

RESEARCH ARTICLE

Assessment of the Effectiveness of Food Safety Management Systems in Beef Abattoirs in Lusaka District, Zambia



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Abstract

Food safety management systems are central to controlling microbial hazards in abattoirs, yet their effectiveness depends on consistent implementation beyond documented procedures. In Zambia, persistent foodborne risks suggest that FSMS performance in beef abattoirs remains inadequately characterised. This study sought to assess the effectiveness of FSMS in beef abattoirs of Lusaka. A cross-sectional descriptive study was conducted in three consenting beef abattoirs in Lusaka district. The Food Safety Management System Diagnostic Instrument was used to evaluate core control and assurance activities, while the Microbial Assessment Scheme assessed microbiological performance. Fifty samples were collected across five critical sampling locations including carcasses at key processing stages (32), operators' hands (9), and knives (9). Samples were analysed using selective culture media and biochemical confirmation. Data were analysed in SPSS version 28 using descriptive statistics and inferential statistics to compare contamination patterns across abattoirs. All abattoirs had implemented foundational FSMS like GMPs and SSOPs; however, only one facility had adopted the HACCP system. FSMS-DI results showed average performance for core control activities (mean = 1.86) and basic-to-average performance for assurance activities (mean = 1.78) and food safety indicators (mean = 1.56). Microbiological analysis detected *Staphylococcus* spp. (70%) and *Escherichia coli* (54%) as the most prevalent organisms, particularly at CSLs involving operator hands and knives. *Klebsiella* spp. (22%), *Streptococcus* spp. (24%), and *Shigella* spp. (6%) were also detected, while *Salmonella* spp. was not isolated. Significant differences in contamination were observed for *E. coli* and *Klebsiella* spp. across abattoirs ($p < 0.05$). Microbiological safety ratings classified of the beef abattoir was between poor to moderate. Despite the presence of foundational FSMS elements, inconsistent implementation particularly at critical sampling locations, highlights the need for strengthened HACCP adoption, targeted hygiene control, and enhanced regulatory oversight to improve beef safety in Lusaka.

Keywords: *Beef, abattoir, food safety management system, HACCP, prerequisite programs, implementation, hygiene.*

1.0 INTRODUCTION

A food safety management system (FSMS) is a systematic approach for identifying, controlling, and preventing food safety hazards to ensure that food produced is safe and of acceptable quality for consumption¹. FSMS combines hazard analysis and critical control points (HACCP) with prerequisite programs (PRPs) and control measures to ensure hygiene, prevent contamination, and verify food safety effectiveness during production^{2,3}.

Globally, inadequacies in FSMS in abattoirs have been noted and are often associated with microbial contamination, product recalls, and recurrent foodborne disease outbreaks⁴. An abattoir also known as a slaughterhouse is an authorised food establishment where food animals are slaughtered for human consumption and vital meat products are processed⁵. During the processing stages at the abattoir, meat is highly susceptible to microbial contamination when hygiene and sanitary practices are not upheld leading to food poisoning^{6,7}. Some foodborne pathogens associated with meat such as *Clostridium botulinum*, *Clostridium perfringens*, *Salmonella* spp., *Staphylococcus aureus*, *Bacillus* spp., *Escherichia coli*, *Campylobacter* spp. *Listeria monocytogenes*, *Yersinia*, Enteroviruses, *Cysticercus*, *Trichinella* among others have been identified as significant challenges to food safety and may result in serious human health effects^{8,9}. Contamination of meat with these pathogens is a major public health concern worldwide, with poultry-related *Salmonella* estimated to cause over 80 million cases of foodborne illness annually and beef-associated *Campylobacter* contributing to approximately 96 million cases globally¹⁰. These trends highlight the importance of risk-based FSMS in controlling food safety hazards across the entire meat value chain.

