The Role of Pork Meat Traceability and Processing along the Value Chain to ensure Meat Safety from Farm to Fork in KwaZulu-Natal Province, South Africa

BY

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Declaration

I, Progress Mnqophiso Sodella, declare that this dissertation has not been submitted to any institution and is my original affiliated with the Discipline of Animal and Poultry Science, School of Agricultural, Earth and Environmental Sciences within the College of Agriculture, Engineering, and Science at the University of KwaZulu-Natal in Pietermaritzburg, South Africa. Work conducted under **Dr Zikhona Rani-Kamwendo's** supervision. The research was approved by the University of KwaZulu-Natal research ethics committee (**AREC/00007480/2024**). The study's contents have not been presented in any manner to another university, and unless explicitly acknowledged in the text, the reported results are attributed to the investigations conducted by the candidate.

Signed …[redacted]**.** **Date: 03 February 2025**

Progress Mnqophiso Sodella (Candidate)

As supervisor of the candidate, I agree to the submission of this dissertation.

Signed: … [redacted]**…** **Date: 05 February 2025**

Dr Z. T. Rani-Kamwendo

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General Abstract

Meat safety remains crucial to public health, consumer confidence, and economic sustainability in the livestock sector. This study evaluated the role of meat traceability and processing along the value chain to ensure meat safety from farm to fork in KwaZulu-Natal, South Africa. The research investigated key factors influencing meat quality, including on-farm animal management, pre-slaughter handling, microbiological safety, and consumer perceptions of meat from informal markets. By adopting a multidisciplinary approach, the study identified contamination risks, and proposed strategies to enhance transparency and accountability within the meat industry. Microbiological analysis, observational studies, and consumer surveys were conducted to determine the influence of farm management, transportation, and slaughterhouse practices on meat safety. The findings highlighted critical contamination points within the supply chain, particularly in feed, water, faeces, and carcass handling. Poor hygiene practices, environmental management, and inadequate biosecurity measures were identified as significant contributors to microbial contamination, including pathogens such as *Escherichia coli*, *Salmonella*, and *Staphylococcus aureus*. The study further explored the impact of pre-slaughter stress on meat quality, emphasizing that poor handling, rough transportation conditions, and inadequate animal welfare practices resulted in physiological changes that compromised carcass integrity and increased microbial load. An essential focus of the research was the role of traceability systems in ensuring meat safety. The study revealed that while commercial supply chains have structured monitoring mechanisms, informal meat markets often lack regulatory oversight, making them highly susceptible to contamination and foodborne illnesses. The absence of standardized record-keeping and quality control measures in these markets poses a significant challenge to consumer health and food safety compliance. To address these challenges, the study recommended an overall approach incorporating improved farm management, robust biosecurity protocols, optimized transportation systems, and enhanced slaughterhouse hygiene. Additionally, consumer education and awareness programs are necessary to promote demand for safe meat products and encourage compliance with meat safety regulations. The findings emphasized the need for cost-effective traceability technologies that can be adopted in both formal and informal markets to enhance food safety and consumer confidence. It was concluded that strengthening the meat value chain through the integration of traceability, improved handling practices, and regulatory enforcement is vital for reducing contamination risks and ensuring sustainable meat production. Future research should explore innovative and affordable traceability solutions tailored for small-scale and informal markets, while also investigating alternative strategies to mitigate pre-slaughter stress and microbial contamination. By addressing these factors, the meat industry can enhance resilience, protect public health, and support the economic viability of meat producers and retailers in South Africa and beyond. Overall, this study demonstrates that strengthening the meat value chain through the integration of effective traceability systems, improved management practices, and stronger regulatory enforcement is essential for reducing contamination risks, ensuring meat safety, and promoting consumer confidence. The findings offer valuable guidance for developing practical interventions that can enhance the resilience and sustainability of both formal and informal meat markets in KwaZulu-Natal.

Keywords: Meat traceability, food safety, microbiological contamination, animal welfare, pre-slaughter stress, supply chain, consumer perception, informal markets, biosecurity

Dedication

This dissertation is dedicated to my late mother **Gertrude Vangile Sodella** (maGcina), though a car accident changed your life, it never diminished your spirit. You raised me with unwavering love and determination, teaching me that no challenge is too great when faced with courage. Your wisdom and sacrifices you made to ensure I have a bright future are the foundation of my life today. I'm forever grateful for the life lessons you instilled in me, and I will carry your legacy of perseverance and love in all that I do. You sharpened my future as if you knew that your time on earth would be shortened, and prepared me, for that, I will be eternally thankful. Continue to rest in peace, knowing that your light continues to guide me every day.

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Thesis Outputs:

Progress Mnqophiso Sodella, Zikhona Theodora Rani-Kamwendo, Mthokozisi Mzuzuwentokozo Buthelezi. A Systematic Review on the Impact of Pre-Slaughter Handling, Stress, Animal Welfare, and Traceability from Farm to Abattoir on Meat Quality and Food Safety. Submitted to the Sustainability Journal, Journal of Food Safety and Quality (Under review)

Conferences and articles in preparation for publication

Progress Mnqophiso Sodella, Zikhona Theodore Rani-Kamwendo: Assessment of microbial load in feed, water, and feaces and their interconnected roles in the pig production chain to ensure production efficiency, animal welfare, and meat safety along the value chain

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List of abbreviations

GIT	-	Gastrointestinal Tract
COD	-	Chemical oxygen demand
WHO	-	World Health Organisation
FAO	-	Food and Agricultural Organisation
APC	-	Aerobic Plate Count
APC	-	Plate Count Agar
RVS	-	Rappaport Vassiliadis Soy
MKTTn		Muller-Kauffman Tetrathionate Novabiocin
XLD	-	Xylose Lysine Deoxycholate
MPN	-	Most Probable Number
PBW	-	Peptone Water Buffer
SAPPO		South African Pork Producers Organisation
MAP	-	Modified Atmospheric Packaging
WHC	-	Water Holding Capacity
LMP	-	Lean Meat Percentage
FMD	-	Foot and Mouth Disease
KZN	-	KwaZulu-Natal
SA	-	South Africa
AI	-	Avian Influenza
DFD	-	Dark, Firm, and Dry
PSE	-	Pale, Soft, and Exudative
EC	-	E.Coli

FC	-	Fecal Coliform
TC	-	Total coliform
SAPPO		South African Pork Producers Organization
SD	-	Standard Deviation
RFID	-	Radio Frequency Identification
DAFF	-	Department of Agriculture, Forestry, and Fisheries
MSA	-	Meat Safety Act

Chapter 1: General Introduction

1.1 Background of the study

The Consumer Protection Act (Act No.68 of 2008) provides consumer protection regarding labeling, and it enforces the origin and production process of food products, including meat (Viswanathan 2008). The traceability aspect of this act ensures that consumers have access to information on the source of their food. Due to the increased lack of trust and fatal incidents that have occurred recently in most societies in South Africa related to food safety (Boatemaa *et al.* 2019) consumers are susceptible to food production conditions, and traceability can assist companies and retailers in increasing consumer trust. The main challenge this research aims to address is the lack of transparency within the meat industry's internal processes, transparency in the animal's life from the moment of its birth, following the value chain, and transparency towards the consumer.

Traceability refers to the ability to use a unique identifier to follow the movement of food products and their ingredients through every step of the supply chain. Meat traceability starts on the farm with the animal, and obtaining information about what the animals are fed is crucial for meat production. (Ren *et al.* 2022). According to Yu *et al.* (2022) meat traceability ensures quick identification of the sources of contamination in the case of foodborne illnesses while allowing for rapid recalls and minimizing consumer risk. However, an important aspect of meat traceability significantly impacting consumer health is the risk of pathogen contamination. Between the years 2017-2018, South Africa experienced an outbreak of processed meat contamination known as

Listeriosis, which affected infants, pregnant women, and individuals with weakened immune systems (Kaptchouang Tchatchouang *et al.* 2020).

Processed meat products were recalled from local enterprises due to the outbreak. This also affected South African meat exports as deaths and illnesses were recorded in the country resulting in economic losses. The outbreak imposed a negative effect and resulted in vast economic losses to the meat industry and the South African health department. According to Tabit (2018), Listeriosis is one of the severe foodborne diseases that has a mortality of 20-30%. A total of 172 deaths and 915 cases were reported as the largest in the country and worldwide (Marquis *et al.* 2015). The public was encouraged to follow the World Health Organisation's five keys to safer food which are the basic commandments that individuals should be aware of: 1. Keep Clean, 2. Separate Raw and Cooked, 3. Cook Thoroughly, 4. Keep Food at Safe Temperatures, 5. Use Safe Water and Raw Materials (Mwamakamba *et al.* 2012). These keys have been put in place to protect consumers against foodborne diseases. Consumers generally perceive meat traceability as an essential factor in ensuring the safety and quality of the products they purchase (Gellynck *et al.* 2006, Yuan *et al.* 2020). Nowadays, consumers are very critical about their health and the style of living continues to change. Therefore, providing transparency and security to customers who require healthier products with high quality and the best nutritional characteristics is important as this ensures consumer trust in producers. With the increasing societal need for guaranteed food quality and provenance, traceability has been considered an important tool for all stakeholders along the food chain (Trienekens *et al.* 2014). This is important for consumers as they lack knowledge of the detailed steps involved in processing during food production. Consumers need to be assured of food safety and consistent quality. The need for traceability could be strengthened by the increased food calamities that have called for massive food product recalls (Adam *et al.*

2016, Haleem *et al.* 2019). It is crucial that all the stakeholders in the production chain must comply with consumer demands and legislation. Compliance with traceability standards is critical in the meat industry to ensure the safety and quality of food products. It helps maintain public health and enhances consumer confidence by providing transparency and accountability throughout the supply chain. Compliance with traceability systems means that each step from the farm to processing, packaging, and distribution is properly monitored and documented, ensuring that any potential risks, such as contamination or mislabelling, are minimized or quickly addressed. For example, in 2002, the European Union introduced the European General Food Law which aims to trace back products to their origin. Moreover, this could optimize the business process of the value chain to improve efficiency and minimize lead times as well as food waste (Van der Vorst 2006).

Effective traceability supports the rapid identification and withdrawal of unsafe products from the market, limiting the scope of foodborne disease outbreaks and reducing public health risks (Marvin *et al.* 2009, Singh and Puniya 2024). International standards, such as ISO 22005:2007, provide a structured framework for implementing traceability systems, requiring the documentation of product flows, unique identification of batches, and systematic record-keeping across all stages of the supply chain (ISO 2007). These systems are not only crucial for compliance with regulatory bodies but also form a key part of quality assurance and third-party certification programs. In developing economies, where informal markets dominate the food sector, adopting basic traceability practices can be a transformative step toward improving food safety, protecting consumers, and opening access to higher-value markets that require proof of product origin and safety compliance. Therefore, fostering compliance with traceability standards is essential not just for public health protection, but also for enhancing market competitiveness and building a resilient, transparent meat supply chain

In South Africa, meat that is sold to consumers is derived from commercial farmers through commercial abattoirs where meat handling is strictly governed by the Meat Safety Act of 2000. While the Meat Safety Act is robust in theory, implementation remains uneven particularly in informal meat markets and rural abattoirs, where resources, infrastructure, and enforcement capacity are limited. As such, informal sector compliance with the Act continues to be a significant policy and public health challenge in South Africa (Skinner 2018). However, the products are outsourced by both commercial retailers and informal traders from the abattoirs for market to consumers. The increasing competition between commercial retailers and informal traders could pose a significant challenge to traceability, as the majority of consumers in developing countries prioritize affordable meat (Ortega and Tschirley 2017). This increases the risk of consuming untested meat from informal traders entering the market, potentially compromising food safety and consumer health. Opara and Mazaud (2001) highlighted that traceability has its functions in the food value chain, this includes, 1. Risk management, 2. control and verification, 3. Supply chain management and efficiency, 4. Provenance and quality assurance of products, and 5. Information and communication to the consumer. Most countries do not have any regulations which have been put in place for street vendors, and this has impacted the food and nutritional security in developing countries (du Plessis and Gerrie 2012). Rani *et al.* (2017) suggested that street vendors and informal meat traders be educated about meat safety and handling for consumer safety and health. However, there is limited information on the healthiness of food produced by the informal sector since they are not traceable. In a study conducted by the World Health Organization (WHO) in Ghana, there were unacceptable levels of bacterial contamination from the samples collected from street vendors, in which only 511 food samples were within the acceptable limit (Mensah *et al.* 2002). According to FAO/WHO (2021) it was concluded that this could be due to a lack of knowledge about sanitary practices, such as water scarcity and vehicle pollution, which all play a part in the likelihood of street foods being prone to poor hygiene.

In South Africa and other developing countries, tracing the production chain of red meat may pose a challenge and uneasy access because the meat trade is either the formal or informal sector (Van Zyl *et al.* 2008). The meat trade from the formal sector is governed by the Meat Safety Act No. 40 of 2000, which allows for the traceability of red meat supplied to retailers. The formal sector has meat inspectors who approve meat before it is sold for human consumption, however, there is still a need to perform microbiological tests since the microbiological threat cannot be detected by the naked eye (Govender *et al.* 2013). The question with limited information usually imposed is, what could be done to improve the quality of meat supplied by the informal sector? The informal sector does not follow any measures to ensure meat safety, nor trace the origin of the meat provided to them (Adzitey 2011). With the world's population rate, there is an increasing demand for quality meat.

Many factors determine the quality of meat, this includes farm management of animals reared or grown to produce meat, transportation, and the activities that take place at the abattoir. Ferguson and Warner (2008) highlighted that meat quality is affected by pre-slaughter conditions, this effect could transpire during transportation (Vimiso and Muchenje 2013) and the slaughtering techniques used at the abattoir (Muchenje *et al.* 2009). Further to the methods used in the abattoir, at post-slaughter Rani *et al.* (2023) found a high microbial load in meat packaged and prepared for retailers. There is vast information that has been shared in relation to the effect of pre-and post-slaughter stages on meat quality (Chulayo and Muchenje 2013, Njisane and Muchenje 2016), however, there is a paucity of research on the impact of farm feeding. In addition, studies that focus on traceability of meat and its products from farm to fork are limiting. Hence, this study seeks to follow the whole value chain of meat production from farm to fork and incorporate traceability as the major element in the production chain. In South Africa, according to the Meat Safety Act No. 40 of 2000, the Minister may establish a scheme for the improvement of meat safety. Therefore, ways to enhance meat safety that will incorporate traceability assessment of meat along the production chain are encouraged. Hence the broad objective of the study was to investigate on-farm animal management practices and their influence on meat production and safety. In addition, the study aimed to assess the impact of animal selection methods and transportation from the farm to the abattoir, as well as the effects of pre-and post-slaughter handling on red meat safety.

1.2 Problem statement

A couple of factors that have been identified led to strengthened public inspection of the food value chain before being supplied to consumers. This could range from concerns about consumer food safety, the welfare of farm animals, the environmental and ecological impact of food production, and agro-processing has become increasingly vital. Alarming concerns about food poisoning and contamination, from the recent outbreak of a gram-positive bacteria referred to as listeriosis that affected processed meat (polony) have been raised (Olanya *et al.* 2019). Not only have reports of fatalities from this bacterium, but also from food poisoning due to *Salmonella* in poultry eggs, *Escherichia coli* contamination of meat and its products, and the occurrence of other emerging food pathogens which have reduced consumer confidence in the safety of food systems (Louwa and Van der Merwe 2020). Such situations are further worsened by the release of food products grown from genetically modified materials. These genetically modified materials are used to formulate animal feed, which affects animal welfare, for example, genetically engineered crops might express proteins that could cause adverse animal reactions (Aumaitre *et al.* 2002). This further affects the quality of meat. This increases the importance of the traceability of meat production from farms to retailers. As a result, there has been a concern about the use of growth promoters in animal feed formulation (Ronquillo and Hernandez 2017), which has resulted in a need for researchers to come up with reports declaring a threat to human health, which has been found to either affect consumers directly through residues of these growth promoters in meat or indirectly through the selection of antibiotic-resistant determinants. It is now a mandate for producers to be increasingly subjected to greater inspection of their meat production and post-slaughter handling practices. Due to fatal incidents that have been recently recorded especially those which are related to child fatalities, consumers are increasingly demanding greater assurance, transparency, and traceability in the production chain. There is still a great concern about the transparency and untraceable meat from meat producers especially retailers which could affect human health (Sander *et al.* 2018). Due to the fact that this may be because retailers have direct contact with consumers hence consumers tend to put their trust in them, and this could pose a risk to human health. It has been reported that insufficient knowledge about meat and its product handling to prevent microbiological contamination is a key factor contributing to bacterial contamination. Therefore, assessing the value chain through traceability could play a significant role in promoting consumer confidence in the food chain and producers. It could also assist in educating people about the importance of meat quality and safety.

1.3 Justification

Meat is an important source of protein for human consumption, and with the increasing number of formal and informal retailers, there has been an increased demand for the commodity. However, there is limited information about the origin of the meat that both retailers and consumers purchase from the producers. This study aims to follow the full value chain of meat production, from the farm to the abattoir and from the abattoir to the retailers. Due to increasing human population, the demand for meat is increasing, thus ensuring that consumers are served with quality and pathogen-free meat is important. By adopting this, it could assist to improve human health and the quality of meat produced in the country since some of the produce is exported to other countries. Several studies have focused on pre- and post-slaughter handling of meat (Adzitey 2011, Loudon *et al.* 2019, Njoga *et al.* 2023, Sullivan *et al.* 2022, Terlouw 2005), while a paucity of research focused on the effect of farm management and the welfare of animals (Chulayo and Muchenje 2015, Skaperda *et al.* 2019, Velarde *et al.* 2015). It is important to note that feed that is fed to animals plays a crucial role in the quality of meat that is produced. Hence, it is important to trace the value chain of meat production. This study suggests the importance of tracing the value chain of meat to cater for cleaner, healthier, and safer meat production.

1.4 Objectives

The broad objective of the study was to assess the role of red meat traceability and packaging along the value chain to ensure meat safety from farm to fork in the KZN Province of South Africa.

Specific objectives were to:

- Assess and review the Impact of Pre-Slaughter Handling, Stress, Animal Welfare, and Traceability from Farm to Abattoir on Meat Quality and Food Safety
- To determine consumer's attitudes and health risks aligned to meat safety in the informal meat markets

- Assess microbial load in feed, water, and feaces and their interconnected roles in the pig production chain to observe production efficiency, animal welfare, and meat safety along the value chain
- Examine the welfare and management of animals and their impact on meat production
- To assess meat safety along the value chain from post-slaughter to packaging in preparation for transportation to retailers

1.5 Hypothesis

Specific hypotheses tested were the following:

• Pre-slaughter handling, stress, animal welfare, and traceability practices significantly influence meat quality and food safety indicators (e.g., microbial contamination levels, pH, or consumer acceptability);

• Consumer attitudes and health risks aligned to meat safety in two informal meat markets were similar;

• Microbial load in feed, water, and feaces and their interconnected roles in the pig production chain to ensure production efficiency, animal welfare, and meat safety along the value chain were similar;

• The welfare and management of animals and their impact on meat production, to improve production efficiency, ensure animal well-being, and enhance the quality of meat products will be similar,

• Meat safety along the value chain from post-slaughter to packaging in preparation for transportation will be similar,

1.6 References

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Chapter 2: Literature Review

2.1 Introduction

Over the past decade, there has been an increase in demand for enough safe and nutritious food to sustain life and promote good health for the ever-increasing human population. Foodstuffs containing bacteria or viruses have caused over 200 diseases (FAO/WHO 2006), ranging from diarrhea to cancer. Unsafe food has also created a vicious cycle of disease and malnutrition in developing countries, particularly affecting infants, young children, adults, and patients. These foodborne illnesses enter the body through contaminated food, in which many foodborne illnesses may lead to long-lasting disability and death. According to FAO/WHO (2006) every year at least one in ten people gets ill by consuming unsafe food. The burden of foodborne diseases on public health and the economy has often been underestimated due to underreporting and difficulty in establishing causal relationships between food contamination and resulting illness or death. This has attracted the attention of researchers, raising many questions, especially about how the problem could be resolved. Of the foodstuff consumed, few studies focus on the pre-slaughter management of farm animals to yield healthy meat for human consumption. This involves on-farm activities and processes an animal undergoes before slaughter. Such processes take place on the farm, during transportation, lairage, and techniques used to slaughter. Although it takes a longer period to raise an animal to its desired age, weight, and quality, literature has reported that poor handling could bring change within a few days which would reduce their weight, thus affecting the characteristics of meat (Warriss 2000).

Pre-slaughter stress could be a result of bruises, injuries, starvation, tiredness, and handling during loading and offloading. Lawrie and Ledward (2014) found that when animals are subjected to increased stress levels, poor-quality meat is imminent. Poor handling at pre-slaughter could also result in broken bones, skin blemishes, and contamination by pathogens and PSE and DFD meat. A carcass with bruises may accumulate excessive blood which has to be trimmed off during processing (Lawrie and Ledward 2014), if not trimmed it could serve as a substrate for microbial growth causing meat spoilage earlier than normal. A Carcass containing broken bones may cause bone splinters in meat that would be dangerous to consumers if not detected during processing (Warriss 2000). Therefore, the main focus of the researchers should be on the farm to fork whereby the technology used in meat production and microbiological meat quality would be given attention at the production stage before slaughter (Rani 2015). When meat-producing animals are poorly handled, muscle glycogen could be depleted, which may result in higher pH (Kannan et al. 2002). It has been reported that meat with higher pH values is undesirable because of its dark color (Silva *et al.* 1999). Increased pH levels also promote microorganism growth, leading to bad smells. O'Neill *et al.* (2006) reported that pre-slaughter stress and the animal's physiological response to stress are the underlying factors contributing to glycogen depletion in animals and further affect the parameters of meat quality such as pH, tenderness, cooking losses, and color. Pre-slaughter stress has also been observed in fish by Digre *et al.* (2010) and Erikson *et al.* (2016) where a rapid decline in muscle pH accompanied by a more rapid onset of rigor mortis was reported.

There is still a need to educate people about on-farm handling of meat animals, loading before transport, and offloading to lairage. Animals that display less fear behavior, especially during routine handling and management at the farm are less likely to suffer during transportation or loading before transportation. An animal that is transported under stress could respond to stressors and that response results in decreased quality of meat (Mareko 2005). The quality of meat depends on the supply chain to which an animal is exposed (Birhanu 2020). Therefore, there is a need to measure stress levels in meat animals, especially in developing countries. Other developed countries have been using enzymes and hormones as proxy indicator of stress level (Lefcourt 1986, Schaefer *et al.* 1997). Several supplements have been used and found to reduce pre-slaughter stress, this includes Magnesium, Chromium Tryptophan, electrolytes, and vitamins (Birhanu 2020). However, these have been said to put human life at risk. The use of such feed additives could not be an easy task for developing countries, therefore, the best way could be to improve livestock management.

A good collaboration between researchers, producers, and consumers is needed to help ensure food safety and stronger food systems. In developing countries, live animals are sold to local or commercial markets or directly from farms to abattoirs for slaughter. However, there is limited literature on the effect of pathogens arising at the farm that could impact the quality of meat—for example, the length or period of feed and water withdrawal pre-slaughter. Any stressor could affect the conversion of muscle to meat and subsequently the quality of meat (Foury *et al.* 2011). The relationship between animal welfare, pre-slaughter stress, and meat quality has been a topic of increasing interest in recent years. As consumers become more conscious of ethical and sustainable food choices, understanding how pre-slaughter conditions, including those that reflect animal welfare, such as handling, transport stress, and lairage conditions, impact meat quality and safety is crucial. This literature review aims to explore the existing research on the effect of pre-slaughter stress and welfare on meat characteristics, as well as its implications for the overall consumer experience.

2.2 On-farm animal handling

2.2.1 Feeding and Housing

The farm animal growth performance that helps to yield quality meat depends on handling from the producers. This includes rearing conditions, feeding level, housing and environmental conditions, and production systems (Rosenvold and Andersen 2003, Terlouw 2005). Diets or feed are formulated based on previous research and are improved each time, the components of the feed are consequently readily transferred to the muscle and tissues, and these affect the quality of meat. Literature has shown that muscle glycogen stores seen during slaughter could be manipulated through feeding formulated feed (Rosenvold *et al.* 2001, 2002), however, there is also an effect of feed restriction that is applied to control the amount of fat deposited which affect meat quality. Lebret *et al.* (2007) reported a 27% decrease in growth rate when a 25% feed restriction was imposed on pigs during the growing-finishing stage. feed restriction affects mostly fat deposition since it highly increases with age in contrast to the deposition of protein (Hollis 1993), therefore, feed restriction affects fat more than lean tissue at the finishing stage. While leaner carcasses are preferred in some markets due to consumer demand and carcass grading systems, this aspect is more relevant to carcass quality and marketability rather than directly to meat safety (Jones 2020). Therefore, the influence of feeding strategies on fat deposition is discussed here in the context of animal performance and product characteristics, rather than food safety or traceability.

Some feed ingredients are considered in stress-reducing strategies such as amino acid tryptophan and magnesium, which can potentially improve pork quality. However, there is limited literature to consider these ingredients as stress-relieving strategies, and much research is still needed. Hansen *et al.* (1993) discussed that tryptophan is involved in the formation of skatole in the large intestines which contributes to the deposition of skatole in lipids or muscle of pigs. Skatole has been said to enhance the development of boar taint, however, only if supplemented as a poorly indigestible amino acid. Some studies have shown that magnesium supplementation pre-slaughter improves meat quality (Apple *et al.* 2000, Apple and Yancey 2013, D'souza *et al.* 2000, Warner *et al.* 2011) which could improve meat water holding capacity (WHC). For an animal to yield quality meat, proper housing should be provided in case of intensively reared meat animals. Chromium, as an essential mineral, has been said to play an important role in glucose metabolism (Birhanu 2020), This mineral could also increase glycogen deposition thereby stimulating the efficiency of insulin. This means that supplementing with chromium could aid in improving the glycogen reserves that could play a role in reducing the depletion of glycogen pre-slaughter (Schaefer *et al.* 2001). On the other hand, minerals such as sodium have been discussed as the main factor of extracellular and total body water. At the same time, potassium has been said to be the primary determinant of intracellular fluid volume (Birhanu 2020).

A controlled environment has a temperature and feed controlled, where the ambient temperature is high there is a reduction in the growth rate of an animal due to a drop in feed intake. The ambient temperature influences the energy requirements and growth performance of animals, as the temperature decreases below critical temperature the energy for maintenance requirements increases (Lebret and Čandek-Potokar 2022). Ambient temperature has been vital with greater carcass lean meat percentage (LMP) during cold temperatures where energy requirements are not met (Faure *et al.* 2013). This shows that housing conditions could have an impact on meat quality by affecting muscle metabolic properties. Lebret (2007) found that when pigs are subjected to low ambient temperature there is an increase in muscle glycogen stores specifically in white muscles (loin and ham), which could lead to lower pHu and meat WHC.

The most effective means to consider when trying to minimize pre-slaughter stress is to ensure proper animal handling to enable efficient movement of livestock and that farm workers are trained on animal handling. It is very important to handle livestock calmly to prevent injuries to animals and stock persons. For animals reared intensively, objects that could tear the skin or cause bruises such as hanging wire or boards should be looked at.

2.2.2 Animal welfare

Animal welfare has been taken as a major concern for meat-producing animals based on the belief that they can suffer. An ongoing consumer demand stipulates that meat animals be reared, handled, transported, and slaughtered by trained stock people to improve their welfare. Broom (2007) defined animal welfare as the state of an animal as it attempts to cope (both physically and mentally) with environmental changes. As this change in the environment occurs, animals tend to be incapable of adapting behaviourally and physiologically (Birhanu 2020), leading to stress due to failure to cope. Stressors affect an animal's fitness and could have negative implications for its welfare. Adzitey (2011) discussed that when an animal is stressed it becomes prone to weight loss which could result in poor meat quality. Animals should be handled in a way that avoids distress or harm, in that case, a combination of both physiological and behavioural measures have been used to assess the welfare of animals. Figure 1 represents the indicators of animal welfare that should be considered for meat-producing animals, this could benefit both local and commercial producers. The displayed indicators in Figure 2.1 are well described by Sejian *et al.* (2008). There has been an increased focus on the welfare of farm animals in recent years (Tosi *et al.* 2001), in Europe, they have developed animal welfare assessment systems that focus on the housing systems and management. Sejian *et al.* (2008) found that including more measures on animals could improve the welfare assessment systems. Therefore, there is still a need to develop health and behavioural indicators that could assist the system and management parameters (Albright 1983, Broom 1991). A couple of studies have shown that ruminants, sheep, and cattle, react to stressors at the abattoir with increased concentrations of catecholamines and creatine kinase (Chulayo *et al.* 2011, Muchenje *et al.* 2009). When these hormones and enzymes are released, Lund *et al.* (2006) found that they adversely affected the quality of meat because of rapid glycolysis and increased lactate production which resulted in elevated blood lactate. This further suggests that animal welfare could be directly linked to meat or carcass quality. Moreover, if an animal cannot cope with the environment or difficulty, it could be said that its welfare has been compromised. The response to such conditions could affect the meat and carcass quality. Other consequences could be that the animal would take longer to produce meat, or the carcass could be condemned during meat inspection. From the literature on the welfare of farm animals, future research should focus on a deeper understanding of human-animal interaction. This is because most of the literature has been focused on identifying various states of suffering to eliminate them in animal production.

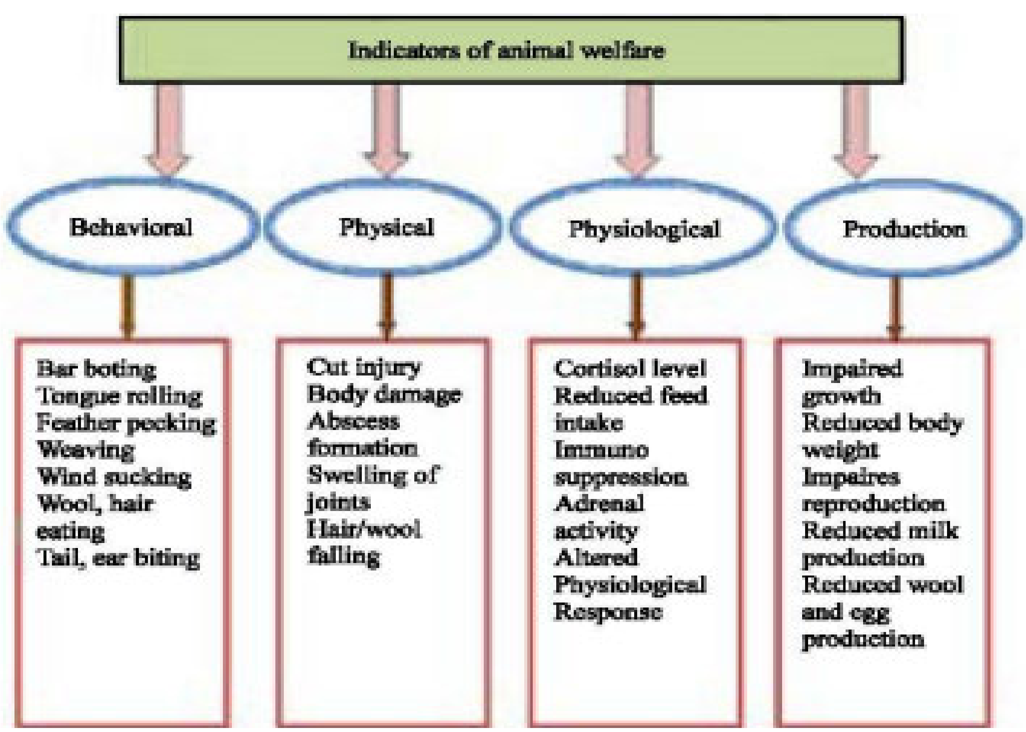

Figure 2.1:Indicators of farm animal welfare as they affect meat yield (Ko *et al.* 2018)

2.2.3 Biosecurity and Disease Control

Farm biosecurity refers to measures that are used to prevent the entry and spread of pests and diseases on farms. Diseases could affect the quality of meat and pose a threat to consumers' health. Therefore, it is vital to consider measures that prevents the spread and development of diseases from one farm to another. Diseases affect animal production and growth (Callan and Garry 2002) and could harm the producer's economy. Other countries such as Australia have biosecurity measures that have worked well for many years using border security (Beshears *et al.* 2008). However, in the year 2001, an outbreak of foot and mouth disease was reported in the United Kingdom highlighting the impact of exotic diseases and the importance of on-farm surveillance and biosecurity (Hernández-Jover *et al.* 2016). Small-scale farmers have little or no knowledge of farm biosecurity, it is important also to consider educating and training farmers to follow strict biosecurity measures. Previous studies' findings indicated that although livestock producers have been committed to the health of their animals, their knowledge and implementation of biosecurity are limited (Hernández-Jover *et al.* 2016). In 2017, the Australian meat and livestock organization made it compulsory for producers they must create a formal biosecurity plan for their properties as part of the livestock assurance scheme. On-farm biosecurity could benefit meat producers by reducing the use of vaccines, which sometimes threaten meat consumers.

Vaccination has been used to protect meat animals against diseases and decrease production due to pathogens (Sharma 1999). The common disease that has affected meat animals is foot and mouth disease (FMD), which has limited market access for developing countries and increased costs related to testing and slaughter (Ko *et al.* 2018). An outbreak of FMD was reported in South Korea in 2011 and it affected the whole country, the government opted for a vaccine in response to the emergency. After the vaccine was administered, there were side effects, including abscesses, pain, redness, swelling, or a small lump at the injection site (Van den Broeke *et al.* 2016). The abscesses that develop after the vaccine is administered do not disappear even post-slaughter, as a result, a portion of the muscle would have to be removed, which increases economic losses (Valtulini *et al.* 2005). This could be because the adipose tissues do not have blood supplies, hence, the absorption is delayed, and therefore, abnormal meat could be formed. It is also important that the vaccine be administered by a well-trained person or veterinarian, this would ensure that the needles used are not contaminated which could contribute to the development of tissue necrosis and carcass damage. Figure 2.2 represents the FMD vaccine site on pork samples after administration by Ko *et al.* (2018). It was found that muscles were discolored, and economic losses were calculated after the affected area was trimmed.

