirical evidence for decision-making and risk mitigation in informal market systems (Häsler et al., 2019).

In an integrated approach, focus group discussions (FGDs) with ranking techniques, ethnographic studies, prevalence surveys, literature reviews, and demographic surveys can be used for hazard identification and characterisation. Ethnography, observational studies, and modelling can be applied in exposure assessment. Risk characterisation can be calculated by integrating the results using probabilistic methods such as Monte Carlo simulation (Grace et al., 2008). Based on the results, proper interventions and mitigation strategies to reduce risk can be applied.

In our case, an integrated risk-based approach was used for hazard assessment. This involved conducting systematic literature reviews to quantify hazard levels and identify priority foods. Participatory approaches

were used to determine priority foods from the community's perspective and to map exposure pathways. Additionally, a survey assessing knowledge, attitudes, and practices, along with a prevalence study, was conducted to understand the underlying cognitive factors among informal actors, the point prevalence of hazards, and their associated risk factors.

Systematic literature reviews

Systematic literature reviews (SLRs) are widely regarded as the most reliable source of evidence for evidence-based practice. SLRs aim to synthesise findings from multiple studies using a rigorous and transparent protocol, ensuring consistency and minimising bias. When combined with meta-analysis, SLRs provide quantitative summaries that strengthen the overall evidence base to answer specific research questions and identify the gaps (Dekkers et al., 2019; Paul & Leeflang, 2021).

Having originated in the medical field, they have primarily been used to test different medical interventions (Higgins & Thomas, 2024). The value of SLRs lies in their ability to present comprehensive, unbiased evidence. However, their validity can be compromised by inadequate appraisal or the inclusion of low-quality studies (Dekkers et al., 2019; Higgins & Thomas, 2024).

Few SLRs have been conducted to analyse levels of priority pathogens in foods on the African continent, where evidence on the burden of foodborne disease has been scarce. Even so, only a handful have been conducted in EAC. Our study was conducted to understand the levels of priority hazards in foods and their risk factors. This evidence can contribute to the estimation of disease burden in Africa.

Participatory approaches

Participatory epidemiology was first used in pastoral areas of East Africa to investigate livestock disease patterns (Catley, 2000; Chambers, 1994). It has since evolved and been applied in public health epidemiology, food security, nutrition, and socio-economic studies (Catley et al., 2018; Häsler et al., 2019; Roesel et al., 2019; Wong et al., 2018).

Participatory tools include ethnography, FGDs, key informant interviews (KIIs), observations, ranking and scoring, and pairwise matrices. These tools promote adult learning and help bridge the gap between literate and illiterate

populations. Scores obtained can be analysed quantitatively, providing more insight into the question under study. Triangulation is also used to confirm findings and improve the reliability of results (Alders et al., 2020).

Participatory approaches can be time-consuming, require proper logistical planning and support, and demand appropriate training and skill in the use of methods and tools. Additionally, due to their socio-cultural approach, some scientists have a negative attitude towards participatory approaches, which may limit their application (Catley, 2000).

Despite their limitations, participatory methods are said to be more cost-effective and useful in low-resource settings, complementing conventional risk-based methods and integrating indigenous knowledge into epidemiology and risk prevention. They are also applied to understanding exposure pathways, social perceptions and drivers of risk in community settings, which may not be captured through quantitative methods or clinical diagnostics (Catley & Mariner, 2002).

Participatory approaches have been recommended as a risk-based method for understanding exposure to risks and describing dynamic processes in informal market systems. They also involve communities and various levels of actors and are therefore considered a more ethical approach to governance, planning, and decision-making regarding food safety in informal systems (Grace et al., 2008). However, few studies have attempted to use these methods in food safety. Existing studies focus on animal health and disease patterns (Dione et al., 2014; Nthiwa et al., 2019).

We employed a participatory approach through FGDs, KIIs and a stakeholder meeting to investigate perceptions on food and food safety and assess priority hazards and risk factors among communities in Burundi and Kenya.

Questionnaire surveys

Questionnaire surveys are used to collect data from a representative subset of the population, and the results can be generalised to the entire population. Questionnaire surveys should be probabilistic, with each participant having a non-zero and equal chance of participating, thereby reducing selection bias and providing accurate insights into the population. Questionnaire surveys involve three phases: question design, sampling, and data collection.

Participation involves providing information by answering questions (Fowler, 2009).

An example of a questionnaire survey is a knowledge, attitude and practice (KAP) survey. This is a behaviour change learning model that posits knowledge and attitude as unobservable constructs. The model supports that knowledge and attitude are correlated and that knowledge forms and shapes attitudes, which in turn influence behaviour (Valente et al., 1998). KAP surveys rely on structured and standardised questionnaires to assess what people know, believe, and do within a given population.

Knowledge refers to the understanding of a subject (which can be scientific, social, indigenous, implicit, or self-reflective) (Hulme, 2018). Attitude refers to personal feeling or positioning regarding a subject, while practice refers to regular activities that constitute a behaviour. Other factors that can influence practices include beliefs, socio-cultural norms, demographic factors and environmental factors (Macías & Glasauer, 2014).

These types of questionnaire surveys can be limited because they are more extractive; people are unable to express their views or influence the process. Conventional food surveys also provide point prevalence of food contamination with limited information on seasonal variation. They are also time- and resource-consuming, and require logistical support, especially if face-to-face interviews are conducted. Other studies have questioned the validity of KAP, based on the reliability of measurement scales. However, this limitation can be addressed using psychometric scales (Dohoo & Emanuelson, 2021)

Nonetheless, KAP surveys play an important role in public health research in situational analysis of knowledge gaps, cultural beliefs, and behavioural patterns that influence risk. They can also highlight priority needs and barriers to the effective delivery of intervention programmes. KAP surveys provide evidence for designing targeted interventions, communication strategies, and public health programmes to address risky practices. They are also valuable for establishing baseline levels and evaluating changes following interventions. (WHO, 2008).

Fewer studies have been done based on the KAP learning model, especially in studying the safety of ASF in informal markets. Some studies have adopted a participatory approach to understand KAP among meat

consumers (Roesel et al., 2019). Others have used structured questionnaires (Kimindu et al., 2024), while some have focused on practices and their association with demographic characteristics among slaughterhouse workers (Wambui et al., 2017). We employed KAP and prevalence surveys to understand factors associated with meat contamination in the retail node in Kenya.

Intervention studies

Intervention studies are recommended to improve food safety knowledge and promote behaviour change among stakeholders. Common strategies employed in food safety interventions include; capacity building, communication campaigns, and the provision of technologies and infrastructure (Madjdian et al., 2024; Malavi et al., 2021; Takeuchi et al., 2017). While most interventions emphasise training, evidence suggests that education alone is not sufficient to influence behaviour (Singh et al., 2016). The most effective outcomes are achieved when multiple approaches are combined. These typically involve education-based sessions conducted by trained personnel, dissemination of media messages such as radio broadcasts and audio-visual content, provision of tools, and the creation of an enabling environment to reinforce key messages and sustain change (GAIN, 2021; Kwoba et al., 2023; Takeuchi et al., 2017).

Several factors consistently contribute to the success of interventions. Programmes delivered regularly over extended periods, often using a longitudinal and participatory approach, tend to be more impactful (Lindahl et al., 2018). Stakeholder consultations and iterative implementation with monitoring and evaluation strengthen engagement (Samaan et al., 2012). Considering contextual factors, such as tailoring training to specific groups based on cultural norms, educational levels, and individual needs, is also important (Singh et al., 2016). The design of interventions is also significant. For example, randomised controlled trials are considered more reliable, while observational studies are more prone to bias (Grace et al., 2018).

Despite achievements in food safety interventions, challenges remain. High turnover and the itinerant nature of market actors may disrupt continuity, whereas limited time and commitment to programme activities

can hinder long-term impact (Singh et al., 2016). Additionally, a poor policy environment and lack of support from regulatory authorities, key infrastructural challenges, and discontinuity in access to tools and technologies previously provided by research teams raise concerns about the scalability and sustainability of interventions (Bekele et al., 2025; Grace et al., 2019).

2. Aims of the thesis

The overall aim was to understand the food safety situation in the domestic markets of East African Community countries, the hazards that occur in food, contamination levels, associated risk factors and effectiveness of a food safety intervention.

The specific objectives were;

1. To synthesise literature on priority foodborne disease hazards and risk factors in seven EAC countries.
2. To understand food safety and foodborne hazards in Kenya from the perspective of key stakeholders in the food chain.
3. To assess the effectiveness of a non-randomised intervention programme in Kenya, based on KAP, handwashing practices, and bacterial prevalence between treatment and control groups.
4. To understand food safety and foodborne hazards in Burundi from the perspective of key stakeholders in the food chain.
5. To assess the prevalence of food safety hazards in meat in Burundi

3. Materials and methods

3.1 Study design

The overall thesis followed a mixed methods design, encompassing a secondary review of literature, qualitative methods (FGDs, KIIs and stakeholder meetings), and quantitative methods (KAP and prevalence survey).

3.2 Ethical Considerations (Papers II-IV)

All studies involving human participation (Papers II-IV) were conducted adhering to ethical standards and considerations. Institutional ethical approvals were obtained from the International Livestock Research Institute (ILRI), followed by national approvals according to established guidelines in the respective countries.

3.2.1 Informed consent (Papers II-IV)

Participants were informed about the study and its objectives before data collection began. Those who agreed to participate provided written informed consent, which included consent to take pictures. Participation was voluntary, with no victimisation or consequences regarding future activities. Participants were free to withdraw at any time during the interviews.

3.2.2 Anonymity and pseudonymisation (Papers II-IV)

Participants were assured of anonymity before taking part in the interviews. The identities and geographical locations (global positioning system, GPS coordinates) of the butcher shops and markets where meat sampling was done (Papers III and IV), were recorded during the visit for potential follow-up, such as future intervention programmes. These details were included in the dataset but were not presented in the results during manuscript preparation or journal publication.

Names and phone numbers of participants were collected after the interviews solely for compensation purposes and were not included in the

datasets nor made public. Instead of their real identities, pseudonyms were used to identify butcher shops/meat stalls visited and individual participants during data analysis and manuscript preparation.

3.2.3 Compensation (Papers II-IV)

Participants in FGDs and KIIs were compensated for the time spent during the interviews. Compensation was agreed upon with government and ILRI officials, ensuring it was clear this was not payment for information, but compensation for time spent during the interviews. A rate equivalent to USD 10 was used in both countries. Meat samples (100 g) used for microbiological analysis were purchased at prices set by the butcher shop or meat seller.

3.2.4 Use of large language models and artificial intelligence

AI-powered Google Translate (https://translate.google.com/) and MS Word built-in document translator were used in language translation (Paper IV). Language proofing for the thesis and papers was done using Instatext (https://instatext.io/) and Microsoft Copilot (https://copilot.microsoft.com/).

3.3 Study sites (Papers I-IV)

The studies were conducted in East Africa, with primary data collected in Burundi and Kenya, and secondary data gathered from five of the seven EAC countries. Due to limited food safety research in Burundi, as established by a previous scoping review (Mutua et al., 2021), the country was identified as a suitable site for generating evidence to inform policy and decision-making. Kenya was purposively selected as a potential representative of a vibrant informal economy within the EAC and other LMICs. Figure 1 is a map of Africa, with the EAC highlighted.

Paper I: The systematic literature review was conducted across EAC countries to cover all seven member states at the time (as of 2022): Burundi, Democratic Republic of Congo, Kenya, Uganda, South Sudan, Tanzania, and Rwanda.

Paper II: The setting was the informal markets in Kenya. Two markets were selected: Kangemi Market in Nairobi and Masii Market in Machakos, representing urban and rural settings, respectively.

Figure 2 (left) shows the locations of the study sites. Markets were selected to reflect urban and rural settings and for their broad coverage considering, adequate representation of retail and wholesale actors, and multiple value chains, including ASF, fruits and vegetables, and ready-to-eat foods.

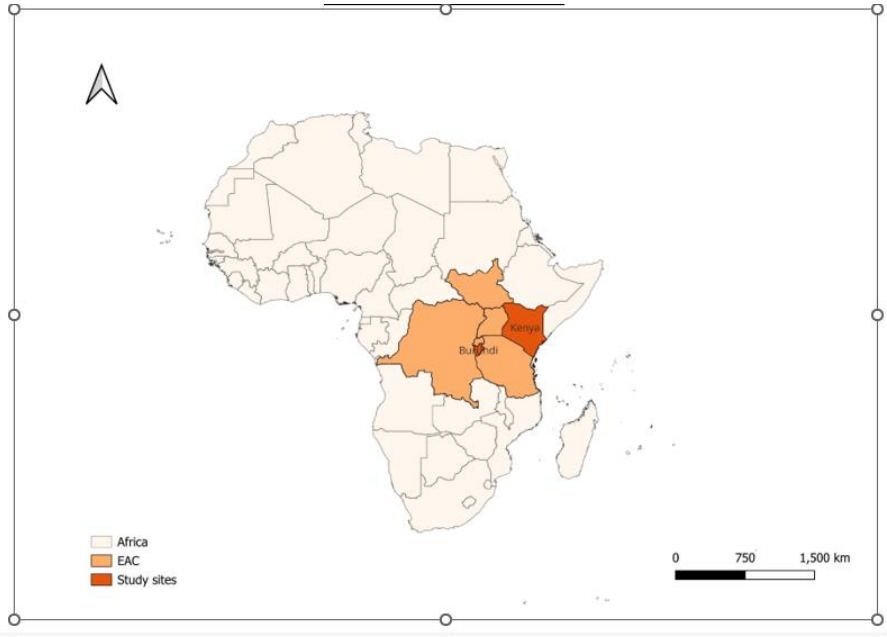

Figure 1: Map of East African Community countries, nested within Africa. Created with QGIS (https://qgis.org/)

Paper III: The setting was Nairobi, Kenya. Four administrative units were chosen as a follow-up to a previous study (Koech et al., 2024) and a food safety intervention carried out in the area.

Paper IV:

Qualitative component

The setting was informal markets in Burundi. Two markets were selected: Cotebu Market in Bujumbura and Matana Market in Bururi, representing urban and rural settings, respectively. Figure 2 (right) shows the location of the study sites. These markets were chosen for their strategic location, accessibility, daily sales, inflow of consumers and goods, the presence of

both retail and wholesale actors, and the opportunity to include actors representing various value chains, such as ASF, fruit and vegetables, and ready-to-eat food products.

Quantitative component
The setting was open-air markets selling meat in the capital, Bujumbura. Bujumbura Mairie, the urban province consisting of three communes (northern, southern and central), was selected due to ease of access, proximity to the laboratory, and the likelihood of finding a representative number of meat-selling stalls. All three communes were included in the sampling.

3.4 Study populations and selection of participants (Papers I-IV)

Paper I: The SLR included foods sampled from domestic markets in EAC countries.

Paper II: Traders and consumers were selected as participants in FGDs. In addition, stakeholders within the value chain, including animal health practitioners, public health officials, market and community leaders, and researchers, were involved in KIIs. Selection was done with the assistance of market heads, community leaders and officials from the Department of Public Health.

Paper III: Sampling included the area where the qualitative study in Paper II was conducted to allow for a comprehensive understanding of the food safety situation. Meat sellers in butcher shops in Nairobi formed the sampling population. A mapping exercise had been conducted in the study area, which established that there were 430 butcher shops, which formed the

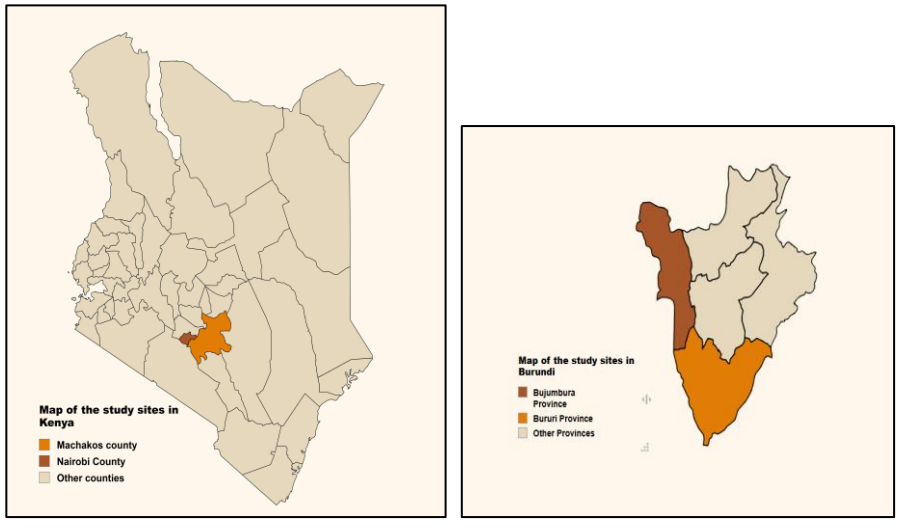

Figure 2: Map of the study sites in Kenya (left) and Burundi (right). Created using MapChart (https://www.mapchart.net/)

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among meat sellers in the area. Participants were therefore selected at random from the list and categorised into two; treatment (had participated in the intervention) and control groups (had not participated in the intervention).

The minimum allowable statistical power of 0.8 and an expected effect size of at least 0.4 were used in sample calculation (Cohen et al., 2003). The total calculated sample size was 210, comprising 70 participants who had taken part in the intervention and 140 who had not. These sample sizes were considered sufficient to detect differences between participants in the intervention and control groups, minimise Type II errors and for practical feasibility.

However, during data collection, only 59 of the 70 who participated in the intervention were available and willing to take part in this study (84% of the 70). Additionally, only 111 (79% of 140) butcher shops could participate as controls. This reduced the actual sample size to 170 butcher shops, compared to the calculated sample size of 210. This difference in sample size is a limitation of the study, as it may have affected statistical power and the ability to detect small effect sizes.

Paper IV:

Qualitative study

Similar to Paper II, traders and consumers were involved in FGDs, while other stakeholders were involved in KIIs.

Quantitative study

A scoping visit was conducted before the main data collection, which identified a total population of 200 meat-selling stalls in nine markets across three communes. All nine markets were included in the sampling. Assuming a 50% prevalence of microbial pathogens, based on the literature (Dang-Xuan et al., 2019; Dinede et al., 2023; Gazu et al., 2023), with a 10% margin of error and a 95% confidence interval, a sample size of 96 was calculated. After applying the finite population correction factor, adjusting for clustering, and accounting for possible non-participation, a final sample size of 103 was used. Meat-selling stalls were selected randomly using random

numbers from the obtained list. In markets where there were too few stalls (<10), all were sampled.

3.6 Questionnaire development and interviews (Papers II and IV)

3.6.1 Focus group discussion and key informant interview guides (Paper II and IV)

FGD and KII guides were developed in consultation with food safety experts. The guides included probing questions to ensure clarity, and the facilitator followed up with additional questions during the interviews as needed. The guides included questions on food choices, how and where food purchases are made, practices that compromise food safety along the chain, the occurrence of foodborne illness in the community, food safety challenges, and proposed solutions. These provided data about priority foods for food safety interventions, consideration of food safety in purchase decisions, risky practices that can compromise food safety, foodborne disease occurrence patterns and how the community manages food safety and foodborne illnesses.

3.6.2 Focus group discussions and key informant interviews (Paper II and IV)

The tools were piloted before use in both countries. For use in Burundi, the tools were translated into French and *Kirundi* by local speakers. Interviews were therefore conducted in English and Swahili (in Kenya) and in French and *Kirundi* (in Burundi). For triangulation, questions asked of traders were also posed to consumers and key stakeholders. In addition, key informants were asked technical questions relevant to their fields of expertise, including veterinary public health, human health, community and market leaders, consumer organisation representatives, and researchers.

In total, 16 FGDs and 33 KIIs were conducted in both countries. Two stakeholder meetings involving consumers, traders and key informants were held in Kenya to confirm results from the FGDs and KIIs. This was not possible in Burundi due to time and cost constraints.

3.7 Evaluation of the effectiveness of a food safety and hygiene intervention programme (Paper III)

A non-randomised intervention programme was conducted in December 2023 by ILRI and other partners. The intervention included a training workshop for meat sellers, held at the four locations where a survey had previously been conducted. Meat sellers were trained on hygiene, handling, and proper handwashing to reduce microbial contamination in meat. Tools were provided to participants, including a poster with a message on proper handwashing (Figure 3), which was displayed on the walls of the meat shop, as well as personal protective equipment (PPE) and plastic and bamboo cutting boards.

Based on the intervention, the participants were divided into treatment and control groups, as described in section 3.4. Our team utilised the KAP questionnaire and sample analysis to assess whether there were changes in KAP and meat contamination between the two groups, following the intervention (Paper III). In addition, hand rinse water was collected to assess the effectiveness of handwashing practices among meat sellers following the intervention programme.

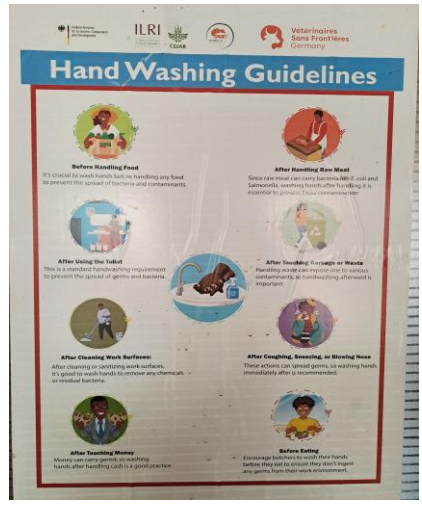


Figure 3: Poster on handwashing guidelines for meat sellers in Nairobi, Kenya. Photo credit: ILRI

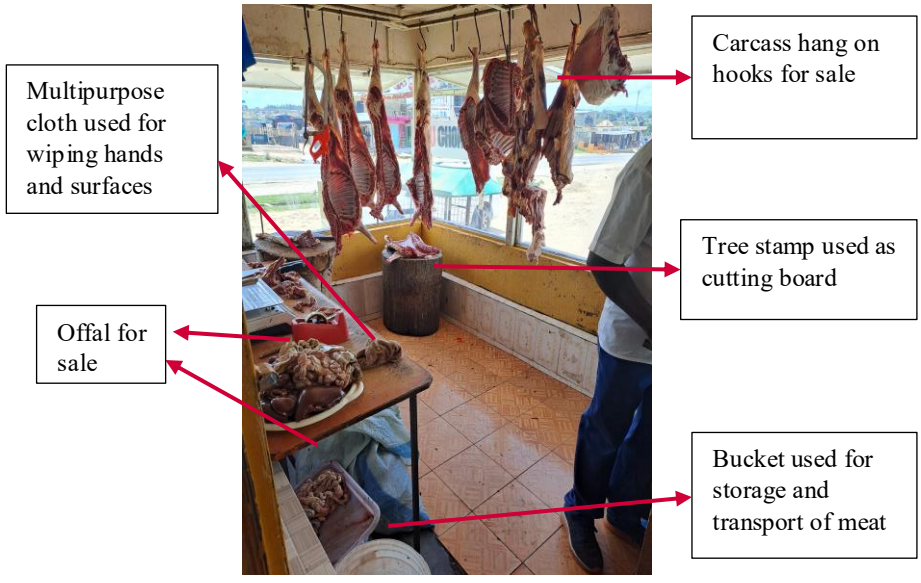


Figure 4: Typical layout of a butcher shop in Nairobi, Kenya. Photo credit: author

3.7.1 Knowledge, attitude and practice questionnaire

The questionnaire used was adapted from a previous study (Koech et al., 2024). Questions were reviewed for clarity in consultation with experts, and a pilot was done before actual use.

Questions included demographic and business characteristics, source of meat and transport means, cleaning routine, KAP questions, and possible incentives for improving food safety. These provided data on demographic, business and behavioural factors that could be associated with meat contamination.

3.7.2 Questionnaire Interviews

Face-to-face interviews with participants in both treatment and control groups were conducted using the open data kit (ODK) tool (https://getodk.org/). One-on-one interview approach minimised non-response errors, as the main questions were set as mandatory in the tool and therefore could not be skipped. Where the respondent was unfamiliar with

English, the questions were translated into Swahili during the interviews, further allowing better comprehension and evading non-response.

Alongside the questionnaire interviews, observation was conducted using a checklist that covered cleaning and sanitation, handwashing practices, use of PPE, and hygiene and handling of meat.

3.8 Microbiological analyses (Papers III and IV)

The meat samples were collected at the end of the interviews and processed to evaluate the levels of *E. coli* and coliform bacteria using MC-Media Pads (MC-Media Pad®; Millipore, Merck Life Science, Germany). This method was selected as a convenient and rapid approach for detecting *E. coli* and coliforms. Based on colour coding, selected *E. coli* colonies were picked and sub-cultured on MacConkey agar for confirmation.

Detection of *Salmonella* spp. was carried out according to the ISO 6579-1:2017 horizontal method for the enumeration and detection of *Salmonella* spp. This culture-based method was selected because it includes enrichment steps that increase the likelihood of detecting *Salmonella* spp.
Other rapid methods, such as PCR, are sensitive and provide more information on the genetic characteristics of the microbes. However, due to cost, time constraints, and limited access to the technology in some study areas (Burundi), culture-based methods were used.