Despite this global evidence, FSMS implementation remains limited in many abattoirs in Africa, where facilities often operate without formalised, preventive food safety systems^{11,12}. Key challenges include inadequate worker training, poor adherence to established procedures, limited availability of hazard related data, insufficient funds, lack of knowledge, and weak policies and regulatory oversight, all of which undermine effective hazard control¹¹. In several African abattoirs, food safety control is still largely reliant on ante-mortem and post-mortem inspection aimed at detecting visible zoonotic diseases, such as tuberculosis, brucellosis, foot and mouth disease while overlooking microbial foodborne hazards¹³. Although visual inspection remains important, it is insufficient on its own and should be complemented by preventive control measures targeting pathogens such as *Salmonella*, *Campylobacter*, and *Escherichia coli*¹⁴.

FSMS in Zambia have not been comprehensively evaluated for effectiveness since earlier assessments that focused mainly on microbiological contamination and hygiene practices, without examining core control and assurance components^{14,15}. Despite rising meat demand in Lusaka and claims of HACCP implementation by some abattoirs, foodborne illnesses linked to contaminated meat persist, indicating ineffective or poorly enforced FSMS and weak regulatory oversight, including the absence of mandatory HACCP requirements in national legislation^{14,16}. Recurrent outbreaks of foodborne diseases, including diarrhoea, bovine tuberculosis and anthrax, have further highlighted public health risks associated with inadequate hygiene, poor compliance, and limited training in meat processing facilities^{14,17,18}. Consequently, this study assessed both FSMS performance and microbiological quality in beef abattoirs in Lusaka to identify critical gaps and inform evidence-based improvements to food safety standards and public health protection.

2.0 MATERIALS AND METHODS

2.1 Study design:

This study used a cross-sectional descriptive design with a quantitative approach to assess the effectiveness of FSMS in beef abattoirs in Lusaka District. Data were collected at a single time point using two complementary approaches: the FSMS Diagnostic Instrument (FSMS-DI) to evaluate the implementation and performance of GMPs, SSOPs, and HACCP, and the Microbial Assessment Scheme (MAS) to determine the presence of *E. coli*, *Salmonella* spp., and *S. aureus* at critical sampling locations.

2.2 Study setting and population:

The study was conducted in Lusaka District, an area characterised by rapid population growth and increasing demand for meat and meat products. According to records from the Lusaka City Council, four beef abattoirs were operational during the study period, and three consented to participate after initial site verification visits. The study population included all beef abattoirs actively slaughtering cattle and food safety personnel who oversaw hygiene and safety practices and could read and understand English. Beef abattoirs that were non-operational or declined participation, and personnel who did not consent, were excluded.

2.3 Study selection and size:

A census sampling approach was used, including all beef abattoirs operating in Lusaka district during the study period. Sample size determination for microbiological analysis followed Cochran's formula.

$$n_0 = \frac{Z^2 \cdot p(1-p)}{e^2} = \frac{1.96^2 \cdot 0.879(1-0.879)}{0.05^2} = 163.43549376 = 163 \dots \dots \dots \text{Equation 1}$$

However, this sample was further adjusted to align with the total daily throughput of carcasses (85). The adjusted sample was 56, and this was increased by a 10% mark-up value to **62 samples** to enhance statistical power. Below is how the sample was adjusted.

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} = \frac{163}{1 + \frac{163 - 1}{85}} = 56.09311740890689 = 56 \text{ samples} \dots \dots \dots \text{Equation 2}$$

Where, n_0 = initial sample size, $Z = 1.96$ at a 95% confidence level, $P = 87.9\%$ ¹⁹, $e = 0.05$, n = estimated sample size and $N = 85$, a sum of daily throughput of the abattoirs.

Samples were allocated proportionally across abattoirs based on throughput and distributed across five critical sampling locations: carcass after hide removal, carcass after evisceration, knife used for evisceration, operator's hands, and carcass at chilling.