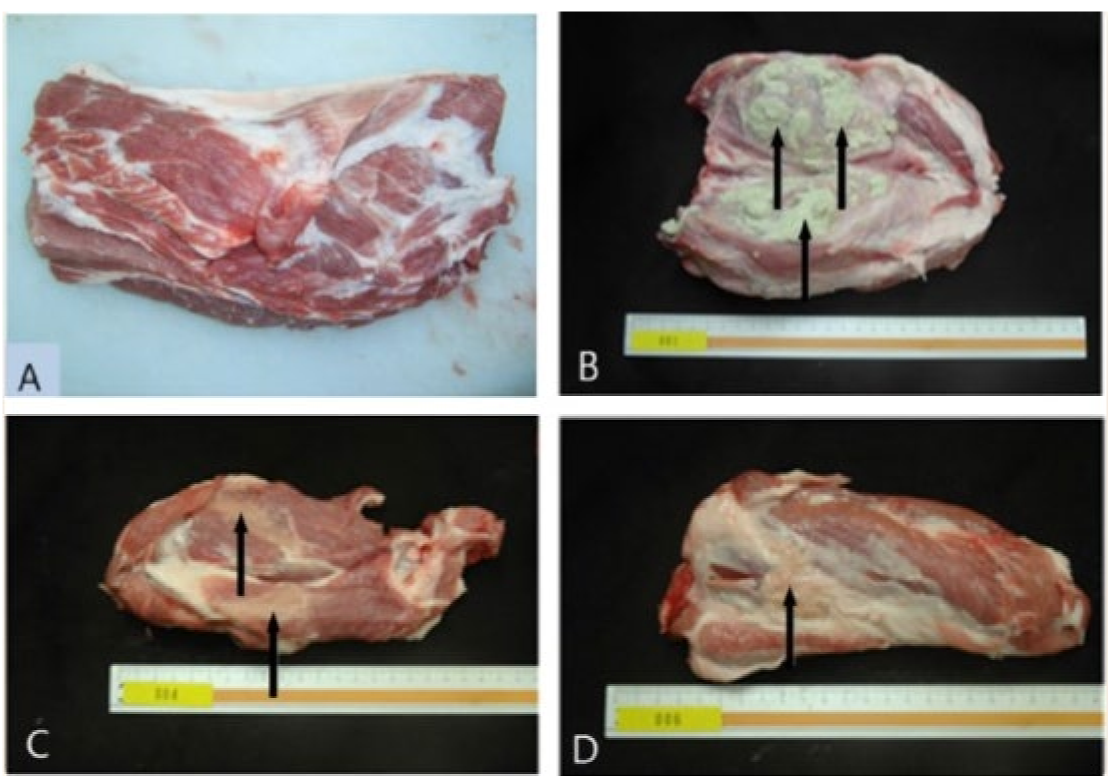

Figure 2.2: A morphological examination of pork samples at the FMD vaccine injection site (Ko *et al.* 2018)

2.2.4 Use of non-conventional feed sources

The ever-changing inflation rate and rising demand for meat have significantly influenced meat production in developing countries. One notable impact is the increase in feed prices, which has forced smallholder farmers to seek alternative, low-cost feed resources. In many cases, this results in the use of indigenous feedstuffs guided by traditional knowledge systems that may lack scientific validation. Although some of these feed materials are accessible and affordable, they often lead to inconsistent meat quality due to their imbalanced nutritional profiles. Such imbalances can result in excessive fat deposition or unintended weight loss in animals, outcomes that are frequently attributed to anti-nutritional factors and low nutrient density (Chharang, 2018). Additionally, when these non-conventional feedstuffs are inadequately processed or stored, there is an increased risk of contamination from pathogenic microorganisms and mold development (Chharang, 2018).

A promising alternative to conventional feed sources is the use of plant by-products (PBPs), which are derived from a variety of agricultural and industrial processing streams. These include by-products from brewery and biofuel production (e.g., distillers grains, gluten feed), sugar production (e.g., bagasse, molasses), fruit and vegetable processing (e.g., pomace, peels, seed meals), root and tuber processing (e.g., cassava and potato residues), oil production (e.g., oilseed cakes), and herb or tree processing (e.g., nut shells, tea residues) (Alao *et al.* 2017). When appropriately processed to remove anti-nutritional elements, PBPs offer a sustainable, nutrient-rich alternative for animal feeding, contributing to cost-effective production without compromising meat quality.

Furthermore, considerable research has emphasized the critical role of animal nutrition in regulating both the physicochemical and metabolic properties of muscle tissue, which directly affects meat quality. Optimized nutritional strategies have been shown to enhance parameters such as tenderness, water-holding capacity, and oxidative stability, all of which contribute to improved shelf-life and consumer acceptability of meat (Loyer *et al.* 2020). Therefore, the integration of scientifically evaluated feed resources, including PBPs, is essential for promoting sustainable livestock systems and enhancing the quality of meat products in resource-limited settings.

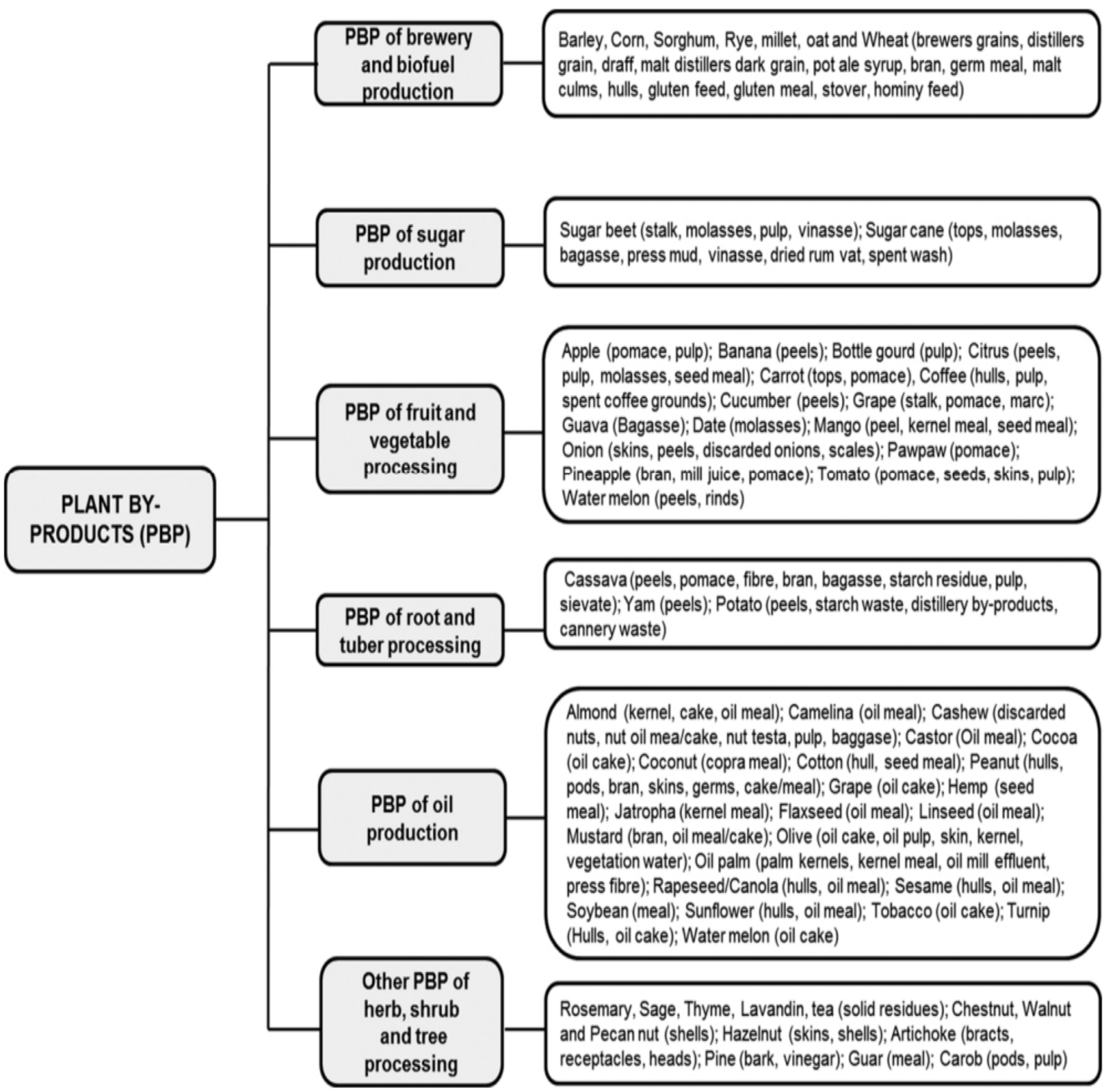

Figure 2.3: Non-conventional byproducts that are available for animal feed (Salami *et al.* 2019)

2.3 Pre-slaughter stress and management

2.3.1 The animal

Stress affects animals differently, and their stress response is not the same. Therefore, the type of species being handled under stressful conditions is essential in determining how much meat quality is affected. Usually, monogastric (Pig and Poultry) animals are more susceptible to stress than ruminant animals (Adzitey 2011). This means pork and poultry meat would be affected more under stressful conditions. There is always a difference in the ability to withstand stress amongst individual breeds. Literature has proven that muscular animals are more susceptible to stress than non-muscular animals. For example, young calves are more susceptible to transport stress (Cockram and Spence 2012). Broiler chicken's meat is more tender and has less cooking loss than indigenous chickens, this is because indigenous chickens are slaughtered at a much older age. However, in cattle, late-maturing breeds are preferred because under high plane nutrition they produce heavier carcasses with less fat and are more tender (Irshad *et al.* 2013).

In lamb production, mutton meat in particular, the use of early maturing breeds has allowed quick finishing of small-size lambs with good carcass composition (Irshad *et al.* 2013), however, the use of late-maturing larger breeds of sheep could result in lambs with fewer carcass fats.

2.3.2 Marketing and Transportation

The marketing and transportation stages are critical phases in the meat production chain that directly influence animal welfare, carcass quality, and the final consumer experience. Despite being often overlooked, the marketing environment, including auction sites, collection points, and sale yards, exposes animals to unfamiliar settings, noise, excessive handling, and commingling with unfamiliar animals. These conditions heighten stress levels and can lead to aggressive interactions, bruising, and fatigue, which affect meat quality. Poor handling during marketing has also been associated with increased cortisol levels and muscle glycogen depletion, both of which influence meat characteristics such as pH and tenderness (Terlouw 2005).

Transportation is widely recognized as one of the most stressful events for animal's pre-slaughter. The stress responses triggered during transport, such as increased heart rate, dehydration, and hormonal imbalance, can significantly alter meat quality. Prolonged or poorly managed transportation can lead to the depletion of muscle glycogen reserves, resulting in a high ultimate pH and the development of dark, firm, and dry (DFD) meat in ruminants (Gregory and Grandin 2007, Tarrant 1990). DFD meat has a reduced shelf-life, darker colour (lower L* value), firmer texture, and poor water-holding capacity, all of which reduce consumer appeal.

In pigs, transport-induced stress often leads to the production of pale, soft, and exudative (PSE) meat, particularly when animals are slaughtered shortly after exposure to acute stress. PSE meat is characterized by low pH (typically, below 5.5), excessive drip loss, poor WHC, and undesirable pale colour (higher L*, lower a* values), making it less acceptable to consumers (Hambrecht *et al.* 2005, Warner *et al.* 2011).

Physical injuries such as bruises, hematomas, and broken bones caused by overcrowding, slippery truck floors, and aggressive handling result in carcass trimming, reduced yield, and financial loss (Grigor *et al.* 1997, Knowles *et al.* 1993). Transport-related factors such as poor ventilation, long durations, and extreme ambient temperatures further exacerbate animal distress and affect meat quality. For instance, extended road transport during high heat can cause animals to lose up to 7% of live weight due to dehydration (Gebremedhin *et al.* 2007), while elevated stress levels increase muscle protein degradation and oxidative stress, negatively affecting tenderness and lipid stability (Zamora *et al*. 2021).

In the South African context, where road transport is the primary mode of livestock movement, efforts should be made to optimize vehicle design, space allowance, and driver training. Although many commercial farms are located near abattoirs, particularly in KwaZulu-Natal, poor infrastructure, overloading, and improper handling can still induce significant stress. Allowing animals to rest for at least 3–4 hours post-transport, as demonstrated by Van der Wal *et al.* (1997), helps restore muscle glycogen levels and can improve meat pH and colour.

2.3.3 Traditional vs. Modern Slaughter

Slaughter techniques have evolved, transitioning from traditional methods to more modern, technologically advanced practices. This topic will explore the differences between traditional and modern slaughter techniques, focusing on their impact on animal welfare, meat quality, and the overall sustainability of the meat industry. Traditional methods often involve manual handling, including stunning and slaughter by skilled workers using handheld tools (Mwondu 2017). Many traditional techniques are deeply rooted in cultural and religious practices, shaping the approach to animal slaughter in various communities. Traditional methods may lack the technological advancements seen in modern techniques. Modern approaches often incorporate mechanization and automation for stunning, bleeding, and processing, leading to increased efficiency (Sazili *et al.* 2023). Advanced technologies, such as controlled atmosphere stunning and electrical stunning, aim to minimize stress and improve animal welfare. Modern methods are designed to comply with strict regulatory standards for animal welfare, hygiene, and food safety (Buhot 2018). Prevention of Stress-Related Changes, modern techniques may contribute to better meat quality by preventing stress-related changes in muscle physiology, such as glycogen depletion.

Table 2.1: Effect of animal handling on carcass quality and economics

Species	Pre-slaughter handling	Carcass and meat quality effect	Source
Cattle	Overloading	Injury and carcass damage	Tarrant (1990)
	Waiting area disturbance	Bruise	Eldridge (1988)
	Transportation	Spread of pathogens on the hides	Avery *et al.* (2002)
	Transportation >24h	Shedding of Salmonella spp	Barham *et al.* (2002)
	Feed withdrawal period	Carcass yield was reduced by 1.7 %	Warriors et al., (1992)
	Transportation time >2h	1.5 % loss in carcass yield	Smith *et al.* (1982)
	After 12 hours of transportation	2.5 % loss in carcass yield	Smith *et al.* (1982)
	Prolonged stress	Meat appears darker and a heat ring is formed	Buyck *et al.* (1985)
	Poor handling	4.1 % of dark-cutting beef	Brown *et al.* (1990)
	Overloading	Animal injury and damage to the carcass	Tarrant (1990)
	Longer journey	Associated with a significantly larger live weight loss	Gallo *et al.* (2003)
	Prolonged lairage time	Decreased muscle luminosity and increased DFD	Gallo *et al.* (2003)
	High stocking density	Increased bruising and reduced dressed carcass weight	Flores *et al.* (2008)
	High stocking density	Serious injuries and death	Flores *et al.* (2008)
	Impatience from the crew and overloading	Increase bruises and injuries	Grandin *et al.* (1999)
	Longer journey	Lost weight	Monahan *et al.* (1990)

2.4 Effect of Government decisions on meat production and safety

Meat imports and consumer preferences

It has been believed that meat imports have an important role in supplementing domestic supply while meeting consumer preferences and addressing market gaps. However, the influx of imported meat also has multifaceted effects on various stakeholders, the economy, and the broader agricultural sector in developing countries (Hertel and Baldos 2016). Meat imports influence the dynamics of the South African meat market by providing consumers with a wide range of choices (Muchenje *et al.* 2018), however, health is not guaranteed from the imported meat. This could be a risk factor for the consumers since most of the consumers are driven by affordability rather than quality. Imported meat often includes cuts or products not readily available from local producers and caters to diverse consumer preferences (Ponnampalam *et al.* 2019). This variety enhances consumer welfare by offering affordable options and promoting competitive markets or competition within the marketplace. In South Africa, this has resulted in some commercial meat producers closing and leasing out their farms to contract growers. Even though this is an opportunity, it still poses a threat to consumer health since there are few or no studies that have been conducted to test meat imports.

Imported meats may be sourced from countries with different food safety standards and regulatory frameworks, leading to potential risks of contamination and foodborne illnesses. Improper handling, storage, or processing of imported meats during production, transportation, or distribution can increase the likelihood of bacterial contamination such as Salmonella, E. coli, or Listeria, posing health risks to consumers. The use of antibiotics in livestock production is common in many countries, including those that export meat to South Africa. Imported meats may contain residues of antibiotics used for growth promotion or disease prevention in livestock farming. Prolonged exposure to low levels of antibiotics in meat products can contribute to the development of antibiotic-resistant bacteria, posing a threat to public health by reducing the effectiveness of antibiotics for treating bacterial infections in humans (Capita and Alonso-Calleja 2013).

Inadequate regulatory oversight and enforcement measures in the meat supply chain can increase the risk of mislabeling, adulteration, or fraudulent practices with imported meats. Mislabeling may involve inaccurate information regarding meat products' origin, species, or production methods, leading to consumer deception and potential health risks associated with undisclosed ingredients or processing methods. Zoonotic diseases, which are infectious diseases transmitted between animals and humans, pose a concern with imported meats. Meat products sourced from regions with endemic zoonotic diseases or inadequate veterinary control measures may harbor pathogens capable of causing diseases in humans, such as avian influenza (bird flu), bovine tuberculosis, or brucellosis, posing risks to public health through consumption or handling of contaminated meats (Mackenzie *et al.* 2013).

Imported meats may also pose risks of allergen cross-contamination for individuals with food allergies or sensitivities (Uraipong *et al.* 2021). Inadequate allergen control measures during processing or packaging of imported meats may lead to unintentional cross-contamination with allergenic ingredients, potentially triggering allergic reactions in susceptible individuals (Hattersley and Ward 2014).

2.5 Conclusion

In conclusion, the interplay between pre-slaughter stress, animal welfare, and meat characteristics is a complex and multidimensional relationship. As the demand for ethically produced and high-quality meat continues to grow, a comprehensive understanding of these dynamics becomes essential. Future research should focus on developing sustainable practices that prioritize both animal welfare and meat quality, thereby meeting the evolving expectations of conscious consumers. This literature review provides a foundation for further exploration into this critical intersection of animal science, ethics, and consumer behaviour.

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Chapter 3

A Systematic Review on the Impact of Pre-Slaughter Handling, Stress, Animal Welfare, and Traceability from Farm to Abattoir on Meat Quality and Food Safety

Abstract

This systematic review examines the evolving landscape of research on meat traceability, safety, animal welfare, and water quality, emphasizing their critical role in sustainable food systems. A dataset of 53 journal articles was analyzed using bibliometric, geographic, and thematic approaches. Publication trends, spanning from 1990 to 2025, revealed fluctuating research activity, with notable peaks in 2007, 2010, 2018, and 2020, suggesting responses to advancements and global challenges. However, sharp declines in 2019 and 2021, possibly linked to funding constraints or events like the COVID-19 pandemic, underscore the need for sustained support in these key areas. Geographically, Asia, particularly India, and China, led research output, highlighting their commitment to improving meat safety systems. However, Africa's limited representation signals the need for broader, more inclusive research efforts. Collaborative networks reveal significant international partnerships, with prominent researchers and strong intra-regional collaborations, though there remains potential to strengthen cross-cluster partnerships for integrated solutions. The thematic analysis identified key areas, including the integration of animal welfare and nutrition, and the growing importance of meat traceability in ensuring food safety and combating fraud. The review highlights both progress and gaps in the research, advocating for enhanced global collaboration and expanded focus on underrepresented regions.

Keywords: Meat traceability, Animal Welfare, Water quality, meat safety, Food safety, Consumer health

3.1 Introduction

Over the past decade, there has been an increasing demand for safe and nutritious food to sustain life and promote good health for the ever-growing global population. Foodborne illnesses, often caused by contaminated food containing bacteria are responsible for over 200 diseases (FAO/WHO 2006), ranging from mild illnesses such as diarrhea to chronic diseases like cancer. Unsafe food contributes to a vicious cycle of disease and malnutrition, particularly in developing countries, where infants, young children, adults, and vulnerable populations are most affected. FAO/WHO (2006) reported that every year, at least one in ten people fall ill from consuming unsafe food. Despite the significant burden on public health and the economy the true impact of foodborne diseases is often underestimated due to underreporting and the challenge of establishing causal links between food contamination and resulting to illness or death (WHO 2015). This has prompted increased attention from researchers, policymakers, and public health organizations to better understand the sources of foodborne risks and how to mitigate them. While much of the focus on food safety has been on post-slaughter handling and food processing, relatively few studies have explored the critical role of pre-slaughter management in ensuring the quality and safety of meat. Pre-slaughter management refers to the on-farm activities and processes animals undergo before they are slaughtered (Sullivan *et al.* 2022). This includes animal handling, transportation, lairage conditions, and slaughter techniques. It has been well documented that poor animal handling during this period can have immediate effects on the quality of meat, leading to conditions such as bruising, muscle damage, and contamination (Lawrie and Ledward 2014, Patel *et al.* 2023, Warriss 2000). For instance, pre-slaughter stress resulting from handling, transportation, or fasting can cause muscle glycogen depletion, leading to undesirable meat characteristics such as higher pH, poor colour, and reduced tenderness (Davis 2023, Sullivan *et al.* 2022). In addition, increased pH values in meat favour the growth of microorganisms, which can lead to spoilage and off-flavors, further diminishing meat quality (Khadijah 2014). Thus, improving on-farm practices and reducing pre-slaughter stress are vital for producing high-quality meat. One of the growing concerns in the meat industry is the traceability of meat products tracking the movement of animals through the supply chain from farm to fork. Meat traceability is the ability to track and trace the origin, processing, and distribution of meat and meat products, which is increasingly important for ensuring food safety, preventing contamination, and verifying the quality of the final product. Traceability systems help identify the source of foodborne pathogens in the event of an outbreak and enable prompt actions to mitigate risks (Yu *et al.* 2022). These systems are particularly critical in the context of pre-slaughter stress and animal welfare, as they allow producers, processors, and consumers to monitor and verify the conditions under which animals are raised, transported, and slaughtered (Davis *et al.* 2022). Traceability also supports the implementation of best practices in animal welfare and can incentivize producers to maintain higher standards to meet consumer expectations regarding food safety, ethics, and sustainability (Babcock *et al.* 2010). The importance of meat traceability extends beyond food safety to ethical concerns. Consumers are increasingly aware of the environmental and social impacts of meat production and seek assurance that their food choices align with their values. The traceability of meat, therefore, plays a key role in supporting transparency within the food system and fostering consumer trust (Herring *et al.* 2010). Traceability systems can also facilitate compliance with regulatory requirements and certification schemes, such as organic or welfare-friendly certifications, which further enhance the credibility and marketability of meat products (Adzitey 2011). As such, enhancing traceability systems is critical to improving overall food system integrity and reducing risks associated with poor meat quality and safety. Despite the importance of pre-slaughter conditions, many developing countries still face challenges in managing livestock and implementing effective traceability systems. In these regions, live animals are often sold directly from farms to local markets or abattoirs with limited oversight, which can increase the risk of contamination and poor animal welfare (Njoga *et al.* 2023). Moreover, the use of feed additives such as magnesium and chromium to reduce pre-slaughter stress in some developed countries may not be a feasible solution for low-resource settings due to economic constraints and concerns over human health risks. Instead, improving livestock management through better training for farmers, improved handling practices, and better transportation conditions may offer a more sustainable solution. A comprehensive approach to improving meat quality and safety requires addressing issues at every stage of the production chain from farm to fork (Nicastro and Carillo 2021). This includes improving pre-slaughter animal handling, reducing stress, and implementing robust meat traceability systems. Collaboration among researchers, producers, and consumers is essential to ensure food safety and strengthen food systems. This review will explore the existing research on the effects of pre-slaughter stress and welfare on meat quality and the role of traceability in ensuring the safety and quality of meat products in modern food systems.

3.2 Methodology

This review systematically analyzes studies on the effects of pre-slaughter handling, animal stress, transportation, stunning methods, and the role of traceability in meat production. The current review evaluated studies conducted on various livestock species, including cattle, swine, and poultry. The study utilized a systematic review methodology used by Leteane *et al.* (2021), it also aligns with the preferred reporting items for a systematic review and meta-analysis (PRISMA) protocol by Moher *et al.* (2015) which is a 17-item checklist designed for systematic reviews.

Step 1: Literature search

A comprehensive search of peer-reviewed journal articles published in English was conducted in Scopus, Science Direct, Google Scholar, and Web of Science. The search query used for retrieving articles in all four repositories involved a set of keywords ('Meat safety' OR 'animal welfare' OR 'Meat traceability' OR 'Pre-slaughter stress' OR "Animal transportation' OR 'on-farm animal handling'). The search was not filtered by year of publication, but language restriction was included, and only English articles were used. The Google Scholar search yielded 418 articles, while Science Direct provided 24 articles, Scopus yielded 314, and Web of Science 44 relevant articles.

Step 2: Inclusion and exclusion (screening)

A total of 800 articles were retrieved from the search sites, Google Scholar, Scopus, Science Direct, and Web of Science. They were subjected to a rigorous selection process. Screening of the 800 journal articles followed the inclusion and exclusion criteria presented in Table 3.1. To remove duplicates, all the journal articles (n=800) were added to a list in Scopus that automatically removed the duplicates (n=84). After the duplicates were removed, the remaining articles (n=716) were screened using their titles and abstracts. Articles that did not fit the inclusion criteria were discarded (n=643). The articles (n=73) that met the inclusion criteria were exported to Endnote 21 (Analytics, www.clarivate.com) and were re-evaluated through a meticulous examination of their full texts, resulting in the exclusion of 20 articles, leaving the study with n=53 journals that satisfied the inclusion criteria, and those were used for data extraction.

Table 3.1: The criteria for determining the inclusion and exclusion of publications in the review process.

Inclusion criteria	Exclusion
Journal articles addressing animal welfare and meat quality	Journal articles that did not address the main areas of interest
Journal articles addressing meat traceability systems	Where full texts were not available or required payment
Publications written in the English language	Conference and review papers
Publications addressing water quality in livestock farming	

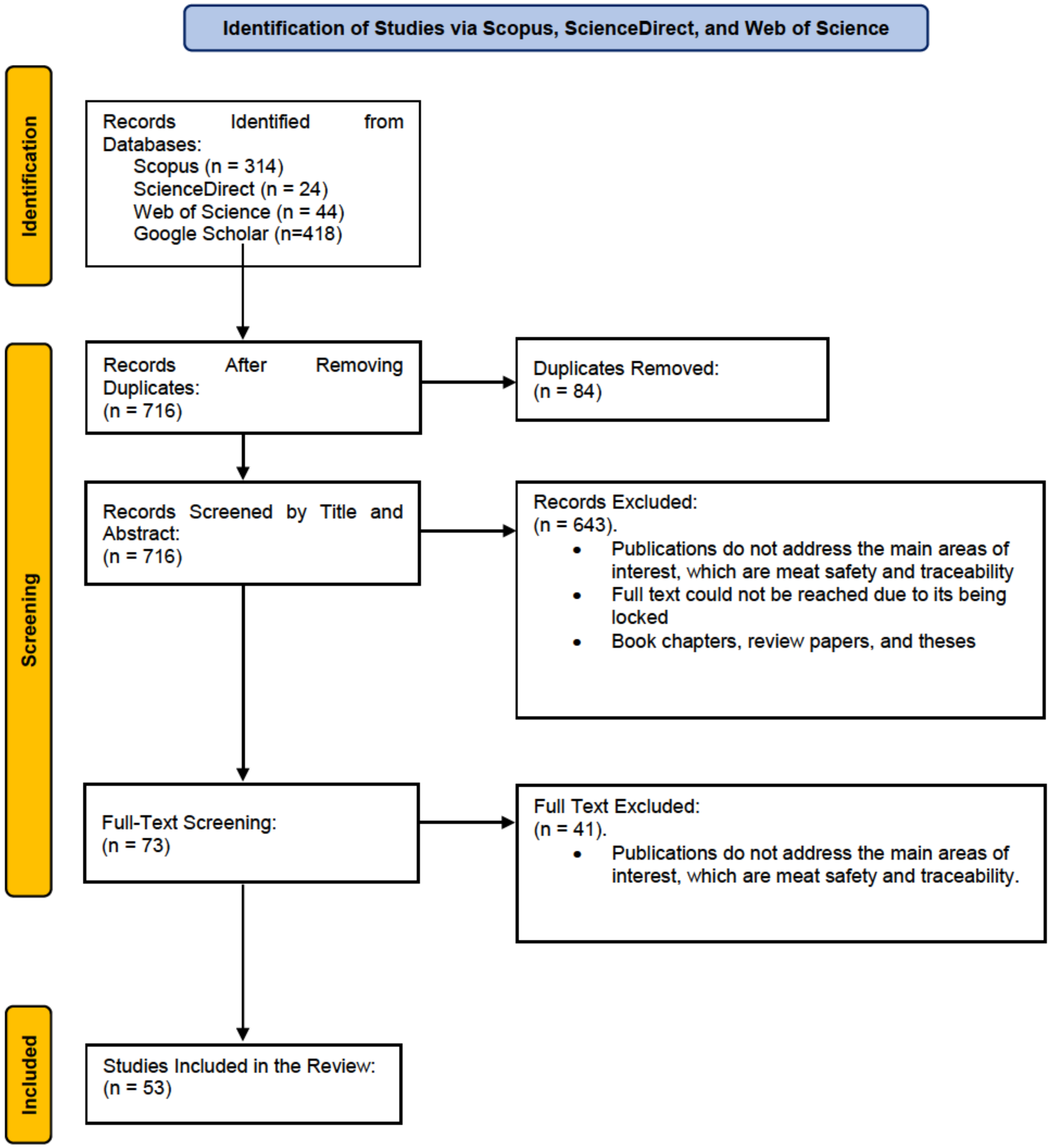

Figure 3.1: The PRISMA flow diagram for a systematic review illustrates the database search process, the screening of publication records, and the number of full-text articles included

Step 3: Data extraction

A total of 53 journal articles were identified based on the inclusion and exclusion criteria detailed in Table 3.1. The full texts of these articles were thoroughly reviewed to gather the necessary information to achieve the objectives of this study. Information extracted included a year of publication, name, and affiliation of authors, the location where the studies were conducted, the scale of the studies, and keywords from each article.

Step 4: Data Analysis

The data analysis derived from publications in Step 3 followed the methods outlined by Khan *et al.* (2003). Initially, a frequency analysis was carried out by counting the number of journal articles published each year. Secondly, a bibliometric analysis was conducted, focusing on author patterns by examining intra-author relationships. The review utilized VOSviewer version 1.6.16 to visualize these author patterns, a software tool commonly used for creating and displaying collaboration or network maps (Mardiastuti *et al.* 2021). VOSviewer was also used to generate visual maps showcasing the most frequently used keywords in publications related to meat safety and traceability and water quality for livestock use. Subsequently, a geographical analysis was performed, considering the study's scale (global, continental, national, or sub-national) and the locations of the specific study areas. It is important to mention that for studies covering multiple countries, all those countries were included in the count. Lastly, a detailed analysis of meat traceability, meat safety, and water quality used in food safety assessments was carried out by recording the frequency of satellite usage and the years of their application. Additionally, an evaluation was conducted on the variables chosen, methods applied, and criteria used to assess their performance. Figure 3.1 illustrates the overall methodology of this review.

3.3 Results and Discussion

3.3.1Frequency analysis

Figure 3.2 illustrates the annual distribution of journal publications related to meat safety, traceability, animal welfare, and water quality in livestock production systems. Frequency analysis, supported by scatter plots, provides a foundation for understanding temporal trends in scholarly activity and helps reveal shifts in research emphasis over time (Fischer *et al.* 2020). The data demonstrates a fluctuating trend in publication frequency, which reflects both evolving research interest and the development of the field.

Between 1990 and 2000, the number of publications remained relatively low, fluctuating between one and three annually. This suggests that during the early phase, these topics were either under-researched or not widely recognized as critical to food safety and livestock production systems (Lawrie and Ledward 2014). However, a steady increase is observed in the early 2000s, with publication rates stabilizing between three and seven articles per year, indicating a growing academic focus and likely a response to increasing global concerns about foodborne diseases and livestock handling standards (Bosona and Gebresenbet 2013).

Noticeable peaks occur in 2007, 2010, 2018, and 2020, with seven publications each year. These surges could align with significant developments in traceability technologies and global policy shifts. For instance, the implementation of traceability systems following several food safety crises, such as the 2000s BSE (mad cow disease) outbreak in Europe, likely stimulated research interest (Regattieri *et al.* 2007). Furthermore, advancements in digital technologies, such as blockchain and RFID, have enabled improved transparency and accountability in meat supply chains (Bosona and Gebresenbet 2023), possibly explaining the peak observed in 2018.

The sharp decline in 2019 (with only one publication) followed by a rebound in 2020 may be attributed to external disruptions, particularly the COVID-19 pandemic, which temporarily impacted research activity and resource allocation globally (Basu *et al.* 2022). While publication numbers recovered in 2020 (six articles), the significant drop to one publication in 2021 underscores how global events can drastically affect academic output and focus. This variability reflects findings by Narrod *et al.* (2012), who argue that research in food safety is highly sensitive to political, economic, and health-related global contexts.

The pattern in publication frequency thus reveals not only the developmental trajectory of the field but also external influences shaping research productivity. These trends underscore the need for sustained funding, international collaboration, and adaptive research agendas that can withstand global disruptions while addressing emerging challenges in meat production and safety.