In addition to microbiological analyses of meat, hand rinse water was collected to examine the total bacterial count (TBC) of the hands (Paper III). The method used was adapted from that applied in healthcare (ASTM International, 2021). This method was considered appropriate as it allowed for serial dilution and enumeration of TBC, where contamination levels were too high.

3.9 Data analyses

3.9.1 Meta-analyses (Paper I)

The effect estimate was calculated as the proportion of samples testing positive for each of the three hazards studied. To account for the binomial distribution of prevalence data and high between-study heterogeneity, we used *metapreg* in STATA® version 19.5 (https://www.stata.com/) to fit a logistic-normal random-effects model and estimate pooled prevalence with Wilson 95% confidence intervals. This model accounts for within-study binomial error and between-study heterogeneity without requiring continuity corrections or transformation. *Meta set* command uses logit-transformed inverse-variance meta-analysis. The former offers more robust modelling for sparse data; the latter enables subgroup comparisons. Estimates were similar across methods. Heterogeneity was further explored using subgroup analyses and metaregression.

3.9.2 Qualitative studies (Paper II and IV)

Qualitative data were analysed using NVIVO®14 software (https://techcenter.qsrinternational.com/) and in accordance with *COREQ* (Consolidated Criteria for Reporting Qualitative Research) guidelines (Tong et al., 2007). This enables comprehensive reporting of the design of tools, data collection, and analysis processes. Grounded theory was chosen for data analysis, as it allows themes to emerge naturally from the data.

Rather than starting with a hypothesis, grounded theory enables systematic, cyclical analysis, allowing patterns and themes to develop organically (Corbin & Strauss, 2008). This approach facilitates the exploration of concepts and provides insights without prior assumptions or hypotheses. In addition, content analysis was applied to derive quantitative statistics, which further provide insight into the data (Erlingsson & Brysiewicz, 2017; Hsieh & Shannon, 2005).

3.9.3 Quantitative analyses (Paper III)

Item response theory and classical test theory

Quantitative KAP data were analysed in R, version 4.4.0 (https://cran.r-project.org/) to compare differences between the treatment and control groups. Two-parameter Item response theory (IRT) was used to measure knowledge, while traditional classical test theory was applied to attitude and practice.

The IRT (Item Response Theory) approach was chosen for the knowledge questions as a psychometric method to model the relationship between an underlying unobservable trait (latent trait, in this case, knowledge, represented as theta (θ)) and the probability of an individual responding to specific items (questionnaire questions). Theta denotes a 50 % probability of getting a particular question correct. The unidimensionality of the items, which refers to the consistency of the items in assessing the intended construct, was evaluated using principal component analysis (Cattell, 1966).

In addition, cohesiveness of the items was evaluated using *Cronbach's alpha* test and was used as a first step to identifying misfit items. A value of 0.7 or higher is considered satisfactory (Muloi et al., 2023; Sharma et al., 2024). Theta scores are therefore calculated based on responses to a standardised scale, providing insights into an item's difficulty (how easy the item is) and discrimination ability (how effectively the item distinguishes between individuals with varying levels of ability, θ) (Yang & Kao, 2014).

On the other hand, classical test theory (CTT) was used for the computation of scores for attitude and practice questions. Additionally, personnel hygiene and butcher shop cleanliness were evaluated using this approach. In this method, the underlying trait is measured as the average score of all the given items. CTT is based on the equation (X=T +e), where X is the observed or measured score, T is the true score (the individual's actual score), and e is the random error of measurement, which is assumed to be independent and has a mean of zero. Scores are given as a summation of scores to scale and represent the person's average score (Hambleton et al., 1991).

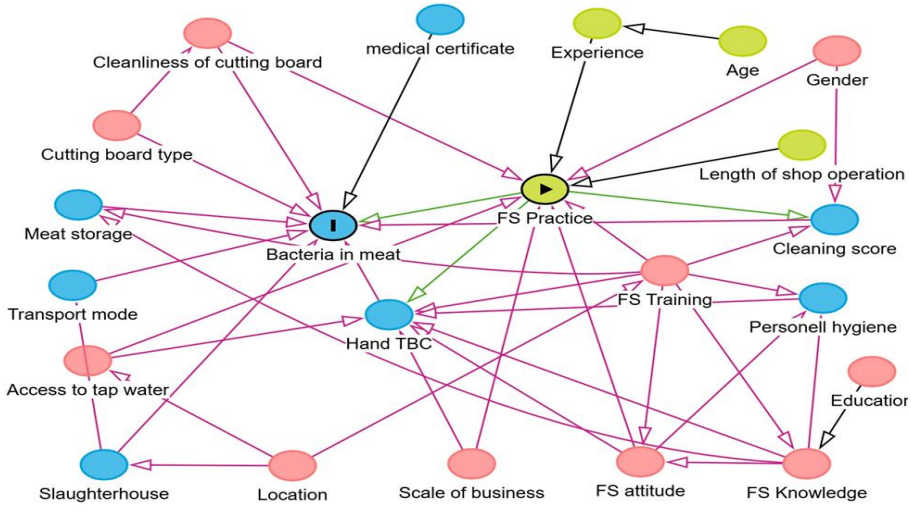
CTT is more test and respondent-dependent; using CTT, the respondent's ability will appear low if the test questions are difficult, while that same respondent will appear to have a high ability if the questions are easier. IRT is more robust than CTT, due to its ability to distinguish individuals with different abilities by separating the characteristics of the individuals and the questionnaire items (Yang & Kao, 2014). However, the application of IRT in our study was limited only to knowledge items because of the low *Cronbach's alpha*, presented by attitude and practice scores, which fell below 0.7.

Regression analyses

Regression models were used to associate contamination levels with predictor variables, including demographic, infrastructural, and KAP variables. Predictor variables were selected using the *Boruta* machine learning algorithm. In this computation, for all features in the original dataset, random copies (shadow features) are created, and classifiers are trained on this extended dataset. The original features are then compared against the shadow features, and only those that are statistically more important than the shadow features are retained as important for modelling (Kursa et al., 2010).

The selected features were then interlinked in a causal diagram or directed acyclic graph (DAG). A DAG displays assumptions about the relationships between variables (often called nodes). The relationships are indicated with a line and an arrow, pointing in the direction of the effect. A DAG is also acyclic, meaning there are no feedback loops. Figure 5 displays the causal diagram used to model the relationship between predictor variables and outcome variable (meat contamination), thereby identifying confounders (Textor et al., 2016).

Model and regression analyses significance was considered at p-value=0.05. Additionally, differences in frequencies between treatment and control groups were evaluated based on percentage points (pp), which is the arithmetic difference of two percentages.



Blue=confounders
Blue with a mark = outcome variable
Green = indirect predictors
Green with an arrowhead = exposure variable
Pink = Predictor variables to adjust for
The arrow points to the direction of association/effect

Figure 5: Causal diagram illustrating potential variables associated with meat contamination in butcher shops in Nairobi, Kenya. Created using DAGitty (https://www.dagitty.net/)

4. Results and discussions

4.1 Prevalence of pathogens in foods (Paper I, III and IV)

Paper I analysed levels of *E. coli*, *Salmonella* and *Campylobacter* spp. in foods, as these pathogens are most associated with diarrhoeal diseases (WHO, 2015). Many studies in our review (34 out of 53) examined *E. coli* in foods, while fewer studies (13 out of 53) focused on *Campylobacter* spp. in foods. Pooled proportion showed that the prevalence level of *E. coli* across all food types was 41% (95% CI: 34 – 52%).

E. coli prevalence was particularly high in ready-to-drink beverages (66%; 95% CI: 31 – 89%), meat (65%; 95% CI: 30 – 87%), and chicken meat (63%; 95% CI: 36 – 82%). Cooked foods and flours had the lowest prevalence at 12% (95% CI: 2– 43%). These levels are comparable to findings from other African countries (Dinede et al., 2023; Paudyal et al., 2017). Additionally, pathogenic *E. coli,* including enterotoxigenic *E. coli*, enteroaggregative *E. coli* and enteropathogenic *E. coli* were found in chicken meat, milk and infant foods (Odwar et al., 2014; Tsai et al., 2022). Shiga-toxin producing *E. coli* prevalence was 2% (95% CI: 1– 10%), with the highest level in chicken meat and other meat types at 4% (Paper I).

Similarly, high levels were observed in meat in prevalence studies in Burundi and Kenya (Papers III and IV), with 100% and 98% contamination at an average count of 5.17 ± 0.92 log cfu/g and 3.46 ± 1.21 cfu/g and in the two countries respectively.

E. coli is used in the food industry as an indicator of hygiene and faecal contamination (Feng et al., 2020). With over 50% of some foods contaminated with *E. coli* as shown in our study, there is significant concern about hygiene and sanitation in food establishments in EAC. The presence of pathogenic *E. coli* in foods is more alarming as it poses a risk to human health and contributes to the high burden of diarrhoeal diseases in children under the age of five, which compromises their growth and development (Kyu et al., 2025).

Paper I reported a pooled prevalence of 12% (95% CI: 12–27%) for *Salmonella* spp., and 9% (95% CI: 7–30%) for *Campylobacter* spp. across all food categories. The prevalence of *Salmonella* in our review (Paper I) was

similar to findings from the survey in Kenya (Paper III), which reported a 12% prevalence in meat. However, the prevalence survey in Burundi revealed a higher presumptive prevalence of 40% (Paper IV). Findings on *Salmonella* from Papers I and III are similar to results from Burkina Faso (Dinede et al., 2023), while findings in Paper IV are comparable to levels observed in South-East Asia (Dang-Xuan et al., 2019; Rortana et al., 2021). When the prevalence of *Salmonella* spp. is high (>40%), the risk of salmonellosis is estimated to be between 4% and 14.5% per person per year (Rortana et al., 2022). Our findings then indicate a potentially higher risk of salmonellosis from meat in Burundi compared to Kenya. This makes *Salmonella* spp. highly significant for public health, and elevated levels of the pathogen in foods are a cause for concern, necessitating increased efforts to reduce the risk of human infection.

The pooled *Campylobacter* prevalence in our review (Paper I) was lower compared to findings from other African countries (Dinede et al., 2023; Gazu et al., 2021). This result can be linked to the samples analysed under our review, mostly dressed beef carcasses, which have a lower risk of *Campylobacter* contamination compared to other meat types, such as poultry (Havelaar et al., 2022; Inglis et al., 2020).

Salmonella spp., particularly the non-typhoidal type, is a common cause of FBD illnesses and outbreaks in the European Union (EU) and the United States (US), whereas *Campylobacter* spp. is named the leading cause of gastrointestinal infection in the EU (EFSA and ECDC, 2021; Hoffmann et al., 2025). In our review (Paper I), fewer studies analysed *Campylobacter* spp., likely due to the specific conditions required for incubation and culturing, or a lack of necessary technical capacity, which may result in underestimating its burden in EAC. However, data from other countries show a high health and economic burden associated with *Campylobacter* and *Salmonella* spp. In Burkina Faso, the disease burden associated with poultry meat consumption due to *Campylobacter* and non-typhoidal *Salmonella* (NTS) was estimated at 42,600 DALYs in 2017. Economic costs estimated as productivity losses and willingness to pay for reduced risk of death and suffering, related to *Campylobacter* and NTS in Burkina Faso was USD 43 million and USD 280 million, respectively. In the same year, the disease burden from these two hazards linked to beef consumption in Ethiopia was

approximately 15,000 DALYs, while the burden associated with dairy products was slightly higher than that from beef consumption, at 17,000 DALYs (Havelaar et al., 2022). Altogether, the economic costs in Ethiopia were USD 288 million and USD 181 million for *Campylobacter* and NTS, respectively. The estimated economic burden of human salmonellosis, including loss of wages, reduced productivity, and medical costs, exceeds €3 billion in the EU and USD 17 billion in the US, while the economic costs of campylobacteriosis are estimated at €2.4 billion in the EU and USD 11 billion in the US (EFSA and ECDC, 2021; Hoffmann et al., 2025).

Table 4 provides a summary of the levels of *E. coli*, *Salmonella* and *Campylobacter* spp. in the five countries where data were available (Paper I). The prevalence of *E. coli* was significantly higher in wild meat from the Democratic Republic of Congo (DRC) (86%) than in milk from Rwanda (13%). This difference is likely because wild meat analysed in the DRC may have been exposed to various environmental factors, as well as issues related to poor hygiene and inadequate sanitation infrastructure during harvesting and slaughter, which can compromise safety. In contrast, milk sampled from collection centres in Rwanda had lower contamination levels, possibly because higher quality standards were enforced by farmer organisations (Kumar et al., 2013; Nyokabi et al., 2023). Tanzania and Rwanda had higher prevalences of *Salmonella*, above the regional average. This may be associated with the food types analysed, mainly raw meat, fish and milk, which carry a high risk of *Salmonella* infection (EFSA and ECDC, 2021; Hoffmann et al., 2017). No studies were found for *Campylobacter* in Rwanda and Uganda, indicating a data gap.

4.2 Risk factors for contamination (Papers I and III)

Of 53 studies reviewed, three analysed factors associated with food contamination (Paper I). Storage temperature, cleaning and disinfection, use of appropriate PPE and training were significantly associated with contamination. Additionally, lack of access to water and sanitation facilities, and sale of mixed meat products from different species, increased the odds of pathogenic contamination (Carron et al., 2018; Kariuki, 2018; Niyonzima et al., 2017). These findings were comparable to those revealed by the KAP

and prevalence survey (Paper III). Multivariable analyses showed that reduced likelihood of *Salmonella* contamination in meat was linked to access to running water (log OR -1.990; 95% CI: -4.059 to -0.206; p-value = 0.038), and better cleaning practices (log OR = -0.118; 95% CI: -0.225 to -0.030; p-value = 0.017). On the other hand, higher chances of meat contamination with *E. coli* and coliforms were associated with the location of butcher shops (β = 0.876; CI: 0.198 to 1.555; p-value = 0.012), and high bacterial counts on food handlers' hands (β = 0.222; CI: 0.059 to 0.386, p-value = 0.008).

Our findings are consistent with previous reports. For example, in Kenya, contamination of carcasses in slaughterhouses was linked to the personnel's hand hygiene (Wambui et al., 2018). Similarly, in Mozambique, caregivers' practices of washing hands with soap and refrigerating food were associated with a lower likelihood of infant food contamination (Bick et al., 2020). These observations support the assertion that proper handwashing practice and cold chain maintenance remain paramount in food safety.

Mixing and sale of meat from different species, as well as high temperature storage, were associated with an increased risk of *Salmonella* contamination in Vietnam (Ngo et al., 2021), which is consistent with findings from our review (Paper I). Although these practices were common among meat sellers in Kenya (Figure 6), no association with meat contamination was established in Paper III. However, univariable analyses showed that meat shops obtaining meat from a combination of slaughterhouses and storing end-of-day stock in the refrigerator only from the second day (the first day meat is left on hooks at room temperature, see Figure 4), had higher odds of contamination. While there was no direct observation of how meat was transported in our study, it is common for carcasses from different species to be mixed during transport (Gichure et al., 2014; Kunyanga et al., 2021), which can increase the risk of contamination. Additionally, temperature fluctuations between ambient and chilling conditions provide opportunities for microbial proliferation (Fahrion et al., 2013).

Moreover, improving access to essential infrastructure, especially clean water (Paper III), and training of personnel (Paper II) were associated with safer food. These findings are consistent with a study in Nigeria, which

established that access to infrastructure and training promotes awareness and adoption of hygienic and safe handling practices in informal food establishments, thereby contributing to safer food (Grace et al., 2012).

Consistent with our results (Paper III), findings from Uganda revealed that NTS infection was associated with particular locations (Kivali et al., 2024). This may require further investigation to understand environmental and other factors that may contribute to the endemicity of *Salmonella* in specific regions.

4.3 Knowledge, attitudes and practice of meat sellers (Paper III)

4.3.1 Knowledge

Knowledge was evaluated using IRT. Of the 16 items and 5 pictorial statements, ten were selected to form the knowledge questions for analysis, based on a *Cronbach's alpha* of 0.70, which meets the minimum threshold for reliability (Nunnally & Bernstein, 1994). Item difficulty parameters ranged from -0.5 to -2.8, indicating a mix of easy and difficult knowledge questions. Item discrimination parameters ranged from 0.8 to 2.5, implying that most items had a moderate to high ability to differentiate between respondents with low and high food safety knowledge. Additionally, eigenvalue analysis of the item correlation matrix revealed a dominant first eigenvalue (2.8), followed by a marked decline to the second eigenvalue (1.2). The overall pattern and scree plot structure supported essential unidimensionality of the knowledge scale, justifying the use of a unidimensional two-parameter IRT model (Cattell, 1966).

The mean knowledge score (theta) was 0.00001 (± 0.804) across all groups, with -0.04 (± 0.87) in the treatment group and 0.02 (± 0.77) in the control group (Table 7). Our results indicated greater emphasis on meat handlers' experience and age rather than level of education, as the former showed a significant association with knowledge scores. This suggests that experience over time, along with informal learning passed between sellers, as mentioned during the interviews, can be important in gaining food safety knowledge. In Bangladesh and Brazil, more than 10 years of experience as a

food handler was linked to better food safety knowledge (Al Banna et al., 2021; da Vitória et al., 2021), whereas in Ethiopia, older meat handlers demonstrated good knowledge of food safety (Abunna et al., 2023). Other studies have shown an association with the level of education (Akabanda et al., 2017; Al Banna et al., 2021), which was not significant in our study (p-value = 0.9).

The highest score was for item 1, "offal (internal organs) must be separated from other meat during handling, transport and storage", with 161 out of 170 (95%) responding correctly. This may indicate an understanding of the potential risks associated with offal and cross-contamination with meat carcasses. The lowest score was for item 6, "cockroaches can spread foodborne diseases", with 109 out of 170 (64%) responding correctly, which suggests a lower understanding of the role of vectors in the transmission of foodborne pathogens (Heilmann et al., 2016; Moges et al., 2016).

4.3.2 Attitudes

All eleven items in the questionnaire were used to assess food safety attitudes among the meat sellers. The average attitude score, expressed as a percentage, was 76.15 ± 14.8 (mean ± standard deviation). The intervention group had an average score of 77.6 ± 14.1%, while the control group had an average score of 75.34 ± 15.2% (Table 7). There was no statistically significant difference between the intervention and control groups (p-value = 0.32). There were higher odds of a better attitude score among meat handlers with higher knowledge scores and among sellers who handled more kilograms of meat per week. Butcher shops that had been in operation for longer periods were associated with lower attitude scores. Additionally, food safety attitude was associated with location.

This aligns with the KAP model, which supports a correlation between knowledge and attitude (Valente et al., 1998). Furthermore, higher sales volumes of meat may incentivise better food safety attitudes and practices, driven by increased consumer demand and profit, thus presenting food safety from a business perspective (Grace, 2023; Grace et al., 2018). The relationship between food safety attitudes and different locations is not well understood. However, it was observed in this study that locations with significantly different attitudes also showed notable differences in *E. coli*

prevalence. This suggests that attitudes may be connected to practices, which in turn explain contamination levels.

4.3.3 Practices

Ten items were used to evaluate food safety practices. The average practice score was 87.6 ± 5.99%, with 88.7 ± 5.57% in the treatment group and 87.03 ± 6.15% in the control group. The difference between the two groups was marginally significant (p-value = 0.07). The treatment group performed better in handwashing (pp = 16), keeping meat chilled (pp = 11), avoiding the sale of meat from mixed types of species (pp = 9) (Figure 6), and having approved documents for handling meat (pp = 8).

Univariable analyses showed better practices were associated with high attitude scores (β = 3.84; p-value < 0.001), but not with knowledge (β = -0.05; p-value = 0.77), implying that attitudes influenced practices, but knowledge did not. Furthermore, in multivariable analyses, higher practice scores were significantly associated with reduced *E. coli* (β = -0.045; 95% CI: -0.080 to -0.010; p-value = 0.013) and coliform prevalence (β = -0.039; 95% CI: -0.066 to -0.012; p-value = 0.005). This implies a relationship between food safety attitudes, practices and meat contamination.

Practices differed significantly between those who were employed and business owners (β = 0.67; p-value = 0.02), suggesting that employed individuals performed better in practices, probably because this was linked to employment and income; and by weekly volume of meat sold (β = 0.002 ; p-value = 0.01), with more sales showing higher odds for better practices. This had also been observed with attitude scores, confirming that consumer demand can be an incentive for better food safety practices.

History of training, level of education, and experience in the food business have been associated with better practices in other studies (Abunna et al., 2023; Alimi et al., 2022), which was not the case in our study.

Table 4: Average level of *E. coli, Salmonella* and *Campylobacter* spp. in pooled food samples in EAC, January 2000 to June 2022

	E. coli				***Campylobacter* spp.**				***Salmonella* spp.**			
Country	**Sample size**	**Esti-mate**	**CI**	**I^2**	**Sample size**	**Esti-mate**	**CI**	**I^2**	**Sample size**	**Esti-mate**	**CI**	**I^2**
DRC	172	0.86	0.80-0.91	-	364	0.10	0.07-0.14	-	182	0.06	0.04-0.11	-
Kenya	4321	0.35	0.26-0.52	88.89%	1191	0.15	0.02-0.58	3.89%	1398	0.08	0.06-0.23	21.78%
Rwanda	417	0.13	0.10-0.16	-	-	-	-	-	605	0.16	0.11-0.24	21.47%
Tanzania	2068	0.46	0.31-0.62	84.51%	2329	0.05	0.03-0.22	50.53%	2455	0.14	0.11-0.49	4.31%
Uganda	230	0.47	0.19-0.81	90.35%	-	-	-	-	1037	0.12	0.06 -0.39	59.69%

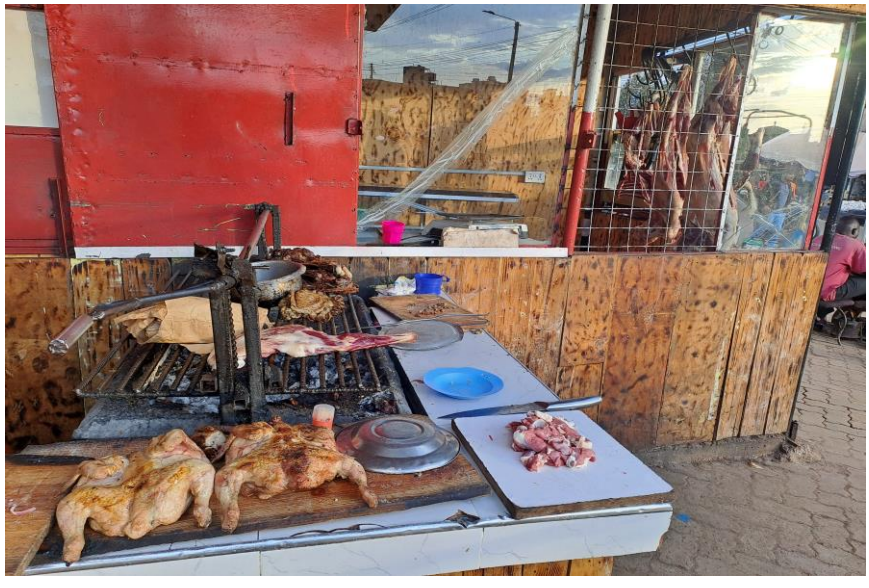


Figure 6: A mix of raw and roasted meat products on sale in a butcher outlet in Nairobi, Kenya. Photo credit: author

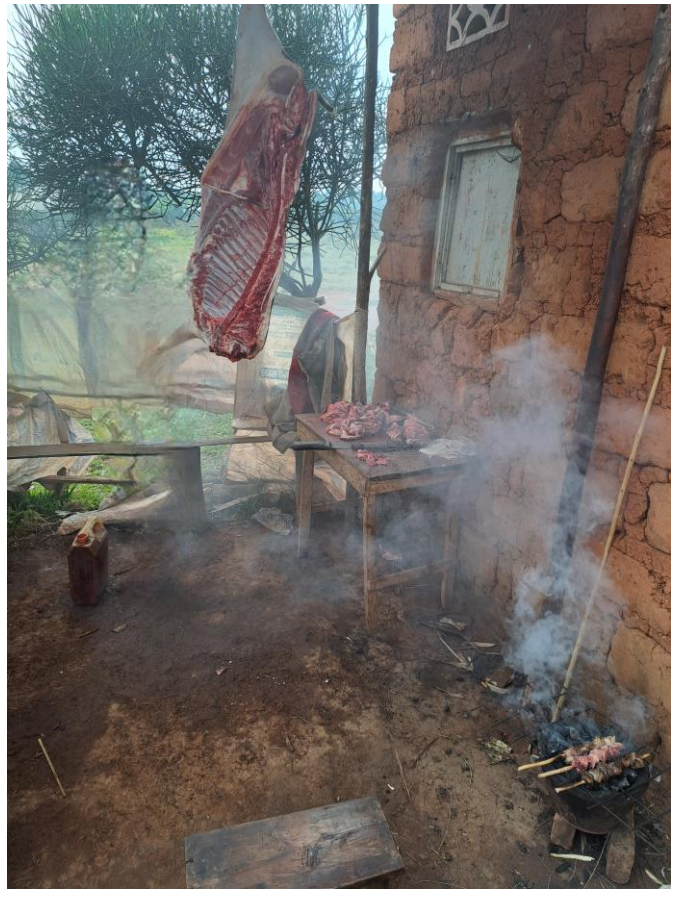


Figure 7: Mix of raw and roasted meat on sale at an outdoor kiosk in Bururi, Burundi. Photo credit: author

4.3.4 Observations

Observations were recorded regarding personal hygiene, adherence to wearing of PPE, environmental hygiene and sanitation. Tables 5 and 6 show the observed personal hygiene practices and environmental hygiene, respectively. There were slight differences in handwashing practices, with more meat sellers in the treatment group washing their hands before and after handling meat (pp = 10 and 15, respectively). However, handwashing before handling meat was associated with a higher prevalence of *E. coli* ($\beta = 0.534$; p-value = 0.007) and coliforms ($\beta = 0.419$; p-value = 0.006).