2.4 Data collection:

Data collection utilised two validated instruments. The FSMS-DI, a semi-structured tool adapted from Cheah *et al.*³ and Jeffer *et al.*¹², assessed core control activities and core assurance activities, using a scoring system ranging from 0 (absent) to 3 (advanced). The tool was pretested to ensure clarity and applicability. The MAS protocol was used to guide the identification of sampling sites, microbial parameters, frequency, and analytical procedures. Indicator organisms included *Escherichia coli* and *Salmonella* spp. as markers of faecal contamination and *Staphylococcus aureus* as an indicator of poor personal hygiene. Sampling was conducted during normal operations to capture routine hygiene practices. Sample collection followed international standards. Carcass samples (25 – 50g) were collected using excision sampling in accordance with ISO 17604:2015, specifically from the brisket and flank locations prone to contamination during dressing and evisceration. Surface samples from knives, tables, and operators' hands were collected using ISO 18593:2018, applying sterile swabs and a 10 × 10 cm template. All samples were placed in sterile containers, transported in ice chest bags maintained below 4°C, and delivered within 72 hours to the bacteriology laboratory at the School of Veterinary Medicine, University of Zambia.

2.5 Laboratory processing:

Samples received at the laboratory were prepared by homogenising beef portions (25-50g) in a stomacher with 225 ml of sterile buffered peptone water for 2 minutes. Swabs from surfaces and operators' hands were vortexed for 60 seconds in 10 ml of sterile buffered peptone water to release attached microorganisms. The homogenised beef samples and swab suspensions were serially diluted with 1% sterile peptone water to obtain dilution factors of 10^{-1} , 10^{-2} , 10^{-3} , and 10^{-4} dilutions. From each dilution, 0.1 ml aliquots were aseptically spread-plated onto selective agar media for the enumeration and identification of target bacteria. All inoculated plates were incubated at 37°C for 24-48 hrs.

Eosin methylene blue agar (EMB; Oxoid, UK) was used for the isolation of *E. coli*. After incubation, colonies showing a characteristic metallic green sheen were presumptively identified as *E. coli*³. These colonies were further confirmed using the catalase biochemical test, where bubble formation upon the addition of hydrogen

peroxide indicated a positive reaction. For the isolation of *S. aureus*, baird-parker (BP; Oxoid, UK) agar was used. After incubation, black, shiny colonies surrounded by a clear halo were considered presumptive *S. aureus*. Confirmatory identification was done using the tube coagulase test⁷. The total number of positive isolates of *E. coli* and *S. aureus* was enumerated. Finally, Xylose Lysine Deoxycholate (XLD; Oxoid, UK) agar was used for the isolation of *Salmonella* spp. Presumptive colonies showing red colouration with black centres were sub-cultured onto Triple Sugar Iron (TSI) agar (Oxoid, UK) for biochemical confirmation. Reactions producing an alkaline slant (red) and acid butt (yellow) with hydrogen sulfide (H₂S) blackening indicated the possible presence of *Salmonella* spp.⁷

2.6 Data management and analysis:

Data from the FSMS-DI and MAS were coded and analysed using SPSS version 28, applying both descriptive and inferential statistics. FSMS performance was assessed using mean scores and standard deviations for core control activities, core assurance activities, and food safety performance indicators, rated on a 0–3 scale from absent to advanced, with predefined cut-off points guiding interpretation. Microbiological results were summarised using frequencies and percentages of positive isolates across critical sampling locations. Differences in contamination among abattoirs were analysed using Chi-square tests or Fisher’s Exact tests, depending on expected cell counts, with significance set at $p < 0.05$. Microbiological safety levels were classified on a 1–3 scale and combined into an overall microbial performance profile to determine FSMS risk level and the need for system improvement³.

3.0 RESULTS

3.1 Food Safety Management Systems Implemented in Beef Abattoirs

All three abattoirs (A, B, and C) had Good Manufacturing Practices (GMP), Good Hygiene Practices (GHP), and Sanitation Standard Operating Procedures (SSOPs) in place, indicating a generally adequate foundation for basic hygiene and operational control (Table 1).

In contrast, implementation of the Hazard Analysis and Critical Control Points (HACCP) system differed among facilities. Abattoirs A and B had not implemented HACCP, whereas Abattoir C had an established HACCP system in place (Table 1). Overall, Abattoir C demonstrated full implementation of all assessed food safety management components, while Abattoirs A and B relied primarily on prerequisite programs without a formal HACCP-based food safety system.

Table 1: Implementation status of FSMS across the assessed abattoirs.