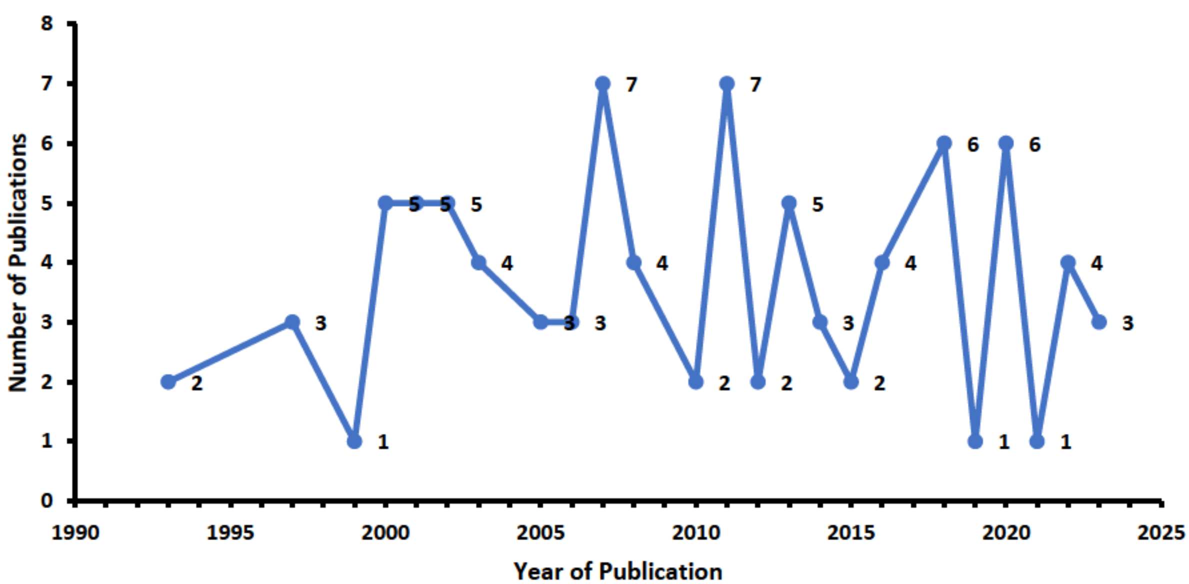

Figure 3.2: A scatter plot displaying the distribution of journals focusing on meat safety and traceability

3.3.2 Graphic analysis

Figure 3.3 presents the global geographic distribution of peer-reviewed journal articles screened in this study, focusing on the domains of meat quality, traceability, and animal welfare. This spatial visualization offers insights into the international scope and regional emphasis of research activities in these fields.

The data reveal significant scholarly contributions from Asia, particularly India and China, which recorded 12 and 10 publications respectively. These figures highlight the growing prioritization of food safety and livestock-related research in emerging economies, where rising population demands and intensified livestock production have created pressing challenges for meat traceability and animal welfare (Li *et al.* 2022, Narrod *et al.* 2012). China's investment in modern agricultural technologies and India's emphasis on regulatory frameworks for livestock care and meat hygiene have contributed to their robust academic output (FAO/WHO 2021).

Moderate contributions are also seen from countries such as the United States, Pakistan, Mexico, and Australia, reflecting active research cultures and strong institutional frameworks supporting food safety and sustainable livestock systems (Bosona and Gebresenbet 2013, Yu *et al.* 2022). For example, the USA's integration of digital traceability technologies and Australia's long-standing welfare policies contribute to their continued involvement in research.

Europe shows a mixed pattern of contribution, with countries like the United Kingdom, Germany, and the Netherlands participating in a moderate number of publications (5–6 each). This aligns with the region's history of proactive food policy interventions following crises such as BSE, which catalyzed the institutionalization of traceability systems (Regattieri *et al.* 2007).

Africa, however, remains underrepresented in terms of publication output. South Africa stands out with the highest contribution on the continent (10–11 publications), possibly due to its relatively advanced research infrastructure and regulatory oversight compared to other African nations (Lambrechts *et al.* 2016). Nevertheless, the limited overall contribution from the continent highlights a persistent gap in scholarly engagement, despite the continent's significant burden of zoonotic risks and food safety concerns. This disparity underscores the need for capacity building, research funding, and international collaboration targeting African nations (Grace *et al.* 2015).

Two studies in the dataset were excluded from the country-level count, one adopting a global focus and the other centered on Sub-Saharan Africa. Their exclusion from the map reinforces the importance of understanding both regional nuances and broader global patterns in literature. The distribution of publications reflects a strong regional bias, with a clear concentration of research in Asia, North America, and parts of Europe and Oceania. This skew suggests that policy, economic development, research funding, and institutional maturity are major determinants of publication output in meat safety, traceability, and animal welfare.

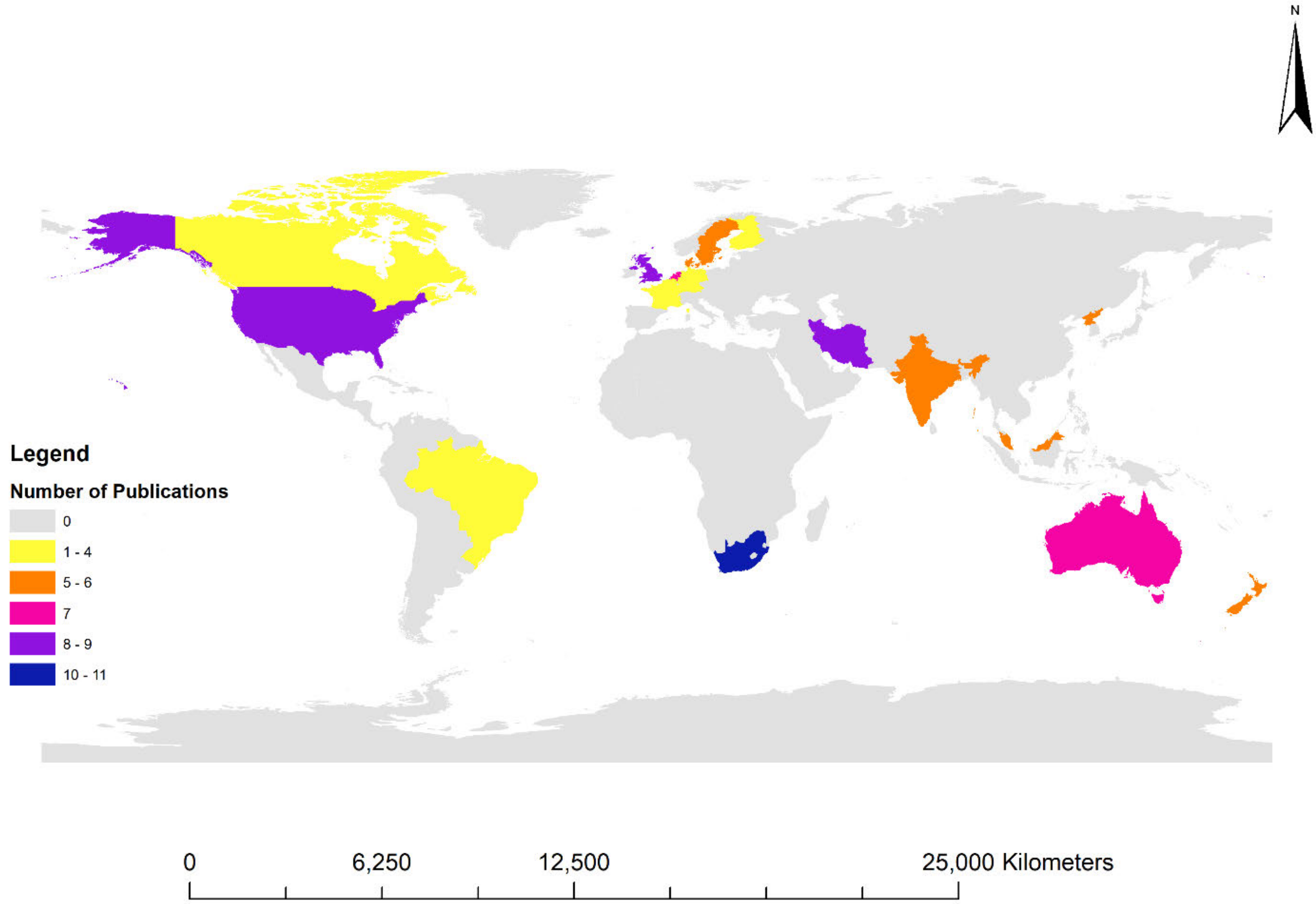

Figure 3.3: Relative distribution by country of the journal articles used in this systematic review

This co-authorship network visualization highlights collaborations among researchers, with each node representing an author and edges indicating co-authored works. The network is divided into three distinct clusters (blue, green, and red), suggesting groups of researchers who collaborate closely within their respective clusters. Muchenje V. emerges as the central figure, acting as a bridge connecting the different clusters, and facilitating interdisciplinary collaboration. Within their clusters, Raats J.G., Ponnampalam E.N., and Muchenje V. appear as influential authors with strong collaboration ties. The thickness of edges reflects the strength of collaborations, with more robust partnerships evident within clusters than across them. This structure underscores a cohesive but modular network, with opportunities for greater collaboration between clusters.

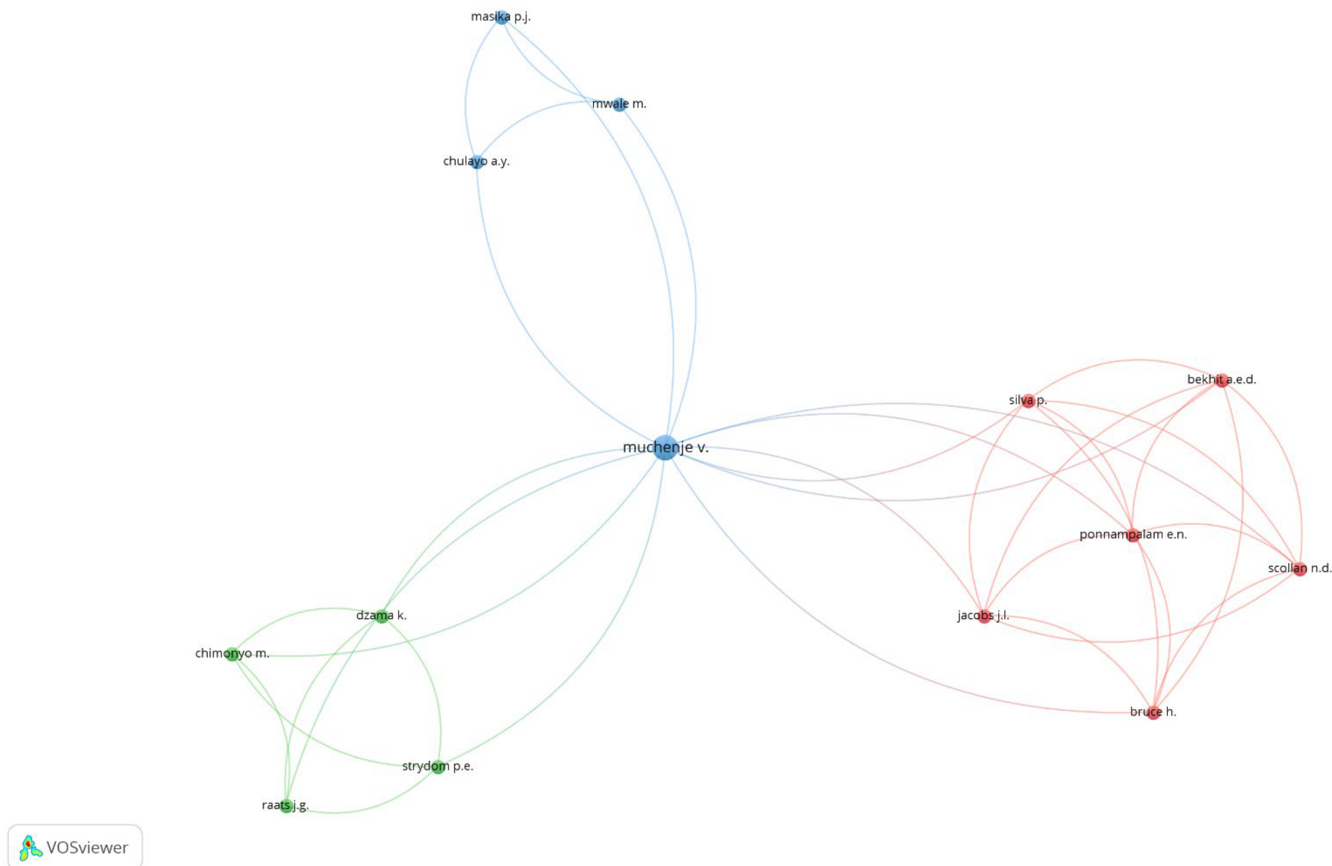

Figure 3.4: Cluster graph produced in VOS viewer showcasing the collaborative relationships among authors throughout the year's

This network visualization illustrates international research collaborations, with each node representing a country and the edges symbolizing co-authored works between countries. The clusters, differentiated by colour, indicate regional or thematic groupings of collaboration. The United Kingdom plays a central role in the blue cluster, connecting closely with countries like Denmark, Germany, and Italy, highlighting strong intra-European partnerships. Similarly, the United States is a dominant hub in the red cluster, linking with Sweden, Finland, and other nations, emphasizing its extensive global reach. The green cluster features South Africa and Australia as key players, fostering ties with countries like Nigeria, New Zealand, and Canada, reflecting strong collaborations across the Southern Hemisphere. The network highlights interconnected but regionally distinct patterns of global academic partnerships, with opportunities for enhancing collaboration between clusters.

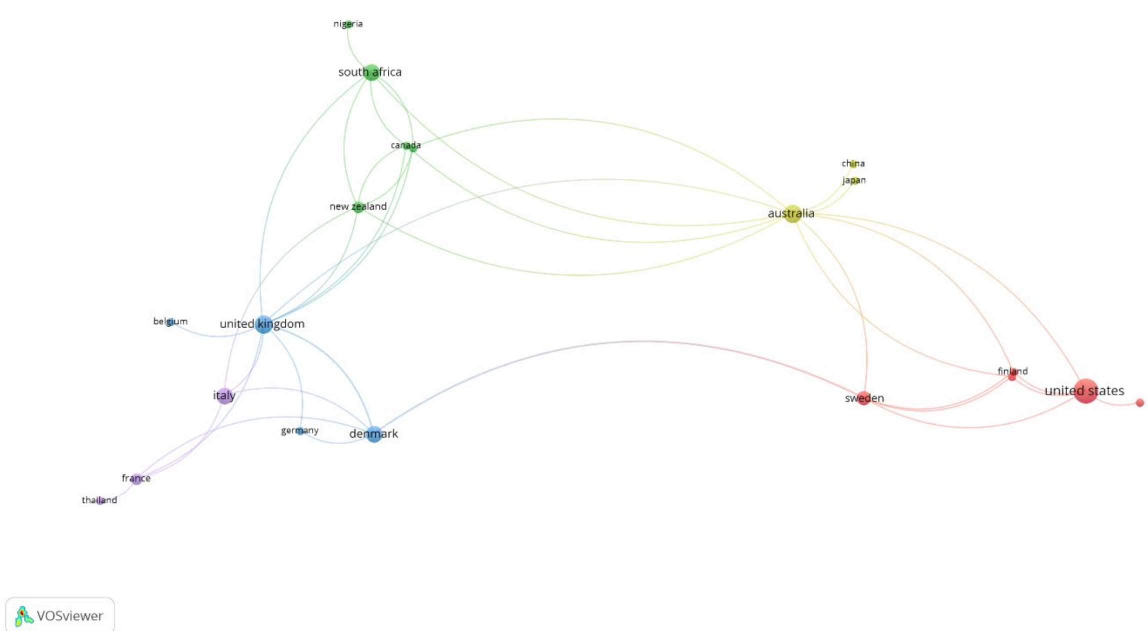

Figure 3.5: The network visualization illustrating international research collaborations from the journals used in this study

This network visualization represents a thematic analysis, likely mapping keywords or research topics. Each node represents a keyword, while the edges indicate co-occurrence or thematic relationships. The network is divided into clusters, highlighting the research's focus areas. The green cluster is centered around "pig," connecting strongly to keywords like "diet" and "porcine plasma," indicating a research focus on animal nutrition and physiology. The red cluster focuses on welfare and food-related topics, while the blue cluster bridges themes such as "association" and "day," potentially linking experimental design or temporal studies. The stronger connections between "pig" and both welfare- and food-related terms suggest interdisciplinary research combining animal science with broader societal or nutritional concerns. The network's structure reveals well-defined thematic areas with opportunities to strengthen connections between welfare and dietary studies.

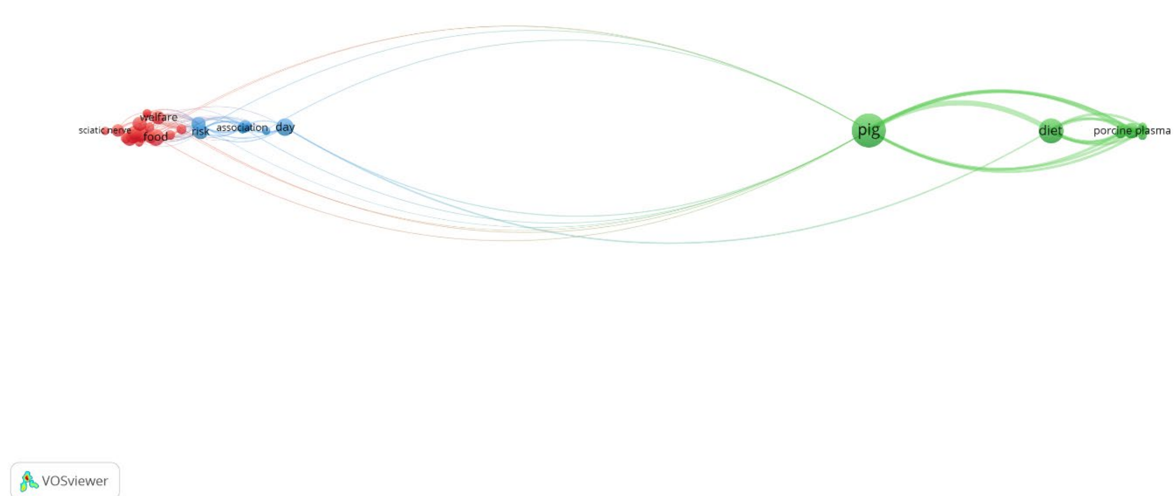

Figure 3.6: Cluster graph produced in VOSviewer showcasing the predominant key terms in the screened publications

3.4 Discussion

The results of this review reveal that meat traceability, safety, animal welfare, and pre- and post-slaughter handling are recurrent themes across global research, as shown by keyword clustering, author collaborations, and geographic publication patterns. These components are deeply interconnected, with each contributing to the overall quality and safety of meat products. While this review aligns with many prior studies, it also reveals unique insights into research gaps, geographic disparities, and the challenges faced in underrepresented regions. The importance of meat traceability in ensuring food safety and mitigating contamination risks has been well-documented in previous studies. For instance, Yu *et al.* (2022) demonstrated that smart technologies, such as blockchain and radio frequency identification (RFID), have revolutionized traceability systems by improving transparency and accountability across the supply chain. This review supports these findings, highlighting the pivotal role of traceability in addressing food fraud and ensuring consumer trust. However, a key difference lies in the geographic disparities identified here. While (Yu *et al.* 2022) emphasized technological innovations, this review points out the limited adoption of such systems in Africa and other underrepresented regions, where infrastructural and financial constraints pose significant challenges. Addressing these barriers is essential for ensuring equitable progress in food safety globally. The geographic analysis further shows that countries like India and China are leading contributors to research on meat traceability and safety, reflecting their growing investment in food systems. Conversely, Africa's underrepresentation indicates a pressing need for capacity-building initiatives, policy support, and increased research funding. Expanding research efforts in these regions is vital to addressing their unique challenges, such as informal livestock markets and limited oversight, which exacerbate food safety risks animal welfare, particularly during pre-slaughter handling, was frequently discussed in the reviewed literature as a key factor influencing meat quality. This was reflected in keyword co-occurrence patterns and thematic clusters, indicating sustained research attention to this relationship. Stress induced by poor handling practices, such as overcrowding during transportation or inadequate lairage conditions, has been shown to negatively affect meat characteristics like tenderness, colour, and pH levels (Sullivan *et al.* 2022). These findings align with Warriss (2000), who reported that stress-related glycogen depletion leads to undesirable meat traits and microbial growth. However, this review differs in its focus on the challenges specific to developing countries. In low-resource settings, poor infrastructure, lack of training, and insufficient regulatory oversight exacerbate welfare concerns. For example, Njoga *et al.* (2023) noted that in parts of sub-Saharan Africa, livestock are often transported under harsh conditions without adequate rest or feeding, leading to high levels of stress and contamination risks. Post-slaughter handling is another critical area influencing meat safety and quality. Effective hygiene practices, temperature control, and contamination prevention are essential for preserving meat integrity (Lawrie and Ledward 2014). By linking traceability to slaughterhouse operations, producers can enhance accountability and ensure compliance with food safety standards. This approach is particularly relevant considering the increasing consumer demand for transparency in the meat industry. Despite advancements, this review identifies gaps in the consistency of post-slaughter protocols across regions. For instance, while developed countries benefit from robust regulatory frameworks and advanced technologies, developing regions often face challenges related to limited resources and inadequate infrastructure. Addressing these disparities requires a holistic approach that incorporates training, policy reform, and investment in cold-chain systems. The bibliometric analysis reveals strong regional collaboration patterns, with researchers like Muchenje V. and Ponnampalam E.N. playing central roles in connecting different research clusters. However, inter-cluster partnerships remain limited, particularly between researchers in developed and developing countries. This review underscores the need for more inclusive and interdisciplinary collaborations that integrate fields such as animal science, supply chain management, and food safety. Mardiastuti *et al.* (2021) similarly emphasized the value of cohesive research networks but focused primarily on intra-regional collaborations. In contrast, this study supports greater international cooperation to address global challenges, such as pandemics and climate change, which disproportionately affect underrepresented regions. Compared to existing literature, this review stands out in its emphasis on systemic issues, such as geographic disparities, research variability, and the integration of pre- and post-slaughter practices with traceability systems. While previous studies often focus on technological advancements or specific scientific findings, this study takes a broader perspective by highlighting the socio-economic and infrastructural barriers that hinder progress in certain regions. By addressing these gaps, future research and policy interventions can create more equitable and sustainable meat production systems.

3.5 Conclusion

This study underscores the importance of addressing key areas such as meat traceability, safety, and animal welfare in livestock farming. The findings highlight progress over time, as reflected in fluctuating publication trends and peaks driven by advancements, funding cycles, and global challenges. Geographic and bibliometric analyses reveal a growing global interest, with significant contributions from Asia, the Americas, and Europe. However, limited representation from Africa and other underrepresented regions indicates the need for more inclusive research efforts. The thematic analysis emphasizes well-defined research priorities, such as the interplay between animal welfare and dietary studies. Moreover, meat traceability emerges as a critical factor in ensuring transparency and accountability across supply chains. While collaboration networks show a cohesive structure with prominent authors and strong regional clusters, opportunities for enhancing inter-cluster and interdisciplinary partnerships remain. The gaps and variability identified in publication trends suggest the necessity of sustained funding and focus to drive further advancements in these critical areas.

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Chapter 4

Assessing the welfare and management of animals and their impact on meat saftey along the value chain in the KZN province, South Africa.

Abstract

The welfare of pigs from farming to slaughter and its impact on meat traceability and safety were evaluated in this study. This study aimed to identify and characterize the major constraints affecting communal pig production in Pietermaritzburg, KwaZulu-Natal Province. A descriptive research design was used, and data were collected through structured questionnaires administered to communal pig farmers. The data was analyzed using descriptive statistics. The results revealed that most of the farmers are small-scale producers practicing semi-intensive production systems, with limited access to veterinary services, poor housing infrastructure, and inadequate feeding practices being the major constraints. Strict biosecurity measures, including slatted flooring and monthly pathogen testing, were observed to contribute to a disease-free environment. Although SAPPO (2019) guidelines for floor space allowance were not followed, no signs of stress or injury were recorded. The transportation process was generally well-managed, with a welfare score of 82/100; however, deficiencies in staff training and emergency preparedness were identified. Longer lairage times were found to improve animal welfare by reducing stress, resulting in more efficient stunning procedures. Humane stunning was conducted effectively, ensuring unconsciousness before exsanguination, which contributed to meat safety and quality. While variations in bleeding duration were observed, no significant impact on meat safety was detected. The findings highlight the critical link between animal welfare, meat traceability, and consumer confidence. It is suggested that improvements in staff training and transport logistics could further enhance welfare standards, ensuring a safer and more transparent pork supply chain.

Keywords: Farm welfare, Meat production, Communal pig production, Rural livelihoods

4.1 Introduction

The welfare of animals and how they are managed significantly impact the quality and safety of the meat produced from them. It is known that the safety of meat along the value chain can be indirectly affected by poor animal welfare such as stress, and injuries, and these could pose a risk of infectious diseases amongst animals (Espinosa *et al.* 2020, Hashem *et al.* 2020). Infectious diseases arising from poor animal welfare are a result of weakened immunity, increased pathogen exposure, and conducive environments for disease spread. These diseases not only harm the animals but also pose significant risks to humans through the contamination of meat and the emergence of zoonotic pathogens. Therefore, ensuring proper animal welfare mitigates these risks, improving both animal health and food safety. These may include foodborne to consumers, one example of how animal welfare might affect food safety is tail biting among pigs, which has been identified as a major welfare concern on pig farms, and it is also a risk factor for increasing the frequency of abscesses and infections in carcasses. Animal welfare encompasses various aspects of animal well-being, including housing conditions, health management, feeding practices, and handling procedures (Fraser *et al.* 2013, Pinillos 2018), which can significantly influence the behavioural, and physiological responses of animals and ultimately affect meat quality attributes such as tenderness, juiciness, flavour, and safety . Following/managing welfare and management of animals using the "Farm to Fork" approach is important as on farm management practice. From animal husbandry techniques to handling procedures, every aspect of on-farm management can influence the final product's characteristics (Webster and Margerison 2022). The feed or nutrition provided to the animals directly affects the quality of meat and its composition (Wood *et al.* 1999), however, the current study focuses not on nutrition but on management and welfare. It has been said that nutrition must balance to ensure optimal growth, muscle development, and fat distribution

(Ahmad *et al.* 2018, Norris *et al.* 2022, Nürnberg *et al.* 1998). All these aspects contribute to the quality of meat being produced, including housing and the environment. According to WHO (1989), proper housing facilities must provide adequate space, ventilation, and cleanliness, this is essential for animal health and wellbeing. Stress-free environments minimize the risk of injuries and diseases, thus contributing to safer meat production.

It is important that producing animals must be free from diseases and this could be ensured by implementing strict biosecurity measures, vaccination protocol, and regular health monitoring programs. These are vital in preventing the spread of diseases amongst animals. Kasimanickam *et al.* (2021) found the use of antibiotics in livestock as essential in preventing antimicrobial resistance and ensuring food safety. Proper management practices, such as administering and adhering to withdrawal periods are necessary to minimize residues in meat. Proper handling techniques and welfare management practices not only ensure the humane treatment of animals but also contribute to improved productivity, meat quality, and overall profitability in the meat production industry (Sinclair *et al.* 2019).

Despite growing recognition of the link between animal welfare and meat safety, there is limited empirical research examining how on-farm welfare and management practices in communal pig production systems affect meat quality and safety, particularly in the context of developing regions such as KwaZulu-Natal, South Africa. Most existing studies focus on commercial systems or laboratory trials, leaving a gap in understanding the real-world implications of welfare management on small-scale or resource-limited farms.

Therefore, the objective of this study is to assess the influence of animal welfare and management practices, including housing, biosecurity, handling, and health protocols on the quality and safety of pork produced at a communal pig farm. By identifying key welfare-related risk factors, the study aims to provide evidence-based recommendations to improve meat safety at the production level. The null hypothesis tested is that animal welfare and management have no significant impact on the quality and safety of the meat produced.

4.2 Materials and Methods

4.2.1 Description of the Study Site

The study was conducted in a communal farm that produces pigs situated in KwaZulu-Natal Province, Richmond municipality, South Africa. It has 540 breeding sows, 14 Boars, and 600 weanling pigs. The farm is 35 km from the University of KwaZulu Natal, Pietermaritzburg campus. This is between 29.6985491,30.2840289. The area has a high-temperature average of 22^{o} C to 28^{o} C and lows between 3^{o} C and 18^{o} C. The farm produces pigs and supplies an abattoir that is situated 15 km away. The abattoir only slaughters 600 pigs a day, purchasing from communal and commercial pig-producing farms. The farm has a total of three housing units that are kept for the growing stage after weaning, pigs are kept for five months before they are sent to the abattoir or any markets. The farm only keeps breeding stocks (sows, boars, and selected gilts).

4.2.2 Ethical considerations

The study adhered to ethical (**AREC/00007480/2024)** guidelines from the University of KwaZulu-Natal for research involving animals. These guidelines include obtaining informed consent from the farm owner or manager, minimizing stress and discomfort to animals during data collection, and ensuring the humane treatment and welfare of animals throughout the study period.

4.2.3 On-farm visit and observations

To gather data on farm management practices at the communal farm, a structured questionnaire was used in the interviews with farm managers. This method allowed for a standardized approach to capturing qualitative information regarding various aspects of the farm's operations, including productivity, resource management, and operational challenges. The questionnaire was specifically designed to elicit detailed responses from the farm managers, ensuring a comprehensive understanding of the practices and challenges involved in pig farming.

Interview Questions:

The interview questions were crafted to address key elements of farm management and to explore areas critical to the farm's success and sustainability. Questions asked include:

- What are the main challenges you face in pig production on the farm?
- How do you manage resources such as feed, water, and housing for the pigs?
- What strategies do you implement to ensure the health and welfare of the pigs?
- How do you approach training and managing farm staff?
- What are your long-term goals for the farm, and how do you plan to achieve them?
- What sustainable practices do you employ in waste management and environmental conservation?

These questions were designed to provide insights into the farm's operational dynamics and to explore how the managers address day-to-day challenges while maintaining production levels.

Interview Conduct:

The interviews were conducted by **Progress Sodella and Thembeka Khwela**, who had prior experience with structured interviews and a solid understanding of agricultural practices. This ensured that the interviews were conducted professionally and that the responses were accurately captured and analyzed.

Language of Interviews:

The interviews were conducted primarily in IsiZulu and English, depending on the preference of the interviewees. In instances where language barriers existed, a translator was utilized to ensure effective communication and accurate interpretation of the responses. This approach helped maintain clarity and allowed for a clearer understanding of the interviewees' perspectives.

Visual Inspection Methodology

In addition to the interviews, a visual inspection was conducted as part of the data collection process to assess the physical condition of the pig farm and its infrastructure. This inspection aimed to gather real-time, observable data on farm management practices, infrastructure quality, animal health, and overall operational effectiveness.

Purpose of Visual Inspection:

The visual inspection was conducted to complement the interview data by offering an on-the-ground perspective of the farm's conditions. It provided an opportunity to directly observe the physical environment where the pig farming activities took place, ensuring that the managers' responses during the interviews were reflected in the actual operational context. The inspection focused on the following areas:

- Pig Housing: To assess the adequacy of the facilities, including space, ventilation, temperature control, and cleanliness.
- Animal Health: To observe the condition of the pigs, signs of diseases, and the general health of the livestock.
- Feed and Water Supply: To examine the quality and availability of feed and water for the pigs.
- Waste Management Systems: To evaluate the farm's waste disposal and recycling methods, which are crucial for sustainability.
- Farm Infrastructure: Including fences, roads, equipment, and staff areas, to determine their functionality and maintenance status.

4.2.4 On-farm Biosecurity, Animal Health, And Welfare

The farm has a 1.8m high fencing with a concrete base to prevent entry of wild animals that dig holes into the farm such as warthogs and other vectors. These could be a threat since they might carry diseases into the farm. Employees have cell phones which are required to remain inside the animal house unit and any personal items or belongings are prohibited from reaching the animal housing facility. Farm workers are required to follow biosecurity measures by bathing, changing personal clothing, and using on-farm working gear every morning before they get into the animal facility. This also applies to farm visitors; they are not permitted to bring personal items and must follow farm biosecurity measures. Each housing facility is provided with a foot bath at each entrance to prevent the circulation of pathogens from house to house. This also prevents pathogens from animals returning from the loading ramp if they get infected. Farm workers are prevented from entering the loading truck, they are only responsible for directing the animals on the loading ramp. The truck is washed and disinfected after each load before it returned to the farm. Before anyone is employed, there is a strict or stipulated rule that states that farm workers are not allowed to own pigs to avoid the transmission of diseases. The farm vaccination plan is kept confidential, but there is a regular veterinary visit. This also applies to the water quality used to feed the animals.

Each housing facility accommodates 480 pigs that are kept in a group of 10 per pen. Animals are given enough space within the pen by following SAPPO (2019) guidelines, each pen is 4x2.78 m with a space allowance of 1.11 square meters. There is a total of 48 pens in each house with slatted floors. The farm has a post-mortem area and manure dams far from the river or water source. All dead animals are collected and donated to the lion park, which is located 25 minutes away from the farm, and then mortality is recorded. Manure is used as fertilizer in the crop production unit of the farm, with excess manure donated to the community or spread in the fields to support grass growth.

4.2.5 Selection of animals for slaughter

The farm uses an *in-all-out* method, meaning all animals in a house must be cleared simultaneously to open space for another batch. However, the farm does pre-loading assessment for animals that are stressed or not ready to be loaded, those were given rest thereby isolating them from the group and loaded on a second or third load. Resting stressed pigs and delaying their loading to subsequent transport rounds is an essential practice for maintaining animal welfare, improving meat quality, and complying with welfare standards. This process involves segregation, providing a comfortable and stress-free resting environment, careful monitoring, and re-assessment before transport (Faucitano and Goumon 2018). All pigs that were restless or making sounds were left for the next loading. This was done to ensure welfare and minimal stress for the quality of meat.

4.2.6 On-farm loading and abattoir offloading of animals

A total of 40 growing pigs were immediately brought to the loading zone when the truck was ready. They were directed to the loading zone using whiteboards or empty feed bags without physically pushing the animals. They were directed via a rough concrete ramp to avoid any possible slipping and muscle contraction which could affect meat quality. The transport truck has 3 floors with each floor having 4 (4x3 m) pens that accommodate 12 pigs. It also has water sprinklers that are used to cool the bodies of the pigs during transportation. All animals were loaded between 5:00-5:30 am and arrived at the lairage between 6:30-7:00 am with the truck traveling at a maximum speed of 80 km/h. The farm abattoir is located 50 minutes away and only slaughters pigs.

4.2.6 Abattoir and lairage duration

The abattoir also purchases pigs from other smallholder producers; however, the pigs are separated at the lairage. At the abattoir, all animals were offloaded by the abattoir workers and directed to holding pens that had concrete floors (4.5 x 4.5 m) with water provided for drinking. Lairage duration is provided in Table 5.1. Lairage stocking density was provided following the SAPPO guidelines to prevent injuries or any aggressiveness towards each other. The delivery truck was sent to the wash bay, disinfected, and washed before returning to the farm for another load. The records of animal behaviour and welfare were recorded (Table 5.1). Space is separated into dirty areas where animals are slaughtered, dressed, and moved to more hygienic and cleaned areas with workers specializing in dressed carcasses.