This is highly likely, as most meat sellers (66%) were observed washing their hands and then wiping them with a multipurpose cloth, which was also used to wipe blood and meat debris from the cutting boards, see Figure 4. Consequently, visibly clean cutting boards had higher coliform contamination than those considered less clean due to blood and meat debris ($\beta = 0.893$; p-value = 0.02). Using separate cloths for wiping meat, equipment, and hands has been found to reduce the likelihood of *Salmonella* contamination in pork (Dang-Xuan et al., 2019; Ngo et al., 2021). Therefore, the practice of using a multipurpose cloth in meat handling could be a potential vehicle for the transmission of pathogens.

Wearing PPE, particularly work aprons (log OR −1.159; p-value = 0.07) and hair-covers (log OR= 0.98; p-value=0.09), were associated with lower odds of *Salmonella* contamination, though this association was non-significant. While the evidence presented in our analyses is weak, other reports suggest that PPE is important for preventing cross-contamination of food by personnel (Kariuki, 2018).

Table 5 : Observations on meat handlers' personal hygiene and use of personal protective equipment in Nairobi, Kenya (n=170)

		Control (n=111)		Treatment (n=59)		Total (n=170)	
Observations on personal hygiene	**Desired answer**	**Number**	**%**	**Number**	**%**	**Number**	**%**
Is the seller wearing an apron?	Yes	36	32%	21	36%	57	34%
Is the seller wearing a face mask?	Yes	1	1%	2	3%	3	2%
Is the seller wearing a hair cover?	Yes	39	35%	25	42%	64	38%
Is the seller wearing jewellery or watch?	No	85	77%	42	71%	127	75%
Is the seller wearing visibly clean clothes?	Yes	108	97%	56	95%	164	96%
Does the seller look sick?	No	110	99%	56	95%	166	98%
Has the seller smoked?	No	111	100%	59	100%	170	100%
Does the seller have clean hands and nails?	Yes	103	93%	55	93%	158	93%

Table 6: Observations on environmental hygiene and sanitation factors around butcher shops in Nairobi, Kenya (n=170)

Observations on environmental hygiene and sanitation		**Control (n=111)**		**Treatment (n=59)**		**Total (n=170)**	
	Desired answer	Number	%	Number	%	Number	%
Is the hand-washing station visible?	Yes	44	40%	24	41%	68	40%
Sellers owns a fridge at the shop	Yes	84	76%	44	75%	128	75%
Seller handles money while selling meat	No	96	86%	45	76%	141	83%
Is there presence of houseflies	No	93	84%	50	85%	143	84%
Is there presence of cockroaches	No	8	7%	8	14%	16	9%
Is there presence of rodents	No	3	3%	0	0%	3	2%
Is there presence of cats	No	13	12%	10	17%	23	14%
Is there presence of dogs	No	11	10%	9	15%	20	12%
Seller washes hands before handling meat	Yes	42	38%	28	47%	70	41%
Seller washes hands after handling meat	Yes	12	11%	15	25%	27	16%
Is the cutting board kept in a clean condition	Yes	105	95%	58	98%	163	96%

4.3.5 Evaluation of food safety intervention

KAP and point prevalence of *E. coli* and coliforms were analysed between intervention and control groups to assess the effectiveness of the intervention programme. Table 7 presents KAP and contamination levels for the treatment and control groups. There was no significant difference in KAP scores or contamination levels between the treatment and control groups (p-values > 0.05). Only cleanliness scores differed significantly between the two groups (p-value = 0.03).

There were slight differences in knowledge between the groups regarding flies as vectors of FBD (pp = 7), and the use of antibiotics in animal health (pp = 10), with the control group responding better than the treatment group. On the other hand, there were differences in attitudes and practices towards authority and adherence to set guidelines for licensing, with the treatment group responding better than the control group (Paper III). Observed practices showed that more meat sellers in the treatment group washed their hands before and after handling meat and kept meat chilled (pp > 10), (see Table 6).

Since the intervention was not a controlled trial, there might have been a spillover of information between those who attended the training and those who did not. Additionally, due to high staff turnover, some workers who had attended the training were no longer employed at the business, one year later, during our interviews and may not have passed on the knowledge. These factors may have impacted the effectiveness of the intervention.

A few interventions have failed to demonstrate changes in knowledge and behaviour (Grace et al., 2019; Singh et al., 2016), which could help to draw lessons for better impact in future. Successful intervention programs have included iterative sessions, utilised participatory and co-creation approaches in the preparation and delivery of messages, and incorporated monitoring to ensure effective comprehension of the information and adoption of the recommended practices (Grace et al., 2012; Lindahl et al., 2018; Takeuchi et al., 2017). In our case, these elements were absent. Furthermore, the design of the intervention may have contributed to its limitations. In the past, designs such as randomised controlled trials or experimental pre-post training with the same group of food handlers have proved successful (Beyene et al., 2025; Grace et al., 2018; Madjdian et al., 2024).

Table 7: Comparison of knowledge, attitude, and practice scores, as well as point prevalence of hazards, between meat sellers in the treatment and control groups in Nairobi, Kenya

Category	**Total (n=170)**	**Treatment (n=59)**	**Control (n=111)**	**P-value**
Knowledge score with IRT (θ)	0.00001 ± 0.80	-0.04 ± 0.87	0.02 ± 0.77	0.67
Attitude score with CTT (%)	76.15 ± 14.8	77.6 ± 14.1	75.34 ± 15.2	0.32
Practice score with CTT (%)	87.6 ± 5.99	88.7 ± 5.57	87.03 ± 6.15	0.07
Coliform counts (Log cfu/g)	5.12 ± 0.99	5.0779 ± 1.0	5.1487 ± 0.99	0.66
E. coli counts (Log cfu/g)	3.46 ± 1.21	3.34 ± 1.26	3.53 ± 1.19	0.36
Hand TBC (Log cfu/ml)	5.59 ± 0.94	5.517 ± 0.956	5.636 ± 0.934	0.44
Salmonella spp.				0.78
Negative	150/170	51/59	99/111	
Positive	20/140	8/59	12/111	
Personnel hygiene score (%)	66.84 ± 10.99	66.95 ± 12.45	66.78 ± 10.18	0.93
Cleanliness score (%)	76.51 ± 8.5	78.49 ± 8.8	75.46 ± 8.2	0.03*

4.4 Food safety and foodborne illnesses from the perspective of stakeholders (Papers II and IV)

Alongside cereal-based foods, fruits and vegetables, ASF were commonly consumed in both countries. However, their consumption by low-income earners was limited by high prices, so other protein alternatives were used. In Kenya, low-income consumers relied on non-choice parts such as offal, which were sold at lower prices. In Burundi, some households relied on sardines, which were less expensive than large fish or meat options. High prices can hamper access to nutrient-dense animal-protein-based diets (Wong et al., 2018). Other available and cheaper options may be of lower quality and safety, exposing communities to risks (DiSantis et al., 2013).

In both countries, consumers and traders confused safety with quality. Freshness of food products was frequently mentioned instead of food safety. Physical attributes and appearance were considered more important. Consequently, physical quality and heuristic cues were used to assess food safety. It has commonly been found that consumers often rely heavily on quality aspects of food rather than safety when making decisions about food purchases (Brown et al., 2022; Nordhagen et al., 2024). Lack of proper awareness can motivate this, as both the quality and safety of food are essential and synergistic for the well-being of an individual. For example, the growth of bacteria in foods reduces their nutritional quality; while consumption of nutritionally poor diets compromises immunity and increases susceptibility to illnesses, including foodborne infections (Nordhagen et al., 2022).

In Kenya, most participants could accurately identify food hazards, including bacteria and aflatoxins. Chemical hazards, mainly pesticide and antimicrobial residues and aflatoxins, were considered the most dangerous to human health. This has been shown in previous studies (Bukachi et al., 2021), and may be attributed to media coverage of chemical residues in food (Daily Nation, 2017, 2019) and aflatoxin outbreaks reported in previous years (Lewis et al., 2005). In Burundi, drug and pesticide residues were widely mentioned, but fewer FGDs mentioned bacteria. Words such as ‘mould’ or ‘mouldy’ were used instead of aflatoxins.

Experts have argued that biological hazards are of greater concern in food safety than chemical hazards (Grace, 2017; Grace et al., 2018; Vossen-Wijmenga et al., 2022). This is also shown in FBD burden metrics, where over 70% of FBD burden in Africa was attributed to diarrhoeal agents, mostly non-typhoidal *Salmonella,* pathogenic *E. coli*, *Vibrio cholerae* and *Taenia solium* (WHO, 2015). A lack of awareness of food safety hazards and risks could result in an under- or over-estimation of their effects and magnitude (Grace, 2017; Slovic & Peters, 2006). Lack of awareness of hazards may also indicate that proper mitigation strategies within the households are limited, thereby exposing the population to food safety risks.

Consumers may be exposed to food safety risks due to practices reported during the interviews, including adulteration, poor hygiene and handling, excessive use of pesticides and antibiotic residues resulting from failure to observe withdrawal periods. In Kenya, urban agriculture using wastewater was identified as an additional concern. This may be valid, as heavy metal residues and pathogenic bacteria have been found in vegetables (Karanja et al., 2011; Sayo et al., 2020; Tomno et al., 2020), with a high risk index for human health (Negassa et al., 2025).

In Burundi, facilities such as slaughterhouses were reported to be few. Therefore, slaughter activities could take place in open fields (Figure 8) or in backyards without oversight by veterinary practitioners, which can also raise issues about animal welfare (Sentamu et al., 2022). In both countries, diseased or dead animals were said to enter the supply chain through unscrupulous channels. Furthermore, poor hygiene and handling practices by traders at the retail nodes were widely mentioned as a concern by consumers Figures 5 and 6 illustrate meat-selling environments in Kenya and Burundi, respectively. In both countries, it was common to sell raw and cooked meat in the same space, increasing the chances of cross-contamination. The inadequacy or absence of essential infrastructure, including clean water in markets and at critical points such as slaughterhouses, poor surveillance and control systems and a lack of proper facilities were also reported in both countries.

Clean water and sanitation, proper infrastructure and proper surveillance systems remain paramount in food safety to avoid the introduction of risks. A study in rural Kenya found that many slaughterhouses operated under poor infrastructural conditions, often lacking clean water or oversight authorities (Cook et al., 2017). This has been seen to lead to contamination of carcasses and the accumulation of bacteria along the supply chain (Kivali et al., 2024; Wambui et al., 2018); as well as occupational risks for those in close contact with animals (Cook, 2015; Kivali et al., 2024). Poor vending environments for ASF and fresh produce, some of which are eaten raw, have also been linked to contamination (Karanja et al., 2011; Koech et al., 2024; Kunyanga et al., 2019; Schoder et al., 2013).

Foodborne illnesses were reported to be common, evidenced by gastrointestinal symptoms, particularly among children and women. Most interviews identified ASF as the most risky in terms of disease causation. Figure 9 presents a ranking by proportional piling in Burundi, where milk was considered the most risky. Eating outside the home and illicit brews were also mentioned in both countries as possible causes of FBDs, especially for men.

Some of the observations and concerns by stakeholders are validated by empirical studies. For example, the 2015 WHO FBD report found that diarrhoeal agents were the leading causes of FBD and that children were disproportionately the most affected group (WHO, 2015). Animal source foods have also been implicated in many foodborne disease events (EFSA and ECDC, 2021; Hoffmann et al., 2017). Restaurant and street foods are often contaminated with pathogens due to poor hygiene and handling, thus eating out of home may expose consumers to a higher risk for FBDs (Birgen et al., 2020; Kivali et al., 2024; Ndoboli et al., 2018; Odhiambo et al., 2017).

In addition to foodborne illnesses, malnutrition-related disorders and soil-transmitted helminthiasis were commonly reported in Burundi. Together, these disorders can severely affect child growth and development and further exacerbate health challenges, making children even more vulnerable to many forms of disease attacks (Kyu et al., 2025; Madewell et al., 2024)

Figure 8: Young men slaughtering a pig in an open field, adjacent to sanitation facilities in Bururi, Burundi. Photo credit: author

Figure 9: Proportional piling method for ranking risky foods during an FGD in Burundi. Photo credit: author

5. Conclusions

This thesis adopts an integrated approach to present comprehensive new evidence on the food safety situation in East African Community countries, covering hazards in food, exposure to risks from stakeholders' perspectives, risk factors for contamination, and the effectiveness of a food safety intervention. Highlights from our study are presented below:

- Our review revealed that many studies focused on *E. coli*, with fewer studies on *Campylobacter* spp. The pooled prevalence of *E. coli, Campylobacter*, and *Salmonella* species was high, at 42%, 9%, and 12%, respectively.
- A review of risk factors revealed that a lack of training among food handlers, poor hygiene and handling practices, and inadequate infrastructure, including access to clean water, were associated with the high levels of contamination in food.
- Evidence on the prevalence of pathogens in foods from Burundi and South Sudan was missing. Additionally, fewer studies were retrieved from Rwanda and the Democratic Republic of Congo, revealing data gaps.
- Stakeholder interviews revealed that consumers and traders in Burundi and Kenya predominantly based their purchasing decisions on the physical characteristics of food. As a result, organoleptic assessments and heuristic cues were commonly used as indicators of food safety. However, reliance on sensory evaluation alone may not accurately reflect the true safety of food products.
- Consumers were likely to be exposed to food safety risks due to poor hygiene and handling practices along the value chains. Additional factors include a lack of proper knowledge during traditional food processing, as well as food fraud issues such as adulteration, non-compliance with chemical withdrawal periods, and the unscrupulous introduction of contaminated food into the supply chain.

- Traders and consumers expressed concerns about chemical risks in foods, particularly from pesticide and antimicrobial residues, while biological hazards were viewed as lower risks. However, more knowledgeable stakeholders viewed biological hazards as more risky. Foods derived from animals were considered the most hazardous in relation to foodborne diseases.
- Foodborne diseases were common in both countries, as indicated by gastrointestinal symptoms. Children and women were considered the most affected groups. In addition, malnutrition disorders and soil-transmitted helminths were widely reported in Burundi.
- The responsibility for improving food safety was perceived to rest with the government, with little effort expected from traders, consumers, and other stakeholders.
- Knowledge, attitude, and practice (KAP) survey among meat sellers in Kenya revealed high KAP scores, with over 75%. Knowledge scores correlated with attitude scores, and attitude scores correlated with practice scores. In turn, practice scores were associated with contamination. This supports the KAP learning model that posits that knowledge shapes attitudes, which in turn influence practices.
- In Kenya, the point prevalence of *E. coli* in meat was found to be 98%, while in Burundi it was 100%. *Salmonella* was detected in 12% of meat samples from Kenya and in 40% of samples from Burundi (provisionally). Both countries reported levels of *E. coli* and *Salmonella* that exceeded the recommended standards set by the East African Community.
- Hand contamination with bacteria, high knowledge scores, and the location of the butcher shop were associated with increased odds of meat contamination. Higher practice and cleanliness scores, as well as access to clean tap water, were associated with reduced contamination of meat with *E. coli*, coliforms, and *Salmonella*.
- Evaluation of the food safety intervention showed no significant difference in KAP scores or meat contamination in the treatment group compared to the control group. However, cleanliness scores were higher in the treatment group than in the control group.

6. Recommendations and policy implications

6.1 Training and capacity building

Our results show that most traders and consumers lacked proper knowledge of food safety, as indicated by their engagement in risky behaviours. Practical and context-specific training for informal actors is recommended regularly, focusing on personal hygiene, handwashing, safe food handling, cleaning and sanitation, and cross-contamination prevention. This could be initiated by the public health departments and supported by local governments, which have closer access to the communities. Training materials should be co-created with the actors and take into account users with varying literacy levels and other contextual factors, to ensure that the information is received and adopted.

Additionally, nudge materials, including posters, pictorial guides and media communication, can be provided at all levels of the value chain as reminders and gentle prompts to support daily practice. For the sustainability of proper practices, peer educators, market champions, and extension officers or community health promoters could be engaged for regular follow-up and monitoring to reinforce training messages. Food safety and hygiene training can also be integrated into basic education and learning, enabling learners to grasp the core principles of food safety and develop a food safety culture among the population from a young age.

6.2 Surveillance

Our study shows that pathogens are prevalent in food at levels exceeding national and regional allowable limits. This underscores the need for routine surveillance to identify risks promptly, prevent foodborne disease events, and institute effective management strategies. Employing sufficient, trained inspectors is recommended. Inspectors should be provided with basic testing kits, digital tools, and transport to enhance surveillance coverage and efficiency. Inspections should prioritise monitoring and supportive actions aimed at risk reduction, rather than focusing solely on penalties. Coordination among public health, veterinary, and local government sectors

can be strengthened through a One Health approach to support routine surveillance and facilitate information sharing.

6.3 Provision of necessary infrastructure

Stakeholders widely reported a lack or inadequacy of essential infrastructure as a barrier to implementing proper hygiene and handling practices in informal markets (Papers III and IV). Investment in infrastructure by both the government and private sector is therefore recommended. Local governments could prioritise investment in basic food safety infrastructure within informal markets, which would promote food safety and public health. Such investments include ensuring reliable access to safe water, sanitation facilities, and adequate drainage systems within markets. Actors could also adopt simple and cost-effective solutions at critical points, such as the use of foot-operated handwashing facilities.

Furthermore, through public-private partnerships, facilities such as sustainable energy production for electricity (for example, solar or wind systems), shared refrigeration equipment, water reservoir stations, aggregation centres for fresh produce, and local laboratories could be provided strategically. Additionally, as part of urban planning and public health policy, local governments should designate specific areas for activities such as open-air vending, slaughter, and waste collection, located away from potential sources of contamination.

6.4 Promote food safety standards and regulations

Our interviews indicated that many activities along the value chain did not comply with the established code of practice for food safety and hygiene. This non-compliance may partly result from limited awareness of these standards among many actors. In addition to technical regulations, simplified guidelines and standard operating procedures tailored to the context of informal markets could be developed to improve awareness. These should be practical and achievable for informal actors while remaining risk-based. A graduated approach could be adopted, allowing informal actors to comply with various guidelines step by step, with an emphasis on continuous improvement rather than punishment.

For effective enforcement of regulations, collaboration rather than antagonism between regulatory agencies and market associations should be emphasised. Additionally, incentives such as certification schemes, public recognition, and other consumer-driven incentives could be implemented to encourage compliance.

7. Future perspectives

This study provides evidence on the prevalence of foodborne hazards and exposure pathways that may result in a risk of foodborne infections to consumers. This forms a background for future studies that could extend this work to characterise and estimate the actual risk to consumers.

Our review revealed a lack of data in some EAC countries, including South Sudan, Burundi, the Democratic Republic of Congo, and Rwanda. More effort is required in these countries to understand the food safety situation, including the occurrence of foodborne diseases, and effective mechanisms to reduce the burden of foodborne diseases.

In Burundi, only a qualitative study and a prevalence survey have been conducted. A KAP survey could provide further information on the underlying cognitive factors among actors related to food safety and food contamination in the country.

While our study focused on KAP, future research could include additional human and environmental factors within a One Health framework. This would provide a more comprehensive understanding of contamination pathways and support the implementation of appropriate measures. Although our study used culture-based methods, incorporating molecular and genomic techniques for pathogen characterisation in future research could yield deeper insights into foodborne disease surveillance.

Many stakeholders interviewed expressed concern about chemical hazards. It would be beneficial to understand the occurrence of these hazards in foods and the actual risk they pose to consumers, in order to address these concerns and formulate relevant risk communication messages.

Given the high prevalence of hazards in foods, effective interventions are essential. Our evaluation of a previous food safety intervention in Kenya identified some limitations. Drawing on these lessons, more rigorous interventions could be implemented. For example, future interventions could use co-creation and participatory approaches to promote project ownership among stakeholders. In addition, robust designs should be adopted, incorporating the three elements essential for sustainable and scalable interventions: tools and training, an enabling environment, and incentives.

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Popular summary

Foodborne diseases (FBD) are illnesses that occur after consuming food contaminated with harmful agents, known as hazards. Foodborne hazards are mainly bacteria, parasites, chemical substances, or even physical materials. In 2010, 31 hazards, mostly bacteria and parasites, were reported to have caused an estimated 600 million illnesses and 420,000 deaths globally. These figures are considered conservative, as there are world regions where data were unavailable. One region with limited evidence is Africa. The food safety situation and occurrence of FBD in many African countries are largely unknown, despite the fact that these countries bear the greatest burden of foodborne diseases in terms of health effects and productivity losses.

In many African countries, food is sold in informal markets, defined as traditional, non-registered outlets likely to escape oversight and control by relevant authorities. While these markets are important for providing nutrition and livelihoods for many people, the high burden of FBD could be linked to these markets. However, fewer studies have been conducted to understand food safety in these markets and how practices are related to unsafe food.

Given this context, this thesis aimed to understand the food safety situation in informal markets in East African Community (EAC) countries, focusing on hazard levels in food, risky behaviour by actors, and other risk underlying factors linked to bacterial food contamination. Additionally, we sought to assess the performance of a food safety intervention based on changes in knowledge, behaviour, and contamination levels.

This research was conducted in three phases. The first phase involved a review of literature to determine levels of bacteria in food across seven EAC countries: Burundi, the Democratic Republic of Congo, Kenya, Rwanda, South Sudan, Tanzania, and Uganda. Secondly, we conducted interviews with stakeholders, including traders, consumers, and other key players in the food system in Burundi and Kenya, to understand the food safety and FBD situation in the communities. Thirdly, we conducted a survey among meat sellers in Kenya to analyse food safety knowledge, attitudes, and practices (KAP), and how these were associated with meat contamination. In addition,

during this phase, we analysed meat samples in Burundi for levels of bacterial contamination.

The results revealed that food was highly contaminated with bacteria, often exceeding the limits set by EAC standards. Contamination was linked to poor hygiene practices and a lack of understanding of food safety among food handlers, primarily due to inadequate training. The importance of proper handwashing, cleaning and sanitation in food establishments was emphasised as crucial for ensuring food safety. Additionally, our findings highlighted that basic infrastructure, such as access to clean water, plays a vital role in promoting hygiene and reducing food contamination.

Knowledge was linked to attitude, and attitude to practice. This means that as the knowledge of meat sellers increased, their attitudes improved, leading to better practices. However, there was no direct correlation between knowledge and practice, indicating that food safety knowledge alone could not explain the practices observed. An evaluation of a food safety intervention highlighted some limitations leading to no significant changes in KAP or levels of contamination between the trained and untrained groups.

Stakeholders, particularly traders and consumers, lacked a complete understanding of food safety, often confusing physical attributes and food safety. Animal-derived foods were believed to pose the greatest risk for diseases, which is consistent with evidence from published literature. Foodborne illnesses were frequently reported, particularly affecting children and women. Additionally, chemicals were identified as the most dangerous threats in food, a perception possibly heightened by media coverage. However, studies have shown that the greatest disease burden comes from bacteria and parasites.

This thesis presents comprehensive evidence of the food safety situation in informal markets in EAC. The results are useful in further understanding the risks presented by hazards in foods. In addition, this study provides valuable lessons that could be considered in designing future interventions to reduce high levels of food contamination and mitigate the risk of foodborne diseases in the population. Finally, it highlights the importance of awareness of food safety and the risks of foodborne diseases among the stakeholders.

Populärvetenskaplig sammanfattning

Livsmedelsburna sjukdomar (FBD) är sjukdomar som uppstår med anledning av att man har ätit mat som är förorenad, vanligen med bakterier, parasiter eller kemiska ämnen och ibland till och med fysiska ämnen som kan hamna i livsmedlet. År 2010 rapporterades 31 olika faror i livsmedel, mestadels bakterier och parasiter, ha orsakat uppskattningsvis 600 miljoner sjukdomar och 420 000 dödsfall globalt. Detta anses vara lågt uppskattade siffror, eftersom det finns världsregioner från vilka data saknas. En region med begränsat underlag är Afrika. Livsmedelssäkerhetssituationen och förekomsten av FBD i många afrikanska länder är till stor del okänd, trots att dessa länder bär den största bördan av livsmedelsburna sjukdomar vad gäller hälsoeffekter och produktivitetsförluster.