Food Safety Management Systems	Food Safety Management Systems Implemented		
	Abattoir A	Abattoir B	Abattoir C
Good Manufacturing Practices			
Good Hygiene Practices			
Sanitation Standard Operating Procedures			
Hazard Analysis and Critical Control Points			
Key			
Implemented			
Not Implemented			

The evaluation of prerequisite food safety programs demonstrated marked differences in implementation status among the three abattoirs (Table 2). Abattoir B and Abattoir C showed comprehensive implementation of most prerequisite programs, whereas Abattoir A exhibited several critical gaps. Notable deficiencies were observed in Abattoir A with respect to biosecurity protocols, quality control and assurance, and waste management, all of which were not implemented. In contrast, these components were fully implemented in Abattoirs B and C. Pest control was implemented only in Abattoir A, while both Abattoirs B and C lacked formal pest control programs. Overall, Abattoirs B and C demonstrated a higher level of compliance with prerequisite food safety programs,

reflecting more robust foundational FSMS. Abattoir A, despite implementing several basic hygiene-related programs, showed significant weaknesses in critical control areas necessary for effective food safety management.

Table 2: Implementation status of prerequisite food safety programs across the assessed abattoirs.

Prerequisite Programs Implemented	Abattoir A	Abattoir B	Abattoir C
Biosecurity Protocols	Not Implemented	Implemented	Implemented
Employee Training	Implemented	Implemented	Implemented
Equipment Cleansing	Implemented	Implemented	Implemented
Good Hygiene Practices	Implemented	Implemented	Implemented
Good Manufacturing Practices	Implemented	Implemented	Implemented
Good Storage Practices	Implemented	Implemented	Implemented
Meat Inspection	Implemented	Implemented	Implemented
Pest Control	Implemented	Not Implemented	Not Implemented
Quality Control and Assurance	Not Implemented	Implemented	Implemented
Sanitation Standard Operating Procedures	Implemented	Implemented	Implemented
waste management	Not Implemented	Implemented	Implemented
Water quality treatment	Implemented	Implemented	Implemented

Key

Implemented	Implemented
Not Implemented	Not Implemented

3.2 Performance of the Identified FSMS in Beef Abattoirs in Lusaka

The assessment of FSMS performance across the three beef abattoirs in Lusaka District revealed moderate differences among the core components on a scale of 0-3 (Table 3). Core control FSMS activities demonstrated an average performance level (mean = 1.86) indicating that preventive measures such as hygiene protocols, sanitation programs, and raw material controls are generally in place but not consistently applied (Table 3). Core assurance FSMS activities scored in the basic to average range (mean = 1.78) suggesting the presence of verification and validation systems with gaps in systematic implementation and documentation. Similarly, the food safety performance indicator also reflected a basic to average level (mean = 1.56) highlighting inconsistent food safety (Table 3). Lower variability in core assurance activities indicated more uniform performance across abattoirs, whereas greater variability in core control and food performance indicators reflected differences in implementation of preventive and operational controls among the abattoirs.

Table 3: Performance of FSMS activities in beef abattoirs

Variables	No. of Abattoirs	Minimum	Maximum	Mean Score	SD	Performance Category
Core Control FSMS Activities	3	1.08	2.40	1.86	0.700	Average
Core Assurance Activities	3	1.33	2.00	1.78	0.384	Basic-Average
Food Safety Performance Indicator	3	1.00	2.00	1.56	0.770	Basic-Average

Note: The interpretation of mean scores followed these predetermined thresholds in line with the scale: 0-0.2 = absent/low, 0.3-1.2 = basic, 1.3-1.7 = basic to average, 1.8-2.2 = average, 2.3-2.7 = average to advanced, and 2.8-3.0 = advanced performance.

3.3 Microbial Assessment Scheme for Indicator Pathogens

Five microbial species were detected across the five critical sampling locations in the three beef abattoirs, namely *Escherichia coli*, *Staphylococcus* spp., *Klebsiella* spp., *Streptococcus* spp., and *Shigella* spp. Among the 50 samples analysed, *Staphylococcus* spp. (70%) and *E. coli* (54%) were the most prevalent, while *Klebsiella* spp. (22%), *Streptococcus* spp. (24%), and *Shigella* spp. (6%) were detected at lower frequencies, and no samples tested positive for *Salmonella* spp.