4.2.7 Stunning, bleeding, and abattoir welfare

The welfare assessment in the abattoir started at the offloading area, where several behavioral and physical welfare indicators were visually assessed. Specifically, observations included. General fear and stress behaviours, such as reluctance to move, turning back, vocalizations, and agitation.

Reluctance to move was defined as stopping movement for at least two seconds, while turning back was recorded when pigs facing the unloading area turned and faced the truck. Incidence of slipping or falling during offloading, recorded as a percentage of total animals per load. Slipping was defined as a temporary loss of balance without body contact with the floor, while falling involved the body touching the floor. Sickness signs include animals moving slowly, drooling saliva, remaining silent or non-reactive when pushed, or appearing lethargic. Dead-on-arrival animals, counted and recorded on arrival. Shivering (measured by observing irregular body or limb vibrations) and panting (noted as heavy breathing, mouth open, and saliva accumulation) were taken as indicators of acute stress. Once in the lairage, the pigs were group-weighed using a calibrated digital weighing scale to obtain the average body weight per batch. Animals were then moved to the stunning rail, where electrical stunning was performed to ensure humane slaughter. The electrical stunning was carried out by a trained abattoir staff member, using equipment set to 43.5 volts, 1.3 amps, for 3 seconds. This procedure followed national animal welfare regulations as outlined in the Animal Protection Act of 1962 (Act No. 71 of 1962) and South African Pork Producers Organisation (SAPPO) guidelines. The stunning equipment was checked and recalibrated after each use to ensure consistent delivery of the required voltage and amperage. Welfare indicators during stunning were carefully recorded, focusing on: Unconsciousness checks, where the pig should show no response to stimuli immediately after stunning. Observation of movements, shaking, vocalizations, and responses to external stimuli, which could indicate incomplete stunning or distress. Handling practices by abattoir workers, including whether they used excessive force, biting, shouting, or other stressful interactions during movement from the stunning area to the bleeding area. All data were recorded using a standardized recording sheet, and observations were made on a group basis, with assessments focusing on the batch rather than individual pigs due to the high throughput of the abattoir. Photographs and videos were occasionally used as supportive documentation for certain welfare indicators.

4.4 Statistical analysis

The data obtained through observation checklists, visual assessments, and semi-structured interviews (as described in Sections 4.2 and 4.3) were analysed using both descriptive statistics and thematic analysis. Quantitative data were entered into Microsoft Excel and analysed to generate frequencies, percentages, and summary statistics. These descriptive statistics were used to interpret observable trends in farm practices (Section 4.2.1), transport conditions (Section 4.2.2), and abattoir processes (Section 4.2.3), and were visually presented in tables and figures.

4.5 Results and Discussion

4.5.1 On-farm observations and interviews

The farm employs strict biosecurity measures and is the only piggery farm in the area. No signs of sickness were observed in the animals, which demonstrated that the environment or housing facility was disease-free. The slatted house floors that were used also played a good role in preventing bacterial growth from the faeces, which could infect and spread pathogens within the farm. However, there could be a possible pathogen transfer from the feed since the farm uses a manual feeding system, which could be from the feed supplying company. However, an interview with the farm manager it was recorded that the farm does a month-to-month analysis of the presence or absence of pathogens in the feed and water. It was stipulated that the results are kept confidential and cannot be shared. The farm does not follow the SAPPO (2019) guidelines for minimum floor space allowance based on the weight of pigs to have a correct stocking density. SAPPO (2019) states that for slatted floors the minimum space should be 0.86 square meters. This provides a free allowance for feed and water and for the farm workers to move during inspection and feeding. However, there were no injuries or stressors observed from the farm's 1.11 square meter allowance. The animals had free space to rest, feed, and drink water.

4.5.2 Loading to abattoir and lairage observations

Delays or inefficiencies can be identified and improved by documenting loading and offloading times. Records in Table 4.1 represent no welfare concerns in the abattoir that could result in animals getting injured, such as high stocking density and a non-conducive environment. The transport process met most welfare standards but displayed room for improvement in specific areas. Staff scored low on training and knowledge of emergency procedures. Failing to provide proper training undermines the ethical responsibility to ensure humane treatment of animals (Cochrane and Cooke 2016). Improper handling techniques (e.g., rough handling, excessive use of force) can cause unnecessary stress, bruising, or animal injuries (Shoemaker 2020). Grandin (2021) also discussed that improvement in animal handling is crucial for reducing bruising and improving carcass quality. The abattoir was well-cleaned and disinfected, leaving no room for pathogen circulation from the abattoir or other farms supplying pigs. There are no records of water safety provided at the lairage, whether it contains waterborne pathogens or not.

Table 4.1: Welfare Scoresheet for loading and transportation of animals to abattoir

Criteria	Description	Possible points	Awarded points
	Pre-Transport Preparation		
Loading Area condition	Cleaned and pathogen-safe	5	3
	Adequate lighting and ventilation	5	4
Equipment and Facilities	Properly maintained loading ramps and equipment	5	5
	Availability of water and feed if needed	5	5
Staff competence	Staff trained in animal handling and welfare	10	4
	Knowledge of emergency procedures	5	3
	Loading Process		
Pig Handling	Gentle handling and minimal stress	10	8
Loading Duration	Efficient loading process to minimize time	5	3
	Adequate time for pigs to adapt	5	3
Pigs Condition	No signs of injury or illness	5	4
	Proper size and weight of transport units	5	*
	Transport Conditions		
Truck Condition	Clean and well-maintained transport vehicle	10	10
	Adequate ventilation and temperature control	5	*
Travel Duration	Adherence to legal and welfare regulations regarding travel time	5	4
	Provision for breaks and rest if needed	5	*
Welfare During Transport	Correct stocking density	5	5
	Adequate space for pigs to stand and lie down	5	5
	Arrival And Offloading		
Offloading Process	Gentle handling during unloading	5	4
	Adequate space for pigs to exit the vehicle	5	5
Post Transport Assessment	Immediate health check upon arrival	5	4
	Addressing any signs of stress or injury	5	3
Total Points		**100**	**82**

Scoring and Interpretation

I. Excellent (90-100 points): All welfare aspects are met or exceeded.
II. Good (70-89 points): Most welfare aspects are met, with minor improvements needed.
III. Fair (50-69 points): Some welfare aspects are not fully met; improvements are necessary.
IV. Poor (Below 50 points): Several welfare aspects are unmet; significant improvements are required

The figure below illustrates the percentage of possible points awarded for each category, with horizontal reference lines indicating the performance thresholds. All categories fall into the "Good" range (70-89%) but do not meet the "Excellent" threshold (90% or above). Lowest Performing Category "Pre-Transport Preparation" with 68.5%. Highest Performing Category "Pre-Arrival and Offloading" and "Transport Conditions," each with 80%. The correlation analysis showed no statistically significant relationships between awarded scores and the maximum possible scores across welfare categories ($p > 0.05$), suggesting weak associations between these variables. Pre-Transport Preparation and Transport Conditions performed the best, each achieving 80%. Loading Process falls slightly below the "Good" threshold at 72%. This visual representation highlights that while overall performance is satisfactory, the Arrival and Offloading category requires improvement to meet higher welfare standards.

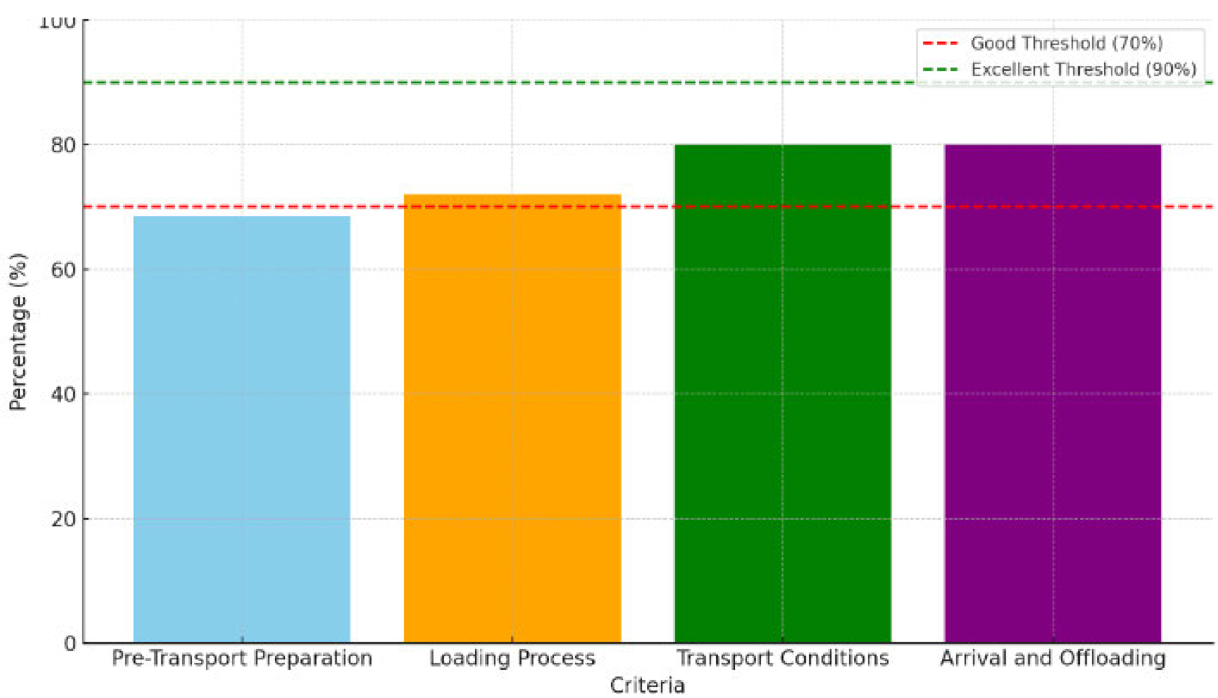

Figure 4.1: Transportation conditions and scoring for pigs transported to the abattoir for slaughter

Loading durations were relatively consistent, while offloading durations varied significantly, suggesting logistical inefficiencies or differences in animal handling practices. Longer lairage times (e.g., 8 hours) coincided with more varied behaviours (feeding, drinking, social interaction, and resting). Longer and shorter lairage times can significantly impact meat quality and carcass characteristics due to their influence on animal behaviour, stress levels, and physiological responses (Dalla Costa et al. 2019). Shorter lairage times (4 hours) were associated primarily with resting, indicating that duration significantly influences animal behaviour. It was observed that they were lying down which could appear to be recovery from transport duration. There was good availability of water, this was seen by pigs drinking without competing and getting injuries. Some were resting in groups showing no signs of aggression, indicating comfort and social resting. Pigs were also observed rooting and exploring the lairage pens displaying normal exploratory behaviour and showing no signs of distress.

Table 4.3: A summary of general observations recorded at the abattoir during and after the stunning

Day time	Loading Duration (s)	Offloading duration (s)	Lairage Duration (h)	Lairage Behaviour	Stunning Duration (s)	Bleeding Duration (s)
Morning	193	440	4	R	33	68
Morning	203	504	6	D, SI	20	54
Morning	188	640	8	D, SI, R	11	57
Morning	207	506	6	D, SI	18	62

R: Resting; D: Drinking; SI: Social Interaction; S: Seconds; H: Hours

4.5.3 Stunning and bleeding observations

Stunning was performed by a trained staff member with more than 10 years of experience in the industry. Animals were slaughtered humanely, and none was conscious during exsanguination. Some pigs showed response stimuli seconds after stunning, some were shaking and kicking with both back feet, but they were hanged only when they were unconscious. All behaviours as shown in Table 4.3 their stunning duration was shorter as compared to other batches. This could be due to the fact that they had a long offloading time, and they were not rushed out of the delivery truck. Their lairage duration was longer than other groups, giving them a long resting period. There was no vocalization or rhythmic breathing observed after the animals were rendered unconscious which displayed the effectiveness of the stunning method used and the staff operating the equipment showed understanding. In a few instances, there was a need for immediate monitoring and action for equipment handling and process efficiency. However, some of the pigs displayed only resting behaviour (Table 4.3) and most of them needed to be stunned again. A slight twitching was observed on the batch with a longer bleeding time, and few were observed on the batch that displayed all lairage behaviours. Blood was washed after bleeding each pig using warm water and washing liquid to avoid creating a breeding ground for bacteria and flies. The staff rinsed the protective boots using provided warm water and washing liquid regularly to keep the slaughter area hygienic.

It was observed that pigs with shorter lairage duration (4 hours) tend to have slightly longer bleeding durations than those with longer lairage duration. For example, pigs at longer lairage duration had bleeding durations between 54 and 65 seconds, while those at 4 hours had between 65 and 70 seconds. There could be a slight positive correlation between lairage duration and bleeding duration, possibly because of rest and blood flow recovery. The observed differences in stunning and bleeding practices appeared minimal during field observation. However, no statistical analysis was conducted; therefore, conclusions about statistical significance could not be drawn. A longer stunning duration might indicate a more complex or less efficient stunning period, which could influence the subsequent bleeding duration, however, the current study demonstrated that after observations, pigs at shorter lairage duration had longer bleeding duration. The correlation between stunning duration and lairage duration appeared weak and could be said to have been influenced by other factors such as loading and offloading duration.

Pigs that were exposed to a longer stunning period (33 seconds) generally had slightly longer bleeding duration (68 seconds), whereas those with a stunning period of 11 and 20 seconds were observed to have shorter bleeding duration. The observation revealed that lairage duration had a significant effect on stunning duration. Pigs that had long lairage duration had short stunning duration. This could be an indication of enhanced efficiency in the stunning process. Pigs were calm and less stressed, improving the human treatment of the animals might also be the contributing factor.

4.5.4 Stunning box-related behaviour

The observations suggest that minimizing distress and resistance in the stunning box could yield effective and humane stunning procedures. Some of the pigs hesitated when directed to the stunning box and, thus, required gentle prompting to enter although the process was completed without welfare concerns. There were pigs from other batches that exhibited backward movement in the stunning box, this indicated distress and resistance from observing other pigs lying on the floor after being stunned.

4.6 Discussion

This study has provided critical insights into the welfare of pigs during their farming, transportation, and slaughter stages. The findings from the on-farm observations, loading, transportation, and stunning procedures illustrate that while animal welfare is largely maintained throughout these processes, there remain areas where improvement is necessary. The overall aim of this analysis is to examine how these welfare practices impact meat traceability and safety, particularly in the context of consumer confidence and public health. The farm maintains robust biosecurity measures, ensuring a disease-free environment, which is vital for maintaining meat safety. As there were no signs of illness among the animals, this suggests the farm's operational practices, such as the use of slatted floors and regular pathogen testing of feed and water, contribute positively to controlling risks of contamination. These practices are essential for safeguarding meat traceability, as the prevention of disease outbreaks ensures that meat can be traced back to its source with assurance of safety. According to Smith *et al.* (2023), implementing strict biosecurity protocols is a key factor in reducing the risk of foodborne pathogens, which could affect both animal health and meat safety. Additionally, the farm's lack of adherence to SAPPO (2019) guidelines on floor space allowance did not result in visible stress or injuries among the animals, further supporting the notion that animal welfare can be achieved without strictly adhering to every guideline, provided that other care measures are properly implemented. While no immediate risk was identified from the farm's feeding practices, the potential for pathogen transfer from feed remains a concern. The practice of monthly pathogen testing helps ensure that the meat produced is safe for consumption. This is critical for meat traceability as any contamination in feed or water could lead to widespread contamination in the pork supply chain, which would directly impact consumer safety (Butucel *et al.* 2022).

The loading, transportation, and offloading processes were generally consistent with good welfare practices, with the welfare scoresheet yielding a score of 82/100. However, there were areas for improvement, particularly in the training and competency of staff handling the pigs. The low scores in staff competence suggest that the quality of animal handling during loading and offloading could affect animal stress levels, leading to potential welfare concerns. Proper staff training is directly linked to animal behaviour during transportation and can reduce injuries or stress that might impact meat quality. As Cochrane and Cooke (2016) emphasize, improper handling during transport increases the likelihood of bruising, stress, and injury, which can compromise meat quality and safety. The findings also suggest that longer lairage times resulted in improved animal welfare, with pigs displaying more natural behaviours such as resting and social interaction. This is important for both animal welfare and meat traceability, as less stressed animals are likely to produce higher-quality meat, free from the physiological changes that stress can induce, such as higher levels of cortisol or altered muscle pH, which can negatively affect meat quality (Dalla Costa *et al.* 2019). The lairage conditions also provide an opportunity for monitoring animal health before slaughter, allowing for better traceability if any health issues arise that could affect meat safety.

The humane stunning process observed in the study where pigs were unconscious before exsanguination aligns with best practices for ensuring that the meat produced is not only safe for consumption but also of high quality. Humane stunning is essential in maintaining both ethical standards and meat safety, as pigs that are not properly stunned may suffer from stress or injury, which can compromise meat safety (WHO 2015). The observed variation in stunning and bleeding durations suggests that longer lairage times may contribute to more efficient stunning, as pigs that were allowed adequate rest were less stressed, resulting in shorter and more effective stunning procedures. This observation further supports the idea that reducing pre-slaughter stress improves both animal welfare and the overall safety of the meat produced, as stressed animals are more likely to carry pathogens that can affect meat safety (Isbrandt *et al.* 2022).

The bleeding duration, while variable, was relatively short for most pigs, aligning with standards for ensuring proper exsanguination, which is critical for meat safety and traceability. Any inefficiencies in bleeding, such as longer durations, could potentially lead to contamination of the meat with residual blood, providing a medium for bacterial growth (EFSA 2018). This highlights the importance of efficient slaughter practices in ensuring meat quality and minimizing the risk of contamination.

The link between animal welfare and meat traceability is evident throughout the study. Proper animal welfare practices such as disease control on the farm, minimizing transport stress, and ensuring humane stunning are crucial for maintaining meat safety and traceability. Any lapse in welfare standards, such as improper handling, can lead to injuries, stress, and illness, which can compromise both meat quality and safety. Additionally, these practices play a role in the traceability of meat by ensuring that any issues with animal health, injury, or stress can be traced back to specific stages in the production process, from the farm to the abattoir. This traceability is essential for ensuring consumer confidence in the safety and quality of meat products.

The farm's ability to trace any potential risks, from pathogens in the feed to issues during transport or slaughter, is essential for public health and regulatory compliance. Studies by Grandin (2021) stress the importance of maintaining comprehensive records and adhering to welfare standards to ensure that meat is safe for consumption. By addressing areas for improvement, such as staff training and optimizing transport and offloading processes, the farm can enhance meat traceability and safety, thus meeting higher welfare standards while minimizing the risk of contamination.

4.7 Conclusion

The farm's practices largely meet welfare standards, with some areas of improvement identified, particularly in staff competence during transport and handling. The relationship between animal welfare, meat traceability, and safety is undeniable. By addressing the weaknesses in staff training and optimizing animal transport and handling procedures, the farm can ensure that meat traceability is maintained while also improving the safety and quality of the meat produced. These improvements will not only enhance animal welfare but also bolster consumer confidence in the safety and traceability of pork products. Thus, the integration of high animal welfare standards into the entire production process is key to ensuring both ethical and safe meat production for consumers.

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Chapter 5

Assessment of microbial load in feed, water, and feaces and their interconnected roles in the pig production chain to ensure production efficiency, animal welfare, and meat safety along the value chain

Abstract

The objective of this study was to assess the physico-chemical and microbial water quality parameters at two locations, the Dam and a Farm, Feed, and Feaces across three sampling occasions. The samples were immediately transported to the laboratory, and the key parameters analyzed included chemical oxygen demand (COD), pH, temperature, fecal coliforms (FC), *Escherichia coli* (EC), total coliforms (TC), and aerobic plate count (APC). The data was analyzed using GenStat 23rd version, and a regression analysis was performed using Microsoft Excel. Results indicated a statistically significant difference in COD levels between the Dam and Farm ($p = 0.015$), with higher values observed at the Dam (13 mg/L), likely due to organic and inorganic pollution. In contrast, no significant differences were found for pH ($p = 0.475$) or temperature ($p = 0.479$) between the two sites. Microbial analysis revealed the absence of *E. coli* and *Salmonella* at both locations, while FC, TC, and APC levels were notably higher at the Dam, highlighting its susceptibility to contamination. Regression analysis indicated that pH and temperature were not significant predictors of COD ($p > 0.05$), suggesting other factors, such as filtration and pollution sources to have played a critical role. These findings highlighted the importance of water treatment at the Farm in mitigating pollution and ensuring water quality. The study suggests that microbial contamination in feed and fecal samples may be influenced by multiple factors, including environmental conditions like temperature, pH, and possibly organic matter levels (COD).

Keywords: *E coli, Salmonella,* Total Coliform, Feed, Water, and Feaces, Aerobic Plate count

5.1 Introduction

Water is a critical component of animal husbandry, and its quality plays a significant role in animal health and welfare. Pathogenic microorganisms in drinking water can pose high risks to animal health, leading to diseases, and reduced productivity, and can be zoonotic through food products. *Salmonella* has been ranked as one of the high pathogens that contribute to foodborne disease outbreaks. According to the Centre for Disease Control and Prevention report, *Salmonella* was estimated to have contributed to about 53.4% of foodborne disease outbreaks reported between 2006 and 2017 (Mkangara 2023). It was further estimated that 32.7% of the foodborne outbreaks were associated with the consumption of farm produce. *Salmonella-related* outbreaks have been discovered to be of animal origin (Haley *et al.* 2009, Sivapalasingam *et al.* 2004). This includes meat and poultry products such as eggs and other products. Therefore, ensuring that water quality is maintained for animal consumption is of paramount importance as it can pose risks to human and animal health. It has been noted that there is limited research on the quality of water supplied to farm animals. The focus has been on food products of animal origin including pork. A total of 1581 cases were reported in Spain, Slovakia, and Poland after a Salmonella outbreak was linked with infected egg consumption (Munck *et al.* 2020). European Centre for Disease Prevention and Control (ECDC) reported that in 2018 *Salmonella* was responsible for causing sickness in 9 857 people in the European Union (EU) (Ehuwa *et al.* 2021). Poor hygiene such as encounters with infected animals and inadequate hand washing were identified as one of the reasons for increasing *Salmonella* cases. Of the instances Ehuwa *et al.* (2021) reported in the EU, *Salmonella* accounted for 33%. In South Africa, studies have similarly identified Salmonella as a common foodborne pathogen in livestock production systems. According to Sanchez *et al.* (2002), Salmonella spp. were isolated from pigs, poultry, and cattle, with contaminated water and feed being possible sources of infection. Moreover, Kambuyi (2018) reported the presence of antimicrobial-resistant Salmonella strains in meat products in South African retail outlets, raising concern over public health risks. These findings highlight the relevance of monitoring water quality and hygiene in livestock systems to mitigate zoonotic transmission risks.

It is important to note that consumer health must be considered during on-farm production of any agricultural produce. This includes foodborne pathogens and hygiene indicators such as *E. coli*. In pigs, *E. coli* has been reported to affect piglets by stimulating the hypersecretion of electrolytes and water leading to diarrhea (Tang *et al.* 2024). A significant percentage of the piglets weight may be lost during this disease known as colibacillosis (Tang *et al.* 2024). This disease easily spreads to other pigs in the pen and incidence increases quickly, a clear case for early intervention. Bacterial *E. coli* is a primary cause of diarrhea in weanling pigs (Xu *et al.* 2023) and can be transmitted between piglets through faeces, water, and feed (Vostrý *et al.* 2008). During pig production, piglets usually ingest *E. coli* either from the mammary glands, pen environment, and or farrowing house (Rhouma *et al.* 2017). This does not only affect pigs but is also susceptible to children in most developing countries and regions (Pan *et al.* 2015, Qadri *et al.* 2005). Chandran and Mazumder (2013) reported that pathogenic *E. coli* poses a significant threat to consumer health through transmission by food and water from pigs to humans. Therefore, tracing the whole value chain of pork production is important. Hence this study assessed feed, water, and feaces to determine the presence of pathogenic bacteria, *Salmonella,* and *E. coli*.

According to Berry and Wells (2018) animals which are exposed to contaminated water and feed could become carriers of foodborne pathogens, affecting final product quality. The ingested contaminated feed or water could colonize the GIT potentially leading to illness thus affecting meat quality. Waterborne pathogens, such as *Salmonella spp* strains, can thrive and multiply in water environments. These waterborne pathogens can contaminate animal drinking water sources, which could lead to colonization of the animal's GIT and shedding of the pathogens with feaces. Such risks could also be escalated during cleaning using contaminated water in the housing facilities, through cross-contamination of animal feed, bedding, and equipment (Sharif *et al.* 2024). Animals could encounter contaminated surfaces thus increasing the risk of pathogen transmission. These pathogens may be ingested through contaminated feed or water which could lead to GIT infections. Once the pathogens are ingested, they can colonize the intestinal tract causing illness and further affecting meat production. This could result in zoonotic transmission of these foodborne pathogens through contaminated water, affecting human health (Van Eenige *et al.* 2013). Humans may be exposed to these pathogens through direct contact with infected animals, consumption of contaminated animal products (meat, milk, eggs), and or exposure to contaminated environmental sources.

In certain circumstances where humans are exposed to consuming contaminated food or water they may encounter foodborne illness, which ranges from mild gastrointestinal symptoms to severe or life-threatening infections (Ünüvar 2018). Water plays a critical role in the transmission of foodborne pathogens to animals and subsequently to humans, this could arise from inadequate hygiene practices and insufficient water treatment that could worsen the risk of foodborne disease transmission from animals to humans. Therefore, there is a need to implement measures to prevent water and feed contamination by feaces and other factors, improve water quality, and mitigate the risk of waterborne pathogen transmission that might affect human health.

The number of waterborne pathogens or microorganisms is bound to increase when conditions are favourable, in which they may either form a biofilm inside an animal drinking system or attach to it (Maes *et al.* 2019). Biofilms in animal water drinking systems are complex microbial communities that develop on the surfaces of water delivery systems (Maes *et al.* 2019), this may include pipes, water troughs, and drinking nipples. These biofilms can harbour diverse microbial populations, including bacteria, fungi, algae, and protozoa (Elhariry *et al.* 2012, Liu *et al.* 2014, Mulamattathil *et al.* 2016). Understanding the formation and impact of biofilms in animal water drinking systems is crucial for maintaining water quality, ensuring animal health, and preventing the transmission of waterborne diseases (Mulamattathil *et al.* 2014). This ensures high-quality meat and products from animals which results in consumer trust and reliability of the food source. It is important that water quality is assessed at the source and sometimes at the end of the drinking lines (Van Eenige *et al.* 2013). Surfaces inside the drinking system have less or no records of assessment or studies, specifically, for meat-producing animals. Moreover, the relationship between water and feed that is consumed by an animal is crucial and needs to be assessed.

To mitigate the risks associated with these microbial contaminants, it is critical to implement regular assessments of feed, water, and feces to monitor microbial load and prevent the spread of pathogens within the production system. Such assessments are key to ensuring meat traceability and safety, as they allow producers to identify and address contamination sources before they can affect the final product. Monitoring microbial contamination along the entire production chain, from feed and water sources to animal health and feces management, ensures that the pork produced is safe for consumption and traceable back to its origin (Murungi *et al.* 2021, Schmithausen *et al.* 2018).

Hence, this study aims to assess the microbial load in feed, water, and feaces in the meat production chain to understand their interconnected roles in maintaining production efficiency, animal welfare, and meat safety. By evaluating the microbial quality of these key components, the study seeks to identify potential risks and establish practices that enhance meat safety and traceability, ensuring a safer food supply from farm to table. This ensures safety and reliability towards the initial stages of the production chain. The null hypothesis tested was that there would be no significant difference in the microbial load of feed, faeces, and water in the pig production chain. Their presence does not impact production efficiency, animal welfare, and or meat safety along the value chain.

5.2 Materials and Methods

5.2.1 Description of study site

Sampling was done in a communal farm that produces pigs in KwaZulu-Natal Province, Richmond municipality, South Africa. The farm was targeted and selected because of the increasing market size of informal meat traders who turn to outsource meat; however, this study's concerns were directed to product safety and human health. The majority of small holder farmers have limited access to resources and infrastructure, such as systems in place for traceability, which is a crucial component of meat safety. The farm is located 35 km away from the University of KwaZulu-Natal, Pietermaritzburg campus. This is between 29.6985491,30.2840289. The area has a high-average temperature of 22^{o} C to 28^{o} C and lows between 3^{o} C and 18^{o} C. The farm is pig-producing and supplies a local abattoir 40 km away from the farm. The abattoir only slaughters pigs and supplies both commercial and local retailers. It slaughters a total of 600 pigs a day.

5.2.2 Ethical considerations

The study adhered to ethical guidelines from the University of KwaZulu-Natal for animal research, including obtaining informed consent from the farm owner or manager and minimizing animal stress and discomfort during sample collection. **AREC/00007480/2024.**

5.2.3 Sample collection

5.2.3.1 Study outline and sites of collection

The study employed a combination of field sampling and laboratory analysis to assess the microbial quality of the animal drinking system. Sampling was conducted at two locations, within the animal housing facility, including the water source (Dam) and the drinking system (Nipple drinkers). In addition, fecal samples were collected inside the piggery, and feed samples from the feeding troughs were assessed to assess the presence of foodborne pathogens and hygiene indicators.

5.2.3.2 Methods used to sample (Water, feed, and fecal samples)

Sampling was conducted for three consecutive months, in which sampling was done once a week for each component (water, feaces, and feed) to collect representative samples from different points within the animal housing facility. Each component had 3 sampling occasions. Water samples were collected using 1000 ml sterilized Scott water bottles, and water temperature was recorded using a HI98194 Hanna multiparameter meter. Targeted areas for water sampling were the water source (the Dam) and the drinking system in the animal house. Collected samples were transported to the laboratory in a cooler box containing ice at 4 degrees Celsius within 6 hours post-collection. Feacal and feed samples were collected in the morning using sterilized plastic zipper bags and were stored in a cooler box during transportation to the laboratory. Fecal samples were collected early in the morning, with the target being on the freshly dropped feaces. Feed samples were collected directly from the feeding trough using sterilized zipper bags, assuming that bagged feed from the commercial supplier is free of pathogens. Sampling was done once during sampling days. All samples were analyzed at the University of KwaZulu-Natal, Department of Agriculture, Engineering, and Science, School of Microbiology.

5.2.3.3 Physico-chemical parameters

The pH was measured at the dam and drinking system water using a 100 ml beaker and a calibrated pH/°C meter (Hanna Instruments, HI8314, Italy). Chemical oxygen demand (COD) was determined using the Merck Nova 60 system (Germany) and Merck COD test kits (with a range of 10-150 mg/L, Merck, Germany), this was done following manufacturer's instructions. This was done to determine whether sampled water has high or low COD, with high COD implying that water is dirty and not good for animal consumption.

5.2.4 Microbiological analysis

4.2.4.1 Aerobic Plate Count Bacteria

Aerobic plate counts for water, feed, and feaces samples were performed in duplicate following the standard method specified in SABS ISO 4833 (2007). Each sample (1 mL) was serially diluted in sterile saline solution (0.85% w/v NaCl) up to a 10^{-5} dilution. A 100 µL aliquot from each dilution was spread onto plate count agar (PCA, Merck) plates. The plates were incubated at 30°C for 48 to 72 hours. Viable colonies were counted, and the weighted means were calculated. Results were expressed as $\log_{10}$ colony-forming units per milliliter ($\log_{10}$ CFU/mL).

All samples (water, feed, and feaces) were analyzed for general microbial burden (APC, Coliform) and hygiene indicator (*E. Coli*), and potentially pathogenic bacteria were determined.

5.2.4.2 Detection of Salmonella spp from water

Salmonella spp was detected using the ISO 6579 (2002) method. This is a standard method used to detect *Salmonella spp* in animal feed and human food. However, it can also be adapted for water analysis with some modifications. Analysis was performed using the following steps:

Pre-enrichment

The water samples from the dam and drinking system were inoculated into a non-selective pre-enrichment broth. Buffer peptone water was pre-warmed (100 ml double-strength, 10 ml double-strength, and 9 ml single-strength) and was inoculated with 100 ml, 10 ml, and 1 ml of water samples collected from the Dam, and the drinking system. The containers were incubated at an appropriate temperature of 37 degrees Celsius for 24 hours (h).

Selective enrichment

The water samples were inoculated into a non-selective pre-enrichment broth. This was carried out in Rappaport Vassiliadis Soy (RVS, Oxoid) broth and MULLER-KAUFFMAN tetrathionate Novobiocin (MKTTn, Merck) broth where it was inoculated with 200 micro-liters of cultures obtained. This was followed by an incubation at 41.5ºC and 37ºC for 24 h. Another step was the subculturing of xylose lysine deoxycholate (XLD, Merck) agar and Salmonella chromogenic agar (Merck), incubated at 37ºC for 24 h.

5.2.4.3 Detection of E. coli from water samples

A 5ml-tube multiple dilutions Most Probable Number (MPN) method was used for total coliforms, fecal coliforms, and *E. coli* in water samples, while a 3-tube MPN procedure was adopted for feed and feaces (solids), as prescribed by the Canadian Standard (MFHPB-19) (Health Canada, 2002).

The MPN method detected total coliform, fecal coliform, and *E. Coli*.

5.2.4.4 Fecal sample analysis (E. coli and Salmonella)

To determine any viable microorganisms, present in faeces. A 10-gram sample was put into a measuring flask containing 90ml of sterile saline to create a solution. The flask with the solution was then placed into a stirring machine for 20 minutes to get a homogenous solution. The solution was then used to create a serial dilution of 8 tubes from 10^{-2} to 10^{-9}. This was used to determine the presence or absence of *E. coli*.

To quantify the presence of Salmonella in the faeces, a 25-gram sample was put into a measuring flask containing 225 ml of peptone water buffer (PBW). It was incubated at 37 degrees Celsius for 24 hours.

5.3 Data analysis

The data of this study was analyzed using GenStat 23rd version (VSN International, 2023). A regression was used to investigate whether pH and Temperature influenced COD as an organic matter presence detector in water. A correlation analysis was also applied between the physical-chemical properties and COD. A regression analysis was performed on Microsoft Excel for the relationship between the total coliform and aerobic plate count for feaces and feed across the three sampling occasions.