I många afrikanska länder säljs mat på informella marknader. Dessa marknader är traditionella, icke-registrerade försäljningsställen, som sannolikt ofta undgår granskning och kontroll av relevanta myndigheter. Även om dessa marknader är viktiga för att erbjuda näring och försörjning för många människor, kan den höga bördan av FBD kopplas till dessa marknader. Få studier har dock gjorts för att kartlägga livsmedelssäkerheten på informella marknader och förstå hur praktiskt handhavande är relaterat till livsmedelssäkerhet. Syftet med denna avhandling är därför att förstå livsmedelssäkerhetssituationen på informella marknader i länderna i Östafrikanska gemenskapens (EAC), framför allt avseende faror i livsmedel, riskbeteende hos aktörer och andra riskfaktorer som kan kopplas till att livsmedel förorenas med bakterier. Dessutom försökte vi bedöma effektiviteten av en utbildningsinsats avseende livsmedelssäkerhet som genomförts genom att mäta förändringar i kunskap och beteende hos de som deltagit samt föroreningsnivåer i livsmedel.

Denna forskning genomfördes i tre faser. Den första fasen innebar en litteraturöversikt för att fastställa bakterieförekomst i livsmedel i sju EAC-länder: Burundi, Demokratiska republiken Kongo, Kenya, Rwanda, Sydsudan, Tanzania och Uganda. För det andra genomförde vi intervjuer med intressenter, inklusive handlare, konsumenter och andra nyckelpersoner i livsmedelssystemet i Burundi och Kenya, för att förstå livsmedelssäkerheten och FBD-situationen i samhället. För det tredje genomförde vi en undersökning bland köttförsäljare i Kenya för att analysera kunskap, attityd och praktik om livsmedelssäkerhet (KAP), och hur dessa är

kopplade till föroreningar i kött. Dessutom analyserade vi under denna fas prover i Burundi för att undersöka förekomsten av bakterier i kött.

Resultaten visade att livsmedel frekvent var förorenade med bakterier, ofta över de gränser som fastställts av EAC:s regler. Kontaminering kopplades till dåliga hygienrutiner och bristande förståelse för livsmedelssäkerhet bland de som arbetade med livsmedel, främst på grund av otillräcklig utbildning. Vikten av korrekt handtvätt, rengöring och sanitet på försäljningsställena framkom som avgörande för att säkerställa livsmedelssäkerheten. Dessutom visade våra resultat att grundläggande infrastruktur, såsom tillgång till rent vatten, spelar en mycket betydelsefull roll för att främja hygien och minska matföroreningar. Kunskap var kopplat till attityd, och attityd till praktik. Detta innebär att när kunskapen hos köttförsäljare ökade, förbättrades deras attityder, vilket ledde till bättre handhavande. Det fanns dock ingen direkt koppling mellan kunskap och praktik, vilket indikerar att kunskap om livsmedelssäkerhet enbart inte kunde förklara de observerade sambanden. Utvärderingen av den kunskapshöjande utbildningsinsats avseende livsmedelssäkerhet som gjordes visade att denna haft begränsad effekt och att inga betydande förändringar i KAP eller föroreningsnivåer i livsmedel kunde ses mellan de grupper som fått utbildning och de som inte fått det.

Intressenter, särskilt handlare och konsumenter, hade en ofullständig förståelse för livsmedelssäkerhet och förväxlade ofta fysiska egenskaper med livsmedelssäkerhet. Animaliska livsmedel ansågs utgöra störst risk för sjukdomar, vilket stämmer överens med kunskap från publicerad litteratur. Livsmedelsburna sjukdomar rapporterades ofta, särskilt drabbade var barn och kvinnor. Dessutom identifierades kemikalier som de farligaste hoten i livsmedel, en uppfattning som möjligen förstärkts av mediebevakningen. Studier har dock visat att den största sjukdomsbördan kommer från bakterier och parasiter.

Denna avhandling presenterar omfattande kunskap om livsmedelssäkerhetssituationen på informella marknader inom EAC. Resultaten är användbara för att ytterligare förstå riskerna med faror i livsmedel. Dessutom ger denna studie värdefulla lärdomar som kan beaktas vid utformningen av framtida insatser för att minska riskerna för livsmedelskontaminering och därmed minska risken för matförgiftningar i befolkningen. Slutligen lyfter den fram vikten av medvetenhet om livsmedelssäkerhet och riskerna med livsmedelsburna sjukdomar för intressenterna.

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I

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Review

Prevalence of *Escherichia coli*, *Campylobacter* spp. and *Salmonella* spp. in the East African Community: a systematic literature review and meta-analysis

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ABSTRACT

Pathogenic *Escherichia coli*, *Salmonella* spp. and *Campylobacter* spp. are bacteria associated with foodborne diseases. This systematic review and meta-analysis investigates the prevalence of these pathogens in foods sold across seven East African Community (EAC) countries and identifies key risk factors for contamination. A comprehensive search for peer-reviewed papers and grey literature was conducted in six databases (PubMed, CAB Direct, African Journals Online, Google Scholar, ScienceDirect, and Web of Science), as well as 12 online repositories. The review encompassed studies published in English and French between January 2000 and June 2022, adhering to the 2020 guidelines for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Eligible studies employed probabilistic sampling and reported the proportion of contaminated samples. Out of 4134 initial records, 53 studies met the inclusion criteria. Most were conducted in Kenya (n = 22) and Tanzania (n = 21), with no eligible studies found for Burundi and South Sudan. *E. coli* and *Salmonella* spp. were the most frequently studied pathogens, while *Campylobacter* spp. was less represented. Using a random-effects model in Stata®, pooled prevalence estimates were 41 % for *E. coli* (95 % CI: 34–52 %), 12 % for *Salmonella* spp. (95 % CI: 12–27 %), and 9 % for *Campylobacter* spp. (95 % CI: 7–32 %). Significant heterogeneity was observed and further explored through meta-regression and subgroup analyses. Contamination levels varied by food type, processing status, sample size, and country. Meat, especially poultry, showed the highest prevalence of bacterial contamination across all pathogens. Alarmingly, beverages were also highly contaminated, with *E. coli* detected in 66.3 % (95 % CI: 31–89 %) and *Salmonella* spp. in 11.8 % (95 % CI: 1–55 %) of samples. Key risk factors included poor hygiene practices, inadequate sanitation, high storage temperatures, and a lack of food safety training. These findings underscore the urgent need for improved food safety measures in the EAC region for improved public health and support trade advancement. The study also highlights critical gaps in surveillance, particularly for *Campylobacter* spp., pathogenic *E. coli*, and data from some EAC countries.

1. Introduction

Foodborne hazards are harmful microbiological, chemical, or physical agents that contaminate food. Consumption of these hazardous agents in food poses health risks ranging from mild illnesses to life-threatening or fatal events (Grace, 2017). Globally, 31 important food hazards, mainly microbiological, were found to cause at least 600 million illnesses and 420,000 deaths in 2010 (Havelaar et al., 2015). Among chemical hazards, four foodborne metals; lead, methylmercury, arsenic, and cadmium, were estimated to cause over one million illnesses and more than 56,000 deaths globally in a year (Gibb et al., 2019).The greatest disease burden is attributed to diarrheal disease agents (Havelaar et al., 2015). Among these, *Campylobacter* spp., non-typhoidal *Salmonella* spp. and pathogenic *E. coli* (enteropathogenic and enterotoxigenic *E. coli)*, are recognised as leading causes of diarrheal diseases (WHO, 2015). Together with *Taenia solium* and *Vibrio cholerae*, these hazards are considered major contributors to the FBD burden in Africa (Dewaal et al., 2010; Havelaar et al., 2015).

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According to the World Health Organisation, (WHO, 2015), the burden of foodborne disease (FBD) varies significantly across global subregions. The African regions bear the highest per capita burden of foodborne diseases (FBD), accounting for 75 % of FBD-related deaths and 53 % of illnesses (Jaffee et al., 2019). However, national estimates of FBD in specific African countries are largely based on expert opinion, due to underreporting of FBD and a lack of empirical evidence (Lake et al., 2015; Sapp et al., 2022). This lack of robust surveillance data poses a major challenge for policy development and the implementation of effective food safety interventions.

Several factors make FBD-related surveillance difficult in low- and middle-income countries. One is the dominance of informal markets, which supply over 80 % of fresh food (Blackmore et al., 2020; Ferris et al., 2014). These markets, common across Africa, are characterised as non-modern, unregistered sale points for fresh and perishable food products, mainly animal-source foods (ASF), fruits, and vegetables (Global Alliance for Improved Nutrition, 2020). While these foods are rich in nutrients, they carry a higher risk of FBD (Grace, 2017).

Although there are challenges related to hygiene, sanitation, and infrastructure in informal markets, they also play a crucial role in supporting the livelihoods of many people by providing ready access to markets for smallholder farmers, particularly women and youth, and offering affordable and nutritious food options to low-income consumers (Ferris et al., 2014; Global Alliance for Improved Nutrition, 2020; Grace et al., 2018).

The East African Community (EAC) is expanding and currently comprises eight member countries, with growing commercial activities among partner states, particularly in food trade (East African Community, 2002). Additionally, efforts to enhance trade have intensified under the African Continental Free Trade Area (AfCFTA) and the recently established Africa Food Safety Agency (AFSA) (African Union, 2025). As trade and the movement of goods and people increase within regional blocs and across the African continent, there is a need for a better understanding of food safety and the implementation of measures that protect public health while facilitating trade.

Despite these developments, few studies have investigated the prevalence of pathogens in food within the EAC, which is essential for risk assessment and management, as well as trade facilitation. Previous reviews have examined *Campylobacter* spp., *Salmonella* spp., and *E. coli* in foods, but none have collectively covered the EAC. Thomas et al. (2020) studied *Salmonella* and *Campylobacter* spp. across the African continent, including four studies from Tanzania, three from Kenya, and one each from Uganda and Rwanda, focusing on both animals and animal-source foods. Another study examined *Campylobacter* spp. in food products in Kenya (Mwangi et al., 2025). A few reviews have been conducted in Ethiopia and Burkina Faso (Belina et al., 2021; Gazu et al., 2021), and a rapid review focusing on the occurrence of hazards, but not including hazard levels, was conducted in the EAC (Mutua et al., 2021).

This current review provides comprehensive evidence on the levels of *Campylobacter* spp., *Salmonella* spp., and *E. coli*, and risk factors associated with their prevalence in foods sold in domestic markets in the EAC countries. Our study contributes to knowledge aimed at improving food safety in informal markets within the EAC region. The findings inform current gaps with regard to the pathogens studied and define future research and intervention strategies for improving food safety.

2. Materials and methods

2.1. Scope of EAC

The EAC (as of 2025) comprises eight partner states: Burundi, the Democratic Republic of Congo (DRC), Kenya, Rwanda, South Sudan, Somalia, Tanzania, and Uganda. Except for the Republic of Somalia, which had not been admitted into the EAC at the time the study was commenced, all other countries were considered.

2.2. PRISMA guidelines

A Systematic Literature Review (SLR) was conducted following Cochrane Review principles and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for reporting (Higgins and Thomas, 2024; Page et al., 2021). The systematic procedures, including the search strategy, syntax and number of references from each database, are presented in Annexe 1 in the supplementary material.

2.3. Research questions

The study addressed the following research questions.

- What is the prevalence of *E. coli*, *Campylobacter* spp. and *Salmonella* spp. in foods retailed in domestic markets in EAC?
- What food value chains are affected by these hazards?
- What factors have been associated with contamination?
- Are there any temporal or seasonal trends observed in occurrence of the hazards?

2.4. Search strategy and study selection

A comprehensive search for peer-reviewed papers, reports and grey literature was made in six databases namely; PubMed, CAB-Direct, African Journals Online, Google scholar, Science Direct and Web of Science. Online searches in 12 East African University repositories were also done.Keywords used were: food, food safety, foodborne, disease, disease burden, illness, infection, outbreak, hazard, risk, health, toxin, pathogen bacteria, *E. coli*, Campylobacter spp. and Salmonella spp., Kenya, Uganda, Tanzania, Burundi, Rwanda, South Sudan, East Africa. These were combined using Boolean operators to form a basic search syntax as given below (refer to Annex 1 for additional information).

> Food AND (Salmonell* OR *Campylobacter** OR "*E. coli*" OR "*Escherichia coli*") AND (Burundi OR DRC OR "Democratic Republic of Congo" OR "East Africa*" OR Kenya OR Tanzania OR Rwanda OR "South Sudan" OR Uganda) AND (safety OR "food safety" OR foodborne OR "food-borne" OR "food borne" OR risk OR disease OR illness OR infection OR outbreak OR toxi* OR health OR symptom* OR outbreak OR microb* OR metabolite OR intoxic* OR "food hygiene" OR hazard OR pathogen OR bacteria OR prevalence OR proportion OR frequency OR fraction OR distribution OR percentage OR magnitude).

Articles were downloaded into Mendeley (https://www.mendeley.com/) and screened for any duplicates. The resultant list was loaded into Rayyan® QCR tool (https://new.rayyan.ai/) for two-level screening by two independent reviewers. A third reviewer resolved conflicts.

2.5. Inclusion and exclusion criteria

The inclusion criteria were; studies published between January 2000 and June 2022, studies that used a probabilistic sampling approach and reported the prevalence of *Campylobacter* spp., *Salmonella* spp. or *E. coli* in foods. The search was done in English and French. Only sampling at the retail node was considered; however, for studies on milk, we considered the farm gate since this is an important retail outlet (Kiambi et al., 2018; Njehu and Omore, 2014).

Studies outside the EAC region, published outside the established time frame and not covering one or more of the pathogens in focus were excluded. Fig. 1 summarises the systematic process of identification and review screening of eligible studies. The initial search yielded 4134 studies after the removal of duplicate records. During the screening of article titles and abstracts, 3876 studies were excluded for several reasons: some were conducted outside the geographical scope, some did not fall within the publication year range, and others did not focus on the

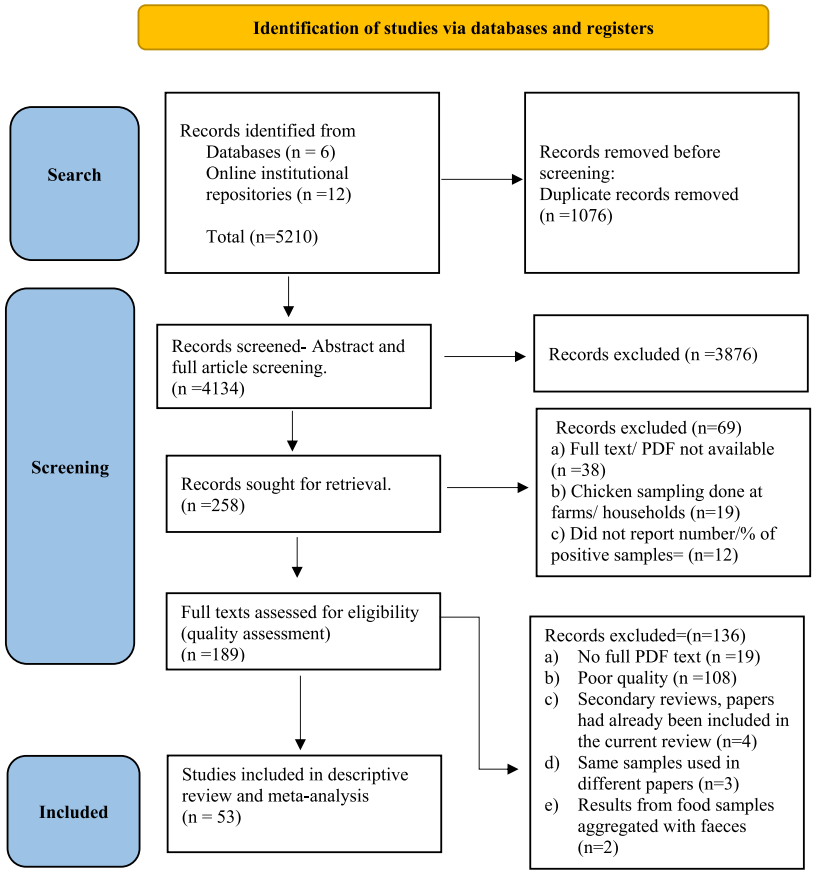

Fig. 1. PRISMA 2020 (Page et al., 2021) flow diagram for systematic review and meta-analysis of foodborne pathogens in EAC countries, January 2000 and June 2022.

three targeted pathogens. Additionally, 69 studies were excluded due to the unavailability of full-text articles or because the sampling was conducted outside the market (see Fig. 1).

2.6. Quality analysis

The resulting 189 studies were assessed for quality using five criteria: absence of bias in the selection of subjects, how appropriate the data analysis method was to the data, use of scientifically sound methods, accurate method description, and accuracy and completeness of reported results. Quality of the papers was rated as "good", "moderate" or "poor". Articles considered adequate for two or fewer of the five quality criteria were classified as "poor", those considered adequate for three or four responses were classified as "moderate", and those considered adequate for all five quality criteria were assigned as "good"(Kwoba et al., 2023). As a result, an additional 136 papers were excluded during this process, resulting in 53 studies (of "good" and "moderate" quality) that were included for data extraction (see Fig. 1).

The data extracted included: year of authorship, year when data was collected, sampling site (country and region), sampling size, sample population, sampling technique used, pathogen studied, microbiological assay method used, proportion of positive samples analysed, and measures of Disability Adjusted Life Years (DALYs), if given.

2.7. Meta-analysis

Descriptive data and frequencies were summarized using graphs and tables. Meta-analysis was carried out in STATA® statistical analysis software, version 19.5 (https://www.stata.com/) by running *metapreg* and *meta set* commands. The estimate was calculated as the proportion of samples testing positive for each of the three hazards studied. To account for the binomial distribution of prevalence data and high between-study heterogeneity, we used *metapreg* to fit a logistic-normal random-effects model and estimate pooled prevalence with Wilson 95 % confidence intervals. This model accounts for within-study binomial error and between-study heterogeneity without requiring continuity corrections or transformation. *Meta set* command uses logit-transformed inverse-variance meta-analysis. The former offers more robust modeling for sparse data; the latter enables subgroup comparisons. Estimates were similar across methods.

Random effects model (restricted maximum likelihood (REML)) was used to estimate heterogeneity (Tau squared or τ^2), assuming overall

variation that is due to study observation and random variation ($T_i = \theta + \mu_i + \varepsilon_i$; where T_i is the effect measure from study i, μ_i is the random effect for study i and ε_i is the error term for study i). Higgin's I^2 statistic was used to express variation not attributed to chance or sampling errors. Cochran's Q statistic was used to express the statistical significance of heterogeneity and differences between the subgroups. Meta-regression was done by applying *mixed* command for mixed-effects regression model. Individual studies were considered as random effects variables, while predictors such as processing state, country of origin, year of publication and sample size were modelled as fixed effect variables. The model and predictors were considered significant at p-value <0.05.

Pooled data were used for each hazard. Where the number of total samples and positive samples were given, this was transformed into percentages and vice versa. To enable subgroup analysis, foods were categorised into respective value-chains (Table 1). All red meat types (pork, beef, goat meat, rabbit meat and wild meat were categorised as meat. Poultry was categorised separately because of a higher risk noted in literature. Other subgroups are as given in Table 1. Where there was only one study in a value chain, this was categorised together with other single studies and designated as "other" for subgroup analysis. In overall meta-analyses, the model and predictors were considered significant at p-value <0.05.

Separate forest plots were generated for each pathogen and used to graphically represent the level of contamination of foods. We used the JBI Critical Appraisal Checklist (Moola et al., 2020), to assess bias and identify the studies to include. After meta-analysis, we checked for small-study effects and publication bias using funnel plots, Egger's test and trim-and-fill method.

Table 1
Food products sampled from domestic markets in the EAC countries, between January 2000 and June 2022, categorised by value chain.

Food category	Food products studied	[a]Number of studies (n)
Beverages	Fruit juice, mixed fruit juice, mango juice, passion juice, tamarind juice, juice, fermented and unfermented cereal beverage, infant porridge, drinking water.	7
Chicken meat	Chicken carcass, raw chicken meat and its products, cooked chicken meat products, roast chicken.	5
Cooked ready-to-eat foods	Mixed dishes, including cereal and cereal products, vegetables, legumes, meat and meat products, starchy roots	2
Grain and flours	Sorghum flour, millet flour, cassava flour, cooked grains and uncooked grains	3
Fish	Freshwater fish, marine fish, fresh and dried silver cyprinid/sardines, Nile perch,	5
Meat	Cattle carcass, cattle meat, roast beef, beef stew, goat carcass, goat meat, rabbit meat, pork carcass, pork meat cuts, offal, wild meat (from *Syncerus caffer* (African buffalo), *Phacochoerus aethiopicus* (desert warthog), *Sylicapra grimmia* (duiker))	14
Milk	Raw milk, pasteurised milk, cow milk, camel milk, goat milk, packaged long-life milk, packaged fresh milk, and unpackaged milk, unpasteurised yoghurt, milk-containing infant foods, milk products.	22
Raw produce	Fresh vegetable salads (mainly sliced tomatoes, onions and cabbage), *Kachumbar*i (mainly onions, tomatoes, green capsicum, chillies, coriander, cabbage, carrots and lettuce (to a lesser extent)), kale, chinese cabbage, tomatoes, raw produce, amaranth, fruit salad.	7

[a] Some studies considered multiple sample types; thus, the number of records here is greater than the overall number of studies included in the review.

3. Results

3.1. Description of studies

Fig. 2 shows EAC countries included in this review. Out of the 53 included studies, the majority were carried out in Kenya (n = 22) and Tanzania (n = 21). Other articles retrieved described studies in Uganda (n = 7) and Rwanda (n = 2), and only one study was conducted in the Democratic Republic of Congo (DRC). No studies retrieved on Burundi or South Sudan.

Fig. 3 is the distribution of studies included in this review by year. The number of studies per year increased during the period studied, with a few declines, the biggest being in 2019 and 2021. In the initial search, most studies (49.3 %) were obtained from the Science Direct database (https://www.sciencedirect.com/) with institutional repositories contributing 11 unique papers to the final list, mainly student theses. The search in French yielded no results. Annex 1 in the supplementary material presents the study protocol and results of the search.

Table 1 gives a summary of value chains, the type of samples and the number of studies included in the review. Most food products included raw, minimally processed, and traditionally processed products (boiled or sun-dried), sampled from different informal and semi-formal retail outlets. Milk was the most studied value chain across the countries (n = 22), followed by meat (n = 13).

Raw produce, fish, and beverages were commonly studied across countries. Only one study was conducted on meat from wild animals (in the DRC) (Mpalang et al., 2013). Grains, flours, eggs and cooked ready-to-eat (RTE) foods were also less studied (Byakika et al., 2019; Gacheru et al., 2016; John, 2016; Tsai et al., 2022). There were no studies on offal.

The supplementary material (annex 2) gives a comprehensive description of the studies included in the review, value chain involved, the point of sampling as well as the food hazard investigated.

3.2. Risk factors associated with pathogen contamination in food

Three studies reported risk factors for contamination using logistic regression models (Table 2). High storage temperature of food products, poor sanitation, low personal hygiene and bad handling practices were reported as risk factors. Some studies reported risk factors without regression analysis. Simforian et al. (2015) compared juice contamination across different vending sites and found that products sold by the roadside, bus stations and restaurants had higher contamination than those sold in food shops and markets (p-value <0.05). In addition, juice stored in cooler boxes were less contaminated than that stored at room temperature (p-value <0.05). Byakika et al. (2019) assessed the microbiological quality of cereal products in relation to food safety knowledge, attitude and practice among vendors. However, no correlation could be established.

3.3. Meta-analyses of the proportion of pathogens in foods

Fifty-three studies were included in the meta-analysis. Fewer records were found for *Campylobacter* spp. (n = 12) than *Salmonella* spp. (n = 26) or *E. coli* (n = 44) in all countries (some studies investigated a combination of the pathogens).

In the analysis, observations on chicken meat were separated from other types of meat, considering the known difference in contamination levels, especially for the hazards studied.