3.3.1 Bacterial Isolation Rate from Carcasses in Processing Line

Bacterial contamination was detected at all processing stages across the three abattoirs, with differences in the prevalence of individual bacterial species. After skinning, Abattoir A recorded the highest range of isolates, with *E. coli* and *S. aureus* each detected in 60% of samples, *Klebsiella* spp. in 40%, and *Salmonella* spp. and *Streptococcus* spp. each in 20%, while *Shigella* spp. was not detected. In Abattoir B, *E. coli* and *S. aureus* were each detected in 50% of samples, whereas Abattoir C showed detection of *S. aureus* only (100%), occurring in all samples (Table 4).

Following evisceration, *E. coli* was detected in all samples from Abattoirs A and B (100%). In Abattoir A, *S. aureus* and *Klebsiella* spp. each in 40%. In Abattoir B, *S. aureus*, *Streptococcus* spp., and *Shigella* spp. were each detected in 50% of samples. In Abattoir C, *S. aureus* and *Streptococcus* spp. were each detected in 50% of samples, with no detection of the other bacteria (Table 4).

At the chilling stage, *E. coli* and *S. aureus* were each detected in 80% of samples from Abattoir A, while *Klebsiella* spp. and *Shigella* spp. were each detected in 20%. In Abattoir B, *E. coli*, *Klebsiella* spp., and *Shigella* spp. were each detected in 50% of samples. In Abattoir C, *S. aureus* was detected in all samples (100%) and *Streptococcus* spp. in 67%, with no detection of *E. coli*, *Salmonella* spp., *Klebsiella* spp., or *Shigella* spp. (Table 4).

Table 4: Prevalence of bacterial isolates of carcasses at different processing stages across the beef abattoirs

Sampling Location	Bacteria	Abattoir	Abattoir	Abattoir
		A	B	C
Carcass after skinning	<i>Salmonella</i> spp.	0 (0%)	0 (0%)	0 (0%)
	<i>Escherichia coli</i>	3 (60%)	1 (50%)	0 (0%)
	<i>Staphylococcus aureus</i>	3 (60%)	1 (50%)	4 (100%)
	<i>Streptococcus</i> spp.	1 (20%)	0 (0%)	0 (0%)
	<i>Klebsiella</i> spp.	2 (40%)	0 (0%)	0 (0%)
	<i>Shigella</i> spp.	0 (0%)	0 (0%)	0 (0%)
Carcass after evisceration	<i>Salmonella</i> spp.	0 (0%)	0 (0%)	0 (0%)
	<i>Escherichia coli</i>	5 (100%)	2 (100%)	0 (0%)
	<i>Staphylococcus aureus</i>	2 (40%)	1 (50%)	2 (50%)
	<i>Streptococcus</i> spp.	0 (0%)	1 (50%)	2 (50%)
	<i>Klebsiella</i> spp.	2 (40%)	0 (0%)	0 (0%)
	<i>Shigella</i> spp.	0 (0%)	1 (50%)	0 (0%)
Carcass at Chilling	<i>Salmonella</i> spp.	0 (0%)	0 (0%)	0 (0%)
	<i>Escherichia coli</i>	4 (80%)	1 (50%)	0 (0%)
	<i>Staphylococcus aureus</i>	4 (80%)	0 (0%)	3 (100%)
	<i>Streptococcus</i> spp.	0 (0%)	0 (0%)	2 (67%)
	<i>Klebsiella</i> spp.	1 (20%)	1 (50%)	0 (0%)
	<i>Shigella</i> spp.	1 (20%)	1 (50%)	0 (0%)

3.3.2 Bacterial Isolation Rate from Operators' Hands and Knives

On operators' hands, Abattoir A recorded *E. coli* and *Klebsiella* spp. each in 80% of samples, while *S. aureus*, and *Streptococcus* spp. were each detected in 40% and 60% respectively. In Abattoir B, *E. coli* was detected in all samples (100%) and *S. aureus* in 50%, with no detection of the other bacterial groups. In Abattoir C, *S. aureus* was detected in all samples (100%) and *Streptococcus* spp. in 50% (Table 5).