5.4 Results and Discussion

5.4.1 Microbiological analysis of on-farm collected samples

5.4.1.1 Microbiological quality of dam and farm water

Table 5.1: Physical Parameters (pH, COD, and Temperature) of Water Samples from Piggery Unit and Supplying Dam

	Dam			Farm			P-Value
Sampling occasion	1	2	3	1	2	3	
pH	6.69	8.25	6.95	7.98	6.98	8.47	0.475
Temperature °C	20.9	20.2	21.6	27.1	18.8	22.5	0.479
COD mg/L	13	12	10	7	5	2	0.015
Hygiene Indicators/Pathogens from water samples							
E. Coli	-	-	-	-	-	-	
Salmonella	-	-	-	-	-	-	

-: No detection, COD: Chemical Oxygen Demand,

Water quality has been an ongoing discussion in the Agricultural sector, especially the pig-producing industry, for over a decade**.** Table 5.1 summarizes the findings of the three sampling occasions. There was a significant difference ($p<0.05$) between the pH levels across both sites, with values between 6.69 and 8.47. However, the values are within the 6.5-8.5 range for agricultural use as stipulated by the Department of Water Affairs and Forestry (DWAF) (DWAF 2008). This guideline is essential for ensuring safe and productive use of water resources and provides limits for water quality parameters while ensuring that water used for livestock does not negatively affect its health. These findings align with Byrne and Murphy (2022), who emphasized that maintaining pH within this range ensures the bioavailability of nutrients while avoiding toxic metal solubility that could harm livestock. Similar observations by Edwards and Crabb (2021) underscored the importance of pH stability for animal health, particularly in pig production.

The pH values showed that water from the dam posed no harm if it was used for animal drinking. Furthermore, the differences in pH could be attributed to the nutrient cycle or the dam's natural self-cleaning. The study also recorded water temperature on all sampling occasions. The temperature fluctuated across the sampling periods, ranging from 18.8°C to 27.1°C. The fluctuation and temperature differences could result from seasonal or environmental changes. Heinke *et al.* (2020) reported comparable seasonal variations in livestock water sources and noted that elevated water temperatures could reduce water intake, increase heat stress, and negatively impact pig performance. Maintaining optimal water temperatures is thus critical, particularly in the South African climate, to ensure animal welfare and production efficiency.

Chemical Oxygen Demand (COD), an important indicator of organic contamination, showed significant differences between dam and farm drinking water, with dam water showing higher COD values (2–13 mg/L). This result aligns with Cao *et al.* (2021), who noted that surface water sources often have elevated COD due to organic runoff and require treatment before livestock use. In this study, the farm’s filtration and treatment system effectively reduced COD levels, which mirrors water management practices recommended by Little *et al.* (2021) to ensure a clean water supply, prevent microbial growth, and avoid digestive or metabolic disorders in pigs. The COD values were below the accepted threshold of 100 mg/L, as stipulated by Nik Daud and Anijiofor (2016), indicating the farm's successful pollution control practices.

This study further determined the presence or absence of waterborne pathogens, targeting *salmonella* and hygiene indicator *Escherichia coli* (*E. coli)* from the collected water samples. None of the pathogens were detected in the water samples (Dam and Farm). This still indicates that the water source is highly maintained, and the method used by the farm to purify water is effective. Since *E. coli* and *Salmonella* were not detected in any of the water samples from either the dam or the farm, statistical correlation analysis between physicochemical parameters (COD, pH, temperature) and fecal indicator bacteria could not be performed. The absence of microbial contamination in all sampling occasions prohibited the possibility of determining a statistical relationship. No clear correlation was observed between temperature and pH in relation to bacteria even though COD differences showed slight contamination which was not significant ($p>0.05$). DWAF stipulates that 20 mg/L COD is considered safe for animal use while a COD of above 100 mg/L is heavily polluted water with reduced oxygen and, therefore, not safe for consumption. This study had a higher COD value of 13 mg/L on the first sampling but was still safe as stipulated by DWAF.

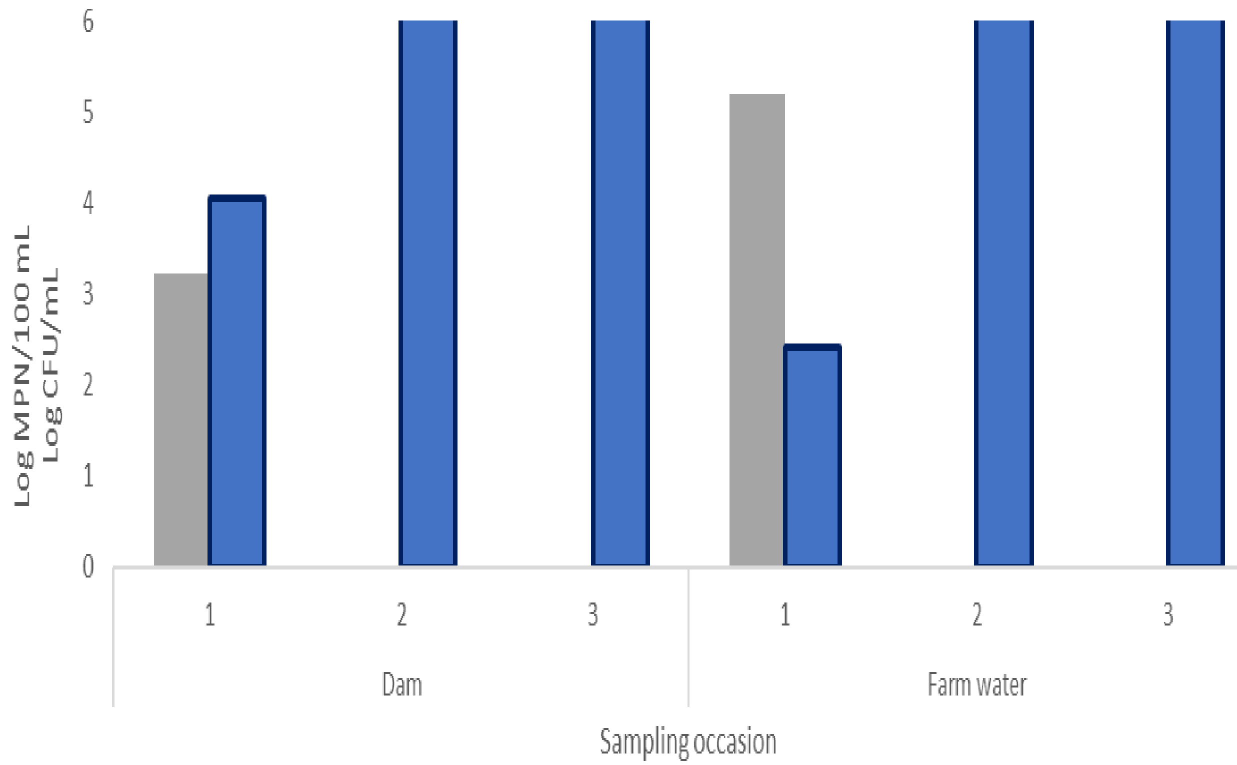

Figure 5.1: General microbial burden of water from the Dam and drinking system within the piggery unit

Figure 5.1 illustrates the microbial load in the dam and farm water across three sampling occasions, comparing the aerobic plate count (APC) and total coliform (TC) levels. The bar graph highlights consistently higher APC values relative to TC levels throughout the sampling periods, except for the first sampling occasion, where the difference was minimal. The variation in microbial counts is indicative of the overall microbial quality of the water sources, with APC values showing a broader range compared to total coliform counts.

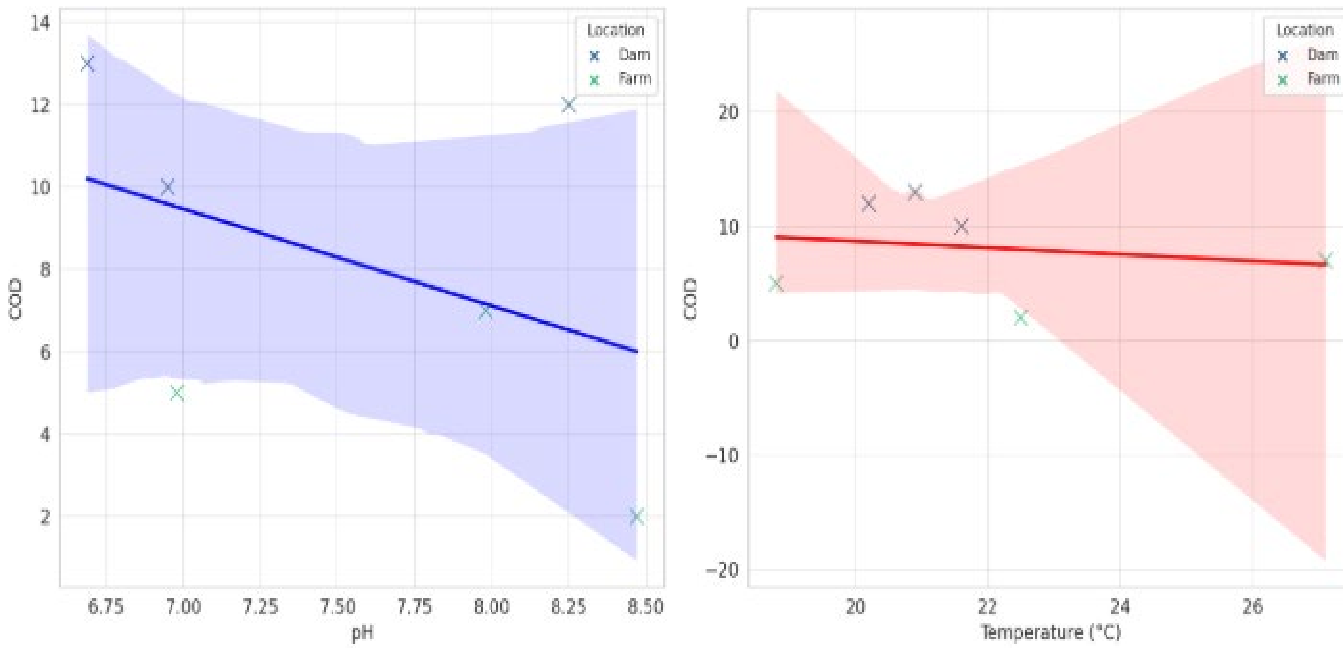

Figure 5.2: A scatterplot illustrating the relationship between pH, Temperature, and COD across sampling occasions for both Dam and farm locations

A regression analysis was conducted to determine whether the physicochemical properties influence COD. The concentration of organic matter present in water for either human consumption or animal use is determined by COD, a high presence of organic matter means water is highly contaminated. After regression analysis from the results of this study, it was indicated that 18% of the variability in COD was explained by water and temperature from sampling occasions. A regression analysis was conducted to assess the relationship between physicochemical parameters (pH and temperature) and chemical oxygen demand (COD) in water samples from both the dam and the farm. COD is an indicator of the concentration of organic matter in water, with higher values reflecting greater contamination. A moderate negative correlation between pH and COD was also observed, showing that as pH increases COD decreases, but there was a positive correlation between temperature and pH, this could mean that they might interact in influencing COD.

Table 5.2: Statistical Analysis of Physico-Chemical Parameters and Regression Model Results

Physico-Chem properties	t-test	P-Value	Interpretation
pH	-0.79	0.475	NSD
Temperature	-0.78	0.479	NSD
COD	4.12	0.015	SD
	Regression model		
Coefficient	**Estimate**	**std error**	**P-Value**
Intercept	26.42	23.77	0.347
pH	-2.29	3.17	0.521
Temperature	-0.043	0.85	0.963

NSD: No significant difference, SD: Significant difference
R^2= 0.181 (18.1% of the variance in COD was explained by the model)
F-statistic value, p-value= 0.741 (Indicated that the model was not statistically significant overall)

The study saw a necessity to conduct a t-test and regression analysis of the physico-chemical parameters since they could reflect environmental or water quality variations. While there was no significant difference in pH and temperature between the two sampling sites, COD levels were significantly lower at the farm compared to the Dam. It is speculated that the farm might be using a water treatment; hence, the lower COD values across the sampling occasions reflected not just natural differences but also the impact of treatment. Suggesting that the COD results from the farm cannot be directly compared to the Dam without accounting for the treatment effect. The COD levels from the Dam are more indicative of environmental and pollution conditions, however, the Dam as a static or slow-moving body of water, can self-clean itself, hence, the accepted levels of COD that are within the agricultural or livestock use. The regression model did not find pH or temperature as a significant predictor of COD, this implied that COD levels are influenced by other unmeasured factors such as the filtration method.

5.4.1.2 General microbial burden (APC and total coliforms)

General microbial burden (APC and TC) was analyzed from three sampling occasions of pig feaces and feed from a communal farm. Monitoring the general microbial burden ensures the safety, hygiene, and quality of the products being produced. As highlighted by Fong and Lipp (2005) and McAllister and Topp (2012), regular microbial monitoring in livestock environments is essential for early detection of contamination that could affect both animal and public health. The results of the analysis are presented in Figure 5.3. APC ranged from 5.2 to 8.47 CFU/g, while TC ranged between 1.56 to 7.04 CFU/g with a geometric mean of 30.21 and 40.86, respectively. These elevated levels of APC and TC in faeces may be attributed to poor cleaning of the feeding troughs and/or the housing facility, a concern previously raised by Ngure *et al.* (2019) in relation to hygiene practices in small-scale pig farms.

APC does not have universal standards, but its typical values can vary widely due to the natural microbial content of feaces (Traverso *et al.* 2002). The results of this study suggest that there could be a potential contamination of pigs, which may be linked to on-farm management. There was a significantly high APC across the sampling occasions when compared to TC; however, there was only a single sampling occasion where TC was higher than APC (Figure 5.3). Such contamination could negatively affect the quality of meat being produced by the pigs from the farm, as indicated in similar studies by Pessoa *et al.* (2021), where increased microbial loads in pre-harvest environments were linked to compromised meat safety.

Furthermore, TC in feaces is naturally high mainly because of coliforms, including *Escherichia coli* (*E. coli*), which is a common intestinal bacterium. Counts above 10^8 CFU/g might indicate that an animal has a gut infection and therefore requires treatment (Foitzik *et al.* 1999). Similarly, this study found counts of 10^8 CFU/g, indicating that the values were within the expected range. Whereas in feed, TCs must be less than 100 CFU/g (Kim *et al.* 2021), and in this study, they were also within the accepted range. Monitoring the APC and TC in feed and faeces is crucial in identifying animal health issues, such as gut microbiota imbalances, and assessing hygiene. This further ensures that the feed provided is safe and free from microbial contamination, aligning with recommendations from EFSA (2018) on animal feed hygiene practices.

The relationship between TC and APC was not statistically significant ($p > 0.05$), which was similar to the F-test (0.993) and its *p-value* (> 0.05), suggesting that the overall regression was statistically not significant. This aligns with observations by Kim *et al.* (2021) and Fosse *et al.* (2009), who noted that microbial indicators may not always show direct linear correlations, especially in complex agricultural environments where multiple variables influence microbial presence..

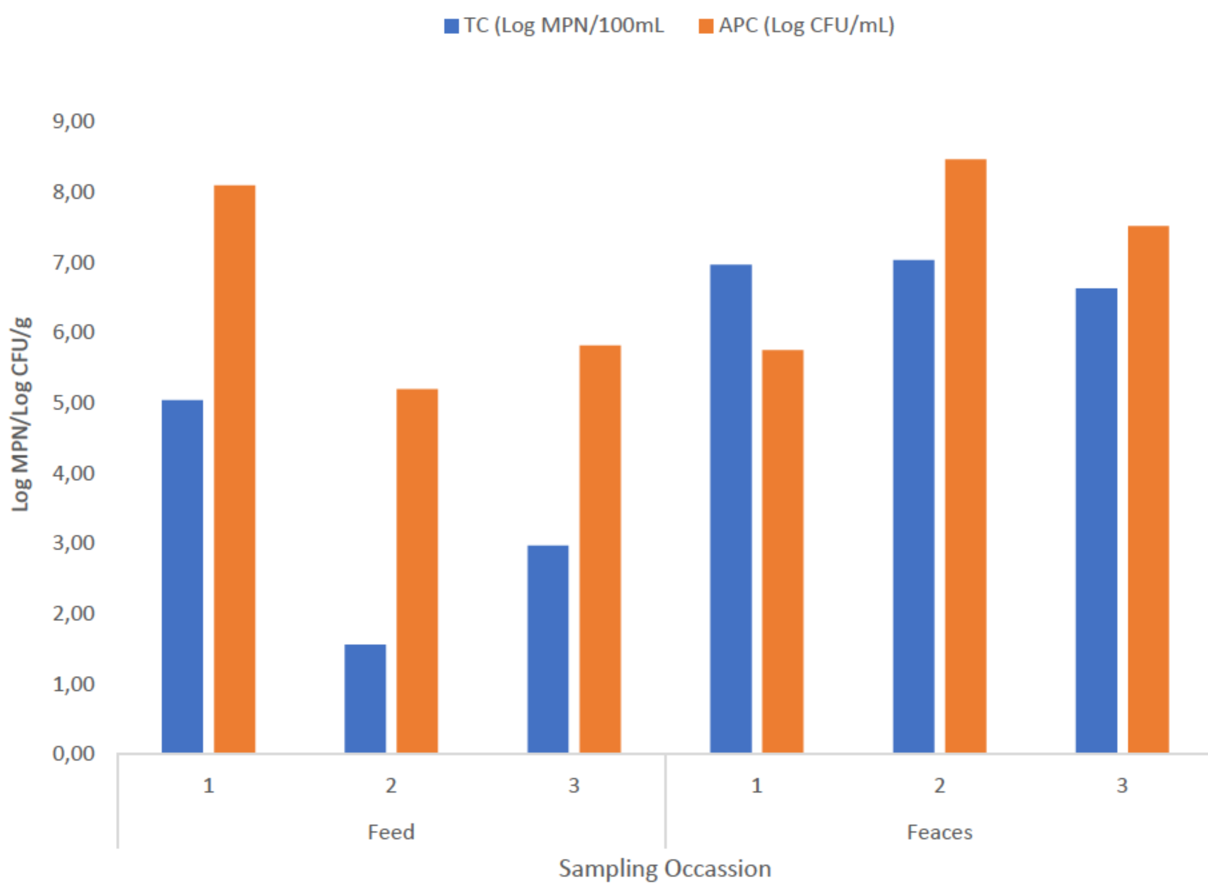

Figure 5.3: General micro-burden of feed and feaces from a communal farm

Fecal indicator bacteria (FIB) have been widely used as a proxy for detecting the presence or absence of pathogenic bacteria in samples collected from environments such as animal feed, soil, and water. Ideally, FIB is bound to be present in the intestinal tract of an animal as the pathogen but must be present only in contaminated samples (Rochelle-Newall *et al.* 2015). Fecal indicator bacteria (FIB) were assessed in this study as a potential pathogen presence of fecal origin. Given the outbreak of meat-related sicknesses in South Africa, the analysis of FIB from the feed and feaces is important.

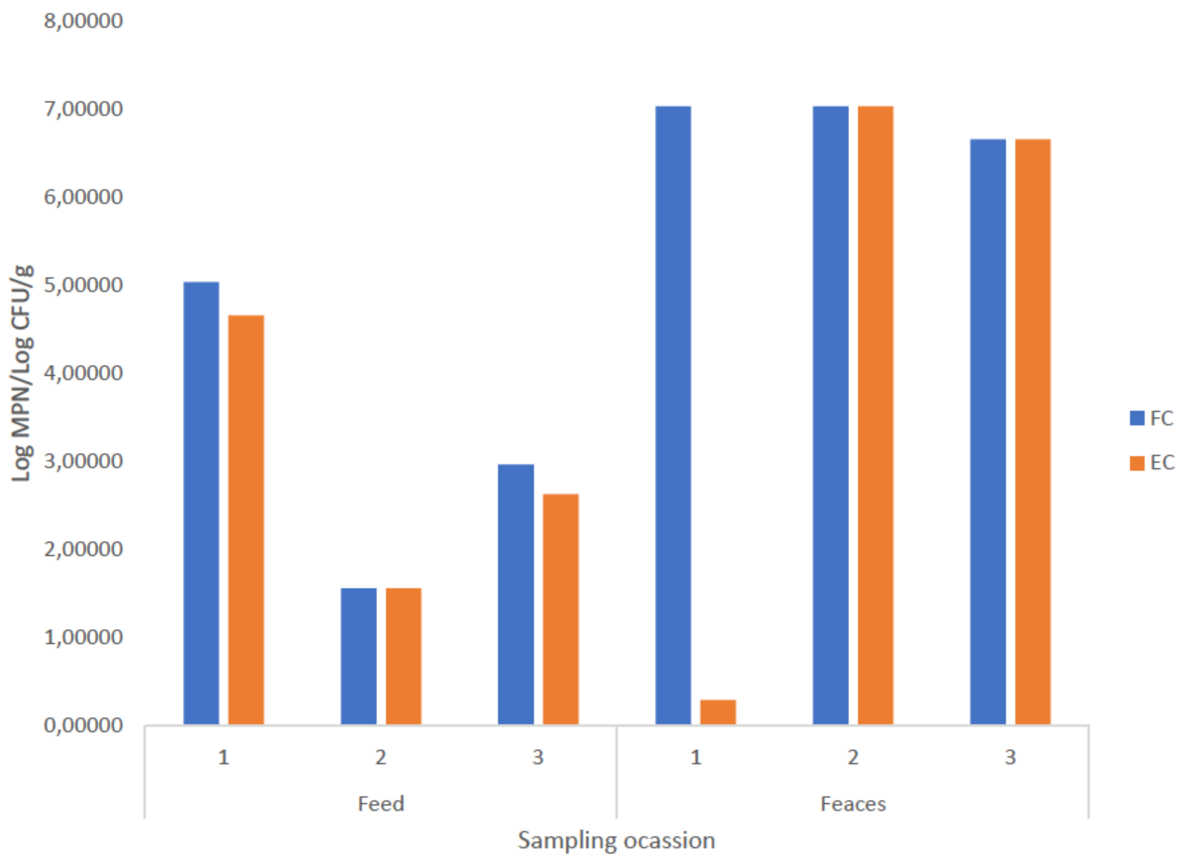

Figure 5.4: General microbial burden of hygiene indicators for feed and feaces from a communal farm

Figure 5.4 represents counts for fecal coliform (FC) ranging from 1.56 to 7.04 CFU/g and *E. Coli* (EC) ranging from 1.56 CFU/g to 7.04 CFU/g with a geometric mean of 23.7 and 22.5, respectively. There was a significant difference in CFU/g between FC and EC ($p<0.05$) for feed and feaces. It was expected that feaces would have higher EC than feed, but the first sampling produced higher EC on feed than feaces, this shows that there could be a source of contamination within the housing facility, feed storage, and or possibly from the feed producers. During the second sampling, a drop by 2.9 CFU/g of EC in feed showed that an action was taken to control the contaminant. On the first sampling, *E. Coli* was not detected in feaces but in the feed, while on the second sampling, there was a higher increase in CFU/g of EC in feaces while it decreased for feed. On the third sampling, feaces still had higher EC and FC, which showed there could be feed contamination. However, the regression model suggested a weak linear relationship between TC and EC, and therefore lack of statistical significance ($p>0.05$). It could be said that the lack of statistical significance of the variables indicates that other factors such as environmental conditions and other microbial indicators might better explain such variation in the independent variables, such as the use of APC. It could also be argued that the type of relationship between EC, FC, and the dependent variable might not be linear or involve more complex interactions that are not captured in a simple regression model.

5.5 Conclusion

While there was a relationship between TC and APC, it was not statistically significant in this study. The study suggests that microbial contamination in feed and fecal samples may be influenced by multiple factors, including environmental conditions like temperature, pH, and possibly organic matter levels (COD). However, the absence of significant results for EC and FC indicates that other factors may be at play.

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Chapter 6

Assessing Meat Safety in the Informal Markets: A Survey on Consumer Attitudes and Health Risks in South Africa

6.1 Introduction

Food safety is an important issue facing current consumers, the food industry, and the government (Liana *et al.* 2010). Since several food safety crises have occurred globally in recent years, the production of safe animal food products has become one of the most important aspects of quality for both consumers and retailers. The high sensitivity of consumers to food safety issues cannot be ignored by the participants. Meat safety is crucial to ensure meat is free from harmful pathogens and contaminants, safeguarding public health. In formal markets, meat is closely monitored by regulatory bodies like the Meat Safety Act (MSA) and inspected by the Department of Agriculture, Forestry, and Fisheries (DAFF) (Jaja *et al.* 2017). Meat safety refers to the measures and procedures taken from slaughter to consumption, ensuring that meat is safe, hygienic, and fit for human consumption. This includes proper handling, processing, packaging, and storage standards, as well as monitoring of slaughterhouse conditions (Ninios *et al.* 2014). When meat is processed in compliance with regulatory standards, it reduces the risk of contamination and foodborne illnesses, ensuring consumer protection. The meat that is sold to consumers in South Africa is derived from commercial farmers through commercial abattoirs where meat handling is strictly governed by the Meat Safety Act of 2000. Even though most regulations that are set to protect consumer health are followed in most abattoirs, the challenge is the meat that is sold. These abattoirs, by nature, lack the strict safety measures required to ensure that meat is handled hygienically and safely. Without regular oversight, such markets face a higher risk of contamination from harmful bacteria, such as *E. coli, Salmonella*, and *Campylobacter* (Baliyan *et* *al.* 2024). These pathogens are notorious for causing foodborne illnesses, which can result in symptoms ranging from mild stomach discomfort to severe food poisoning, and in extreme cases, even death (Gourama 2020). Moreover, the improper handling practices commonly found in informal markets, such as the lack of refrigeration or proper sanitation, exacerbate these risks (Lah 2016). In many African countries, the sale of meat through informal markets is an essential part of the food distribution system, especially in urban and peri-urban areas where access to formal retail outlets may be limited or too expensive for a large portion of the population (Roesel and Grace 2014). The cost-effectiveness of purchasing meat in informal markets, especially for lower-income consumers, often outweighs concerns about its safety (Hoffmann *et al.* 2019). As a result, these markets play a critical role in providing affordable protein to urban populations. However, while they may provide economic access to meat, they also present significant health risks to consumers, particularly when it comes to meat that is sourced from communal or unregistered abattoirs (Sojl *et al.* 2015). At most times in these abattoirs, hygienic handling of carcasses after slaughter is not practiced and this is critical for the prevention of contamination and to ensure meat safety.

A good example of this situation is found in Mai Mai, a multi-tribal market located in Gauteng Province, South Africa. This market has been identified as one of the largest informal markets in Johannesburg, primarily caters to local communities and provides a variety of meat products, including beef, and offal (internal organs), sourced from the communal abattoir (Olivier 2004). While some of the meat sold there comes from registered sources, much of it is from small, independent vendors who lack the necessary health certifications and inspections required by food safety regulations (Mungai 2019). The meat sold at the informal market is often the by-product of beef production, such as head meat, internal organs, and feet. These by-products, while nutritious and culturally significant in many culinary traditions, are highly vulnerable to bacterial contamination, particularly because they are near the animal's intestinal contents (Alao *et al.* 2017). Offal poses significant food safety risks because it is exposed to digestive bacteria during slaughter, which can easily transfer to the meat if proper hygiene protocols are not followed (Sharma *et al.* 2020).

The situation is not unique to South Africa. In Kenya, the challenge of unsafe meat in informal markets is similarly prevalent. A significant portion of the meat sold in urban areas like Nairobi comes from unregistered abattoirs, where conditions are not adequately regulated (Sirma *et al.* 2023). In informal markets, meat, including offal and lesser cuts, is often sold without any form of health certification or proper inspection. Research conducted by (Nkosi *et al.* 2021) revealed that the lack of veterinary inspection in these informal markets has led to numerous outbreaks of foodborne diseases, particularly those caused by *Salmonella* and *E. coli*. Furthermore, the majority vendors in Nairobi's informal markets do not have access to refrigeration, resulting in meat being sold at room temperature, which significantly increases the risk of bacterial growth and spoilage (Mungai 2019). Similarly, in Malawi, informal meat markets are an integral part of the food supply chain, especially in major cities like Lilongwe and Blantyre (Chilanga and Riley 2017). However, these markets also face significant challenges when it comes to food safety. Mwale *et al.* (2016) highlighted that meat sold in these informal markets often comes from unregistered abattoirs where basic hygiene standards are not followed. The sale of offal in particular is common in Malawi, with parts such as liver, kidneys, and tripe being popular among local consumers (Chilanga and Riley 2017). While these cuts are nutritionally rich and widely consumed, they are also prone to contamination, particularly if they are not properly cleaned and handled after slaughter. Without strict regulations or regular inspections, the sale of such meat poses a serious health risk to the public (Sharma *et al.* 2020).

Across sub-Saharan Africa and in most developing underdeveloping countries, the challenges associated with informal meat markets are compounded by the lack of education and awareness among consumers (Johnson *et al.* 2015). In regions where access to formal retail outlets is limited, consumers often lack the necessary information to assess the safety of the meat they purchase. They may not be fully aware of the risks associated with consuming meat from unregulated sources, particularly when it comes to the consumption of offal and other by-products. This lack of consumer awareness further exacerbates the public health risks tied to informal meat trade, as many consumers continue to purchase meat based on price and availability rather than safety standards (Cáceres *et al.* 2018). The informal meat trade, particularly in urban areas of developing countries, also faces the challenge of inadequate infrastructure (Giroux *et al.* 2021). For instance, the lack of refrigeration and proper storage facilities in informal markets means that meat is often kept at room temperature for extended periods, creating an environment conducive to bacterial growth. Meat exposed to the elements for prolonged periods is more likely to become contaminated, particularly in hot climates where bacteria multiply rapidly (Nørrung *et al.* 2009). The lack of sufficient sanitation at slaughterhouses and the absence of proper waste disposal mechanisms further contribute to the risk of contamination in these markets (Cáceres *et al.* 2018). The problem is not confined to Africa alone. In Latin America, informal markets in countries like Peru also face similar concerns. Informal slaughterhouses in cities such as Lima operate with little to no government oversight, and meat is sold in public markets without proper inspection. A report by Cáceres *et al.* (2018) indicates that *Salmonella* and *E. coli* contamination are common in these markets, particularly in offal and other lesser cuts of meat. In some instances, consumers prioritize affordability over safety (Grace 2015), leading to the continued consumption of potentially hazardous meat. Similarly, in Asia, informal meat markets in countries such as India and Indonesia face health risks due to improper slaughter practices and the lack of refrigeration. Research by Sharma *et al.* (2020) discovered that meat from informal markets in India frequently tested positive for harmful bacteria, further highlighting the global nature of the problem. While informal markets provide essential access to meat in many developing countries, the health risks associated with the sale of meat from unregulated or communal abattoirs cannot be overlooked.

The case of informal markets in South Africa, along with examples from Kenya, Malawi, and other underdeveloped nations, demonstrates the widespread nature of this challenge. Offal, head meat, and other by-products, though culturally significant and nutritionally valuable, are particularly vulnerable to contamination if not handled with care. In study by Roesel and Grace (2014), consumers may not be aware of the risks associated with purchasing meat from these informal markets, which further exacerbates the potential for foodborne illnesses. Addressing these concerns will require improved regulation, better consumer education, and greater oversight of meat-handling practices in informal markets across the developing world. Therefore, this study aimed to highlight the critical issues surrounding food safety in informal meat markets, particularly in South Africa, and the associated risks posed by unregulated abattoirs. It emphasized the need for better regulation, increased consumer awareness, and improved hygiene practices to mitigate the spread of foodborne illnesses caused by contaminated meat, especially offal, and other by-products, commonly sold in these markets.

6.2 Materials and Methods

6.2.1 Study site

The study was conducted across two cities of the KwaZulu-Natal province: Pietermaritzburg and Durban. Durban, the economic hub of KwaZulu-Natal, is a bustling metropolitan area that serves as a cultural and commercial center, dominated by various African tribes. It is strategically located close to global meat suppliers, making it a significant site for selling meat by street vendors. The geographical coordinates of Durban are 30° 58' 83" S and 25° 38' 54" E, and it is situated approximately 110 km from the University of KwaZulu-Natal, Pietermaritzburg campus. Pietermaritzburg, on the other hand, is located just 5 km from the university campus. It is also a city rich in cultural diversity, with various tribes engaged in various socio-economic activities, including meat trading in informal markets. Pietermaritzburg's geographical coordinates are also 30° 58' 83" S and 25° 38' 54" E. Both cities were selected due to their significant informal meat market presence and representation of KwaZulu-Natal urban centres.

6.2.2 Ethical considerations

Ethical approval for this study was obtained from the University of KwaZulu-Natal Research Ethics Committee **AREC/00007480/2024**. All respondents were informed about the study's purpose and provided written consent before participation. Participation was voluntary, and respondents were assured that their anonymity and confidentiality would be maintained throughout the study.

6.2.3 Population and Sample

A total of 500 respondents (approximately 250 from each city) were surveyed to capture a broad range of insights regarding consumer perceptions of meat safety. This sample size ensures adequate representation of various socio-economic groups within both cities. The target population for this survey consists of consumers who regularly purchased meat from informal markets and street vendors in Durban (n=250) and Pietermaritzburg (n=250). These consumers were randomly selected since these cities are popular for having significant street vending and informal markets, where meat, including offal and other by-products, is sold. To ensure the sample is representative of the consumer population, a stratified random sampling technique was used. The sample was divided into strata based on key demographic factors such as age, gender, income level, and frequency of meat purchases.

6.2.4 Data Collection Tools

Data was collected using a structured questionnaire designed to gather information on:

1. Demographic Characteristics: Age, gender, income, education, and occupation of the respondents.
2. Consumer Knowledge: Awareness of food safety standards, the source of meat, and common health risks associated with meat consumption.
3. Perceptions of Safety: Attitudes towards meat sold by street vendors, particularly those from communal abattoirs and informal markets.
4. Purchasing Behaviour: Frequency of meat purchases, types of meat commonly bought (e.g., offal, beef, chicken), and preferences for specific cuts.

5. Health Concerns: Awareness of foodborne diseases, concerns about contamination, and specific health risks associated with meat from informal markets.
6. Regulatory Awareness: Knowledge of the regulations surrounding meat safety and inspections in informal markets.
7. Transparency and Traceability: Do you believe that transparency and traceability of meat products (such as source, handling, and inspection history) are important for ensuring consumer safety? Why or why not?

The questionnaire was pre-tested with a small sample (n=10) to ensure clarity and validity of the questions. Feedback from the pre-test helped refine the tool for broader use.