3.3.1. Analysis of Campylobacter spp. in foods

The forest plot for *Campylobacter* spp. in foods was based on a pooled sample of 3,884, as shown in Fig. 4. The samples included milk (n = 1993), meat (n = 1344), chicken meat (n = 323), and "other" category, consisting of fish (n = 185) and raw produce (n = 39). The overall pooled prevalence of *Campylobacter* spp. in food was found to be 9 % (95

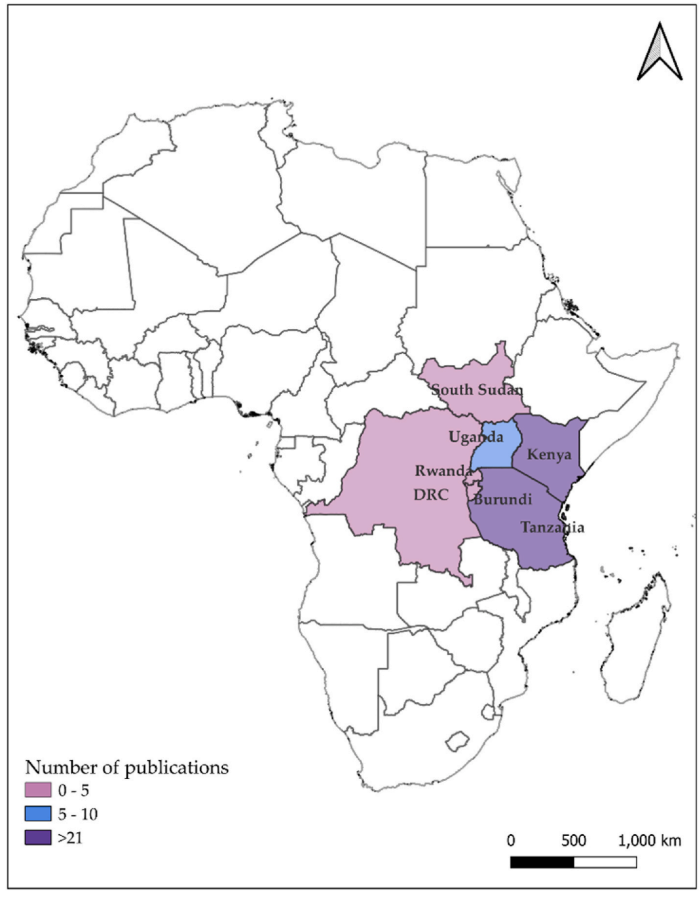

Fig. 2. Map of EAC countries within Africa, and distribution of studies found in the review, between January 2000 and June 2022.

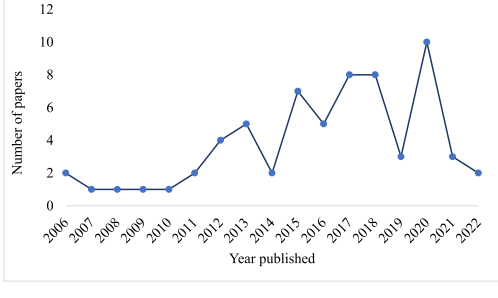

Fig. 3. *Distribution of studies on Campylobacter* spp., *E. coli and Salmonella* spp. *in EAC countries between January 2000 and June 2022.*

% CI = 7–30 %). The prevalence of *Campylobacter* spp. was highest in chicken meat, at 25.9 % (95 % CI = 6.4–45.5 %); in comparison to other types of meat, at only 5.2 % (95 % CI = 3.1–7.3 %). Subgroup analysis indicated borderline significance (p-value = 0.05) in the prevalence of *Campylobacter* spp. across the different food types. *Campylobacter jejuni* was analysed in 1441 samples, revealing a prevalence of 4.5 % (95 % CI = 0.0242–0.0892), whereas *Campylobacter coli* was analysed in 902 samples, with a prevalence of 4 % (95 % CI = 2 %–18 %). Figs. 5 and 6 present forest plots for *C.* coli and *C.* jejuni in various foods, respectively. Table 3 provides a summary of subgroup analysis, including the pooled sample size and pathogen prevalence for the different food products.

3.3.2. Analysis of E. coli in foods

E. coli was the most studied of the three bacteria with a pooled sample of 7208 across seven value chains: meat, chicken meat, fish, milk, beverages, raw produce and cooked foods. Most observations were related to milk (n = 3159) and the least to cooked foods (n = 155) and flour (n = 38), designated as "other" in subgroup analysis. Pooled prevalence was 41 % (95 % CI = 034–52 %), applying *metapreg* command and 42 % applying *meta set* command. Significantly high prevalences were observed in beverages 66.3 % (95 % CI = 41.9–90.6 %) and meat 65.2 % (95 % CI = 36.2–94.2 %). Subgroup "other" had the lowest prevalence at 11.6 % (95 % CI = 1.5–24.7 %). Subgroup analysis revealed a significant difference across value chains, p-value <0.01.

Table 2
Risk factors associated with food contamination in EAC countries, between January 2000 and June 2022.

Risk factor	Pathogen under study	Odds ratio (OR) estimate	p-value	Reference
Low-temperature storage of meat was associated with reduced contamination	*Salmonella* spp.	0.08	<0.05	Niyonzima et al. (2017)
Easy-to-clean and disinfect food-contact surfaces were associated with reduced contamination		0.01	<0.05	
Training of personnel on hygienic handling of food was associated with reduced contamination		0.17	<0.05	
Selling defrosted meat was associated with presence of pathogen	*Campylobacter* spp.	4.69	0.02	Carron et al. (2018)
Use of display surfaces that are not easy to clean was associated with presence of pathogen		7.86	0.03	
Sale of beef alongside chicken meat was associated with presence of pathogen		3.24	0.13	
Number of chicken carcasses sold per week (above 100 carcasses) was associated with presence of pathogen		1.36	0.15	
Using hot water in cleaning equipment was associated with presence of pathogen		4.93	0.09	
Access to running water was associated with reduced contamination	*Salmonella* spp. and *E. coli*	0.36	0.003	Kariuki (2018)
Hand washing before handling food items was associated with reduced contamination		0.02	<0.001	
Use of apron was associated with reduced contamination		0.09	0.02	
Type of toilet facility-use of modern toilet facilities was associated with increased contamination		0.02	0.01	

Fig. 7 is a forest plot of *E. coli* in foods, while Table 3 displays the summary of subgroup analysis.

Pathogenic *E. coli* was detected in various foods, alongside non-pathogenic strains. The pathotypes identified include Shiga toxin-producing *E. coli* (STEC), enterotoxigenic *E. coli* (ETEC), enteropathogenic *E. coli* (EPEC), enteroinvasive *E. coli* (EIEC), and enteroaggregative *E. coli* (EAEC). Non-O157 STEC strains identified in the studies were O45:H7, O9:H21 and ONT:H28 (Baniga et al., 2020). These were excluded from the meta-analysis because the number or percentage of positive samples was not provided; instead, they are listed in Table 4.

Fig. 8 illustrates STEC in 4336 samples, primarily consisting of meat, chicken meat, milk, raw produce and fresh fruit juices. All the records of STEC included in meta-analysis were identified as the O157 strain. The average prevalence of STEC in foods was 2.0 % (95 % CI = 1–10 %). Chicken meat exhibited the highest prevalence at 6.1 % (95 % CI = 3.0–15.2 %). Other types of meat and raw produce each had a prevalence of 3.9 %, while milk had the lowest prevalence at 0.4 % (95 % CI = 0.3–0.8 %).

3.3.3. Analysis of *Salmonella* spp. in foods

The meta-analysis of *Salmonella* spp. in foods included 5677 samples across six value-chains, mainly on meat (n = 2174), and the least on cooked food samples (n = 56). For subgroup analysis, single studies on eggs (n = 50) and cooked foods (n = 56) were categorised as subgroup "other".

Salmonella spp. prevalence across all foods was 12 % (95 % CI = 12–27 %). Subgroup analysis across different value chains indicated significant differences at p-value <0.01. Fig. 9 shows a forest plot of *Salmonella* spp. in foods, and Table 3 gives a summary of subgroup analysis on *Salmonella* spp.

The highest prevalence was found in chicken meat, at 24.4 % (95 % CI = 15.6–33.3 %). Fish and milk were also highly contaminated at 14.1 % (95 % CI = 8–20.3 %) and 13.3 % (95 % CI = 6.5–20.1 %), respectively. *Salmonella* spp. was not detected in cooked RTE foods, eggs, grains and flours (this was adjusted by a corrective factor) (Byakika et al., 2019; Gitahi et al., 2012; John, 2016; Kariuki, 2018; Tsai et al., 2022).

Table 5 summarises the *Salmonella* serotypes detected in food using PCR technology or biochemical tests. The most detected serotypes were *S.* Typhimurium and *S.* Enteritidis, particularly in ASF. Other serotypes identified in our review include S. Singapore, *S.* Typhi, *S.* Enterica, and non-typhoidal *Salmonella*.

3.3.4. Heterogeneity and publication bias across studies

Table 6 provides a summary of observations included in this review and statistics describing heterogeneity across the studies. Heterogeneity describes the measure of variation across studies that is actual differences and not to chance. In this study, the highest heterogeneity observed in *E. coli* studies was 88.5 %, indicating significant variability among individual studies. Other studies displayed moderate heterogeneity, ranging from 34 % to 43 %.

We used meta-regression to explore variation in prevalence. Geographical location of sampling, sample size, processing state (processed or raw) and year of publication were used as predictors. While there was no significant variation in *E. coli* prevalence between countries, levels in the DRC were found to be 60 % higher than in other countries. Processed products (including heated, fermented and sun-dried) were associated with approximately 17 % lower prevalence of *E. coli*. Additionally, larger sample sizes tended to show slightly lower prevalence, although this difference was not statistically significant. The year of publication did not account for any variation in *E. coli* prevalence.

Larger sample sizes were associated with a lower prevalence of *Salmonella* spp. Processed products were also associated with 8 % lower prevalence compared to raw products, while positive prevalence of *Salmonella* spp. was seen to increase with years. There was no significant variation between countries.

Processing was associated with 8 % reduction in prevalence of *Campylobacter* spp.; however this was not significant. Geographical location, sample size and year of publication did not explain variation in prevalence. However, samples from Tanzania showed higher positive rates of *Campylobacter* spp. Table 7 describes the association between

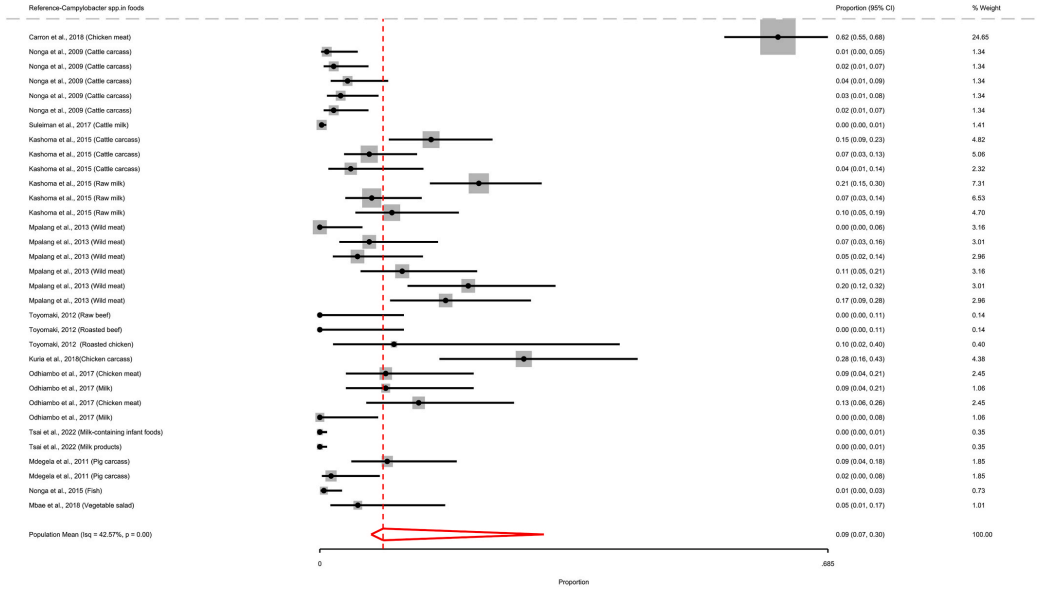

Fig. 4. Forest plot of *Campylobacter* spp. in foods in EAC countries, January 2000 to June 2022.

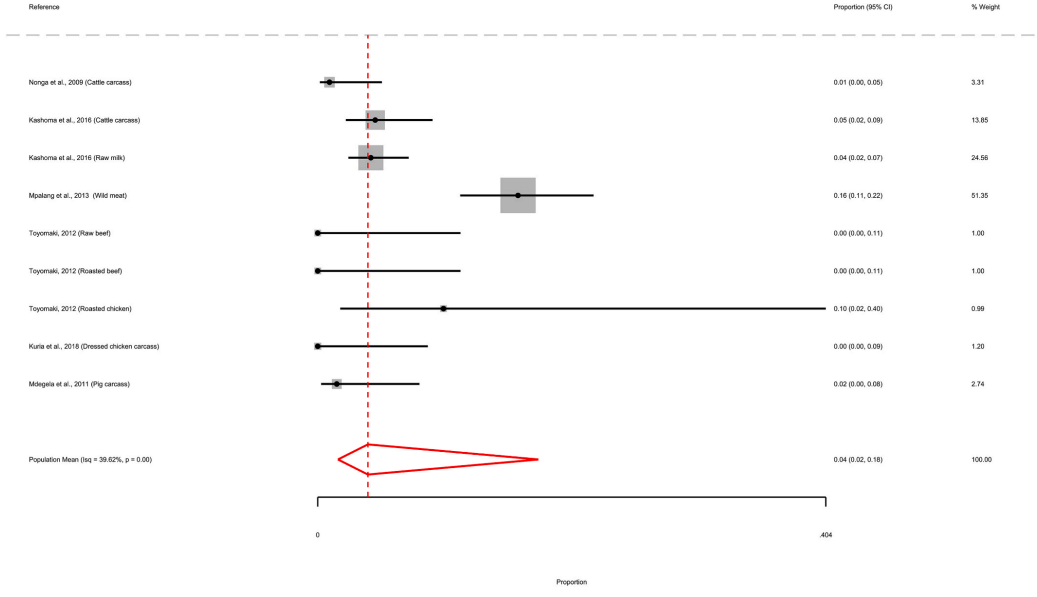

Fig. 5. Forest plot of *Campylobacter coli* in foods in EAC countries, January 2000 to June 2022.

pathogen prevalence and predictors.

Although funnel plot and Egger's test revealed evidence of publication bias (p-value <0.05) in studies on *Campylobacter* and *Salmonella* spp., trim and fill method confirmed symmetry, indicating no small-study bias, with the value of imputed studies being zero. Results on publication bias are presented in Tables 9–10 and Figs. 10–12 in the supplementary material.

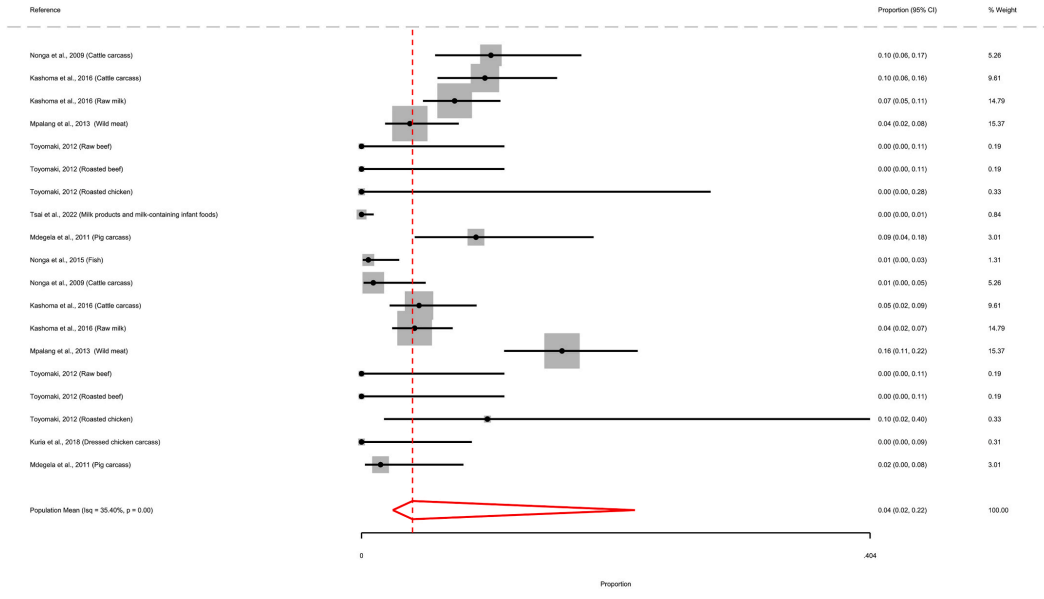

Fig. 6. Forest plot of *Campylobacter jejuni* in foods in EAC countries, January 2000 to June 2022.

4. Discussion

4.1. Inclusion and exclusion of studies

This review was conducted to determine the prevalence of *E. coli*, *Salmonella* spp. and *Campylobacter* spp. in foods consumed in the EAC and the risk factors associated with contamination.

There was a steady increase in the number of food safety studies in the EAC region over the years covered by this review, with a notable rise following the publication of the first WHO report on the global burden of foodborne diseases(WHO, 2015). This, along with funding opportunities, may have stimulated greater interest in the subject. There was also a decline after the COVID-19 pandemic, possibly indicating that research priorities shifted and there was limited capacity to conduct field research activities.

Most studies were conducted in Kenya and Tanzania, with a smaller but significant proportion carried out in Uganda. Gazu et al. (2023) observed that the presence of relevant research institutions can influence the concentration of studies in a particular region or country. No studies were retrieved for Burundi or South Sudan. In Burundi, available reports have been on food control systems (Niragira et al., 2020), milk quality (Iribagiza et al., 2024), and a few on zoonotic diseases (Hakizimana et al., 2020; Isabel et al., 2022; Minani et al., 2022). Most research has focused on food security and nutrition (Niragira et al., 2015; Nkurunziza et al., 2017; Rubyogo et al., 2021), with limited attention given to food safety and epidemiology of the three pathogens under our investigation. South Sudan, which gained independence in 2011 (African Development Bank (AfDB) Group, 2013), had no studies, probably because the available studies were those that had been conducted in Sudan (mainly Khartoum region, n = 7). The absence of studies from these countries highlights a research gap that should be addressed to provide evidence for decision-making and public policy on food safety and public health.

Many studies (n = 108) were excluded during the review process due to poor quality, primarily because non-probabilistic sampling methods were used. In addition, some studies did not adequately describe the microbiological methods or provide a complete description of the results. This may indicate a lack of scientific rigour in the application of methods, which can introduce bias and compromise the reliability of the SLR (Shaheen et al., 2023); therefore, these studies were excluded.

4.2. Value-chains studied

Our review extensively covered milk, meat, and raw-produce value chains, a focus that was also highlighted in a previous African study (Paudyal et al., 2017). Livestock value chains, in particular, have been identified as not only among the most risky in terms of FBD but also the most nutritious (Grace, 2017), and are especially important for vulnerable population groups with increased nutrient requirements (Leroy and Alonso, 2024). Raw-produce value chains, on the other hand, present a greater risk for FBD due to the absence of a pre-treatment step before consumption in many cultures. These factors may have warranted the attention of food safety research.

Food products from cattle, goats, chickens and pigs were commonly studied in our review. Except for pigs, these are also the most common species kept for food security and livelihoods in Africa (Malabo Montpellier Panel, 2020; Robinson et al., 2014). One study in our review specifically focused on rabbit meat (Niyonzima et al., 2017) and another on wild meat (Mpalang et al., 2013). Reports have highlighted the growing significance of unconventional meat sources, such as wild animals, in providing nutrition in Africa (Golden et al., 2011; Grace et al., 2024; Ickowitz et al., 2024; Nasi and Fa, 2015). However, consumption of meat from such species is predominantly localised in rural areas, with only a few points of sale in urban settings. (Staal et al., 2021). In addition, wildlife hunting is illegal or highly regulated in most EAC countries (Lindsey et al., 2015). Thus, market surveys may not explicitly reflect the actual evidence of consumption of unconventional meat sources in East Africa.

Most sampling was conducted in informal and semi-formal outlets including open-air markets, kiosks, slaughter slabs, shops and farm-gate

Table 3
Summary of subgroup analysis showing prevalence and confidence intervals (CI) for pathogen levels in foods in EAC countries, a meta-analysis of studies published between January 2000 to June 2022.

	Subgroup	Pooled sample size	Prevalence	95 % CI interval Lower	Upper
Salmonella spp.	Chicken meat	126	0.25	0.18	0.33
	Fish	675	0.14	0.05	0.55
	Milk	1623	0.15	0.09	0.35
	Ready-to-drink beverages	272	0.09	0.01	0.55
	Raw produce	640	0.10	0.03	0.58
	Meat	2174	0.10	0.07	0.26
	Grains and flours	61	0.01	0.00	0.03
	Others (eggs and cooked foods)	106	0.01	0.00	0.03
	Overall	**5677**	**0.12**	**0.12**	**0.27**
Campylobacter spp.	Chicken meat	323	0.26	0.10	0.55
	Milk	1993	0.06	0.01	0.46
	Meat	1344	0.06	0.04	0.17
	Other (fish and vegetable salads)	224	0.01	0.00	0.04
	Overall	**3884**	**0.09**	**0.07**	**0.30**
E. coli	Ready-to-drink beverages	277	0.66	0.31	0.89
	Meat	2357	0.65	0.30	0.87
	Chicken meat	290	0.63	0.36	0.82
	Raw produce	299	0.46	0.29	0.66
	Milk	3159	0.34	0.26	0.51
	Fish	635	0.27	0.11	0.54
	Others (flours and cooked foods)	191	0.12	0.02	0.43
	Overall	**7208**	**0.41**	**0.34**	**0.52**
STEC[a]	Chicken meat	235	0.04	0.02	0.07
	Meat	2413	0.04	0.04	0.05
	Milk	1614	0.004	0.00	0.10
	Raw produce	74	0.03	0.01	0.09
	Overall	**4336**	**0.02**	**0.01**	**0.10**

[a] Shiga-toxin producing *E. coli.*

locations. Only a few formal sales points, such as retail supermarket chains, were sampled. This is because informal retail outlets remain dominant in low-and middle-income countries (LMICs), and are the preferred primary sources of food for the majority of the population (Blackmore et al., 2020). Consumer preference for informal markets is mainly due to the variety and freshness of foods, convenient locations, and low prices, which are particularly appreciated by low-income earners (Kuboka et al., 2024; Nordhagen et al., 2024). There is considerable debate on the relative safety of formal and informal systems, and the lack of studies on food from the formal systems often promoted on public health grounds is a gap.

4.3. Pathogen levels in food samples

There were fewer studies on *Campylobacter* spp. in foods compared to *E. coli* and *Salmonella* spp., despite this pathogen being known to be prevalent in foods and one of the leading causes of FBD. This may be due to the fact that isolating *Campylobacter* spp. requires specific culture media and incubation conditions. Conventional culture methods are often inefficient because the growth of competing microorganisms can mask *Campylobacter* spp., reducing detection sensitivity. As a result, the prevalence of *Campylobacter* spp. may be underestimated, particularly due to challenges associated with sample transport and culture conditions. However, recovery of *Campylobacter* spp. can be optimised using selective enrichment media and advanced diagnostic techniques (Soto-Beltrán et al., 2023).

The pooled prevalence of *Campylobacter* spp. in our study was 9 % overall, with 26 % in chicken and 5 % in other types of meat. In an SLR by Thomas et al. (2020), prevalence of 21.5 % for *Campylobacter* spp. in poultry and 6.7 % in beef carcasses was observed, which is similar to what we observed in our study. However, a higher prevalence of 36 % was reported in retail chicken meat in India, and up to 63 % in Colombia (Khan et al., 2018; Ortiz et al., 2024). *C. jejuni* was more commonly detected than *C. coli*, which aligns with literature indicating that *C. jejuni* is the most common of *Campylobacter* spp. (WOAH, 2024). *Campylobacter* is a zoonotic pathogen associated with poultry, which serves as its main reservoir. During slaughtering and processing of chickens, carcasses can become contaminated, contributing to the higher prevalence in chicken meat (WOAH, 2024). Cross-contamination of food with livestock faeces can result in *Campylobacter* infections, particularly in children, and these infections can be identified in stool samples (Kiarie et al., 2023; Worku et al., 2024).

In a pooled sample (all food types) of 5677, *Salmonella* spp. was detected with a pooled prevalence of 12 %. This is similar to the 13 % pooled prevalence observed in Burkina Faso (Dinede et al., 2023), although lower rates of up to 3.5 % have been detected in meat in Nigeria (Dagah. et al., 2024; Tafida et al., 2013). Higher prevalences of *Salmonella* spp. have been reported in South-East Asia. In Vietnam, the prevalence ranged between 26 % and 80 %, and a meta-analysis established a pooled prevalence ranging between 30 % and 41 % in meat products (Dang-Xuan et al., 2019; Ngo et al., 2021; Nhung et al., 2024). In Cambodia, one study established a prevalence of 42 % in chicken meat and 45 % in pork (Rortana et al., 2021).

Beverages such as fruit juices, drinking water, and cereal-based drinks, often consumed by infants and children, were also found to be highly contaminated with *Salmonella* spp. at 11.8 %. Our findings are similar to those reported in Ethiopia, where *E. coli* and *Salmonella* spp. were frequently reported in beverages (GAIN, 2022). Higher levels of *Salmonella* spp. were detected in borehole water in Nigeria, with a pooled prevalence of 20% (Oduori et al., 2022). This water is sometimes used in cooking.

Salmonellosis is among the leading causes of hospitalisations and deaths from FBD, even in developed countries (EFSA and ECDC, 2021; Jackson et al., 2013). *S.* Enteritidis and *S.* Typhimurium are the most important serotypes implicated in FBD outbreaks and human infections worldwide (Jackson et al., 2013; EFSA and ECDC, 2021; He et al., 2023). In this review, only a few studies (n = 8) reported specific serotypes, with *S.* Enteritidis and *S.* Typhimurium being the most common. The lack of information on specific serotypes associated with FBD may hinder efforts to accurately determine source attribution and estimate the disease burden in African countries.