6.2.5 Data Collection Procedure

Surveys were conducted in various informal market locations, including street vendor stalls, and adjacent marketplaces. Interviews were carried out in Durban and Pietermaritzburg, with enumerators traveling to different areas within both cities. Surveys were administered in Zulu and English, depending on the respondent's preference, with translators provided when necessary to ensure full comprehension and accurate responses. Consumers were interviewed for 15 minutes, during consumption at the provided tables, after consumption and at point of purchase with permission from the business owners. Informed consent was obtained from all participants before the surveys began. Participants were assured of the confidentiality of their responses and informed of their right to withdraw from the study at any time without penalty.

6.2.6 Data and Statistical Analysis

After data collection, the responses were entered into Microsoft Excel in preparation for statistical analysis. GenStat 23rd version (VSN International, 2023) was used for statistical analysis.

Descriptive statistics were used to summarize the respondents' demographic characteristics and attitudes towards meat safety. Chi-square tests were carried out to assess whether there were significant differences in perceptions and behaviours between respondents from the Durban and Pietermaritzburg cities.

6.3 Results and Discussion

Table 6.1: Sample Data for Comparison Between Durban and Pietermaritzburg

Health concern	Durban (n=250)	PMB (n=250)	Total (=500)
Very concerned	120	100	220
Somewhat concerned	80	90	170
Not Concerned	50	60	110
Total	250	250	500
Willingness to Pay for certified meat			
Willingness to Pay			
1 (Not willing)	30	50	80
2	40	60	100
3	90	80	170
4	60	30	90
5 (very willing)	30	30	60
Total	250	250	500
Purchasing Behaviour (Meat type purchased)			
Meat type			
Beef	120	90	210
offal	70	60	130
chicken	30	40	70
mixed	30	60	90
Total	250	250	500
Perceptions of safety in informal markets			
Perception of safety			
Safe	70	60	130
Unsafe	180	190	370
Total	250	250	500
Transparency and Traceability of Meat Products			
Transparency and Traceability			
Agree	180	150	330
Disagree	70	100	170
Total	250	250	500

PMB: Pietermaritzburg

The data collected from Durban and Pietermaritzburg on various consumer attitudes toward meat safety and purchasing behaviors revealed interesting patterns in health concerns, willingness to pay for certified meat, purchasing habits, perceptions of safety in informal markets, and attitudes toward transparency and traceability of meat products. The null hypothesis tested in this study was that there would be no significant difference in health concerns between Pietermaritzburg and Durban.

Durban respondents showed a slightly greater willingness to pay for certified meat, with 36% of respondents willing to pay (4 or 5) compared to 24% in Pietermaritzburg. A higher proportion of respondents in Durban (48%) expressed being very concerned about health risks associated with meat consumption compared to Pietermaritzburg (40%). Beef was the most purchased type of meat in both cities, with Durban showing a higher preference for beef (48%) compared to Pietermaritzburg (36%). A large portion of both Durban (72%) and Pietermaritzburg (76%) respondents considered meat sold in informal markets to be unsafe. Most respondents in both cities (Durban 72%, Pietermaritzburg 60%) agreed that transparency and traceability of meat products are important for ensuring consumer safety. After performing a Chi-square test using the data, there was a significant difference $p < 0.05$ in health concerns between Pietermaritzburg and Durban.

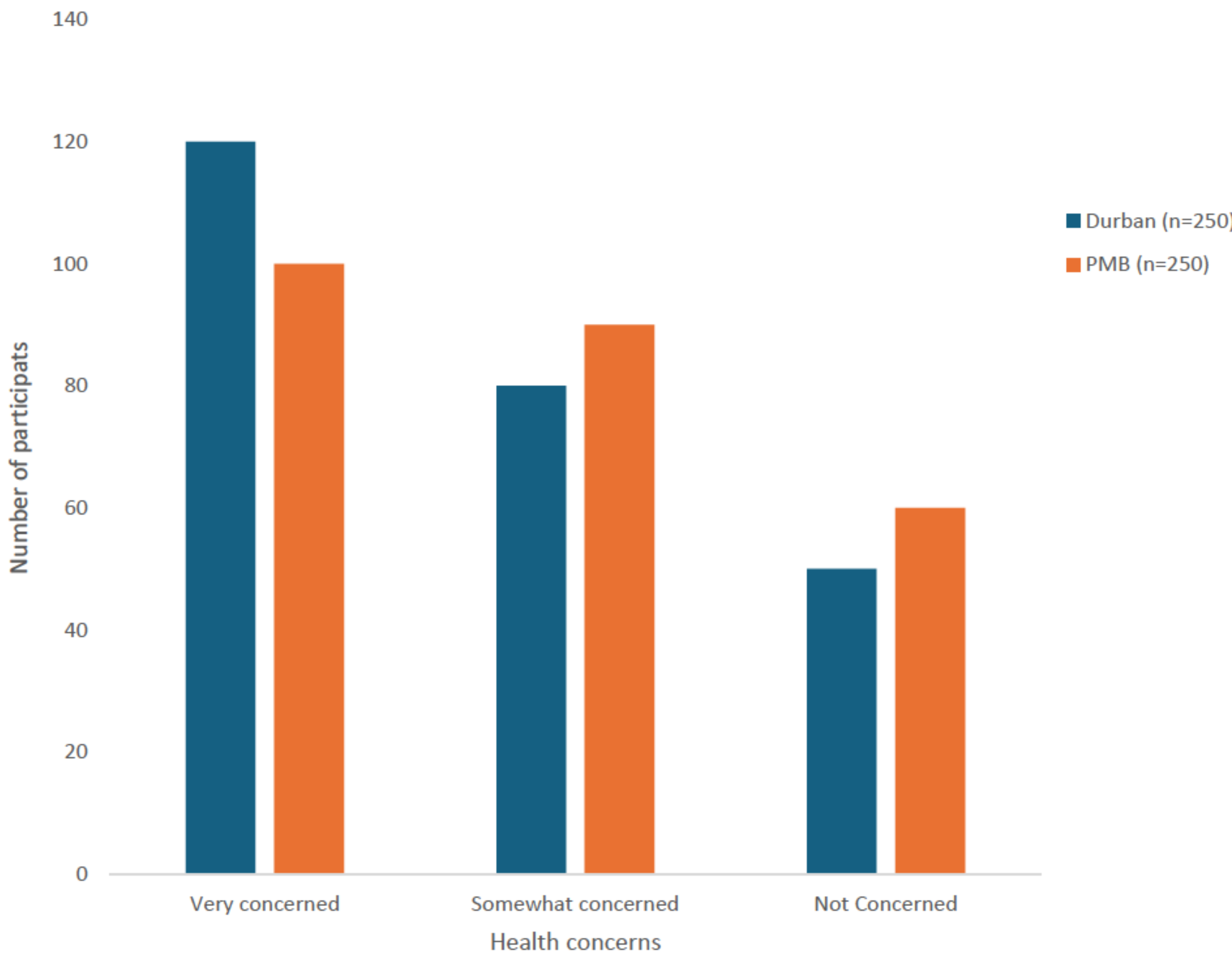

Figure 6.1: Health concern distribution between Durban and Pietermaritzburg informal meat traders

This distribution suggests that while concerns about meat safety are prevalent in both cities, Durban respondents exhibit a higher degree of caution. The difference in concern levels could be attributed to variations in regulatory enforcement, past food safety incidents, or differences in consumer education on meat handling and hygiene practices. The findings from Figure 6.1 align with research conducted in other regions where informal meat markets play a significant role in food supply. For instance, Roesel and Grace (2014) found that in East African informal meat markets, consumer and trader concerns about health risks were high, particularly in urban areas where awareness of foodborne illnesses was greater. Similarly, a study by (Jaja *et al.* 2017) in South Africa indicated that consumers in larger cities, such as Johannesburg and Cape Town, were more cautious about meat safety compared to those in smaller towns due to increased exposure to media reports and regulatory efforts. The difference in concern levels between Durban and Pietermaritzburg observed in Figure 6.1 may be attributed to similar urbanization and awareness trends. Durban, being a larger metropolitan area, likely has stricter health regulations and more publicized food safety concerns, leading to a higher percentage of "very concerned" respondents. In contrast, Pietermaritzburg, while still a significant urban center, may have slightly lower exposure to regulatory enforcement or media coverage, resulting in a comparatively higher proportion of respondents who are only "somewhat concerned" or "not concerned."

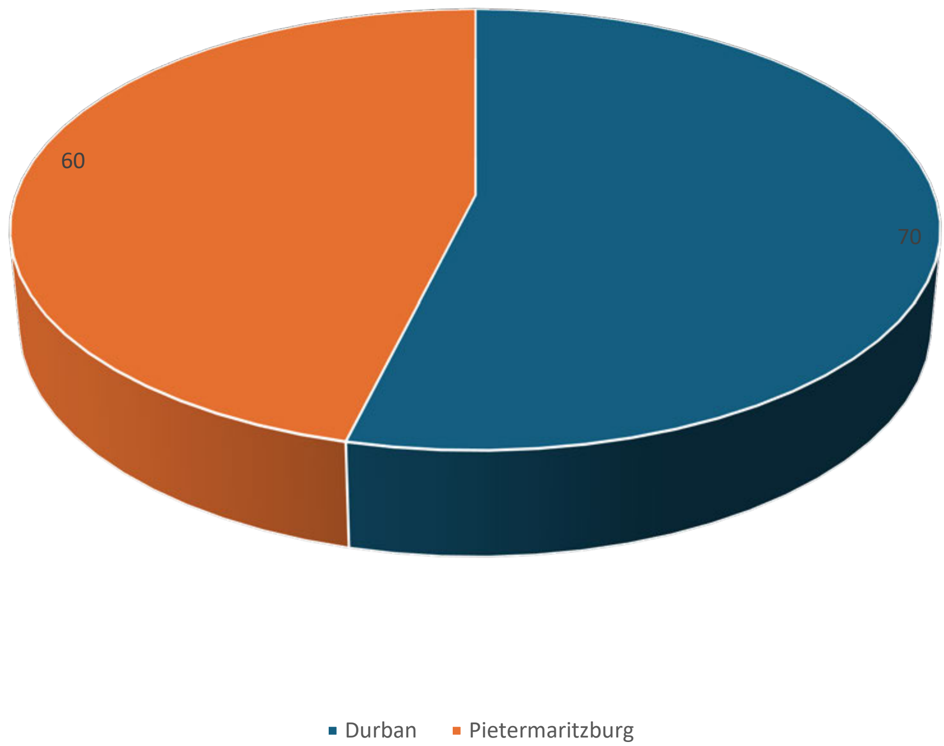

Figure 6.2: Perception of safety in informal markets between two cities (Pietermaritzburg and Durban)

Figure 6.2 presents a comparative analysis of the perception of safety in informal meat markets between Durban and Pietermaritzburg. The pie chart reveals that a higher proportion of respondents from Durban (70%) perceive the informal meat market as relatively safe compared to 60% in Pietermaritzburg. This indicates that Durban traders and consumers may have greater confidence in the handling and quality of meat sold in informal markets. The difference in perception could be attributed to factors such as stricter meat safety regulations, better infrastructure, or a history of fewer reported foodborne illnesses in Durban compared to

Pietermaritzburg. Previous studies, such as those by Jaja et al. (2017) and Hoffman et al. (2019), suggest that urban centers with more structured informal markets often foster greater consumer trust in food safety. However, despite this relatively high confidence, the informal nature of meat markets still presents challenges in enforcing hygiene and safety standards. Future policy recommendations could include increased training for informal traders, regular health inspections, and consumer education programs to improve overall food safety. Several studies have explored consumer perceptions of food safety in informal markets across different regions. Jaja *et al.* (2017) found that in South Africa, consumer confidence in meat safety was significantly influenced by government regulations and past incidents of foodborne illnesses. Similarly, Hoffmann *et al.* (2019) highlighted that consumers in larger urban centers like Cape Town and Johannesburg had a relatively higher perception of food safety due to improved market organization and increased media coverage of food safety practices. A study by Hoffmann *et al.* (2019) in Kenya revealed that urban consumers were more likely to trust informal meat markets when they observed visible safety measures such as proper meat handling, refrigeration, and vendor adherence to hygiene practices. This aligns with the trend seen in Durban, where traders might be more likely to adopt such safety measures compared to their counterparts in Pietermaritzburg.

Table 6.2: Comparative Analysis of Consumer Perceptions, Purchasing Behaviour, and Health Concerns Regarding Meat Safety in Durban and Pietermaritzburg

Category	Test	Chi-square	Df	Critical Value (0.05 level)	Results
Health concern	CST	3.29	2	5.99	NSD
Willingness to pay for certified meat	CST	9.79	4	9.488	SD
Purchasing behavior	CST	6.46	3	7.815	NSD
Perception of safety in informal markets	CST	0.91	1	3.841	NSD
Transparency and Traceability of Meat Products	CST	5.78	1	3.841	SD

CST: Chi-Square Test, NSD: No Significant Difference, SD: Significant Difference, Df: Degrees of Freedom

The chi-square value is 3.29, which is less than the critical value (5.99) meaning there is no significant difference in health concerns between the two cities. The chi-square value is 9.79, which is greater than the critical value (9.488) indicating a significant difference in the willingness to pay for certified meat between Durban and Pietermaritzburg. The chi-square value is 6.46, which is less than the critical value (7.815), and there was no significant difference in the meat types purchased between the study areas. The chi-square value is 0.91, which is less than the critical value (3.841), meaning there was no significant difference in the perceptions of safety between Durban and Pietermaritzburg. The chi-square value is 5.78, which is greater than the critical value (3.841), indicating a significant difference in the transparency and traceability perceptions of meat products between Durban and Pietermaritzburg.

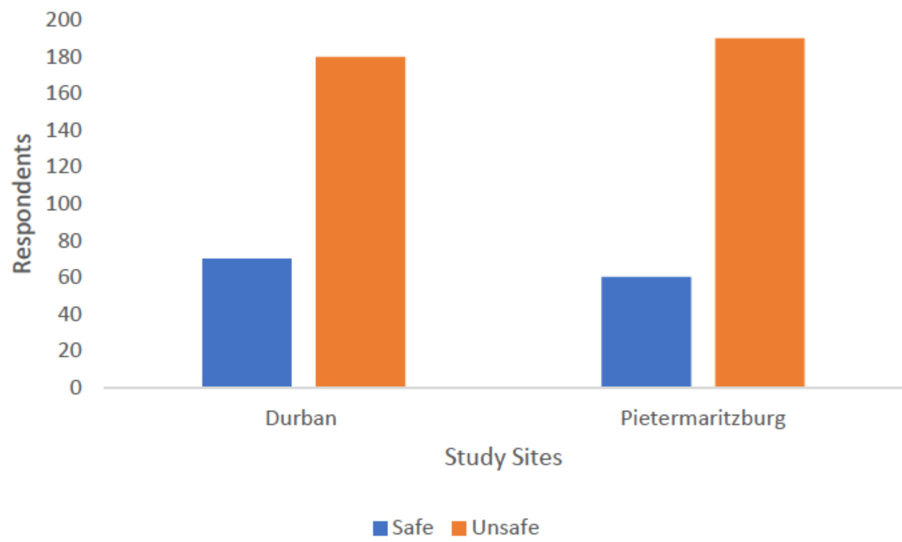

Figure 6.3: Perception of meat safety in informal markets between two cities (Pietermaritzburg and Durban)

The perception of meat safety in informal markets, as illustrated in Figure 6.3, indicates that a significant majority of respondents in both Durban and Pietermaritzburg consider meat from these markets unsafe. In Durban, 72% of respondents expressed concerns about meat safety, while in Pietermaritzburg, this percentage was slightly higher at 76%. However, the chi-square test results ($p = 0.359$) suggest that this difference is not statistically significant, indicating that negative perceptions of meat safety are a widespread issue in both cities rather than one being considerably worse than the other. The primary reasons for these perceptions may include inadequate refrigeration and storage, poor hygiene practices among vendors, exposure to environmental contaminants, and past experiences with foodborne illnesses. These concerns could discourage consumers from purchasing meat from informal markets, potentially affecting vendors' livelihoods. Addressing these issues requires targeted interventions, such as vendor training on proper food handling, the provision of refrigeration facilities, and the enforcement of hygiene standards. Additionally, public awareness campaigns could help educate consumers on how to identify safe and properly handled meat. Overall, the findings highlight the urgent need for policy measures and infrastructure improvements to enhance meat safety in informal markets and restore consumer confidence.

Discussion

The findings of this study align with previous research on food safety concerns in informal meat markets, particularly in developing countries. It was revealed that a significant proportion of consumers in both Durban and Pietermaritzburg perceive meat from informal markets as unsafe, which is consistent with similar studies (Hoffmann *et al.* 2019, Jaja *et al.* 2017). Studies in Kenya, Malawi, and Latin America have also shown that consumers are highly concerned about contamination risks in informal markets, primarily due to inadequate hygiene and weak regulatory enforcement (Cáceres *et al.* 2018, Nkosi *et al.* 2021). These results underscore a global pattern, where informal markets, while essential for food security, pose substantial public health risks.

This study found that 72% of respondents in Durban and 76% in Pietermaritzburg considered meat from informal markets unsafe, which supports previous research that has documented high contamination rates in unregulated meat markets. For example, Nkosi *et al.* (2021) identified informal markets in Nairobi as major sources of foodborne pathogens like Salmonella and E. coli, mainly due to poor refrigeration, improper handling, and exposure to environmental contaminants. In Malawi, Chilanga and Riley (2017) found that informal meat vendors lacked clean slaughtering facilities, resulting in high rates of foodborne illnesses. These studies illustrate that the risks identified in South Africa's informal meat markets are not isolated but rather part of a broader challenge faced in developing nations.

The risk of foodborne diseases linked to informal meat markets has been well-documented. (Lah 2016, Wambua 2023) highlight the unsanitary conditions in informal slaughterhouses, which often fail to prevent bacterial contamination. Additionally, a study by Sharma *et al.* (2020) in India revealed that offal and other meat by-products, commonly sold in informal markets, are particularly vulnerable to contamination due to exposure to intestinal bacteria. The findings of this study corroborate this concern, as many respondents expressed unease about the safety of offal sold in informal markets in both Durban and Pietermaritzburg.

Another significant finding from this study was the variation in consumers' willingness to pay for certified meat between the two cities. In Durban, 36% of respondents indicated they would pay a premium for certified meat, compared to only 24% in Pietermaritzburg. This is consistent with Hoffmann et al. (2019), who found that urban consumers in Kenya and South Africa were more willing to pay for certified meat due to higher exposure to food safety campaigns and stricter regulations. Similarly, Jaja *et al.* (2017) reported that consumers in Johannesburg and Cape Town exhibited greater trust in certified meat products when informed about proper meat handling and inspection. The higher willingness to pay in Durban can likely be attributed to better consumer education and greater exposure to regulated markets, as suggested by Grace (2015), who notes that urban populations are generally more aware of food safety issues and more likely to seek out certified products.

Additionally, the study found significant differences in consumer perceptions of transparency and traceability of meat products between Durban and Pietermaritzburg, with respondents in Durban placing more importance on these factors. This is in line with trends observed in other regions. For instance, Cáceres *et al.* (2018) found that consumers in Latin America trusted food systems with clear traceability mechanisms. Research by Giroux *et al.* (2021) also indicated that consumers in sub-Saharan Africa preferred meat from vendors who could provide information about sourcing and handling practices. The study further confirmed that transparency plays a crucial role in reducing health risks. According to Ninios *et al.* (2014), traceability systems that allow consumers to verify the source and handling of meat can significantly enhance trust and improve food safety outcomes. The stronger emphasis on traceability in Durban may be attributed to its larger urban context, which tends to have stricter health regulations and greater consumer exposure to food safety campaigns, as supported by Roesel and Grace (2014), who found that urban consumers in East Africa were more likely to demand transparency and regulation.

Overall, the results of this study align with existing literature on food safety concerns in informal meat markets. High consumer concern about contamination risks, a willingness to pay for certified meat, and increased demand for transparency are consistent with studies conducted in Kenya, Malawi, and India. The differences observed between Durban and Pietermaritzburg highlight the influence of urbanization and consumer education on food safety perceptions. Addressing these concerns through enhanced regulatory frameworks, consumer education, and better market infrastructure will be essential for improving meat safety in informal markets and reducing health risks.

Conclusion

Overall, the results of this study align with existing literature on food safety concerns in informal meat markets. The high levels of consumer concern regarding contamination risks, willingness to pay for certified meat, and the demand for greater transparency are consistent with findings from studies in Kenya, Malawi, India, and Latin America. The significant differences between Durban and Pietermaritzburg in willingness to pay and transparency perceptions highlight the influence of urbanization and consumer awareness on food safety attitudes. Addressing these concerns through stronger regulatory frameworks, consumer education, and improved market infrastructure will be crucial in mitigating health risks and improving meat safety in informal markets

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Chapter 7

Ensuring Pork meat safety along the value chain from post-slaughter to packaging in preparation for transportation to retailers

Abstract

The objective of this study was to investigate the microbial contamination of pork carcasses at different stages post-slaughter, focusing on the presence or absence of *E. coli, Salmonella*, and *S. aureus*. The research examines the microbial load over time (0, 12, 24, 48, and 72 hours) to understand the dynamics of bacterial growth at the post-slaughter stage. A total of 75 pork carcass samples were collected post-slaughter to evaluate microbial contamination levels. The data collected from the microbial contamination analysis were subjected to descriptive statistics to summarize the microbial loads (CFU/cm²) for each pathogen. GenStat version 23rd and Microsoft Excel were used to perform statistical analysis. Results show a consistent increase in microbial load, with *S. aureus* demonstrating the most aggressive growth, followed by *E. coli* and *Salmonella*. Higher contamination levels were observed at the abattoir compared to retail stores, indicating the critical need for enhanced hygiene protocols at the abattoir level. Additionally, fluctuations in transport temperature significantly influenced microbial growth, highlighting the importance of maintaining a stable cold chain. The study also explored the relationship between sanitation scores and consumer confidence, demonstrating a positive correlation. Findings highlighted the importance of implementing traceability systems that monitor and document key control points, including slaughterhouse hygiene, transport conditions, and retail handling. Effective traceability can mitigate contamination risks by providing transparency, facilitating targeted interventions, and ensuring compliance with food safety regulations. It was concluded that integration of traceability systems, alongside improved sanitation and cold chain management, is essential for enhancing food safety, consumer confidence, and public health in the meat supply chain.

Keywords: Traceability, Microbial contamination, welfare, slaughterhouse, hygiene

7.1 Introduction

The safety of meat products is paramount due to the potential health risks associated with consuming contaminated or improperly handled meat (Behravesh *et al.* 2014, Lianou *et al.* 2021). Foodborne illnesses caused by pathogens such as *Salmonella*, *Escherichia coli* (*E. coli*), *Campylobacter*, and *Listeria monocytogenes* pose significant threats to human health. According to Sargeant (2007) these can result in severe illness, hospitalization, and even death. South Africa has reported an outbreak of *Listeriosis,* which ended up affecting consumer trust and belief in food safety and resulted in widespread illness and substantial economic losses during that year. The outbreak was recorded in one of the meat products (polony) used mostly as an affordable meat product for human consumption. Most consumers have a high preference for polonies as it stands out as a convenient customer favourite, but continues to face threats from a range of microbial contaminants (Asiegbu *et al.* 2020). *Listeria monocytogenes* is notoriously mentioned among these. Its ubiquitous nature of adaptability allows *L. monocytogenes* to thrive in cold, moist environments where other organisms weaken, thus allowing it to be a persistent and insidious presence in food production facilities (Okutani *et al.* 2004). In 2017, the gravity of this threat became clear during South Africa's most horrible outbreak, where L. monocytogenes claimed over 200 lives, marking it as the country's biggest outbreak to date (Smith *et al.* 2019). Ensuring meat safety is not only a matter of public health but also essential for maintaining consumer trust in the meat industry and upholding regulatory standards (Vos 2009). The World Health Organization (WHO) has implemented appropriate measures to minimize food risk (FAO/WHO 2006). This is important as it enforces an understanding between consumer perception versus expectation. Van Dijk *et al.* (2008) highlighted that consumer confidence in meat products has been reported to be influenced by what the public perceives as the best.

Food safety risk analysis has been used to assess the risk associated with public health from foodborne illnesses (Todd 2020). The analysis has been detected through meat inspections and laboratory analysis. However, Buncic (2006) argued that testing of meat samples collected from abattoirs is not practical and cannot guarantee the absence of foodborne pathogens. Therefore, it is crucial to control foodborne pathogens in abattoirs by ensuring that the hygiene process is followed. Meat safety encompasses not only ensuring the abattoir is free from foodborne pathogens but also addressing biological hazards stemming from animal handling in the lairage and during offloading at the processing plant (Nørrung and Buncic 2008).

Post-slaughter processing encompasses a series of steps to prepare meat for consumption while minimizing the risk of contamination and spoilage (Rani *et al.* 2017). This includes evisceration, washing, chilling, cutting, trimming, and packaging. Each step plays a critical role in maintaining meat safety by preventing cross-contamination, controlling microbial growth, and preserving meat quality (Sohaib *et al.* 2016). However, inadequate sanitation, equipment hygiene, and temperature control can compromise meat safety during post-slaughter processing (Rani 2015). Therefore, microbiological tests are encouraged to assess how effectively the operator manages slaughter, dressing, and processing to reduce contamination. Such tests would yield results that assess how effectively the operator managed the slaughter, dressing, and processing to reduce contamination.

Packaging is a crucial aspect of meat safety as it serves as a protective barrier against physical, chemical, and microbial contamination during storage and transportation (McMillin 2017). Proper packaging helps maintain the freshness, colour, texture, and nutritional quality of meat while preventing exposure to external contaminants (Ahmed *et al.* 2018). Common packaging methods that are used for meat include vacuum packaging, modified atmosphere packaging (MAP), and shrink wrapping. However, factors such as packaging material selection, integrity, and storage conditions can influence the effectiveness of packaging in ensuring meat safety.

Transportation of meat from processing facilities to retailers requires attention as this is considered the most crucial stage, hence, additional challenges in maintaining meat safety may arise. Temperature control during transportation is critical to prevent bacterial growth and ensure the freshness and safety of meat products. Improper handling, inadequate refrigeration, and extended transit times can increase the risk of contamination and compromise meat safety. Effective transportation practices, including proper packaging, temperature monitoring, and sanitation protocols, are essential to mitigate these risks. Improving processing practices does not significantly reduce the presence of pathogens, nor does it impact consumer confidence in meat safety. Essentially, it implies that current methods, regardless of improvements, do not have a measurable effect on the safety or consumer perception of meat products. The objective of this study was to assess the microbial quality and safety of pork carcasses at different time intervals. There is no significant difference in the microbial contamination levels (APC, TC, EC, and FC) of pork carcasses between abattoir and retail environments across different post-slaughter time intervals.

7.2 Materials and Methods

7.2.1 Description of the study site

The study was conducted at a communal abattoir in the Umgungundlovu district of Pietermaritzburg, South Africa. The facility is approximately 45 km from the University of KwaZulu-Natal Pietermaritzburg campus, at the geographic coordinates 29.6985491°S, 30.2840289°E. This abattoir specializes exclusively in pork and pork products, processing an average of 800 pigs per day. The facility has modern infrastructure to meet industry standards for hygiene, animal welfare, and meat processing. It is a key supplier to local markets and plays a significant role in regional meat production. The site was selected for its high throughput and operational focus on pork, providing an ideal setting to evaluate transportation, sanitation, and microbial safety in pork production systems.

7.2.2 Ethical considerations

The study adhered to ethical guidelines from the University of KwaZulu-Natal for animal research, including obtaining informed consent from the farm owner or manager of the abattoir through contact from the state veterinarian under **AREC/00007480/2024.**

7.2.3 Meat Sample Collection and Preparation

In this study, a total of 75 pork carcass samples were collected at various time points post-slaughter to evaluate microbial contamination levels. Meat cuts were collected directly from pork carcasses at the abattoir in the Umgungundlovu district. Specifically, loins measuring approximately 5 cm x 4 cm were harvested. The carcasses were randomly selected immediately after slaughter and before delivery for transportation. To ensure the accuracy of the results, trained abattoir staff, following strict hygienic handling protocols, collected the samples under supervision to maintain sterility and the integrity of the meat. Each carcass was sampled once per time point, with 3 samples per pathogen collected from each carcass to represent the three primary pathogens of interest: *E. coli*, *Salmonella*, and *S. aureus*. The time points for sampling were 0, 12, 24, 48, 72, and 96 hours post-slaughter. The collected samples were placed in sterile zipper bags and stored in a cooler box containing ice to maintain freshness. Each occasion involved a new batch of freshly slaughtered carcasses. A total of 25 carcasses were sampled per occasion, bringing the overall number of carcasses to 75 (25 carcasses × 3 occasions). This approach allowed for better representation and reduced potential sampling bias. The samples were transported to the laboratory within two hours of collection to ensure they remained fresh, and all samples were from fresh carcasses that had not been frozen. In the laboratory, the samples were analyzed for microbial contamination, specifically the presence of *Salmonella* and *S aureus*, as well as a hygienic indicator, *Escherichia coli (E. coli).* Analysis was conducted immediately after slaughter to detect any viable foodborne pathogens present in the samples. Swabbing was carried out from high-risk areas of contamination, including the external skin of the carcass, the cutting edges of slaughterhouse equipment, and muscle tissue exposed during dressing at a measured area of 20 cm^2. These locations are known to harbor microbial pathogens from environmental exposure or cross-contamination during processing.

The meat cuts were chopped into small pieces using sterilized surgical blades and minced with a sterile mincing machine. A 35-gram portion of minced meat was used for microbial testing. Of this, 10 grams were mixed with 90 mL of sterile saline for detecting E. coli, 25 grams were added to 225 mL of single-strength peptone buffer for *Salmonella detection*, and a separate 10-gram portion from the same sample was used to test for *S. aureus* using Baird-Parker agar after serial dilution. Of this, 10 grams were mixed with 90 mL of sterile saline to prepare a stock solution for detecting *E*. *Coli*. The remaining 25 grams were added to 225 mL of single-strength peptone buffer to create a solution for testing the presence or absence of *Salmonella*.

7.2.3 Microbial examination of meat post-slaughter

Swabbing was performed at four time points post-slaughter: immediately after dressing, and then after 12, 24, and 48 hours. At each time point, randomly selected carcasses were swabbed to ensure a representative sample. High-risk areas of microbial contamination were targeted, including the external skin, exposed muscle tissue, and cutting edges of equipment that come into contact with meat during dressing. For consistency, a standard 20 cm^2 area was swabbed on each surface using a sterile frame measuring 5 cm x 4 cm. This allowed for uniform sample collection across all carcasses and time points. After swabbing, samples were placed into sterile containers and immediately stored in cooler boxes with ice to preserve microbial integrity prior to analysis. Samples were transported to the laboratory within two hours of collection and were never frozen. Laboratory analysis focused on detecting *Salmonella spp*., *Escherichia coli* (*E. coli*), and *Staphylococcus aureus* (*S. aureus*) key foodborne pathogens relevant to meat safety. Strict hygienic protocols were followed during all sampling and testing procedures to prevent cross-contamination and ensure accuracy. This methodology aimed to capture changes in microbial load over time due to handling, storage, and exposure post-slaughter.

7.4 Statistical analysis

The data collected from the microbial contamination analysis were subjected to descriptive statistics to summarize the microbial loads (CFU/cm^2) for each pathogen (*E. coli*, *Salmonella*, and *S. aureus*) at each time point (0, 12, 24, 48, 72, and 96 hours post-slaughter). The mean and standard deviation (SD) were calculated to describe the central tendency and variability of the data for each microbial group across the different sampling times. To assess the significance of differences in microbial loads between different time points, a one-way analysis of variance (ANOVA) was performed. This test was used to determine if there were statistically significant differences in the microbial loads between the sampling time points for each pathogen. For comparing microbial contamination between different locations (abattoir vs. retail store), two-sample t-tests were conducted for each pathogen to determine if there were significant differences in microbial loads between the two environments. The results of these tests were also evaluated at $p < 0.05$ to identify any statistically significant differences in pathogen prevalence between the two sampling locations. All statistical analyses were performed using Genstat software and Microsoft Office Excel, and the results are presented as mean ± standard deviation.

7.5 Study Results

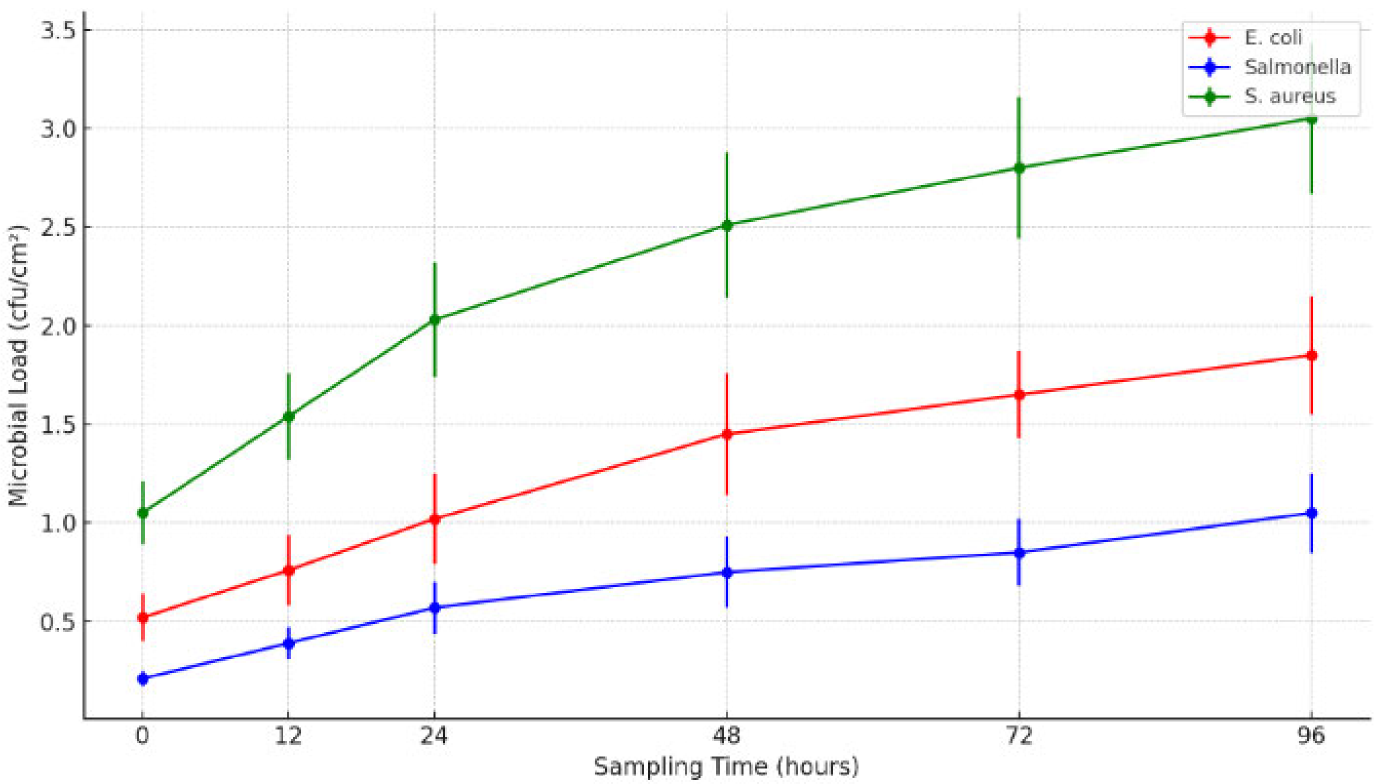

Figure 7.1: Microbial load on pork carcasses at different time points

Bacterial contamination of meat could cause serious illness and even death, with outbreaks of foodborne diseases in South Africa, affecting the country's economic balance. This study assessed the presence or absence of microbial pathogens that could be present in pork meat samples. Figure 5.1 illustrates the microbial load (*E. coli, Salmonella*, and *S. aureus*) on pork carcasses at different sampling times (0, 12, 24, 48, 72, and 96 hours). The error bars represent standard deviations for each microbial load at each sampling point. There was an observed general increase in microbial load over time, indicating the growth of bacteria after slaughter. *S. aureus* is the most aggressive in terms of microbial load growth, making it potentially the most challenging to control. *Salmonella* is relatively slower to grow, suggesting it might be easier to manage under the same conditions.

Table 7.2**:** Displays Microbial load (CFU/cm^2) of *E.Coli, Salmonella*, and *S. aureus* on pork carcasses at different time points

	Microbial Load (CFU/cm^2)		
Sampling Time (h)	***E. Coli***	***Salmonella***	***S. aureus***
Immediately after dressing	0.52 ± 0.12a	0.21 ± 0.04a	1.05 ± 0.16a
12 Hours Post-slaughter	0.76 ± 0.18b	0.39 ± 0.08b	1.54 ± 0.22b
24 Hours Post-slaughter	1.02 ± 0.23c	0.57 ± 0.13c	2.03 ± 0.29c

48 Hours Post-Slaughter	1.45 ± 0.31d	0.75 ± 0.18d	2.51 ± 0.37d

Values represent mean ± standard deviation (n = 18). Different letters (a, b, c, d) indicate statistically significant differences between sampling time points within each microbial group ($p < 0.05$).

Immediately after dressing, the microbial load was relatively low, which suggests that initial contamination at slaughter or dressing is controlled but still present ($p<0.001$). These bacteria may be naturally found in the environment or on animals, but their numbers are kept in check immediately after slaughter. After 12 h, the bacterial counts begin to rise for all three pathogens ($p<0.001$). This indicates that, over time, bacteria can multiply and grow, especially if conditions such as temperature, humidity, and handling practices favour bacterial growth. After 24 h, the bacteria have continued to multiply ($p<0.001$). The increase in counts suggests that the conditions post-slaughter (such as storage or exposure to environmental factors) are promoting further bacterial growth. At this point, improper storage or handling could allow bacteria to thrive and multiply rapidly. At 48 hours, the microbial load has reached its highest value. This shows that bacteria are continuing to grow in number, likely because the meat has not been refrigerated or handled in a way that would halt microbial growth. The longer the meat is left without proper cooling or hygiene, the more bacteria can proliferate, which increases the risk of foodborne illness. The data suggests that without proper cooling, storage, and hygiene, microbial growth increases rapidly in meat after slaughter. This makes it critical to implement effective food safety practices to prevent contamination and reduce the risk of foodborne illness. The continued growth in microbial load is concerning for food safety, especially for pathogens like *S. aureus*, which can produce heat-resistant toxins. Even if the bacteria are reduced or killed by cooking later, the toxins might still be present and cause foodborne illnesses (Mohammad *et al.* 2018).

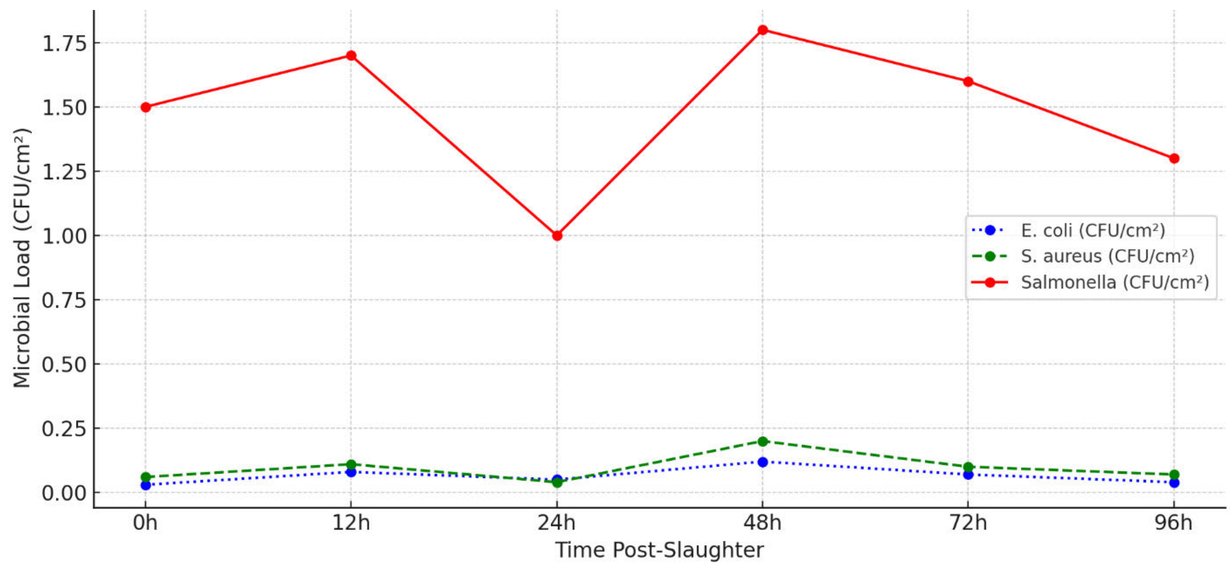

Figure 7.2: This figure represents the microbial load (CFU/cm²) of three bacteria types E. coli, *Listeria*, and *Salmonella* over a range of hours

The graph highlights that *Salmonella* is the most concerning bacterium in terms of microbial load, showing significant variability and higher levels compared to the others. Both *E. coli* and *S. aureus* seem well-managed or controlled, as their levels are minimal and stable. Factors such as transport conditions, temperature, or sanitation may explain the variations, especially the spikes in Salmonella levels.

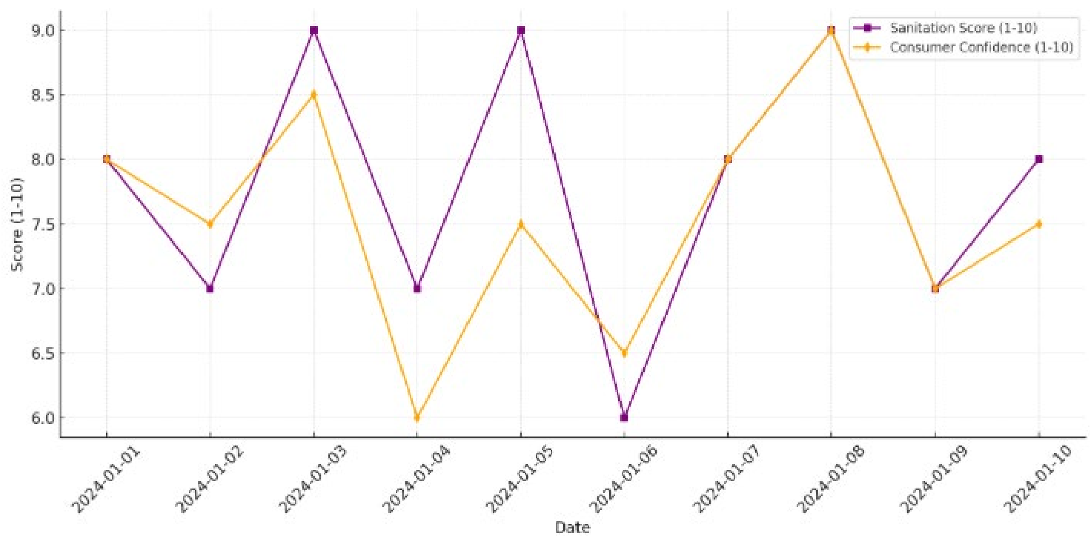

Figure 7.3: This figure compares sanitation scores and consumer confidence ratings (both on a scale of 1 to 10) over a range of dates

The sanitation score fluctuated significantly over the timeline. Peaks at a score of 9 are observed on January 3 and January 8, indicating the best sanitation practices on these dates. A sharp decline is noted on January 6, where the score drops to 6, the lowest in the dataset. It peaks at a score 9 on January 8, mirroring the high sanitation score on the same day. A minimum score of 6 was observed on January 4, which coincides with a dip in sanitation scores. There is a clear correlation between sanitation scores and consumer confidence, as indicated by a strong positive correlation coefficient (r = 0.87), suggesting that improvements in sanitation practices are closely associated with increased consumer trust. For example, High sanitation scores correspond to high consumer confidence (e.g., January 8). Poor sanitation scores (e.g., January 6) are associated with lower consumer confidence. However, some dates (e.g., January 1 and January 4) show slight deviations, where the sanitation score and consumer confidence do not perfectly align.

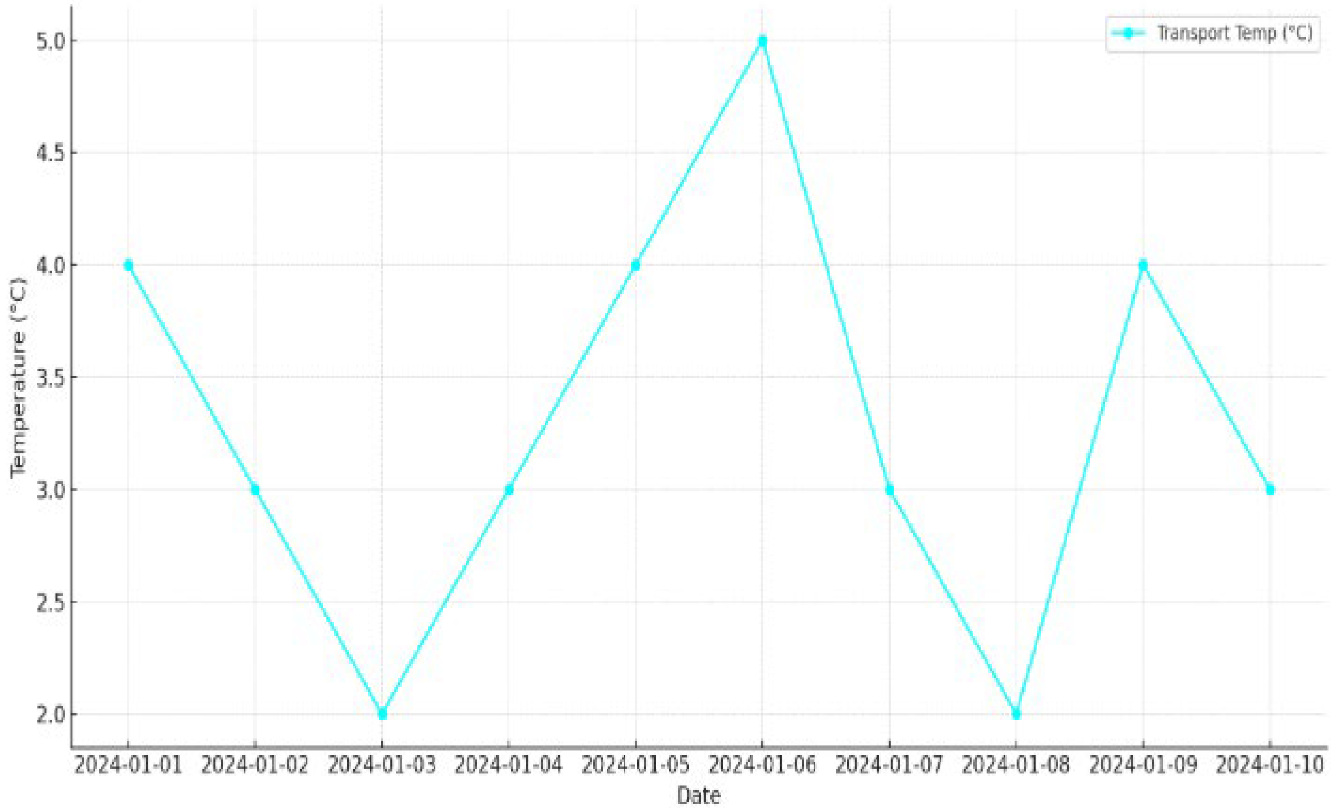

Figure 7.4: The figure shows the variation in transport temperature (°C) over ten days, with noticeable fluctuations

On January 1, the transport temperature started at 4°C but dropped significantly to 2°C on January 2, marking the lowest temperature during the period Figure 6.4. This drop might reflect changes in environmental conditions or deliberate cooling adjustments. The temperature then rises steadily to 4°C by January 5, peaking at 5°C on January 6. This increase might be linked to external factors or insufficient temperature control. Following this peak, the temperature decreases again, reaching 2°C on January 8, indicating a potential restoration of optimal cooling conditions. By January 10, the temperature settled at 3°C, which appears moderate compared to the extremes observed earlier. Figure 6.4 highlights the dynamic changes in transport temperature, suggesting variability in cooling efficiency or environmental influences. These fluctuations could significantly impact product quality, particularly for perishable goods or items sensitive to temperature changes. Maintaining consistent temperatures within an ideal range is crucial to ensure product safety and quality throughout transportation.

Table 6.2: Comparison of Microbial Loads and Related Parameters for Pathogens in Abattoir and Retail Store Environments

Pathogen	Location	TSC	PS	MCL (CFU/g)	SD	LSM (CFU/g)	LSM±SE (CFU/g)	ß	P-Value
Salmonella	Abattoir	2000	300	120	0.45	120	120 ± 3	0.78	<0.001
	Retail Store	2000	120	53	0.39	50	50 ± 2		
E. coli	Abattoir	2000	500	150	0.58	155	155 ± 4	1.02	<0.001
	Retail Store	2000	300	70	0.49	70	70 ± 3		
S. aureus	Abattoir	2000	720	240	0.65	245	245 ± 5	1.15	<0.001
	Retail Store	2000	440	130	0.55	132	132 ± 4		

TSC: Total sample collected, PS: Positive samples, MCL: Mean Contamination Level, SD: Standard Deviation, LSM: Least Square Mean, B: Regression coefficient, SE: Standard Error

The findings of this study highlight significant differences in contamination levels of *Salmonella*, *E. coli*, and *S. aureus* between pork samples from abattoirs and retail stores (Table 6.2). The contamination levels were consistently higher at the abattoirs for all three pathogens. For Salmonella, the abattoir showed a contamination level of 120 CFU/g, compared to 53 CFU/g at the retail store. This difference was found to be statistically significant with a p-value of < 0.001, indicating that the contamination observed at the abattoir is not due to random chance. Similarly, *E. coli* contamination was significantly higher at the abattoir (average of 150 CFU/g) compared to the retail store (average of 70 CFU/g), with a p-value of < 0.001. For *S. aureus*, the abattoir had an average contamination level of 240 CFU/g, while the retail store had 130 CFU/g, with the difference again being statistically significant (p-value < 0.001). The Least Squares Mean (LSM) and LSM ± SE values further confirm these differences, showing that the abattoir consistently has higher contamination levels. The regression coefficients (β) for all pathogens are positive, further supporting that location is a significant factor contributing to the higher contamination observed at the abattoir. These results highlighted the importance of improving hygiene and contamination control measures at abattoirs to reduce foodborne pathogen risks.

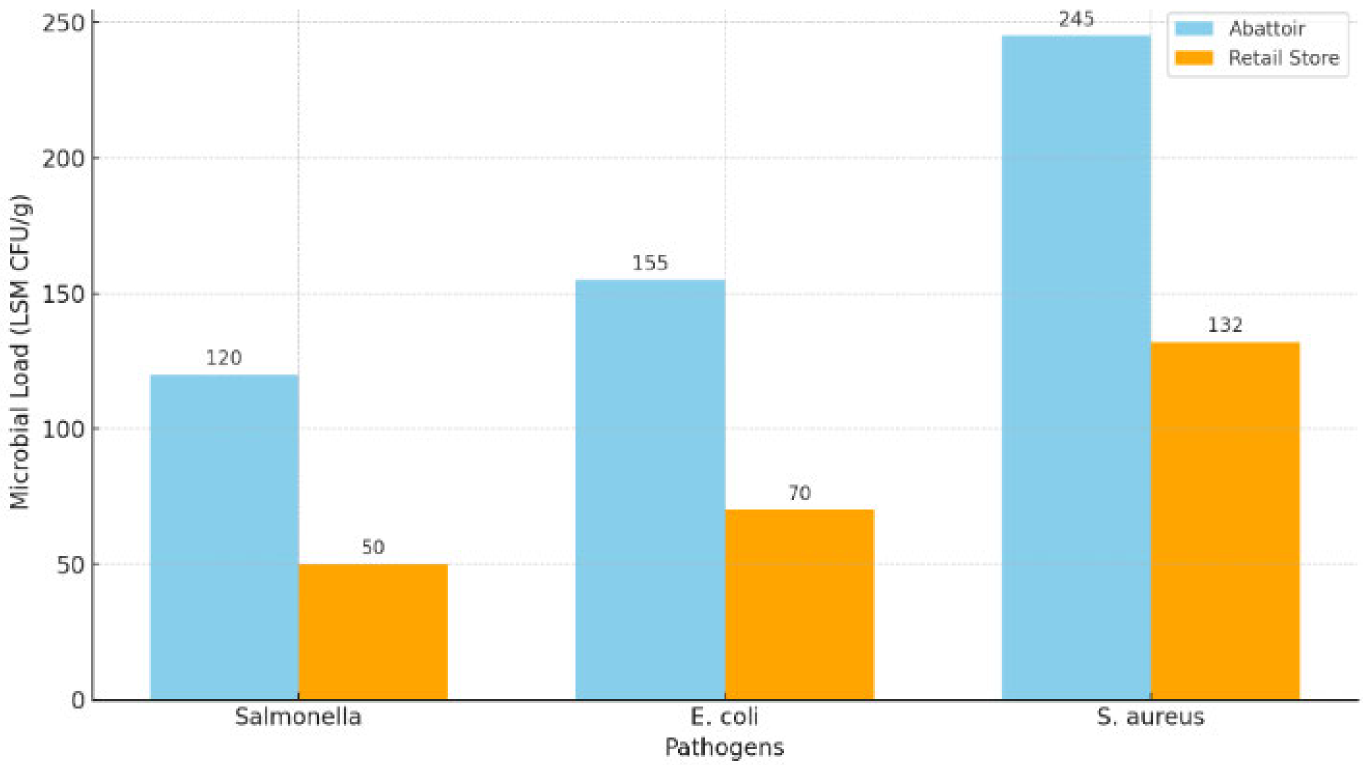

Figure 7.4: A figure comparing the microbial loads (LSM CFU/g) of *Salmonella, E. coli*, and *S. aureus* between the abattoir and retail store

Figure 7.4 highlights significant differences in microbial loads (*Salmonella*, *E. coli*, and *S. aureus*) between the abattoir and retail store environments. Across all pathogens, the microbial loads are substantially higher at the abattoir, indicating greater contamination levels at the source, likely due to the slaughtering process and initial handling practices. For instance, *S. aureus* shows the highest load, reaching 245 CFU/g at the abattoir compared to 132 CFU/g at the retail store, reflecting its resilience and growth potential. The retail store demonstrates a marked reduction in microbial loads for all pathogens, suggesting better sanitation, refrigeration, and handling practices that effectively curb bacterial growth.

7.6 Discussion

The results of this study provide valuable insights into the microbial contamination levels at different points in the meat supply chain, specifically in relation to *E. coli, Salmonella*, and *S. aureus*. By examining microbial loads over time and comparing contamination levels at abattoirs and retail stores, this research highlights the critical points where contamination can occur and where effective traceability systems can be implemented to mitigate these risks. Meat traceability is crucial for enhancing food safety, ensuring that contamination sources can be identified and controlled, thus reducing the risk of foodborne illnesses and increasing consumer confidence in the safety of meat products. The study found significant increases in microbial contamination on pork carcasses as time progressed post-slaughter. *S. aureus* showed the most rapid growth, followed by *E. coli* and *Salmonella*, as reflected in Figure 7.1 and Table 7.1. This indicates that the post-slaughter environment characterized by improper cooling, handling, or environmental factors plays a pivotal role in microbial proliferation. The increase in microbial load over time underscores the importance of monitoring and controlling these environmental conditions, and traceability systems play an essential role in this process. For instance, real-time data on the handling, cooling, and transport of meat can be captured and monitored through traceability systems, allowing for quick identification of where the contamination occurred and at what stage of the supply chain it started to proliferate. Technologies such as RFID tags and blockchain can help trace the journey of meat from slaughter to retail, ensuring that every step, from slaughterhouse hygiene to transport temperature control, is documented and can be reviewed in the event of a contamination incident (Pirovani et al., 2020). This makes traceability a key tool in preventing and managing microbial risks.

One of the most significant findings of this study was the higher contamination levels at abattoirs compared to retail stores (Table .2 and Figure 5.4). The higher microbial loads at the abattoir, particularly *S. aureus*, point to the slaughter process itself as a critical control point for contamination. Cross-contamination can occur from the use of contaminated equipment, improper handling, or failure to adhere to hygiene practices (Zhao et al., 2018). Traceability systems that monitor hygiene protocols, equipment sanitation, and environmental conditions at the abattoir are crucial for identifying contamination sources and facilitating corrective actions. For example, if a batch of pork is found to have elevated levels of contamination, a traceability system can pinpoint whether the contamination occurred due to improper equipment cleaning or inadequate refrigeration in the abattoir. This allows for targeted interventions, such as retraining workers or improving cleaning procedures, which are essential for reducing the risk of contamination at the source.

Temperature control during transport is another critical aspect of meat safety, as shown by the fluctuations in transport temperature (Figure 7.4) that likely contributed to varying levels of microbial growth, particularly Salmonella. These findings align with previous studies that emphasize the importance of maintaining a stable cold chain throughout the meat supply chain to prevent bacterial growth (Taylor *et al*., 2021). Traceability systems that monitor temperature conditions in real-time can help detect deviations from safe temperature ranges during transport. By implementing automated alerts and real-time tracking systems, any temperature fluctuation that could potentially allow pathogens like Salmonella to proliferate can be immediately addressed. These systems can also provide detailed records for regulatory compliance and consumer assurance, which is critical in preventing outbreaks and maintaining public trust in the safety of the product.

The relationship between sanitation scores and consumer confidence (Figure 6.3) further emphasizes the link between traceability and consumer trust. As shown in the study, high sanitation scores were generally associated with higher consumer confidence in meat safety. However, discrepancies between sanitation scores and consumer confidence on certain dates suggest that consumers may require more transparency on how sanitation practices are carried out and monitored. Here, traceability systems can play a key role by providing consumers with clear, accessible information about the meat they purchase. By integrating traceability systems that record sanitation protocols at both abattoirs and retail points, consumers can gain greater confidence in the safety of the products they are buying. For example, if a consumer can see that a piece of meat has been processed in an abattoir with high hygiene standards, transported under optimal temperature conditions, and stored safely at the retail store, their confidence in the product will be significantly higher.

Effective traceability is not only a tool for improving food safety but also for ensuring compliance with regulatory standards. In light of the contamination levels observed at the abattoir, traceability systems that record and document every step of meat handling from slaughter to retail can help meat producers, regulators, and consumers ensure that all necessary food safety regulations are being met. For example, temperature tracking and sanitation records can demonstrate that the meat has been processed and transported in compliance with safety standards, minimizing the risk of contamination and supporting food safety regulations. This level of documentation is particularly important in regions like South Africa, where outbreaks of foodborne diseases have significant public health and economic implications (Smith *et al.* 2019). The ability to trace the origin of contamination and take immediate corrective actions can prevent large-scale outbreaks and bolster the credibility of the meat industry.

7.7 Conclusion

In conclusion, the findings of this study highlight the importance of integrating traceability systems into meat processing, transport, and retail operations. The study demonstrates how microbial contamination is linked to time, environmental factors, and handling practices, and how traceability can serve as an effective tool for monitoring and controlling these risks. From improving sanitation at the abattoir to ensuring stable cold chain conditions during transport, traceability systems can provide the necessary data to identify contamination sources and prevent foodborne illnesses. Moreover, by enhancing consumer confidence through transparent and verifiable safety practices, traceability helps maintain public health standards and supports compliance with food safety regulations. Ultimately, these results emphasize that comprehensive traceability, when combined with effective sanitation, temperature control, and handling practices, is essential to ensuring the safety and quality of meat products.

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Chapter 8

Assessing Meat Safety in the Informal Markets: A Survey on Consumer Attitudes and Health Risks in South Africa

Abstract

This chapter investigates consumer perceptions, purchasing behaviours, and health concerns related to meat safety in informal markets in Durban and Pietermaritzburg, South Africa. Using quantitative data collected from 500 respondents evenly split between the two cities, the study examines demographic profiles, willingness to pay for certified meat, perceptions of safety, and attitudes toward transparency and traceability in informal meat markets. Results show that the majority of respondents (72% in Durban and 76% in Pietermaritzburg) perceive meat from informal markets as unsafe, echoing global trends found in developing countries. The study found statistically significant differences in willingness to pay for certified meat and perceptions of transparency between the cities, with Durban respondents showing higher concern and willingness to invest in safer meat. These differences are attributed to varying levels of urbanization, exposure to food safety campaigns, and regulatory enforcement. The findings align with previous literature from regions such as East Africa, South Asia, and Latin America, which highlight similar challenges in informal food markets. Key themes include the influence of socioeconomic status, education, and employment on food safety awareness, as well as the importance of traceability in building consumer trust. The chapter concludes by emphasizing the need for targeted interventions such as hygiene education, infrastructure improvements, and regulatory reforms to enhance meat safety and protect public health in informal markets.

Keywords: **Informal meat markets, Food safety, Meat traceability, consumer perception**

8.1 Introduction

Food safety is an important issue facing current consumers, the food industry, and the government (Liana *et al.* 2010). Since several food safety crises have occurred globally in recent years, the production of safe animal food products has become one of the most important aspects of quality for both consumers and retailers. The survey participants cannot ignore the high sensitivity of consumers to food safety issues. Meat safety is crucial to ensure that meat is free from harmful pathogens and contaminants, safeguarding public health. In formal markets, meat is closely monitored by regulatory bodies like the Meat Safety Act (MSA) and inspected by the Department of Agriculture, Forestry, and Fisheries (DAFF) (Jaja *et al.* 2017). Meat safety refers to the measures and procedures taken from slaughter to consumption, ensuring that meat is safe, hygienic, and fit for human consumption. This includes proper handling, processing, packaging, and storage standards, as well as monitoring of slaughterhouse conditions (Ninios *et al.* 2014). When meat is processed in compliance with regulatory standards, it reduces the risk of contamination and foodborne illnesses, ensuring consumer protection. The meat that is sold to consumers in South Africa is derived from commercial farmers through commercial abattoirs where meat handling is strictly governed by the Meat Safety Act of 2000. Even though most regulations that are set to protect consumer health are followed in most abattoirs, the challenge is the meat that is sold. These abattoirs, by nature, lack the strict safety measures required to ensure that meat is handled hygienically and safely. Without regular oversight, such markets face a higher risk of contamination from harmful bacteria, such as *E. coli, Salmonella*, and *Campylobacter* (Baliyan *et al.* 2024). These pathogens are notorious for causing foodborne illnesses, which can result in symptoms ranging from mild stomach discomfort to severe food poisoning, and in extreme cases, even death (Gourama 2020). Moreover, the improper handling practices commonly found in informal markets, such as the lack of refrigeration or proper sanitation, exacerbate these risks (Lah 2016). In many African countries, the sale of meat through informal markets is an essential part of the food distribution system, especially in urban and peri-urban areas where access to formal retail outlets may be limited or too expensive for a large portion of the population (Roesel and Grace 2014). The cost-effectiveness of purchasing meat in informal markets, especially for lower-income consumers, often outweighs concerns about its safety (Hoffmann *et al.* 2019). As a result, these markets play a critical role in providing affordable protein to urban populations. However, while they may provide economic access to meat, they also present significant health risks to consumers, particularly when it comes to meat that is sourced from communal or unregistered abattoirs (Sojl *et al.* 2015). At most times in these abattoirs, hygienic handling of carcasses after slaughter is not practiced and this is critical for the prevention of contamination and to ensure meat safety.

A good example of this situation is found in Mai Mai, a multi-tribal market located in Gauteng Province, South Africa. This market has been identified as one of the largest informal markets in Johannesburg, primarily caters to local communities and provides a variety of meat products, including beef, and offal (internal organs), sourced from the communal abattoir (Olivier 2004). While some of the meat sold there comes from registered sources, much of it is from small, independent vendors who lack the necessary health certifications and inspections required by food safety regulations (Mungai 2019). The meat sold at the informal market is often the by-product of beef production, such as head meat, internal organs, and feet. These by-products, while nutritious and culturally significant in many culinary traditions, are highly vulnerable to bacterial contamination, particularly because they are near the animal's intestinal contents (Alao *et al.* 2017). Offal poses significant food safety risks because it is exposed to digestive bacteria during slaughter, which can easily transfer to the meat if proper hygiene protocols are not followed (Sharma *et al.* 2020).

The situation is not unique to South Africa. In Kenya, the challenge of unsafe meat in informal markets is similarly prevalent. A significant portion of the meat sold in urban areas like Nairobi comes from unregistered abattoirs, where conditions are not adequately regulated (Sirma *et al.* 2023). In informal markets, meat, including offal and lesser cuts, is often sold without any form of health certification or proper inspection. Research conducted by Nkosi *et al.* (2021) revealed that the lack of veterinary inspection in these informal markets has led to numerous outbreaks of foodborne diseases, particularly those caused by *Salmonella* and *E. coli*. Furthermore, the majority of vendors in Nairobi's informal markets do not have access to refrigeration, resulting in meat being sold at room temperature, which significantly increases the risk of bacterial growth and spoilage (Mungai 2019). Similarly, in Malawi, informal meat markets are an integral part of the food supply chain, especially in major cities like Lilongwe and Blantyre (Chilanga and Riley 2017). However, these markets also face significant challenges when it comes to food safety. Mwale *et al.* (2016) highlighted that meat sold in these informal markets often comes from unregistered abattoirs where basic hygiene standards are not followed. The sale of offal in particular is common in Malawi, with parts such as liver, kidneys, and tripe being popular among local consumers (Chilanga and Riley 2017). While these cuts are nutritionally rich and widely consumed, they are also prone to contamination, particularly if they are not properly cleaned and handled after slaughter. Without strict regulations or regular inspections, the sale of such meat poses a serious health risk to the public (Sharma *et al.* 2020).

Across sub-Saharan Africa and in most developing countries, the challenges associated with informal meat markets are compounded by the lack of education and awareness among consumers

(Johnson *et al.* 2015). In regions where access to formal retail outlets is limited, consumers often lack the necessary information to assess the safety of the meat they purchase. They may not be fully aware of the risks associated with consuming meat from unregulated sources, particularly when it comes to the consumption of offal and other by-products. This lack of consumer awareness further exacerbates the public health risks tied to informal meat trade, as many consumers continue to purchase meat based on price and availability rather than safety standards (Cáceres *et al.* 2018). The informal meat trade, particularly in urban areas of developing countries, also faces the challenge of inadequate infrastructure (Giroux *et al.* 2021). For instance, the lack of refrigeration and proper storage facilities in informal markets means that meat is often kept at room temperature for extended periods, creating an environment conducive to bacterial growth. Meat exposed to the elements for prolonged periods is more likely to become contaminated, particularly in hot climates where bacteria multiply rapidly (Nørrung *et al.* 2009). The lack of sufficient sanitation at slaughterhouses and the absence of proper waste disposal mechanisms further contribute to the risk of contamination in these markets (Cáceres *et al.* 2018). The problem is not confined to Africa alone. In Latin America, informal markets in countries like Peru also face similar concerns. Informal slaughterhouses in cities such as Lima operate with little to no government oversight, and meat is sold in public markets without proper inspection. A report by Cáceres *et al.* (2018) indicates that *Salmonella* and *E. coli* contamination are common in these markets, particularly in offal and other lesser cuts of meat. In some instances, consumers prioritize affordability over safety (Grace 2015), leading to the continued consumption of potentially hazardous meat. Similarly, in Asia, informal meat markets in countries such as India and Indonesia face health risks due to improper slaughter practices and the lack of refrigeration. Research by Sharma *et al.* (2020) discovered that meat from informal markets in India frequently tested positive for harmful bacteria, further highlighting the global nature of the problem. While informal markets provide essential access to meat in many developing countries, the health risks associated with the sale of meat from unregulated or communal abattoirs cannot be overlooked.

The case of informal markets in South Africa, along with examples from Kenya, Malawi, and other underdeveloped nations, demonstrates the widespread nature of this challenge. Offal, head meat, and other by-products, though culturally significant and nutritionally valuable, are particularly vulnerable to contamination if not handled with care. In a study by Roesel and Grace (2014), consumers may not be aware of the risks associated with purchasing meat from these informal markets, which further exacerbates the potential for foodborne illnesses. Addressing these concerns will require improved regulation, better consumer education, and greater oversight of meat-handling practices in informal markets across the developing world. Therefore, this study aimed to highlight the critical issues surrounding food safety in informal meat markets, particularly in South Africa, and the associated risks posed by unregulated abattoirs.