Other serotypes reported in our review included *S.* Hivingtoss, which was responsible for FBD outbreak in Australia in 2017 (Smith et al., 2020); *S.* Newport, which was linked to a *Salmonella* outbreak caused by raw cheese in France (Robinson et al., 2020); and *S.* Seftenberg, which was linked to 75 confirmed clinical cases in multiple countries in the EU (ECDC and EFSA, 2023).

Of the 53 included studies in our review, 41 (77.4 %) examined *E. coli* in foods. The predominance of *E. coli* studies is a common finding in many FBD-related reviews (GAIN, 2022; Gazu et al., 2021; Paudyal et al., 2017). Pooled prevalence for *E. coli* in our study was 41 %, comparable to what was found in foods in West Africa (40 %), South-East Asia (21.8 %–48.1 %) and different African countries (35.4–37.6 %) (Dinede et al., 2023; Desiree et al., 2021; Paudyal et al., 2017). However, some studies have reported prevalences exceeding 50 % with levels above the national allowable maximum limits (Kagambèga et al., 2013; Koech et al., 2024).

E. coli is a commensal microorganism, naturally found in the gastrointestinal tract of humans and animals. Due to poor hygiene and faecal-contamination, food and beverages can become contaminated (Feng et al., 2020). Most *E. coli* strains are non-pathogenic and have no adverse effects in humans. However, some strains, such as O157:H7, produce toxins that can lead to adverse effects in humans, including kidney failure, as seen in the case of haemolytic uremic syndrome (Tserenpuntsag et al., 2005; WOAH, 2004). In addition, some *E. coli*

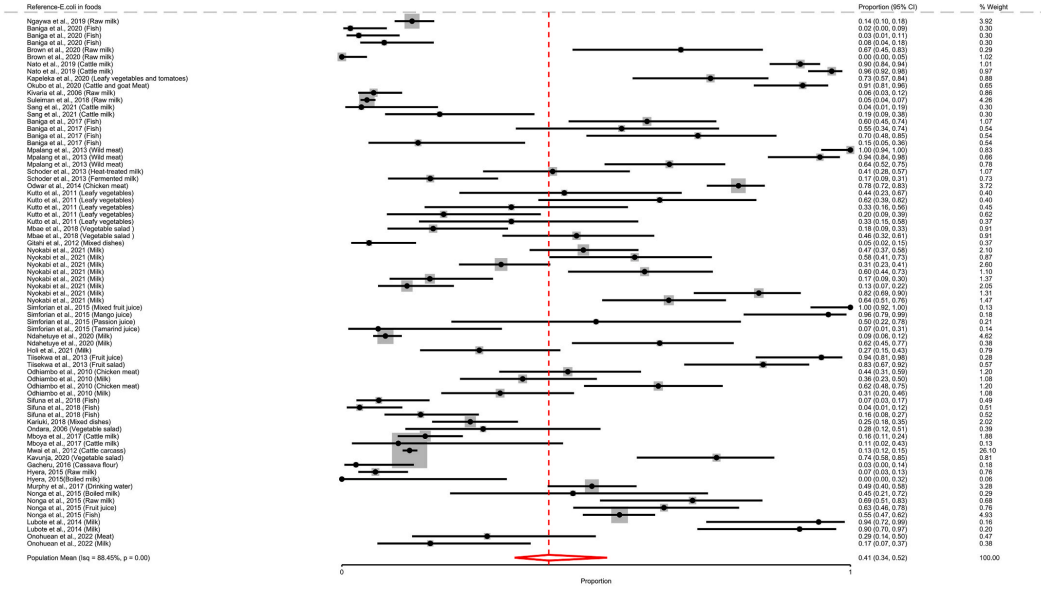

Fig. 7. Forest plot of *E. coli* in foods in EAC countries, January 2000 to June 2022.

Table 4
Pathogenic *E. coli* detected in foods from retail sale points in EAC countries, between January 2000 to June 2022.

Reference	Pathotypes identified	Method of detection	Point of sampling	Specific food	Country
Odwar et al. (2014)	EPEC, ETEC, EIEC, EAEC	Microbial culture, biochemical test and PCR	Butcheries and supermarkets	Chicken meat	Tanzania
Tsai et al. (2022)	EAEC, EPEC, ETEC	Microbial culture and qPCR	Market	Milk products and milk containing infant foods	Kenya
Baniga et al. (2020)	Non-O157 STEC (09:H21) (045: H7) (ONT:H28)	Microbial culture, API system and whole-genome sequencing	Fishing ground, landing sites and markets	Fish	Tanzania

PCR = polymerase chain reaction.
qPCR = quantitative polymerase chain reaction.

strains produce extended-spectrum β-lactamases, which render them resistant to antibiotics (Brolund, 2014; Koech et al., 2024), making this bacterium an important concern in public health.

In our review, the O157 STEC strain was detected mostly in ASF with a pooled prevalence of 2 %. In Ethiopia, STEC was found in beef carcasses at a prevalence of 4.5 % (Beyi et al., 2017), while in Burkina Faso, the prevalence in chicken carcasses was 4 % (Kagambèga et al., 2013). Higher prevalences of up to 9.7 % have been observed in meat in Vietnam (Duc et al., 2024). Non-O157 STEC strains such as O45:H7 and O9: H21which also harbour virulence genes, were reported in this review (Baniga et al., 2020). These have also been associated with foodborne diseases (Bertoldi et al., 2013; Mellmann et al., 2009). In addition, other pathogenic strains observed in our review, such as ETEC, EPEC, EIEC and EAEC, have been implicated in diarrheal diseases (Bii et al., 2005; Okumu et al., 2023; Schlosserová et al., 2024).

4.4. Risk factors associated with contamination

Storage temperature and proper hygiene remain important factors in food contamination and were identified as significant risk factors in our review. Similarly, Ngo et al. (2021) found that increasing the temperature by one degree and selling mixed types of meat increased the likelihood of *Salmonella* contamination in Vietnam. Refrigerated storage and frequent sanitisation were associated with reduced contamination of pork carcasses with *Campylobacter* spp. in Nepal (Ghimire et al., 2014). Additionally, decreased frequency of cleaning and sanitation, as well as proximity to other meat carcasses, were associated with the incidence of *Campylobacter* spp. in chicken meat in Colombia (Ortiz et al., 2024).

One study in our review found a link between food safety training and decreased contamination levels (Niyonzima et al., 2017). Although few studies are available, research among food handlers and dairy farmers in Kenya and Ethiopia has shown that training on food safety and hygiene improved microbial quality in food and on food-contact surfaces (Beyene et al., 2025; Malavi et al., 2021).

Other risk factors identified in different studies include the effect of seasonal variation on contamination levels (Desiree et al., 2021; Rortana et al., 2021). However, this was not observed in this review.

4.5. Application of standards and public health implications of pathogens

In 2025, the African Union, through its member states, agreed to establish the African Union Food Safety Agency, which will serve as a focal point for harmonising food policies and regulations. Standards will

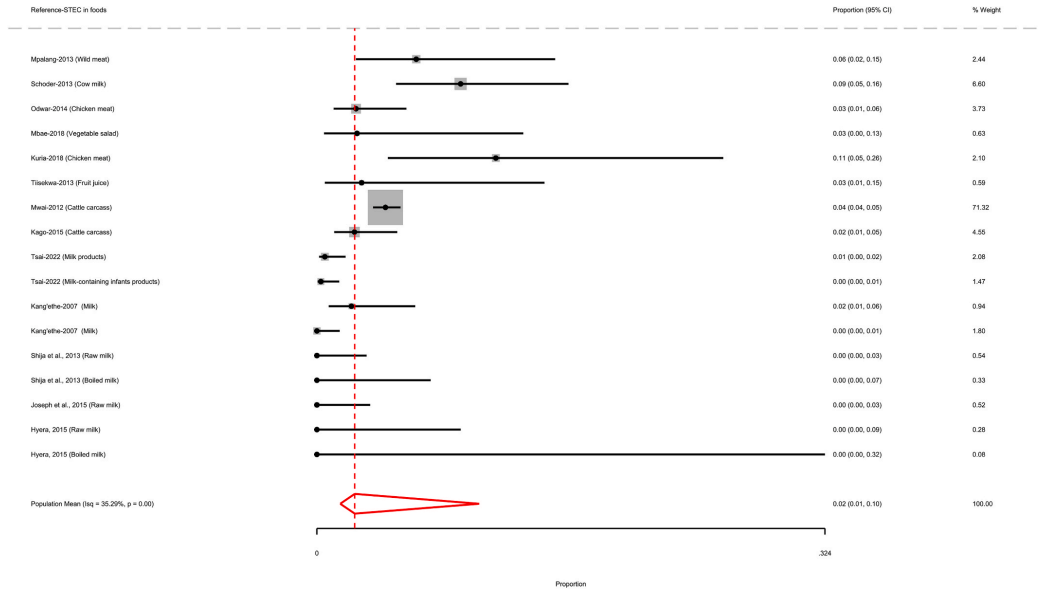

Fig. 8. Forest plot of STEC in foods in EAC countries, January 2000 to June 2022.

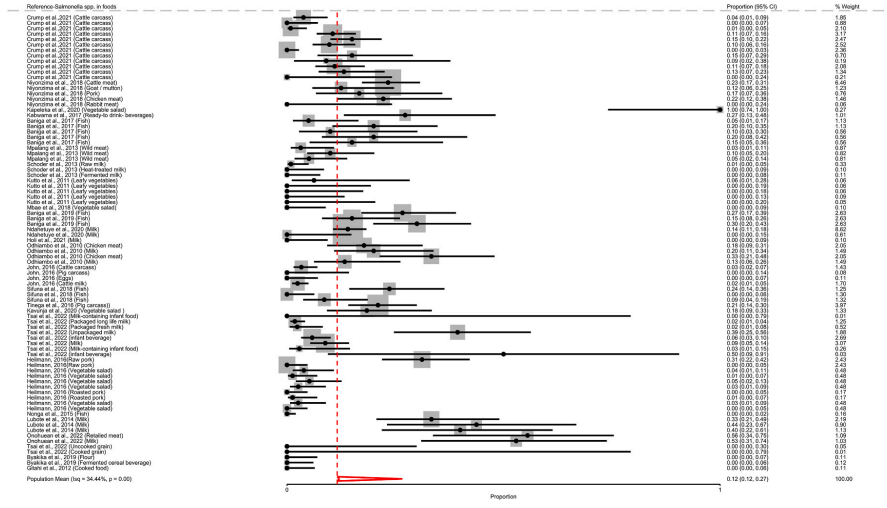

Fig. 9. Forest plot of *Salmonella* spp. in foods in EAC countries, January 2000 to June 2022.

be applied uniformly, thereby promoting food trade under the AfCFTA agreement, while safeguarding public health (African Union, 2025). Meanwhile, standards established by regional bodies such as the EAC, as well as the Codex Alimentarius Commission (CAC), are applied across countries, providing guidelines on food safety.

According to EAC standards, *E. coli* and *Salmonella* spp. must be absent in pasteurised milk and beverage products (Codex Alimentarius Commission, 1981, Draft Kenya Standard Water - based fruit flavoured drinks, 2024, East African Standard, 2006, KEBS, 2024), while a limit of 10^2 cfu/g is set for *E. coli* in meat (East African Standard, 2022). Detection of *Salmonella* spp. and pathogenic *E. coli* in foods, especially RTE categories, indicates a high risk of foodborne illness in humans. Poor or nonexistent hygiene facilities, combined with a lack of understanding among food handlers in cottage industries and food establishments, are possible causes of high contamination in food (Simforian et al., 2015; Tiisekwa, 2013). Stringent hygiene measures are required,

Table 5
Salmonella enterica serotypes reported in foods in EAC countries between January 2000 to June 2022.

Reference	*Salmonella* serotype	Method of detection	Point of sampling	Sample type	Country
Crump et al. (2021)	*S.* Enteritidis *S.* Orion *S.* Typhimurium *S.* Saintpaul II 42:r:	Microbial culture, biochemical test and PCR	Meat slaughter and butcher facilities	Goat and cattle carcass and meat	Tanzania
Kabwama et al. (2017)	Non-typhoidal	Microbial culture, biochemical test	Street vendors	Drinking water	Uganda
Baniga et al. (2017)	*S.* Typhimurium	Microbial culture and PCR	Landing sites, markets and fish vendors (fishermen and processors)	Fish	Tanzania
Baniga et al. (2019)	*S.* Waycross *S.* Hvittinfoss *S.* Typhimurium *S.* Singapore *S.* Enterica *S.* Senftenberg *S.* Newport *S.* enterica subsp. salamae 42:r:	Microbial culture, agglutination tests and PCR	Fishing ground, landing site and markets	Fish	Tanzania
Sifuna and Onyango (2018)	*S. enterica - Group E*	Microbial culture, biochemical tests and API	Landing sites and markets	Fish	Kenya
Tsai et al. (2022)	*S.* enterica	Microbial culture and PCR	Market	Milk products, milk-containing infant foods	Kenya
Heilmann et al. (2016)	*S.* Enteritidis *S.* Offa *S.* Arechavaleta *S.* Gallinarum	Microbial culture, biochemical test and PCR	Pork butcheries	Pork, vegetable salads	Uganda
Odhiambo et al. (2017)	*S.* Typhimurium *S.* Enteritidis *S.* Typhi	Microbial culture, gram-staining and biochemical tests	Commercial food kiosks	Fish	Kenya

Table 6
Summary statistics and level of heterogeneity in meta-analyses of studies in EAC countries, *between January 2000 to June 2022.*

Pathogen	Number of observations	Chi-square statistic	P-value	Tau^2	I^2
Campylobacter spp.	33	611.45	<0.001	4.63	42.57
C. jejuni	19	51.52	<0.001	2.40	35.40
C. coli	9	27.22	<0.001	1.17	39.62
E. coli	74	2455.30	<0.001	3.39	88.45
STEC	17	45.30	<0.001	1.45	35.29
Salmonella spp.	84	396.90	<0.001	3.96	34.44

including testing the water used to prevent the introduction of bacteria into the product. Although our analysis showed a low prevalence of some pathogens, such as STEC, the risk to human health remains significant, particularly through consumption of raw meat, milk, fruit and vegetable products.

In our analyses, there was a significant association between food processing and the prevalence of *Salmonella* spp. and *E. coli*; however, this connection was borderline for *Campylobacter* spp. (p-value = 0.05). Traditional processing of food products, including fermentation, cooking and smoking, is a risk reduction strategy employed by informal actors and households in Africa (Ibnouf, 2012). These strategies reduce the bioavailable moisture and nutrients necessary for microbial growth,

Table 7
Summary of multivariable regression model for predictors of pathogen levels in foods in EAC countries, between January 2000 to June 2022.

Pathogen	Co-variates	Co-efficient	Standard error	P-value	95 % confidence interval Upper limit	Lower limit
Campylobacter spp.	Intercept**	0.20	0.05	0.00	0.10	0.30
	Sample size	−0.00	0.00	0.49	−0.00	0.00
	Processing state	−0.09	0.05	0.05*	−0.18	0.00
	Country					
	Kenya	Baseline	Baseline	Baseline	Baseline	Baseline
	Tanzania	−0.12	0.06	0.04*	−0.24	−0.00
	DRC	−0.01	0.12	0.92	−0.26	0.23
Salmonella spp.	Intercept**	0.18	0.03	0.00	0.13	−0.23
	Sample size	−0.001	0.00	0.03*	−0.00	−0.00
	Processing state	−0.09	0.04	0.02 *	−0.16	−0.01
	Year	0.01	0.01	0.04*	0.00	0.03
E. coli	Intercept**	0.41–0.00	0.07	0.00	0.28	0.54
	Sample size	−0.17	0.00	0.06	−0.00	0.00
	Processing state		0.08	0.04*	−0.33	−0.01
	Country					
	Kenya	Baseline	Baseline	Baseline	Baseline	Baseline
	Tanzania	0.08	0.09	0.35	−0.09	0.25
	Uganda	0.09	0.16	0.58	−0.22	0.40
	Rwanda	0.03	0.26	0.90	−0.55	0.48
	DRC	0.60	0.26	0.02*	0.09	1.11

Intercept** is the expected prevalence when the year is set at baseline and all predictors are zero.
P-value*-significant at 0.05.

thereby decreasing pathogen levels (Tapía et al., 2020). However, poor handling and insufficient processing can also result in microbial contamination (Dzikunoo et al., 2021). *Campylobacter* spp. is highly sensitive to heat and low moisture conditions. Proper heating to temperatures up to 70 °C is important and considered sufficient to destroy bacteria and some toxins that may have formed (Nguyen et al., 2006; Oosterom et al., 1983). Therefore, insufficient heating or post-process contamination of products may have led to equally high prevalence of *Campylobacter* spp. in processed products compared to raw food products.

Although there was no significant variation in prevalence among different countries, notably higher *E. coli* levels were observed in the DRC, while *Campylobacter* spp. was more prevalent in Tanzania. This may be because the studies focused on meat, especially wild meat in DRC, which is classified as a high-risk food. Higher prevalences are therefore expected, given the potential for poor production and hygiene practices, as well as interaction with environmental factors (Grace et al., 2024; Staal et al., 2021).

4.6. Limitations

Moderate to high heterogeneity was observed across the studies, which may limit the interpretation of our findings. However, by applying subgroup analyses to explore sources of heterogeneity (Higgins and Thompson, 2002), we confirmed significant differences in the prevalence of *E. coli* and *Salmonella* spp., which could be attributed to the different types of samples analysed. Heterogeneity was particularly high for studies on *E. coli* ($I^2 = 88.45$ %), which may limit confidence in precise point estimates. Nonetheless, our review provides pooled estimates that compare studies across countries and are weighted by sample size, offering regional policymakers broad magnitude estimates needed for AfCFTA food safety harmonisation efforts.

Meta-regression analyses were used to explore variation in prevalence. Notable variation was attributed to processing sample sizes, countries and year of publication, thus providing additional data on variation that may explain high heterogeneity in our study meta-analyses.

Methodologically, *meta* command has been widely used in meta-analysis of proportions; however, it was unsuitable in our study, where there were proportions with zero or 100 % positive samples. Application of *Metapreg* in STATA® allowed estimation of pooled prevalence using a logistic-normal random-effects model, with Wilson confidence interval. The key advantage of this command was that it handled zeros without the addition of a continuity correction factor (Nyaga and Arbyn, 2024).

While Egger's test showed evidence of small-study effects, the trim-and-fill method revealed no asymmetry, confirming no publication bias.

5. Conclusion and future directions

Our review reveals that some countries within the EAC, specifically, Burundi, the DRC and South Sudan, have been overlooked in food safety research. Investment in food safety research in these countries will help to understand and mitigate the burden of foodborne illnesses.

Our findings indicate that chicken meat was more contaminated than other types of meat, although there were fewer studies focused specifically on chicken. Similarly, unconventional meat sources, such as wild meat, had also been understudied. Ready-to-drink beverages frequently showed contamination with *E. coli* and *Salmonella* spp. While our study was focused on contamination levels in foods, risk assessment studies are needed to link exposure to these pathogens with the occurrence of foodborne illnesses.

Most studies were focused on *E. coli*, revealing high levels of contaminated food, which is an indication of poor hygiene and sanitation practices. However, fewer studies characterised *Salmonella* serotypes and *E. coli* pathotypes. Consistently, even fewer studies analysed *Campylobacter* spp. Modern diagnostic techniques for characterisation of pathogens can be expensive and are often unavailable in LMICs settings. Investing in laboratory infrastructure is crucial for improving the understanding of FBD burden.

Although pathogen levels in food were found to be considerably high, only a small number of studies reported associations between risk factors and contamination levels. Moreover, there were no studies that went beyond hazards to assess actual risk to human health, which is the most crucial information. By understanding risk factors, targeted interventions to counter contamination can be designed. Additionally, risk assessment studies will offer valuable evidence to inform policy direction on food safety and health.

With the increased calls for intra-African trade, there is a need for guidelines and stringent measures to protect food safety and public health. The establishment of the African Food Safety Agency is crucial and timely to safeguard public health while promoting livelihoods and trade.

CRediT authorship contribution statement

Maureen Kuboka: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ianetta Mutie:** Writing – review & editing, Software, Methodology, Investigation, Conceptualization. **Karin Artursson:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Johanna Lindahl:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Gunnar Carlsson:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Florence Mutua:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Delia Grace:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial or personal interests that could have influenced the work reported in this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fm.2025.105004.

Data availability

Data will be made available on request.

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Food safety in informal public markets in Kenya: perceptions of stakeholders in the food chain

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Introduction: Informal markets play a crucial role in providing fresh and nutritious foods for people in low and middle-income countries. However, the safety of food sold in these markets remains a major concern, contributing to a high burden of foodborne illnesses.

Methods: This study was designed to analyze stakeholder perceptions of food safety in selected informal public markets in Kenya. Eight focus group discussions and 15 key informant interviews were conducted. In addition, two workshops were held to validate the findings.

Results and discussion: We found that consumers and vendors confounded food quality, especially freshness, with safety, and paid more attention to appearance and physical qualities than food safety. Information (such as branding and expiry dates) and heuristic cues (such as the flow of buyers and the presence of flies) were used to assess food safety. Meat was perceived as the food most likely to cause disease. Chemical hazards in fresh produce and aflatoxins in maize were mentioned as priority hazards by both vendors and consumers. Stakeholders more knowledgeable about food safety considered microbial hazards as a top priority. Although diarrheal diseases were reported to be prevalent in the communities, these were often thought to be the result of agri-chemical residues in fresh produce or the consumption of high-fat foods, and not commonly linked to bacteria in food. Gaps identified during the interviews included poor infrastructure, inadequate food safety knowledge, insufficient or prohibitive policies, insufficient political will, and poor food safety-related practices. There were few mentions of lack of motivation or incentives for behavior change, or insufficient consumer demand for food safety. To fill the gaps, several opportunities were discussed, including contextualizing policies and regulations, investing in infrastructure, capacity building, and training, and promoting involvement and collaboration among various stakeholders.

Conclusion: This study has highlighted gaps and misperceptions that need to be addressed through proper knowledge and awareness to effectively combat foodborne disease challenges. Behavioral change approaches to improve food safety are recommended.

KEYWORDS

foodborne disease, food value chain, risk perception, participatory, public markets, East Africa

Introduction

Food safety is a global public health challenge. In 2010, 31 foodborne disease (FBD) hazards were found to be responsible for 600 million illnesses, 420,000 deaths, and a loss of 33 million years of healthy life globally (Havelaar et al., 2015). In the same study, four heavy metals were found to be responsible for one million foodborne illnesses, over 56,000 deaths, and more than nine million lost years of healthy life in 2015 (Gibb et al., 2019). Foodborne diseases also adversely impact trade, economic development, and livelihoods (Grace, 2015).

Evidence proves that low-and middle-income countries (LMICs) are disproportionately affected by the burden of FBD. Despite making up only 41% of the global population, LMICs account for 75% of FBD-related deaths, 53% of illnesses and economic losses estimated at USD 116 billion annually. African countries have the highest *per capita* FBD burden of 2,455 disability-adjusted life years (DALYs) per 100,000 inhabitants against a global average of 477 DALYs per 100,000 population (Havelaar et al., 2015; Jaffee et al., 2019).

In African countries, food is mostly distributed through informal markets; by which we mean sale points that are not modern retail outlets; these include open public markets, small shops or kiosks, street food, and eateries (Roesel and Grace, 2014). In most cases, informal markets are under-regulated and compliance with food safety regulations is poor. However, these markets are essential to low-income consumers because they are easily accessible and provide a wide range of fresh and nutritious foods at low cost. The informal market system also provides livelihoods to many households and is an important source of work, particularly for women (Global Alliance for Improved Nutrition, 2020). Our study is focused on open public markets and their environs, an important part of informal retail markets.

Food safety is a shared responsibility, and all actors in the food system have a part to play in ensuring that the final product is safe and will not cause harm to the consumer (Grace, 2017). Food vendors and consumers are the primary stakeholders operating in public open markets (Kiambi et al., 2020). Other stakeholders include governance actors (market authorities, food inspectors, officials from relevant ministries and local governments) and transporters who bring food to and from retail points.

Level of trust in the food system can impact perceptions on food. In addition, other factors such as information, personal experience, social influence, culture, and beliefs play an important role in determining consumers' perceptions on food and associated risks (Isanovic et al., 2023). Although perceptions may not reflect reality, it is important to examine them since they influence purchase decisions and how people manage food risks (Hansen et al., 2003; Bukachi et al., 2021).

Consumers have been reported to rely on observable hygiene practices and recommendations of the vendor by other consumers; the latter is mostly driven by the vendor's reputation, warmth, and interpersonal relationships (Liguori et al., 2022; Isanovic et al., 2023). Understanding the behaviors underpinning consumer preferences and practices could inform the design of fit-for-purpose interventions and policies. Information on behavior and practices can be generated through qualitative studies, using open-ended questions, to explore the underlying cognitive factors and belief systems (Green and Thorogood, 2004). However, quantitative designs, especially knowledge, attitude, and practice surveys, have been used more commonly to study behavior. Quantitative studies are typically researcher-led and extractive. In contrast, participatory approaches promote involvement of stakeholders in identifying and prioritizing public health needs, and may be more effective in understanding and solving health-related problems (Alders et al., 2020).