8.2 Materials and Methods

8.2.1 Study site

The study was conducted across two cities of the KwaZulu-Natal province: Pietermaritzburg and Durban. Durban, the economic hub of KwaZulu-Natal, is a bustling metropolitan area that serves as a cultural and commercial center, dominated by various African tribes. It is strategically located close to global meat suppliers, making it a significant site for selling meat by street vendors. The geographical coordinates of Durban are 30° 58' 83" S and 25° 38' 54" E, and it is situated approximately 110 km from the University of KwaZulu-Natal, Pietermaritzburg campus. Pietermaritzburg, on the other hand, is located just 5 km from the university campus. It is also a city rich in cultural diversity, with various tribes engaged in various socio-economic activities, including meat trading in informal markets. Pietermaritzburg's geographical coordinates are also 30° 58' 83" S and 25° 38' 54" E. Both cities were selected due to their significant informal meat market presence and representation of KwaZulu-Natal urban centres.

8.2.2 Ethical considerations

Ethical approval for this study was obtained from the University of KwaZulu-Natal Research Ethics Committee **AREC/00007480/2024**. All respondents were informed about the study's purpose and provided written consent before participation. Participation was voluntary, and respondents were assured that their anonymity and confidentiality would be maintained throughout the study.

8.2.3 Population and Sample

A total of 500 respondents (approximately 250 from each city) were surveyed to capture a broad range of insights regarding consumer perceptions of meat safety. This sample size ensures adequate representation of various socio-economic groups within both cities. The target population for this survey consists of consumers who regularly purchased meat from informal markets and street vendors in Durban (n=250) and Pietermaritzburg (n=250). These consumers were randomly selected since these cities are popular for having significant street vending and informal markets, where meat, including offal and other by-products, is sold. To ensure the sample is representative of the consumer population, a stratified random sampling technique was used. The sample was divided into strata based on key demographic factors such as age, gender, income level, and frequency of meat purchases. Income levels were self-reported by respondents during the survey. The questionnaire included predefined income brackets (e.g., less than R2000, R2000–R5000, R5001–R10,000, and more than R10,000), which were based on commonly used socio-economic classifications in South Africa. This allowed for consistent stratification and comparison across the two study sites.

8.2.4 Data Collection Tools

Data was collected using a structured questionnaire designed to gather information on:

1. Demographic Characteristics: Age, gender, income, education, and occupation of the respondents.
2. Consumer Knowledge: Awareness of food safety standards, the source of meat, and common health risks associated with meat consumption.
3. Perceptions of Safety: Attitudes towards meat sold by street vendors, particularly those from communal abattoirs and informal markets.

4. Purchasing Behaviour: Frequency of meat purchases, types of meat commonly bought (e.g., offal, beef, chicken), and preferences for specific cuts.
5. Health Concerns: Awareness of foodborne diseases, concerns about contamination, and specific health risks associated with meat from informal markets.
6. Regulatory Awareness: Knowledge of the regulations surrounding meat safety and inspections in informal markets.
7. Transparency and Traceability: Do you believe that transparency and traceability of meat products (such as source, handling, and inspection history) are important for ensuring consumer safety? Why or why not?

The questionnaire was pre-tested with a small sample (n=10) to ensure clarity and validity of the questions. Feedback from the pre-test helped refine the tool for broader use.

8.2.5 Data Collection Procedure

Surveys were conducted in various informal market locations, including street vendor stalls, and adjacent marketplaces. Interviews were carried out in Durban and Pietermaritzburg, with enumerators traveling to different areas within both cities. Surveys were administered in Zulu and English, depending on the respondent's preference, with translators provided when necessary to ensure full comprehension and accurate responses. Consumers were interviewed for 15 minutes, during consumption at the provided tables, after consumption and at point of purchase with permission from the business owners. Informed consent was obtained from all participants before the surveys began. Participants were assured of the confidentiality of their responses and informed of their right to withdraw from the study at any time without penalty.

8.2.6 Statistical Analysis

After data collection, the responses were entered into Microsoft Excel in preparation for statistical analysis. GenStat 23rd version (VSN International, 2023) was used for statistical analysis. Descriptive statistics were used to summarize the respondents' demographic characteristics and attitudes towards meat safety. Chi-square tests were carried out to assess whether there were significant associations between city of residence (Durban or Pietermaritzburg) and respondents' perceptions and behaviours regarding meat safety.

7.3 Results and Discussion

The demographic profile of respondents highlights key factors influencing consumer perceptions and purchasing behaviors in informal meat markets in Durban and Pietermaritzburg. The sample is nearly evenly split between males (49%) and females (51%), with the majority falling within the 25-44 age range (60%), indicating that middle-aged adults are the primary consumers. Education levels vary, with 40% having completed high school and 35% possessing post-secondary education, while a smaller portion (7.5%) have no formal education, which may affect food safety awareness. Employment distribution shows that 27.5% work in the informal sector, 27.5% in the private sector, and 17.5% are unemployed, suggesting economic constraints play a role in meat purchasing decisions. Income levels reveal that a significant portion (35% in Durban and 45% in Pietermaritzburg) earn less than R2000 per month, reinforcing the financial limitations impacting willingness to pay for certified meat. These findings suggest that affordability and education are key determinants in consumer attitudes toward meat safety, emphasizing the need for targeted interventions such as food safety awareness campaigns, affordable certification programs, and stronger regulatory enforcement in informal markets.

Table 8.1: The demographic profile of informal meat markets in Durban and Pietermaritzburg

Category	Durban %	Pietermaritzburg %	Total %
Gender			
Male	48	50	49
Female	52	50	51
Age Group			
18-24 years	15	18	16.5
25-34 years	30	28	29
35-44 years	32	30	31
45-54 years	13	14	13.5
55+ years	10	10	10
Education Level			
No formal education	5	10	7.5
Primary school	15	20	17.5
High school	40	40	40
Post-secondary	40	30	35
Employment Status			
Unemployed	15	20	17.5
Student	10	15	12.5
Informal worker	25	30	27.5
Private sector	30	25	27.5
Government worker	20	10	15
Monthly Income (R)			
Less than 2000	35	45	40
2000 - 5000	30	25	27.5
5001 - 10,000	20	20	20
More than 10,000	15	10	12.5

The data collected from Durban and Pietermaritzburg on various consumer attitudes toward meat safety and purchasing behaviors revealed interesting patterns in health concerns, willingness to pay for certified meat, purchasing habits, perceptions of safety in informal markets, and attitudes toward transparency and traceability of meat products are presented in Table 8.2.

Durban respondents showed a slightly greater willingness to pay for certified meat, with 36% of respondents willing to pay (4 or 5) compared to 24% in Pietermaritzburg. A higher proportion of respondents in Durban (48%) expressed being very concerned about health risks associated with meat consumption compared to Pietermaritzburg (40%). Beef was the most purchased type of meat in both cities, with Durban showing a higher preference for beef (48%) compared to Pietermaritzburg (36%). A large portion of both Durban (72%) and Pietermaritzburg (76%) respondents considered meat sold in informal markets to be unsafe. Most respondents in both cities (Durban 72%, Pietermaritzburg 60%) agreed that transparency and traceability of meat products are important for ensuring consumer safety. After performing a Chi-square test using the data, a significant association ($p<0.05$) was found between respondents city of residence (Pietermaritzburg or Durban) and their level of concern regarding meat safety

Table 8.2: Sample Data for Comparison Between Durban and Pietermaritzburg

Health concern	Durban (n=250)	PMB (n=250)	Total (=500)
Very concerned	120	100	220
Somewhat concerned	80	90	170
Not Concerned	50	60	110
Total	250	250	500
Willingness to Pay for Certified Meat			
Willingness to Pay			
1 (Not willing)	30	50	80
2	40	60	100
3	90	80	170
4	60	30	90
5 (very willing)	30	30	60
Total	250	250	500
Purchasing Behaviour (Meat type purchased)			
Meat type			
Beef	120	90	210
offal	70	60	130
chicken	30	40	70
mixed	30	60	90
Total	250	250	500
Perceptions of safety in informal markets			
Perception of safety			
Safe	70	60	130
Unsafe	180	190	370
Total	250	250	500
Transparency and Traceability of Meat Products			
Transparency and Traceability			
Agree	180	150	330
Disagree	70	100	170
Total	250	250	500

PMB: Pietermaritzburg

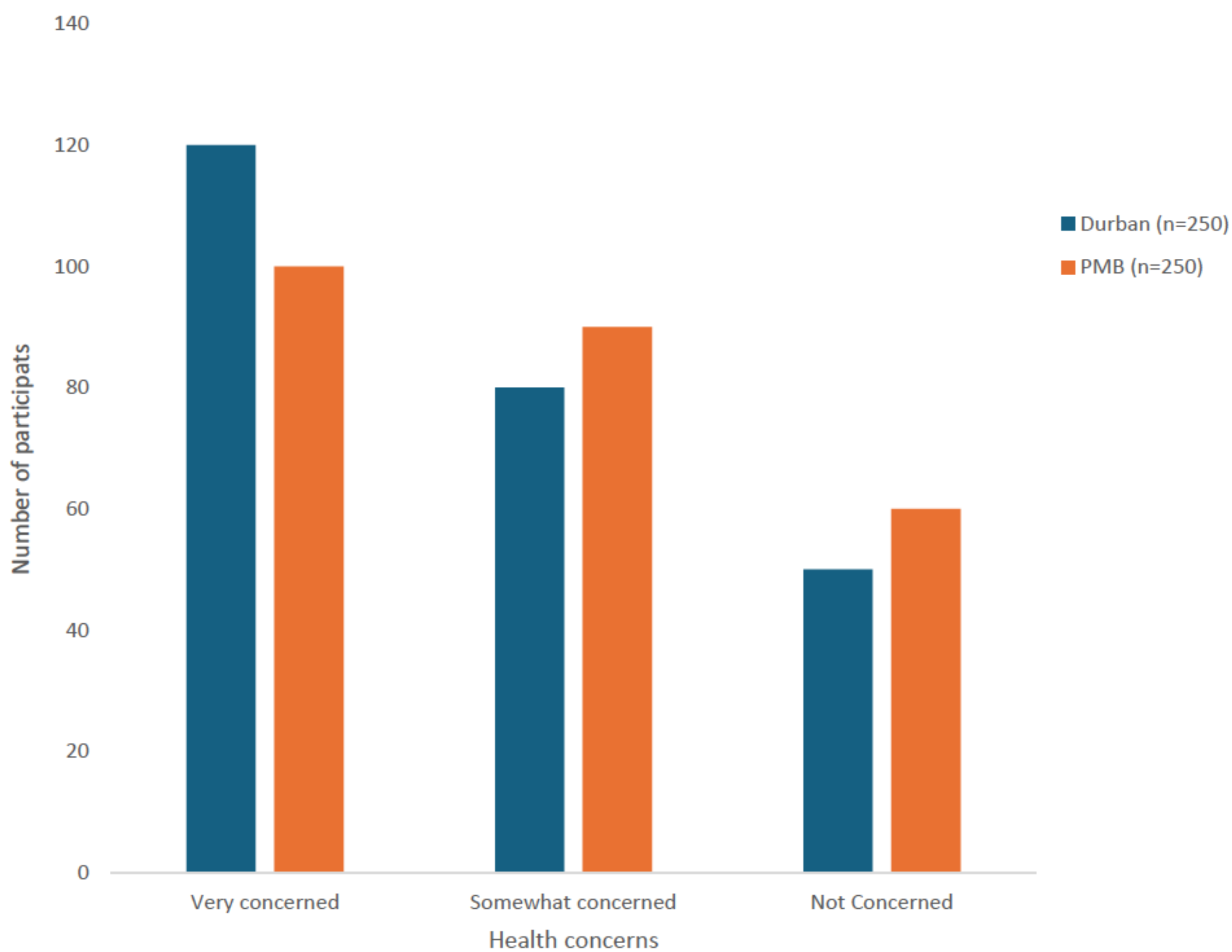

Figure 8.1: Health concern distribution between Durban and Pietermaritzburg informal meat traders

This distribution suggests that while concerns about meat safety are prevalent in both cities, Durban respondents exhibit a higher degree of caution. The difference in concern levels could be attributed to variations in regulatory enforcement, past food safety incidents, or differences in consumer education on meat handling and hygiene practices. The findings from Figure 8.1 align with research conducted in other regions where informal meat markets play a significant role in food supply. For instance, Roesel and Grace (2014) found that in East African informal meat markets, consumer and trader concerns about health risks were high, particularly in urban areas where awareness of foodborne illnesses was greater. Similarly, a study by Jaja *et al.* (2017) in South Africa indicated that consumers in larger cities, such as Johannesburg and Cape Town, were more cautious about meat safety compared to those in smaller towns due to increased exposure to media reports and regulatory efforts. The difference in concern levels between Durban and Pietermaritzburg observed in Figure 8.1 may be attributed to similar urbanization and awareness trends. Durban, being a larger metropolitan area, likely has stricter health regulations and more publicized food safety concerns, leading to a higher percentage of "very concerned" respondents. In contrast, Pietermaritzburg, while still a significant urban center, may have slightly lower exposure to regulatory enforcement or media coverage, resulting in a comparatively higher proportion of respondents who are only "somewhat concerned" or "not concerned.

Table 8.3: Comparative Analysis of Consumer Perceptions, Purchasing Behaviour, and Health Concerns Regarding Meat Safety in Durban and Pietermaritzburg

Category	Test	Chi-square	Df	Critical Value (0.05 level)	Results
Health concern	CST	3.29	2	5.99	NSD
Willingness to pay for certified meat	CST	9.79	4	9.488	SD
Purchasing behavior	CST	6.46	3	7.815	NSD
Perception of safety in informal markets	CST	0.91	1	3.841	NSD
Transparency and Traceability of Meat Products	CST	5.78	1	3.841	SD

CST: Chi-Square Test, NSD: No Significant Difference, SD: Significant Difference, Df: Degrees of Freedom

Chi-square tests revealed varying associations between city of residence and different consumer perceptions and behaviours. Significant associations were found in respondents' willingness to pay for certified meat and in their views on the importance of transparency and traceability of meat products ($p < 0.05$). However, no significant associations were observed in health concerns, purchasing behaviour, or perceptions of safety in informal markets. These findings highlight that while some attitudes differ between cities, many concerns about meat safety are common across both Durban and Pietermaritzburg. The chi-square value is 6.46, which is less than the critical value (7.815), and there was no significant difference in the meat types purchased between the study areas. The chi-square value is 0.91, which is less than the critical value (3.841), meaning there was no significant difference in the perceptions of safety between Durban and Pietermaritzburg. The chi-square value is 5.78, which is greater than the critical value (3.841), indicating a significant difference in the transparency and traceability perceptions of meat products between Durban and Pietermaritzburg.

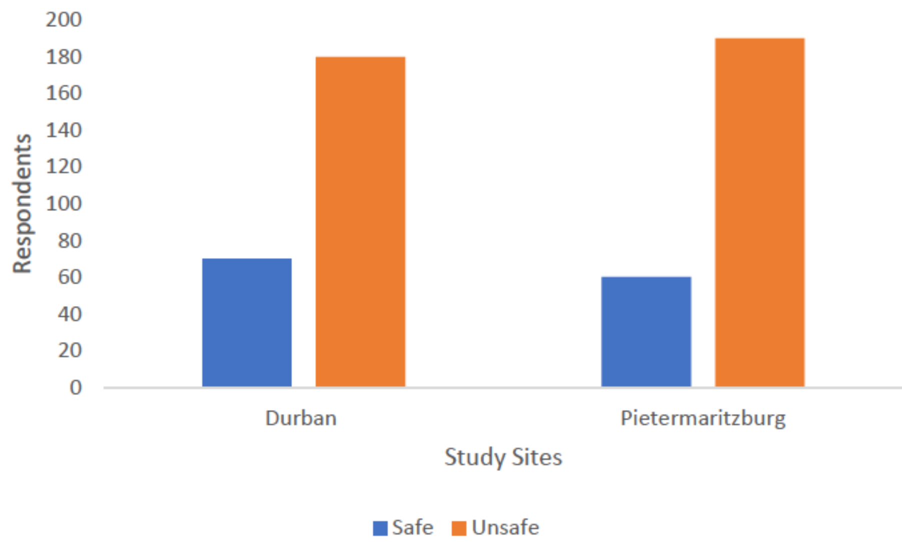

Figure 8.2: Perception of meat safety in informal markets between two cities (Pietermaritzburg and Durban)

The perception of meat safety in informal markets, as illustrated in Figure 6.3, indicates that a significant majority of respondents in both Durban and Pietermaritzburg consider meat from these markets unsafe. In Durban, 72% of respondents expressed concerns about meat safety, while in Pietermaritzburg, this percentage was slightly higher at 76%. However, the chi-square test results ($p = 0.359$) suggest that there is no significant association between city of residence and perceptions of meat safety, indicating that negative views toward meat safety are a common concern in both cities. The primary reasons for these perceptions may include inadequate refrigeration and storage, poor hygiene practices among vendors, exposure to environmental contaminants, and past experiences with foodborne illnesses. These concerns could discourage consumers from purchasing meat from informal markets, potentially affecting vendors' livelihoods. Addressing these issues requires targeted interventions, such as vendor training on proper food handling, the provision of refrigeration facilities, and the enforcement of hygiene standards. Additionally, public awareness campaigns could help educate consumers on how to identify safe and properly handled meat. Overall, the findings highlight the urgent need for policy measures and infrastructure improvements to enhance meat safety in informal markets and restore consumer confidence.

8.9 Discussion

The findings of this study align with previous research on food safety concerns in informal meat markets, particularly in developing countries. It was revealed that a significant proportion of consumers in both Durban and Pietermaritzburg perceive meat from informal markets as unsafe, which is consistent with similar studies (Hoffmann *et al.* 2019, Jaja *et al.* 2017). Studies in Kenya, Malawi, and Latin America have also shown that consumers are highly concerned about contamination risks in informal markets, primarily due to inadequate hygiene and weak regulatory enforcement (Cáceres *et al.* 2018, Nkosi *et al.* 2021). These results underscore a global pattern, where informal markets, while essential for food security, pose substantial public health risks.

This study found that 72% of respondents in Durban and 76% in Pietermaritzburg considered meat from informal markets unsafe, which supports previous research that has documented high contamination rates in unregulated meat markets. For example, Nkosi *et al.* (2021) identified informal markets in Nairobi as major sources of foodborne pathogens like Salmonella and E. coli, mainly due to poor refrigeration, improper handling, and exposure to environmental contaminants. In Malawi, Chilanga and Riley (2017) found that informal meat vendors lacked clean slaughtering facilities, resulting in high rates of foodborne illnesses. These studies illustrate that the risks identified in South Africa's informal meat markets are not isolated but rather part of a broader challenge faced in developing nations.

The risk of foodborne diseases linked to informal meat markets has been well-documented. Lah (2016) and Wambua (2023)highlight the unsanitary conditions in informal slaughterhouses, which often fail to prevent bacterial contamination. Additionally, a study by Sharma *et al.* (2020) in India revealed that offal and other meat by-products, commonly sold in informal markets, are particularly vulnerable to contamination due to exposure to intestinal bacteria. The findings of this study corroborate this concern, as many respondents expressed unease about the safety of offal sold in informal markets in both Durban and Pietermaritzburg.

Another significant finding from this study was the variation in consumers' willingness to pay for certified meat between the two cities. In Durban, 36% of respondents indicated they would pay a premium for certified meat, compared to only 24% in Pietermaritzburg. This is consistent with Hoffmann et al. (2019), who found that urban consumers in Kenya and South Africa were more willing to pay for certified meat due to higher exposure to food safety campaigns and stricter regulations. Similarly, Jaja *et al.* (2017) reported that consumers in Johannesburg and Cape Town exhibited greater trust in certified meat products when informed about proper meat handling and inspection. The higher willingness to pay in Durban can likely be attributed to better consumer education and greater exposure to regulated markets, as suggested by Grace (2015), who notes that urban populations are generally more aware of food safety issues and more likely to seek out certified products.

Additionally, the study found a significant association between city of residence and consumer perceptions of transparency and traceability of meat products, with Durban respondents more likely to consider these factors important. This is in line with trends observed in other regions. For instance, Cáceres *et al.* (2018) found that consumers in Latin America trusted food systems with clear traceability mechanisms. Research by Giroux *et al.* (2021) also indicated that consumers in sub-Saharan Africa preferred meat from vendors who could provide information about sourcing and handling practices. The study further confirmed that transparency plays a crucial role in reducing health risks. According to Ninios *et al.* (2014), traceability systems that allow consumers to verify the source and handling of meat can significantly enhance trust and improve food safety outcomes. The stronger emphasis on traceability in Durban may be attributed to its larger urban context, which tends to have stricter health regulations and greater consumer exposure to food safety campaigns, as supported by Roesel and Grace (2014), who found that urban consumers in East Africa were more likely to demand transparency and regulation.

Overall, the results of this study align with existing literature on food safety concerns in informal meat markets. High consumer concern about contamination risks, a willingness to pay for certified meat, and increased demand for transparency are consistent with studies conducted in Kenya, Malawi, and India. The differences observed between Durban and Pietermaritzburg highlight the influence of urbanization and consumer education on food safety perceptions. Addressing these concerns through enhanced regulatory frameworks, consumer education, and better market infrastructure will be essential for improving meat safety in informal markets and reducing health risks.

8.10 Conclusion

Overall, the results of this study align with existing literature on food safety concerns in informal meat markets. The high levels of consumer concern regarding contamination risks, willingness to pay for certified meat, and the demand for greater transparency are consistent with findings from studies in Kenya, Malawi, India, and Latin America. The significant differences between Durban and Pietermaritzburg in willingness to pay and transparency perceptions highlight the influence of urbanization and consumer awareness on food safety attitudes. Addressing these concerns through stronger regulatory frameworks, consumer education, and improved market infrastructure will be crucial in mitigating health risks and improving meat safety in informal markets

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Chapter 9

8.1 General Discussion

This study examined the critical role of red meat traceability and processing throughout the value chain to ensure meat safety from farm to fork. By delving into the interconnected aspects of on-farm animal handling, pre-slaughter practices, transportation, animal welfare, meat quality, and the importance of traceability systems, this research contributes to enhancing food safety and meat quality in both South Africa's formal and informal meat production sectors. The investigation began with a comprehensive analysis of on-farm animal handling practices, which underscored the significant impact of feeding, housing, and overall animal welfare on meat quality. Studies such as Buchanan *et al.* (2017) and Grandin (2014) showed that appropriate feeding strategies and housing conditions directly influence the growth performance of livestock and, in turn, the quality of the meat they produce. The use of stress-reducing feed additives like magnesium and chromium was highlighted as a potential method to alleviate pre-slaughter stress while maintaining the nutritional integrity of the meat (Schaefer *et al.* 2001). The study further emphasized that poor animal welfare practices could result in various physiological changes in animals, which maybe increased pH and heightened microbial susceptibility, which significantly compromise meat's quality. In line with Mellor (2016), who emphasized the importance of welfare management in preventing stress-related meat defects, these findings suggest that enhancing on-farm practices to reduce animal stress can lead to better-quality meat products. This includes providing optimal housing environments, proper feeding regimens, and managing stress levels to prevent physiological changes that reduce meat quality.

Pre-slaughter practices were identified as a crucial area influencing both animal welfare and meat quality. It was found that stress, particularly during transport and handling, negatively affects meat quality. Prolonged transport times, improper handling during loading and unloading, and inadequate rest periods were all shown to exacerbate stress, leading to undesirable outcomes such as bruising, weight loss, and poor carcass quality (Rushen *et al.* 2012). As supported by Mellor and Stafford (2008), it is well-established that improper pre-slaughter handling practices, such as overcrowding and suboptimal transport conditions, significantly intensify stress in animals, which in turn affects meat quality. The study further revealed that minimizing transport duration, providing adequate rest, and optimizing the conditions during handling can mitigate these stress effects. In this regard, ensuring proper loading densities, minimizing handling times, and improving vehicle conditions are key measures that can enhance both animal welfare and meat quality.

The study also focused on the importance of transportation as a critical stage in the value chain. It was found that substandard transport conditions such as overcrowding, inadequate ventilation, and excessive journey times contributed significantly to stress and compromised the quality of the meat. This aligns with the research by Schuetze *et al.* (2017), who demonstrated that animals subjected to poor transport conditions exhibit increased levels of stress, which can result in physiological changes detrimental to meat quality. In particular, these conditions can lead to an increase in muscle glycogen levels, which, when converted to lactic acid, can cause undesirable effects like lower pH and decreased meat tenderness. By improving transport logistics, such as reducing journey times, enhancing vehicle ventilation, and ensuring proper animal loading, the meat industry can reduce stress and improve both animal welfare and meat quality.

The microbiological safety of meat along the value chain emerged as another key area of concern in this study. Findings revealed that contamination risks, stemming from poor hygiene practices at various stages of production from water and feed on farms to slaughterhouses and retail environments pose significant health risks to consumers. This was consistent with Biasino (2019), who showed that the microbial load in the meat supply chain can be significantly impacted by poor sanitation at both the farm and abattoir stages. Furthermore, informal markets, which often operate with less stringent regulations, were found to be particularly susceptible to microbial contamination. These findings stress the need for enhanced hygiene protocols at all stages of production and processing, as well as the implementation of rigorous testing and monitoring procedures to ensure food safety. Proper handling of water, feed, and faeces, alongside regular sanitation measures, is crucial in minimizing microbial risks. Moreover, addressing contamination at early stages can prevent the spread of pathogens that could endanger consumer health.

Traceability systems were examined as essential tools for enhancing transparency and ensuring the safety of meat products throughout the value chain. This study highlighted the critical role of traceability in identifying sources of contamination, facilitating rapid responses to food safety incidents, and promoting consumer trust. As demonstrated by (Zhang and Bhatt 2014), traceability systems help track and document meat safety from farm to retail, ensuring that safety standards are consistently met. However, challenges persist, especially with limited adoption of traceability technologies in informal markets and inconsistent enforcement of safety regulations. The study noted that overcoming these challenges requires collaborative efforts from all stakeholders farmers, transporters, abattoirs, retailers, and policymakers to harmonize safety standards and promote the widespread use of traceability systems. Ensuring that traceability is integrated into both formal and informal markets will be essential for enhancing overall meat safety.

Consumer perceptions and preferences were also explored, revealing a growing demand for high-quality, safe, and ethically produced meat. Studies such as Rahman *et al.* (2024) show that consumers are increasingly prioritizing meat that is not only safe but also produced under ethical conditions. This shift in consumer preferences highlights the need for production practices to align with these expectations. Informing consumers and informal traders about the importance of safe meat handling and the role of traceability systems in ensuring meat quality and safety can help foster greater trust in the industry. Educational campaigns targeted at consumers, particularly in informal markets, can help bridge the gap in understanding regarding meat safety, handling practices, and the benefits of traceability systems.

9.2 Conclusion

In conclusion, ensuring meat safety from farm to fork requires a comprehensive, integrated approach that addresses animal welfare, pre-slaughter handling, transportation, microbiological safety, and robust traceability systems. By improving on-farm practices, optimizing transportation and handling conditions, maintaining strict hygiene measures, and implementing effective traceability systems, the meat industry can improve product quality, safeguard consumer health, and build trust in the overall meat production process. A holistic approach that addresses these interconnected factors is essential for fostering a safe and sustainable meat supply chain.

9.3 Recommendations

Future research should focus on developing cost-effective traceability technologies, particularly for informal markets, and investigating the long-term impact of consumer education on meat safety practices. In addition, exploring innovative approaches to mitigate pre-slaughter stress, improve biosecurity measures, and ensure feed and water quality can further enhance meat quality and safety. By addressing these areas, stakeholders in the meat industry can work towards a more sustainable and resilient value chain that benefits both producers and consumers.

9.4 References

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List of appendixes

Appendix 1: Consent form and questionnaire

Assessing Meat Safety in the Informal Markets: A Survey on Consumer Attitudes and Health Risks in South Africa

Target respondents:

Purpose: The information gathered through this questionnaire will be used strictly as part of a study about the perceptions and attitudes of consumers towards meat safety from informal markets.

As part of my PhD research in Agriculture (Animal Science) at the University of KwaZulu-Natal, Pietermaritzburg campus, I am surveying consumer perceptions and attitudes toward meat safety in informal markets across two cities, Pietermaritzburg and Durban. Your participation in this questionnaire would be greatly appreciated. All information you provide will be kept confidential.

Consent Form

I………………………… willingly agree to take part in this research study. I understand that my participation is voluntary, and I have the right to withdraw at any time or decline to answer any question without any consequences.

The purpose and nature of the study have been explained to me, and I have had the opportunity to ask any questions.

I acknowledge that I will not receive any direct benefits from participating in this study.

I consent to my interview being audio-recorded and understand that all information I provide will remain confidential and will be securely disposed of at the conclusion of the research.

Signature of respondent Date

Signature of researcher Date

Study Title: ***Assessing Meat Safety in the Informal Markets: A Survey on Consumer Attitudes and Health Risks in South Africa***

Researcher: Progress Mnqophiso Sodella

Institution: University of KwaZulu-Natal

Supervisor: Dr Zikhona Rani-Kamwendo

Introduction:

This questionnaire is designed as part of a research study that investigates consumer attitudes towards meat safety in informal markets in South Africa. The study aims to assess consumer knowledge, perceptions of safety, health risks, and awareness of regulations regarding meat sold in these markets. Participation in this study is voluntary, and all responses will be kept confidential.

Section A: Demographic Characteristics

Please complete the following questions about your demographic characteristics.

1. **Gender**
   - Male
   - Female
   - Other (please specify): ________________
   - Prefer not to answer
2. **Age Group**
   - 18-24 years
   - 25-34 years
   - 35-44 years
   - 45-54 years
   - 55-64 years
   - 65 years and above
3. **What is your highest level of education?**

- No formal education
- Primary school
- High school
- Post-secondary / College
- University degree
- Other (please specify): ________________

4. **What is your occupation?**
    - Unemployed
    - Student
    - Informal sector worker (e.g., street vendor, casual laborer)
    - Employed (private sector)
    - Government worker
    - Other (please specify): ________________
5. **What is your monthly income?**
    - Less than R2000
    - R2000 - R5000
    - R5001 - R10,000
    - More than R10,000
    - Prefer not to answer

Section B: Consumer Knowledge

Please answer the following questions regarding your knowledge of meat safety and handling.

6. **Are you aware of food safety standards related to meat consumption in South Africa?**
    - Yes
    - No
    - Not sure
7. **Where do you usually purchase meat?** (Select all that apply)
    - Supermarket
    - Informal street vendor
    - Local butcher

- Traditional market (e.g., communal abattoirs)
- Other (please specify): _______________

8. **Do you know the source of the meat you purchase? (e.g., farm, abattoir, or vendor)**
   - Yes
   - No
   - Sometimes
9. **How often do you purchase meat from informal markets (e.g., street vendors, informal butcheries)?**
   - Daily
   - Weekly
   - Monthly
   - Rarely
   - Never
10. **What health risks do you associate with consuming meat from informal markets?** (Select all that apply)

- Bacterial contamination (e.g., E. coli, Salmonella)
- Parasites (e.g., tapeworms)
- Chemical residues (e.g., hormones, antibiotics)
- Spoiled or contaminated meat
- Other (please specify): _______________

Section C: Perceptions of Safety

This section evaluates your perception of safety when buying meat from informal markets.

11. **How safe do you feel when buying meat from informal markets?**

- Very safe
- Safe
- Neutral
- Unsafe
- Very unsafe

12. **Do you think meat sold by street vendors, particularly from communal abattoirs, is safe for consumption?**

- Yes
- No
- Not sure

13. **How confident are you in the hygiene practices of vendors in informal markets?**

- Very confident
- Confident
- Neutral
- Not confident
- Very unconfident

14. **What factors influence your decision to buy meat from informal markets?** (Select all that apply)

- Price
- Availability
- Trust in the vendor
- Quality of meat
- Other (please specify): ________________

Section D: Health Concerns

Please answer the following questions about your awareness and concerns related to meat consumption.

15. **Are you aware of any foodborne diseases associated with meat consumption (e.g., Salmonella, E. coli)?**

- Yes
- No
- Not sure

16. **Do you feel concerned about the health risks associated with purchasing meat from informal markets?**

- Very concerned
- Concerned
- Neutral
- Not very concerned
- Not concerned at all

17. **What actions, if any, do you take to minimize health risks when purchasing meat from informal markets?** (Select all that apply)

- Inspect the meat (appearance, smell, etc.)
- Ask the vendor about the source and handling of the meat
- Avoid buying offal or specific cuts
- Cook the meat thoroughly
- No specific actions
- Other (please specify): _______________

Section E: Regulatory Awareness

This section assesses your knowledge of meat safety regulations.

18. **Are you aware of any regulations or laws governing meat safety in informal markets in South Africa?**

- Yes
- No
- Not sure

19. **Do you think there is adequate enforcement of meat safety regulations in informal markets?**

- Yes
- No
- Not sure

20. **Have you ever seen any health certifications or inspections on meat sold in informal markets?**

- Yes
- No
- Not sure

21. **How effective do you think government regulation is in ensuring safe meat consumption in informal markets?**

- Very effective
- Effective
- Neutral
- Ineffective
- Very ineffective

Section F: Transparency and Traceability

This section evaluates your opinions on the transparency and traceability of meat sold in informal markets.

22. **Do you believe that transparency and traceability of meat products (e.g., source, handling, and inspection history) are important for ensuring consumer safety?**

- Yes
- No
- Not sure

23. **Why do you think transparency and traceability are important (or not important) for meat safety?**

- [Open-ended response]

24. **Would you be willing to pay more for meat that is certified and can be traced back to a reliable source?**

- Yes
- No
- Maybe

Section G: Consumer Behavior & Preferences

This section explores your purchasing preferences and behavior regarding meat from informal markets.

25. **What types of meat do you regularly purchase from informal markets?** (Select all that apply)

- Beef
- Chicken
- Pork
- Lamb
- Offal (internal organs)
- Other (please specify): _______________

26. **What cuts of meat do you typically prefer to purchase?**

- Steak
- Mince
- Offal
- Ribs
- Other (please specify): _______________

27. **Would you change your purchasing behavior if you had more access to information about meat safety and traceability?**

- Yes
- No
- Not sure

Conclusion

Thank you for participating in this study. Your insights will contribute to a better understanding of meat safety in informal markets and help in improving regulations and consumer awareness.

Appendix 2: SASAS conference

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