Therefore, we conducted a qualitative study to understand the perceptions of stakeholders in informal public food markets in selected urban and rural areas in Kenya. The study aimed to answer three research questions; (i) How do stakeholders perceive food safety? (ii) What foods, hazards and illnesses are of most concern from a food safety perspective? (iii) What challenges hamper the supply of safe food, and how can these be addressed?

The work contributes to a larger project being implemented by the International Livestock Research Institute (ILRI) and partners, funded by the Federal Ministry for Economic Cooperation and Development, Germany. The overall aim is to improve food safety in informal markets in East Africa. These findings will inform the next steps in the project which include defining priority value chain(s) and food hazards for further research.

Methodology

Study areas

The study was conducted in Nairobi and Machakos counties of Kenya, which were selected to represent urban and rural settings, respectively. One public market in each county was chosen, in consultation with local government officials. This was informed by size of the market, the average number of consumers it serves, and nine food commodities of interest sold, including meat and meat products, eggs, fish, milk and dairy products, cereals and pulses, fruits, vegetables, roots and tubers and composite foods [composite ready-to-eat foods (RTE)]. In Kenya, meat and dairy products are typically sold from kiosks and small shops rather than open-air-markets, we therefore included butchers and small shops selling milk in the vicinity of the two markets. Figure 1 shows the location of the two markets. The figure inserted is the map of Kenya.

Study design

This was a qualitative study involving focus group discussions (FGDs), key informant interviews (KIIs) and two stakeholder workshops. FGDs were used to elicit the perceptions of the primary stakeholders (i.e., consumers and vendors). These were complemented by in-depth interviews with experts with specialist knowledge on food safety (academics, consultants, researchers), and other stakeholders important to the optimal functioning of food markets [market authorities, government officials, vendors associations (there were no consumer associations active in the markets)]. Subsequently, a workshop was conducted in each area with participants who had earlier been engaged in the FGDs and KIIs, to validate the findings.

Sample size

Sample size recommendations for FGDs vary from two to 40 groups with a commonly cited guideline of at least two for each

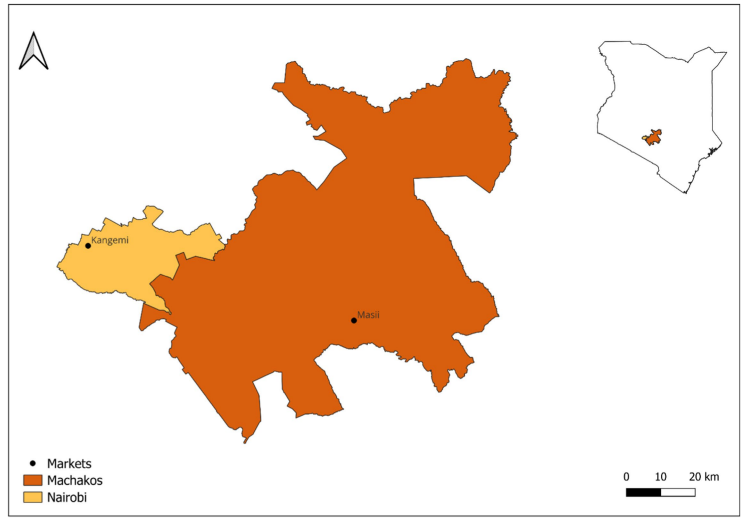

FIGURE 1
Map of the two study counties, their location within Kenya (insert) and location of the markets selected.

defining demographic characteristic (Guest et al., 2017). Based on similarity of informal market settings, we did not anticipate major variation in the study population. Thus, we planned two FGDs with male consumers, two with female consumers, two with male vendors and two with female vendors (eight in total), as recommended by Hennink et al. (2019), in order to reach saturation (the point when issues are repeated, and further data collection adds no new ideas). We aimed to include around eight participants per FGD, as is typically recommended.

Key informant interviews emerged from anthropological research and are now commonly used to gather information from those with high-level and comparative insights or with specialist knowledge. Previous studies have shown variability in the number of KIIs performed (Gröndal et al., 2021; Nitto et al., 2022; van der Vossen-Wijmenga et al., 2022). The number mostly depends on the ability to identify the right experts and their availability (Green and Thorogood, 2004). The expertise of the participants is critical as it determines the validity of the results (Gundumogula, 2020). Involving different food system actors in this study was important for scientific rigor and validation of the results (Mays and Pope, 1995).

Recruitment of participants

Market management, public health officers, government extension officers and community health volunteers were informed about the study and provided support during implementation. Each market was visited two times. In the first visit, the research team was introduced, and the study objectives explained to the market management and vendors. During this visit, a list of vendors willing to participate in the study was drawn and stratified by gender and the nine food commodities of interest. Willing vendors were selected and visited a second time during which an appropriate meeting date, time and venue were agreed on.

Consumers were identified during the second visit to the vendors. They were recruited by approaching every consumer shopping from the already selected vendors. Those willing to participate in the study provided their telephone numbers for follow-up. This formed the consumer list. Later, every second consumer in the list was selected and contacted about the FGD meeting. Vendors and consumers not available to participate in the meetings were replaced by others from the respective lists.

KII participants were identified by snowballing, in consultation with researchers and local contacts, targeting individuals with specialist knowledge on food, food trade and/or food safety supply chain.

Data collection

FGD guide and semi-structured questionnaire for KIIs were developed, with reference to instruments previously used in other studies on food safety in informal markets (Hässler et al., 2018; Roesel et al., 2019). These were developed in English and pre-tested prior to use in the field. The FGD guides drew from participatory methods such as ranking, scoring, pairwise comparison, use of pictures and flip charts for illustration (Alders et al., 2020). The workshop agenda included presentation of findings and discussions including additional gaps in research and recommendations.

In each location, the FGDs were held in a community hall near the selected market. The meetings lasted about 2 h. The study objectives were explained, and expectations for the meeting

outlined, after which informed consent was obtained from the participants. Participants were compensated for costs they had incurred due to their participation (approximately USD 10). Instead of names, study participants were identified using a coding system to maintain confidentiality and anonymity. The discussions were led by one facilitator and a note taker who were trained in the methods and tools used in data collection. The discussions sought to answer three research questions; (i) How do stakeholders perceive food safety? (ii) What foods, hazards and illnesses are of most concern from a food safety perspective? (iii) What challenges hamper the supply of safe food, and how can these be addressed? Questionnaires included probes to elicit further discussions and insights. Flip charts and pictures were used for illustrations. Foods consumed were listed and categorized according to food groups and level of processing. Pairwise comparison table was used in determining the most consumed foods. Ranking and scoring by hand votes were used in determining priority food chains and hazards.

KIIs were conducted at locations convenient to the interviewees, including hotels and offices. Three of these were conducted online. During the interviews, English was used and where appropriate verbal translation to Swahili was done by the interviewer. KIIs were mostly used to answer research questions two and three. Detailed handwritten notes were taken in all interviews and the conversations were audio-recorded. The validation workshops were carried out as open forums with round-table discussions among participants to discuss findings and identify additional research gaps on food safety. Handwritten notes were taken during these sessions.

Data analyses

Verbatim transcription of the FGDs and KII data was done and at the same time also translation from Swahili to English (where Swahili had been used). Transcripts were verified against the recorded audios, read, and cleaned. Version 14 of NVIVO software was used in the analysis. The tool assists qualitative researchers to collate, organize, and visualize the data. Thematic analysis was used to identify common patterns on themes based on inductive analysis framework. Themes were reviewed iteratively, named, defined, analyzed, and reported. Quantitative data from pairwise comparison matrix, ranking and scoring was analyzed in MS Excel and simple data visualization tools used.

Results

This section is divided into five; (i) description of the participants (ii) foods sold and those most consumed, (iii) perceptions on food safety, (iv) foods, substances (hazards) and illnesses of most concern from a food safety perspective (v) challenges and opportunities to improve food safety. Data from all FGDs were combined and not attributed to a specific demographic group. While FGDs covered all of the three study questions, KIIs contributed more to analysis of priority hazards, food chains and diseases, as well as challenges and opportunities in food safety. Verbatim quotes from the participants are given in italics, and modifications in brackets.

Description of study participants

Data was collected between February and September 2023. In total, 83 participants, 18 years and above, participated in the FGDs. Thirty-nine vendors participated in the study (Table 1). They included: stall vendors who typically sold a mixture of products (vegetables, fruits and sometimes fish); fruit vendors who vended whole and cut fruits in carts; milk and egg vendors in small shops and kiosks near the market; fish stall vendors; and butcher attendants. We were unable to find raw meat female vendors. Instead, we found female vendors of meat products like sausages and attendants who worked in restaurants and eateries that sold cooked meat, so these were recruited to join the vendor FGDs. In Machakos, recruitment included smallholder dairy and fresh produce farmers who sold their products at farmgate and/or supplied to the selected market. Additionally, sellers at a nearby milk collection center participated in the FGD meeting.

There were 44 consumers involved, 22 females and 22 males. There were 19 consumers in Nairobi and 25 in Machakos. In Nairobi, four of the selected consumers (3 males, 1 female) were not available to attend the meeting and were replaced by others from the list.

Fifteen participants agreed to be interviewed in the KIIs. All the identified key informants held senior positions in their departments, thus had specialist knowledge of food, food trade and/or food safety. The professional background, number and gender of the key informants are given in Table 2. While recruitment of key informants targeted a one health approach, officials responsible for environment, water and sanitation in the markets could not be identified.

Foods sold in the informal markets

Table 3 describes the various foods sold in the markets/market vicinities, the form, level of processing, and outlets through which the food is sold. The foods were categorized into nine groups and different levels of processing including unprocessed, minimally processed, cooked, traditionally processed and modern processed products.

The products were mostly sold unprocessed. Vendors and consumers in Machakos reported having direct access to fresh products, either from their own farms or neighbor farms, unlike those in Nairobi. Supermarkets and other forms of modern retail outlets were mentioned more in Nairobi than in Machakos. Likewise, hotel, restaurants, and roadside eateries in Nairobi were found to be more popular sources of food than in Machakos. Females with families preferred to purchase raw food for further preparation and cooking at home in both locations, as this was viewed not only as the norm but also as a cheaper option for the family. RTE foods were more popular among males than females and even more popular among the younger population (age < 36).

Frequently consumed foods

Milk was perceived to be the most consumed food in Nairobi, and the third most consumed product in Machakos, after vegetables and cereals/ pulses (Figure 2). It was said to be readily available through

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TABLE 1 Foods in informal markets, form, level of processing and type of outlet where the food is sold.

Location of market	Type of FGD	Vendor profile (number)
Nairobi	Female vendors	Cereal vendors (2) Egg vendor (1)
		Fruit vendor (1)
		Hotel attendant (1)
		RTE Meat product vendors (1)
		Milk vendors (2)
		Vegetable and fish vendors (2)
	Male vendors	Cereal vendor (1)
		Fruit vendor (2)
		Meat vendor (1)
		Milk and eggs (1)
		Milk (2)
		Vegetables (2)
Machakos	Female vendors	Egg vendor (1)
		Cereal vendor (1)
		Hotel attendant (1)
		Milk vendor (2)
		Smallholder dairy farmer (1)
		Smallholder produce farmer (1)
		Vegetable and fruit vendor (2)
	Male vendors	Smallholder dairy farmer (1)
		Smallholder produce farmer (1)
		Milk vendor (2)
		Cereal vendor (2)
		Hotel/RTE kiosk attendant (2)
		Meat butcher attendant (1)
		Vegetable and fruit vendor (1)

TABLE 2 Profile of key informants.

Category of KII	Number of interviews	Gender
Academician	2	Female/Male
Researcher	1	Male
Private food safety consultant	1	Female
Veterinary public health	2	Female/Female
Public health	4	2 Females/2 Males
Administrative officer	1	Male
Market management	3	Female/2 Males
Chair-person, milk vendors association	1	Male
Total	15	

the informal marketing channels such as kiosks and milk bars and affordable to consumers who could purchase it in small quantities depending on economic ability. Milk was perceived to be important to all members of the family as a source of protein, but especially important to children under five who were said to consume milk four to five times a day, mostly as fresh milk and as an ingredient in infant foods.

> *We prefer kiosk vendors because you can get* var*ying quantities of milk depending on the money you have, even if you need milk for KES 20. (~ USD 0.2). Packet milk has a fixed price,* (Male consumer, Nairobi).

Figure 2 below shows the most frequently consumed foods. Comparison in the two locations is given based on pairwise matrix

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TABLE 3 Foods sold in the study markets in Kenya in March, 2023.

Food category	Form in which the food is sold	Level of processing	Where the food is sold from
Meat and meat products (beef, goat meat, pork, mutton, and poultry)	Raw meat cuts	Unprocessed	Meat butcheries, slaughterhouses, supermarkets, smallholder farms
	Raw chopped and minced meat	Minimally processed	Meat butcheries, supermarkets
	Raw offal, head and feet	Unprocessed	Meat butcheries, slaughterhouse, kiosks, street vendors
	RTE meat and offal	Cooked/ traditionally processed	Meat butcheries, kiosks, street vendors, hotels
	RTE meat products- African sausages *(mutura)* and pies *(samosas)* made of meat stuffing and sometimes blood.	Traditionally processed - sometimes served with raw vegetables	Meat butcheries, kiosks, street vendors, hotels
Fish	Whole fish	Unprocessed	Open air markets, kiosks, street vendors, supermarkets
	Fresh fish cuts	Unprocessed	Open air markets, kiosks, street vendors, supermarkets
	Sun-dried fish	Traditionally processed	Open air markets, kiosks, street vendors.
	Fried fish	Traditionally processed	Open air markets, kiosks, street vendors
Milk and milk products	Fresh milk	Unprocessed	Open air markets, dairy bars, shops, milk ATMs (*automated milk dispensing machines*), smallholder farms, milk Research Topic centers,
	Pasteurized and ultra-heated treated	Modern processed, packaged and labelled	Shops, supermarkets
	Boiled milk	Traditionally processed	Open air markets, dairy bars, shops, smallholder farms,
	Fermented milk products, e.g., yoghurt	Modern processed, packaged and labelled	Shops, supermarkets,
	Fermented milk product (*lala*)	Traditionally processed	Dairy bars, shops, smallholder farms
Eggs	Raw	Unprocessed	Open air markets, kiosks, street vendors, smallholder farms, shops, supermarkets
	Boiled eggs,	Cooked- sometimes served with raw vegetables	Open air markets, kiosks, street vendors, hotels
Vegetables (leafy vegetables, tomatoes, onions)	Whole	Unprocessed	Open air markets, kiosks, street vendors, smallholder farms
	Chopped	Minimally processed by chopping prior to cooking	Open air markets, kiosks, street vendors,
	Vegetable salads	Minimally processed by chopping and served as ready-to-eat	Open air markets, kiosks, street vendors, hotels
Fruits	Whole fruits,	Unprocessed	Open air markets, kiosks, street vendors, smallholder farms
	Cut fruits and salads	Minimally processed by cutting, sometimes packed in plastic containers	Open air markets, kiosks, street vendors, hotels
	Juices	Minimally processed by blending/ squeezing, packed in plastic containers	Open air markets, kiosks, street vendors, hotels
Cereals and pulses	Raw	Unprocessed	Open air markets, kiosks, smallholder farms, shops
	Boiled	Cooked by boiling	Hotels, kiosks
	Flour	Minimally processed by milling into flour	Open air markets, kiosks, shops
Roots and tubers	Whole or cut	Unprocessed	Open air markets, kiosks, smallholder farms
RTE foods	RTE foods	Cooked by boiling/frying and served as meals	Hotels, meat butcheries, road-side kiosks

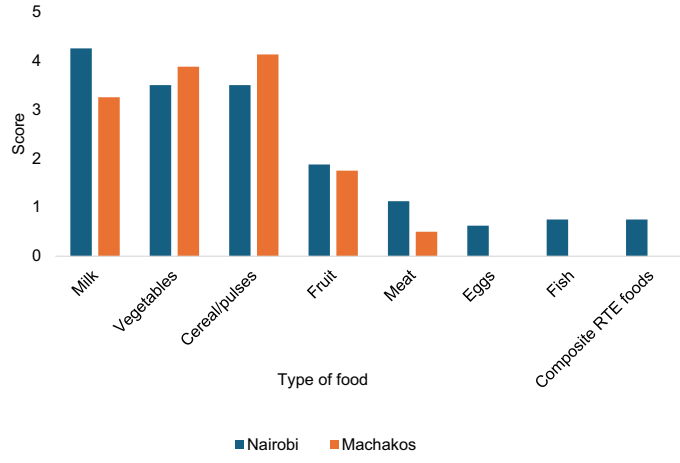

FIGURE 2
Pairwise comparison of the most frequently consumed foods in Machakos and Nairobi.

scores on the y-axis. Cereals and pulses were said to be the most frequently consumed food in Machakos and the second most consumed in Nairobi, alongside vegetables. Milk was overall the most consumed animal-derived food in both locations. Other animal source foods (eggs, fish, meat) were reportedly the least consumed foods in both sites, but noticeably more common in Nairobi than Machakos.

Food safety perceptions

In this sub-section, we first discuss the importance of food safety and how consumers assessed food safety. We then present the practices along the value chain that make food potentially unsafe, as perceived by consumers and vendors. Finally, we present evidence on beliefs and taboos thought to be related to food and food safety.

Food safety was mostly judged in terms of quality attributes such as appeal to the eyes (mostly termed as "goodness"), cleanliness, and freshness. Product freshness was the most salient factor reported by consumers, especially in purchase decisions related to vegetables and animal source foods (ASF). Freshness of ASF was mostly equated to safety, meaning that fresh food was perceived as safe and less likely to contain substances that would cause harm to the consumer.

When probed on food safety, participants spoke more about product freshness. Vendors and consumers preferred freshly stocked products. Food stored or refrigerated for some time was perceived to not be fresh and was thought to contain harmful substances. Vendors were said to use refrigeration not as a means of preservation but to mask products that had already been rendered unsafe.

> *I must ask if it is from the refrigerator. Meat from the refrigerator has been stored for a long time. I must buy fresh meat from the slaughter,* (Female vendor, Machakos).

> *…just by looking at the meat, blood is an indication of fresh meat. The one that is not fresh is dry and hardened, it may have been stored for 3–4 days,* (Male consumer, Machakos).

Price was also considered as important and determined where consumers purchased food products. For example, milk from automated milk dispensing machines (popularly known as milk ATM) and unpackaged informally sold milk was preferred as this could be obtained in small, affordable packages.

> *I buy from the kiosk if the ATM is over. They (ATM sources) are cheap, and you can buy according to what you need,* (Female consumer, Nairobi).

The source of food and values such as loyalty, good reputation and established relationships between suppliers, vendors and consumers were perceived to be important. This not only guaranteed repeat purchases but also provided opportunities for consumers to get food items on credit. Direct relationship with vendors/ suppliers, and the positive attitude consumers received from the vendors were perceived to be more important than considerations on food safety. This relationship with vendors also allowed the consumer to ask questions about the source of food, when the food was purchased (to gauge its freshness) and the price.

> *You know with these foods (generally), there are particular places where you buy. You just do not buy anywhere. You identify one place where you know the food does not always harm you, so you remain loyal to that place… You can also get milk on credit from these (informal) vendors depending on the rapport because we know each other,* (Male consumer, Nairobi).

> *…it very important to know the source of the meat. Some people may sell you meat from dead animals* (Female vendor, Machakos).

Farm-sourcing was preferred especially in rural areas as it offered fresh products in large quantities at a cheaper price.

> *At the farm, it (food produce) is weighed in large quantities and it's a sure bet that its fresh, as you can see where it is coming from,* (Female consumer, Machakos).

It is worth noting that hygiene and food handling practices were mentioned as factors that influenced food purchase decisions only after further probing of vendors and consumers. Hygiene, which participants also referred to as "cleanliness," included personal hygiene (food handler's nails, dressing, appearance), sanitation around the business, and cleanliness of equipment used in the food business. However, it was noted that consumers could also easily forgo hygiene factors for other factors such as relationship and obtaining credit.

> *I consider their (vendors') attitude towards buyers and good relationship with the customers. They can be clean but very proud and cannot give you credit when you do not have money. Another one can be dirty but offers you goods on credit*, (Male consumer, Nairobi).

Information cues such as a veterinary stamp on a meat carcass, expiry dates on packaged foods, or branded food products /food delivery vehicles were sometimes used for assessment of safety of food. However, manufacturing/expiry dates were not seen as entirely reliable, as some vendors were reported to alter the expiry dates on products to give the impression of extended shelf life.

> *You look to see if the meat is from a recognized slaughterhouse by checking whether it has been stamped or not. For example, Meat from Kenya Meat Commission is inspected and approved for sale. Some people here … buy from the slaughterhouse (mentions the name), but others buy from (unidentified places), they do not know if it is tested*, (Male vendor, Nairobi).

> *Where the meat is coming from is important, if the meat comes in with recognized vehicles written "meat" with red colour, that meat is okay,* (Male consumer, Nairobi).

> *If it's packed, you look for the expiry dates. If not packaged we will buy where there is a high turnover of milk, where many buyers (consumers) frequent, because there we know that the milk does not stay overnight, so the milk is fresh*, (Female consumer, Machakos).

Heuristics were also used in food safety assessment. The presence of flies around raw meat selling areas was perceived to be a sign that the food is fresh and had not been preserved using chemicals. Others observed the number of buyers visiting particular shops or vendor stalls, and the frequency of the visits, as this would provide information on how often the food stock is exhausted and replenished, an indication of freshness.

> *I will check to see how long the meat is kept in the butchery if the stock is sold fast. I check how often people buy meat from that butchery. Where there are many people, I know they have fresh meat, it has not been stored for long,* (Female vendor, Machakos).

> *But meat that is delivered at night might not be genuine or could be from wild animals. We also look at butcheries with some flies in them because no flies seen around is a bad sign. Houseflies cannot be attracted to meat with poison (referring to chemicals) because they will die. So, they will settle only on fresh meat,* (Male consumer, Nairobi).

> *Most of us look at the flow of customers because you are likely to get fresh, good quality meat from a butchery with many customers,* (Male consumer, Nairobi).

Other techniques used to assess food safety included clot on boiling for milk and observing unusual changes during the cooking process.

> *After buying milk, you need to heat it a little, if it starts curdling then you know it has a problem. Even by boiling, the bacteria are killed,* (Male consumer, Nairobi).

> *There are places where meat is injected (applied with chemicals) and they turn red. So this meat once you buy and go to cook, it produces foam that fills the cooking pan, when you see this just leave that meat,* (Male consumer, Nairobi).

A simple flow chart was used to describe the food supply chain from suppliers to consumers and describe practices that compromise food safety, as reported by consumers and vendors (Figure 3). At the farm level, the reported malpractices were mostly associated with ASF. Fraudulent behaviors were most notable at the vendor level and were said to be driven by desire for increased profits. Vendors could not trace product beyond their immediate supplier as also did not keep records of suppliers or buyers. Other than fraudulent behavior s, what was perceived to be poor handling practices by vendors was similar to poor practice reported at the consumer level.

Consumption of raw eggs for medicinal purposes or to boost immunity was reported in two groups. Other norms were linked to consumption of some ASF by pregnant women and children under the age of 5 years which was perceived to result in birth complications and interfere with growth of infants.

> *When women give birth, they are advised not to take certain foods like Omena (silver cyprinid fish) and certain leafy vegetables which will reduce breast-milk production,* (Female consumer, Nairobi).

> *There are these cultures in our community (Kamba). If you give meat to a child before they start talking, he or she will never talk,* (Female consumer, Machakos).

> *Pregnant women are not supposed to eat lots of eggs because it might result in complications of childbirth and the child will be overweight. This is commonly known*, (Male consumer, Nairobi).

Foods, hazards and illnesses of concern

FGD participants considered meat to be the food most likely to cause FBD. Most mentioned were ruminant meat, poultry, pork and

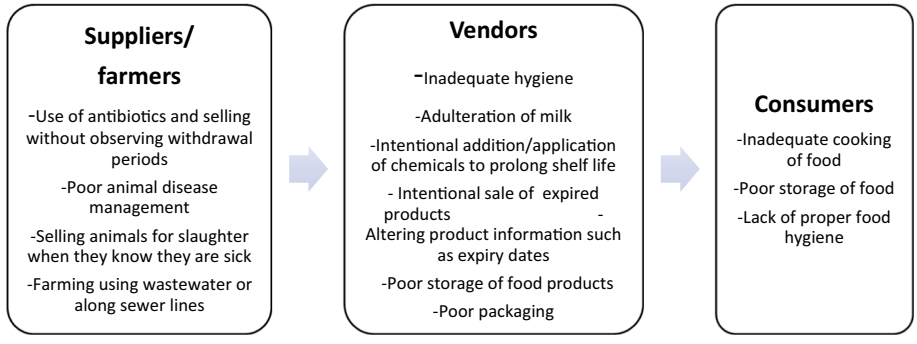

FIGURE 3
Practices that compromise food safety in the supply chain as reported in FGDs.

TABLE 4 The top three dangerous substances possibly present in food.

	Nairobi			Machakos			
Group	Vendors		Consumers	Vendors		Consumers	
Gender	Female	Male	Male	Female	Male	Male	Female
Rank	Chemical	Chemical	Aflatoxins	Chemical	Chemical	Chemical	Chemicals
	Aflatoxins	Bacteria	Chemicals	Aflatoxins	Aflatoxins	Bacteria	Aflatoxins
	Bacteria	Aflatoxins	Bacteria	Bacteria	Bacteria	Aflatoxins	Maggots

traditionally processed meat products (including non-choice parts sold in kiosks and on the streets). The risk of consuming meat from diseased animals and uninspected meat carcasses was also reported.

Although cereals and tubers were thought to be less likely to cause FBD, deaths after consumption of cassava were mentioned. Naturally fermented milk (*lala*) was also linked to hospitalization and death.

> *There was also a case after taking mala (fermented milk) here … The people had diarrhea and died; they were from the same family. When the milk was tested, they said it was poisoning*, (Female consumer, Nairobi).

> *There is cassava* variety *that cannot be eaten when raw. There was a time when children ate cassava, and their stomach became bloated. They were taken to hospital, but two died*, (Female consumer, Nairobi).

For key informants, ASF (especially meat and milk), RTE foods, fruits and vegetable products, and grains (because of mycotoxins) were, in descending order, considered most risky.

Overall, consumers and vendors ranked chemicals as the most dangerous hazards in food (6 out of 7 FGD, see Table 4. One group could not participate in the ranking exercise because of time). By "chemicals" they meant substances used in agriculture such as herbicides and pesticides, insecticides used in preservation of cereals, drug residues from animal production, and other unconventional chemical additives fraudulently added to food such as borax or formalin which are used to preserve milk. Maggots (*mienya* in the local language) in rotten meat, milk adulteration with water, flour or margarine and contamination resulting from farming along sewer lines were also considered to be risky.

Aflatoxins were ranked second. Their occurrence was linked to mold growth *(mbuka)* in maize that had not been dried properly. Bacteria were mentioned in third place and maggots fourth (mentioned by only one group). There was little difference regarding the perception of dangerous substances in foods across the different categories of FGD (consumer/vendor, men/women, rural/urban).

> *We have some customers who will inquire if something has been added in the milk. When you hear this, you know they are asking about added chemicals like formalin which is used in preservation of dead bodies. When formalin is added to milk, the milk cannot spoil. Even broiler carcass is injected with formalin so that it does not spoil. As for meat, if you do not see flies, then know that the meat has added chemicals*, (Female vendor, Machakos).

> *There is also meat that we can buy that has stayed too long in the butchery so when you cut, you find it has some maggots and has rotten and changed colour to greenish… This when eaten can affect you*, (Female consumer, Nairobi).

Allergens in ASF were mentioned by female participants as possible causes of FBD, however, this was not ranked as priority. Key informants prioritized microbial hazards as the main cause of FBD. Microbial hazards were associated with death in one case.

> *So, most of it (cause of FBD) is microbial hazards, due to poisoning, whether you are taking something raw or cross contamination or because of post processing contamination. Last year, towards the end, we had a serious (case of) food poisoning from colleagues in one department who went for a retreat, and the food was provided through external catering service. What they did not know is handling, which could have encouraged growth of microorganisms, unfortunately, one person died. So, it is a serious case,* (Key informant, academia).

The priorities, according to the KIIs were microbial hazards, mycotoxins, followed by chemical hazards such as heavy metals (in fresh produce), and lastly other naturally occurring toxic compounds such as cyanogen and glycoalkaloids.

Consumers and vendors considered diarrheal diseases, specifically, typhoid and cholera to be common in their communities. Typhoid was said to be associated with food contamination, while cholera was associated with poor water and sanitation. Brucellosis, malaria, diabetes, hypertension, gout and stomach ulcers were also mentioned as foodborne illnesses among consumers and vendors.

Diarrhea, vomiting and gastro-intestinal related symptoms were commonly mentioned in relation to food. Sometimes, these symptoms were thought to be as a result of consuming with fatty foods. Chemical hazards in foods were perceived to be associated with diarrhea episodes and cancer.

> *Chicken can also have a lot of oil which can cause diarrhea.* (Female consumer, Nairobi).

> *Sometimes, they (traders) are supplied with vegetables which are sprayed with chemical, and the withdrawal period has not been observed. When these vegetables are consumed the people become ill…they experience gastrointestinal illness,* (Key informant, market management).

Foodborne diseases in the community (apart from cholera), were considered to occur sporadically rather than as outbreaks. For the most part, FBD were not taken very seriously, most cases were not reported and did not receive a diagnosis. For participants who reported a diagnosis, this was likely to be food poisoning with no attribution to a specific agent or food. However, in three instances (two in FGDs, one in KII), there was mention of serious illness and death as a result of consumption of contaminated food (as quoted earlier).

> *The (foodborne disease) cases we have experienced in this area have not been very alarming. What we have experienced are cases where 5 to 10 people are affected, or others as individual cases, which are easily managed at the hospital, but we have not had outbreaks that have affected many people in the community*, (Key informant, administration).

There seemed to be no consensus on population groups most likely to be affected by FBD. However, children and women especially pregnant women were mentioned to be more vulnerable due to low immunity. Men were also mentioned to be more at risk, mostly due to their habit of eating away from home.

> *Those that are affected most are men of the mid-age because they move around a lot. First and foremost, they depend more on food joints along the streets than home-made food. When they leave home in the morning, they will come back late in the evening, so they must eat out during the day. Even at the hospital, most of those who come in with those complaints are men. Another reason why men may be more affected is because of mix-up with other things like alcohol,* (Key informant, administration).

Challenges and opportunities for food safety

Among key informants, food handling practices were perceived to be poor and the capacity to conduct food business hygienically as limited. On the other hand, most vendors thought their practices were adequate for food safety. Vendors reported that they had done their part by stating, "We have tried," and perceived other stakeholders to be more responsible for the poor practices. Improvements on hygiene and sanitation in the markets were observed during the COVID-19 pandemic period. However, these practices were said to have since slacked off.

> *This (handwashing) has reduced, since COVID-19 cases went down. Those practices have been neglected very much, unlike before (during the period of COVID-19 pandemic). You may find the hand washing container or sanitation facility is there, but they are not utilizing it. We (public health department) used to (conduct trainings), but we have not had them after COVID-19 went down. During the COVID pandemic we conducted the forums, from time to time we could visit the markets and talk with the vendors. But this reduced thereafter. Right now, there are many activities that we are engaged in, and because of that we miss getting to the markets*, (Key informant, public health).

Within governmental departments, insufficient personnel in relation to the number of food businesses was said to have constrained inspection, surveillance, and training for improved food safety. Even in this case, there seemed to be less interaction and the relationship between market agents and the authorities was constrained.

> *I can say knowledge is not there, because they (food handlers) have nobody to train them,* (Key informant, milk traders association).

> *(Authorities)…we do not want them to come and manage us…they are not friendly and use a domineering approach which is not welcoming. Some will approach you well, but others do not. They only come for enforcement and do not give room for negotiations, because of that there is always tension*, (Key informant, market management).

In both FGDs and KIIs, lack of infrastructure to support hygiene in the markets was also commonly mentioned as a key constraint. In particular, water and sanitation facilities were perceived to be inadequate, and where present they were considered either inaccessible or poorly maintained. Market structures such as shades and platforms to display products were reported to

be missing and space to allow vendors conduct their business was said to be inadequate. This forced some vendors to move to places not designated for business (e.g., on streets and next to roads). Nonetheless, some vendors were said to prefer trading on the streets even when they had secured spaces for business within designated market grounds and this was said to offer unfair competition.

> *In my opinion, there are several issues related to handling. We are not yet there, and our markets are not very well established, and access to basic sanitation is not always guaranteed. Therefore, we cannot guarantee the safety of foods based on how they are handled,* (Key informant, public health).

> *Some of those trading by the roadside have rented stalls within the market area. Some of them do this by copying those who are there. Some of these traders come from other markets within the city. They believe that trading just close or at the entry of the markets will attract buyers coming into the market, since the same goods they sell are the same ones being sold inside the market, for that reason, some may not be willing to move from the roadside*, (Key informant, market management).

Several stakeholders could not distinguish clearly between regulators (institutions involved in food safety control) and regulations (the regulatory framework that guides and controls food safety), thus these two were used by the respondents interchangeably. Where regulatory framework was mentioned, specific policies and regulation on food safety in informal markets was missing. Public Health Act (2012) (which covers regulation of diseases of public health importance, including infectious diseases) and Food, Drugs and Chemical Substances Act (2012), Chapter 254 (which covers control of chemical substances including food and food additives, cosmetics and drugs), were mentioned by key informants as the only references for food safety regulation. These were considered broad and barely cover the needs of multiple stakeholders, and complex value chains in an informal market context.

> *Let me give you an example, this Act you find in the Public Health Act CAP 242, says you should not sell unwholesome food in the market. Full stop. That's an act. Unwholesome food can mean a lot of things we have talked about, but how do you apply unwholesome food to vegetables? How do you apply this to tomatoes? How do you apply it to meat and milk? How to apply it!* (Key informant, research).

Another key informant observed that food safety mandate was a devolved function in Kenya which lies upon county governments, who adopt policies and regulations from national governments. Where these are insufficient, the county governments are mandated to supplement by setting up complementary regulations. Although some local governments were said to have developed these regulations, implementation and enforcement remained a major bottleneck.

> *The only law that we have that regulates the market is the Public Health Act. Cap 242, that's the one that is applicable across. But looking at the wet markets, the applicability has to be supported by more regulations, which the Nairobi County had developed, but implementation is lacking,* (Key informant, food safety consultant).

A scientist who had conducted research on FBD in informal markets thought food safety had not received the attention and investment it deserves. They pointed out food safety and FBD as not salient in the global 2030 Sustainable Development Goals which is the main agenda for global development. Inadequate policies, poor enforcement of regulations, and the low levels of investment by governments, further demonstrated this neglect of food safety.

> *We set up the sustainable development goals in 2015. And it has taken the international community close to 6 years…for them to realize they will not achieve majority of those goals. Why? They forgot the most important component for safety… If you look at the indicators which the governments are tracking, there is no indicator that is tracking food safety. There is not…they have indicators for other things but not food safety,* (Key informant, research).

A food safety expert opined that quality and price drive food purchase behavior and patterns, and less demand for food safety by consumers created no incentive for supplying safe food. Other experts suggested that vendors and consumers alike seemed to care little about food safety thereby creating no push for stakeholders to take responsibility as they should.

> *I found out two things; some people are aware of the hazards and the risks. But they do it anyway because the consumer does not care… The third gap is that also the consumer does not demand food safety. I'm not sure whether it's because of lack of alternative, because if I do not buy from the food vendor then where would I go? That lack of alternative can make me continue buying from this food vendor…If the consumer could demand more safe products… that would push the vendors to better places,* (Key informant, food safety consultant).

In order to address the gaps, several approaches were discussed including provision of infrastructure (such as providing grounds to carry out trading, market shelters/shades, hygiene and sanitation infrastructure and provision of water); capacity building through training, increased workforce to support surveillance; and review of food regulations and compliance. The national and county governments were thought to have a role in provision of the required infrastructure.

A public health officer highlighted the need to consider multisectoral collaboration in efforts to improve food safety in the markets, given the involvement of multiple agents. As the 'on-ground' change actors, traders and market management proposed inclusivity in decision making.

> *It is impossible to find solutions to these challenges from a single institution. Therefore, collaboration and multi-stakeholder engagement is required. Traders themselves, government and non-government institutions should be involved to come up with workable solutions,* (Key informant, public health).

> *We need to have good relationships between county government and the traders. This can be done if they could include us as part of the committee meetings on issues that relate to us… That way, there will be smooth flow of ideas and knowledge between the top stakeholders and the traders,* (Key informant, market management).

Political will and leadership were perceived important in fostering cooperation and collaboration between the multiple sectors. As in the case of informal markets in Kenya, the county governments seemed to take the oversight role across the various sectors involved in the markets and fostering working relationships.

> *We have NEMA(National Environment Management Authority) because of waste, Nairobi Water and Sanitation because of sewage and sewer system, county government like ward administration. Revenue Research Topic is done by the County Government… Like Nairobi water, in case of any malfunction I always call them, and they respond very fast. Ward administration (local administration office) they give support when necessary … the Governor has encouraged us to work as a team,* (Key informant, public health).

Discussion

This study confirms informal retail outlets as important accessible markets for smallholder farmers, and a source of employment for many, especially women. This is in accordance with the findings of Blackmore et al. (2020) and Global Alliance for Improved Nutrition (2020). Unlike in other LMICs (Grace et al., 2019; Nga et al., 2022), there were few female meat vendors in our study; male domination in meat value chain in East Africa has been reported earlier (Murungi et al., 2021). However, there were more women engaged in the sale of milk and fresh produce.

A wide range of foods were found to be sold in and around public markets. Of these, un-branded and un-processed (or minimally processed) foods predominated. Among processed foods, traditional foods (*lala, mutura, dried fish products*) and cooked foods were more common than modern foods (pasteurized and packaged milk). Previous decades saw many predictions that traditional foods and markets would be rapidly replaced by modern retail in LMICs. Our study shows the continued importance of informal markets, which has also been reported by other authors (Roesel and Grace, 2014; Blackmore et al., 2020).

Consumers are seen to prefer local products in traditional markets and on-farm purchase for freshness and ability to understand the food source (Wertheim-Heck et al., 2019; Brown et al., 2022). However, as the food system expands and the link between producers and consumers becomes complex with many actors and middlemen involved, food traceability diminishes (Jaffee et al., 2019). This complexity presents numerous opportunities for food contamination, thus making it difficult for consumers to understand and trust the source of food (Liguori et al., 2022).

The finding that vegetables, fruit, ASF, and RTE are more consumed in cities has been often reported by others (Smith et al., 2006; Cockx et al., 2019). There has been increasing concern about processed and ultra-processed food (Reardon et al., 2021) and double burden of malnutrition in developing countries (Onyango et al., 2019; Popkin et al., 2020). However, the predominance of fresh, un-processed food is a strength of traditional markets, providing diverse food options for better nutrition.

Vendors and consumers did not clearly distinguish between food quality and safety and appeared to equate freshness to safety. Because of this, physical attributes were mainly used to judge the freshness and hence safety of food. This has been found to be consistent in other parts of Africa (Global Alliance for Improved Nutrition, 2022), as well as Europe (Van Rijswijk and Frewer, 2008). While physical assessment is a first step, this alone cannot be sufficient for food safety assessment (Bukachi et al., 2021).

In addition, and partly because of the confusion with freshness, it is difficult to disentangle the importance given to food safety. Food safety is thought to be a less salient choice motivator in food purchases in LMICs. Instead, price, quality, vendor reputation and social ties are seen to drive purchase decisions among consumers (Liguori et al., 2022; Isanovic et al., 2023). However, other studies report high levels of concern: in Vietnam, food safety was considered the single most important issue ranking higher than employment (World Bank, 2017).

Quality of food is seen to be important among consumers, and refrigerated foods is associated with a lack of freshness (Wertheim-Heck et al., 2019). On the contrary, cold storage is important for maintaining not only quality but also safety of food by retarding microbial growth, thus preserving the keeping quality (Mercier et al., 2019). However, some spoilage and pathogenic microorganisms can grow at chilling temperatures (Jordan and Mcauliffe, 2018), therefore longer refrigeration or storage of already contaminated food can do more harm than good. Temperature fluctuations, common in LMICs due to load-shedding, can also make the food unsafe (Fahrion et al., 2013). With lack of cold storage in most households, food leftovers were reported to be stored at room temperature and consumed the following day, sometimes without proper heating. However, this was not mentioned as a probable cause of FBD in the FGDs, even though left-over food is one the known causes of foodborne illnesses (Pigott, 2008).

Among some consumers in Kenya, flies on meat were considered a sign of freshness and showed meat was not preserved by chemicals (and hence safer). In 2017, an *expose'* on use of chemicals to preserve meat received wide publicity in Kenya (Chege, 2017), which could have caused escalated concern among consumers over chemicals applied on meat. In Nigeria and Uganda, consumers associated flies in food service areas with poor hygiene and as a source of contamination (Heilmann et al., 2016; Nordhagen et al., 2022). In contrast, consumers in Cambodia considered pest damage on fresh produce a sign that chemicals had not been used (Brown et al., 2022). As food systems develop and intensify (Jaffee et al., 2019), and consumers become more urbanized and educated, concerns over dirt tend to decline and worry over chemicals increase.

In Africa as elsewhere, there has been a high level of concern over chemicals in food (Kher et al., 2013; Yeung and Morris, 2015; Bukachi et al., 2021; Amenu et al., 2023). However, food safety experts consider risks from chemical residues and additives relatively low (van der Vossen-Wijmenga et al., 2022) and much less important than biological hazards (Havelaar et al., 2015; Grace et al., 2018; Mutua et al., 2021). Food safety experts interviewed in our study also considered biological hazards more important. Pesticide residues in fresh vegetables have been evaluated in Kenya and other parts of Africa (Kunyanga et al., 2019; Dinede et al.,

2023; Dione et al., 2023), and while residues are often present, the risk to consumers has been considered to be low (Omwenga et al., 2021).

Aflatoxins were perceived to be a concern in the study areas, partly owing to inability to discriminate between hazard and risk (Barlow et al., 2015). The Foodborne Disease Burden Epidemiology Reference Group (FERG) found aflatoxins to be responsible for only 1% of the foodborne disease burden in Africa (Havelaar et al., 2015; Gibb et al., 2019). Studies have shown that consumers tend to over-estimate risks of low probability but high severity (Slovic and Peters, 2006; Kher et al., 2013). This is seemingly true in this case, after the notorious and lethal outbreak of aflatoxicosis in Kenya that led to 125 deaths in 2004, due to consumption of contaminated maize/maize products (Lewis et al., 2005). Notably, part of this study was conducted in Machakos that falls in the Eastern region of Kenya, which has been a hotbed of aflatoxicosis.

Lay people are likely to misperceive foodborne illnesses to be malaria or other febrile illnesses. "Typhoid," "cholera" or "poisoning" have been used in Africa as generic names for diarrheal illnesses and other FBD which rarely receive an etiological diagnosis, leading to under-estimation of FBD (Nordhagen et al., 2022). Aside from misdiagnosis, poor reporting systems and ignorance also leads to underestimation of FBD (Grace, 2015, 2017).

Key informants, some of whom were experts in food safety, mentioned meat, fresh produce and milk value chains as most risky. ASF and fresh produce though important for nutrition, have been reported to account for the greatest proportion of DALYs related to microbial hazards (Hoffmann et al., 2017; Grace, 2023). This has also been confirmed by food safety experts (Grace et al., 2018). Raw milk especially is known to be an important source of protein in many households in Kenya, forming part of the basic diets for infants and children. It is readily accessible and available at affordable prices in the informal outlets, making it a protein of choice for many low-income households (Mtimet and Karugia, 2020; Muunda et al., 2023). However, evidence shows that milk safety in Kenya has been poor, and milk and dairy products shown to be contaminated with bacterial pathogens as well as aflatoxins (Kang'ethe et al., 2007; Kuboka et al., 2019; Hoffmann et al., 2022). Although raw milk is typically boiled before consumption, it has been associated with diarrheal cases in children (Hoffman and Baral, 2019), which may be as a result of post-process contamination (Kilango et al., 2012).

On the other hand, meat, though reportedly less frequently consumed in this study, was associated with foodborne diseases, especially diarrhea. Heightened concern for meat safety has been observed previously, and this was related to the source and handling of ruminant meat and its products (Bukachi et al., 2021). Leafy vegetables were reported to be consumed more because they were considered affordable, readily available and an important accompaniment for most cereal-based dishes. However, vegetables eaten raw as salads and popularly served alongside cooked meat dishes, are known to harbor microbial pathogens, (Ndoboli et al., 2018), though this was not perceived as a risk by vendors nor consumers.

The belief of birth complication in pregnant women and abnormal growth in infants associated with consumption of ASF would instead prompt a shift towards consumption of other foods such as fresh fruits and vegetables products which are equally risky, or staples such as maize, prone to mycotoxin attack (Grace and McDermott, 2015), or packaged and ultra-processed foods with less nutritional benefits (Trübswasser et al., 2021).

Sanitation and hygiene infrastructure is essential for food safety, and their absence or inadequacy was frequently mentioned as a constraint to food safety. Despite facilities like water and handwashing stations being freely provided in some markets, these were not used as expected, were unmaintained and there remained a challenge in sanitary and hygiene practices. It is evident that providing sanitation and hygiene infrastructure alone does not guarantee proper practices. Motivation and incentives that influence behavior and promote food safety practices are required (Arendt et al., 2015; Grace et al., 2019).

National governments are mandated to ensure that the food available in the country is fit for human consumption. In Kenya, the food control system is fragmented with multiple institutions involved with overlapping mandates (Gathura et al., 2020). Food inspection has focused more on the formal and export sector as policymakers promote modernization of food systems in the belief that these will provide safer food (Jabbar and Grace, 2012). Concern about the safety of food sold in informal markets has been expressed, however, penalizing informal food business operators can negatively impact on livelihoods, causing inequities in society and even paradoxically worsening food safety. Improving food safety requires distinctive policy investment which appreciates that different informal settings and value chain players have specific and differentiated needs (Jaffee et al., 2019; Henson et al., 2023).

The solutions discussed by the participants are in line with those recommended by Hoffman and Baral (2019) and Grace et al. (2018) to reduce FBD burden in LMICs. This entails investment in food safety through public investment, private partnerships, and prioritization of hazards. However, opportunities discussed did not consider motivation for behavioral change or importance of consumer demand considered essential for food safety (Grace, 2023). For successful and sustainable solutions for food safety in the informal supply chain, it is imperative that awareness campaigns and simple technologies are integrated along with other initiatives that build on infrastructure and incentives (Henson et al., 2023).

Informal markets present a unique setting with the interaction of human, animal and environmental factors. Multiple players are also involved in the food system. These include national and municipal governments, veterinary and public health departments, researchers, industries, environmental bodies, private institutions, small-scale producers, business operators and vendors involved in distribution, wholesale, and retail sale of food products. This calls for a one health approach in providing holistic and sustainable solutions to improve food safety (Garcia et al., 2020). Inclusion of all stakeholders is crucial in ensuring the success of food safety efforts (Grace et al., 2019). Additionally, this demands for creation of synergies in roles and responsibilities, guided by elaborate, up-to-date policies and regulations contextualized for the informal market environment (Oloo, 2019).

Risks related to chemical hazards were most dreaded by consumers, likely because of massive media coverage, lack of knowledge and the likelihood of causing severe harm (Kher et al., 2013; Yeung and Morris, 2015), even though studies have shown that biological hazards are of more concern because of the burden of disease they cause. Risk communication can help in the framing of messages to address these concerns by consumers (Sato, 2015).

Conclusion

Informal markets remain to be an important source of food for many. However, our study reveals that food safety is yet to achieve prominence among primary players in these markets including vendors and consumers. Instead, other factors such as food quality, economic and social factors take precedence over food safety. Some perspectives driving food purchase decisions were found to be misinformed and could result in risk to human health. Awareness creation and building capacity through knowledge is important to demystify these misperceptions. Critical gaps have been highlighted, which can be addressed by integrating interventions efforts that include sanitation infrastructure, low-cost technologies and incentives for behavior change, while considering a multi-stakeholder approach for sustainability. Insights from this study are useful and can be used to build on further research that seeks to understand food safety behaviors and practices and how these can be influenced to reduce the burden of foodborne disease in LMICs. The results are of importance when developing policies and interventions for food safety in informal food market settings.

Limitation

The study was conducted in two public markets in Kenya and involved a limited number of vendors and consumers sampled from the market areas, as representatives for the general population. Generally, there were fewer female meat vendors, as the food chain is more male dominated. Because of this, female vendors of meat were less represented, while female vendors for fresh produce and cereals were overly represented. However, involvement of other stakeholders in the food chain, such as government officials and food control agents as key informants and validation of the findings through workshop was important for triangulation and to augment the general information.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by ILRI - Institutional Research Ethics Committee (reference ILRI-IREC2019-24/3) and the National Commission for Science, Technology & Innovation, (NACOSTI/P/22/21317). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. DG: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing. KA: Conceptualization, Supervision, Writing – review & editing. JL: Conceptualization, Supervision, Writing – review & editing. GC: Conceptualization, Supervision, Writing – review & editing. FM: Conceptualization, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

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

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Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1411318/full#supplementary-material

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Consumption of unsafe food leads to foodborne diseases (FBD), which cause economic and productivity losses in many countries. The East African Community bears a high burden of FBD, yet there is limited evidence on the food safety status in the region. This thesis uses an integrated approach to investigate food safety in informal markets, the main sources of food in the region. The findings are important for informing risk characterisation and intervention strategies to reduce the prevalence of FBD.

Maureen Kuboka received her doctoral education at the Department of Animal Biosciences, Swedish University of Agricultural Sciences. She obtained her B.Sc. and M.Sc. degrees at the University of Nairobi, Kenya.

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