On knives, Abattoir A showed detection of *S. aureus* in all samples (100%), *E. coli* in 80%, and *Klebsiella* spp. in 20%. In Abattoir B, *S. aureus* was detected in all samples (100%) and *E. coli* in 50%. In Abattoir C, *S. aureus* and *Streptococcus* spp. were each detected in all samples (100%), with no isolation of *E. coli*, *Salmonella* spp., *Klebsiella* spp., or *Shigella* spp. (Table 5).

Table 5: Prevalence of bacterial isolates on operators' hands and knives across the abattoirs

Sampling Location	Bacteria	Abattoir A	Abattoir B	Abattoir C
Operator's Hands	<i>Salmonella</i> spp.	0 (0%)	0 (0%)	0 (0%)
	<i>Escherichia coli</i>	4 (80%)	2 (100%)	0 (0%)
	<i>Staphylococcus aureus</i>	2 (40%)	1 (50%)	2 (100%)
	<i>Streptococcus</i> spp.	3 (60%)	0 (0%)	1 (50%)
	<i>Klebsiella</i> spp.	4 (80%)	0 (0%)	0 (0%)
	<i>Shigella</i> spp.	0 (0%)	0 (0%)	0 (0%)
Knife	<i>Salmonella</i> spp.	0 (0%)	0 (0%)	0 (0%)
	<i>Escherichia coli</i>	4 (80%)	1 (50%)	0(0%)
	<i>Staphylococcus aureus</i>	5 (100%)	2 (100%)	2 (100%)
	<i>Streptococcus</i> spp.	0 (0%)	0 (0%)	2 (100%)
	<i>Klebsiella</i> spp.	1 (20%)	0 (0%)	0 (0%)
	<i>Shigella</i> spp.	0 (0%)	0 (0%)	0 (0%)

3.3.3 Significance of Association in Microbial Contamination

The Fisher's Exact test revealed a statistically significant difference in the distribution of *E. coli* contamination ($p = 0.001$) across the three abattoirs. The distribution of *E. coli* positives differed significantly among the abattoirs. Pearson's Chi-square test showed no statistically significant association between the abattoirs and *S. aureus* contamination ($\chi^2 = 2.89$, $df = 2$, $p = 0.236$). Additionally, Fisher's Exact test found no statistical difference between the abattoirs and the presence of *Streptococcus* spp. ($p = 0.058$) or *Shigella* spp. ($p = 0.175$) while a significant association for *Klebsiella* spp. ($p = 0.006$) was established. No *Salmonella* spp. was detected in any of the abattoirs; therefore, inferential tests were not applicable for this organism.

3.3.4 Microbiological Safety Level Profile in Beef Abattoirs

The microbiological safety level profile was calculated by summing the scores assigned to each of the five critical sampling locations (CSLs), with each location rated on a 0-3 scale based on the combined presence of key microbial parameters (*E. coli*, *S. aureus*, and *Salmonella* spp.), as described by Cheah *et al.*³ This study found varying levels of microbiological safety performance across the three beef abattoirs. Abattoir A scored 4, indicating Poor performance; Abattoir B scored 10, classified as Moderate; and Abattoir C scored 7, falling in the Moderate to Poor category (Table 6).

Table 6: Depicts the summary of microbiological safety level profile across the beef abattoirs.

Abattoir	Total Score	Performance Category
A	4	Poor (1)
B	10	Moderate (2)
C	7	Poor-Moderate (1-2)

Note: The maximum possible total score per abattoir was 15. Performance was interpreted as follows: 3-6: Poor (score 1), 7-8: Poor to Moderate (score 1-2), 9-10: Moderate (score 2), 11-13: Moderate to Good (score 2-3), and 14-15: Good (score 3).

4.0 DISCUSSION

The present study findings revealed that all three abattoirs had implemented the basic forms of FSMS namely GMPs, GHPs and SSOPs. These results demonstrate foundational compliance with PRPs essential for the establishment of a functional FSMS. This is consistent with the assertion by Ahmed and Al-Mahmood²⁰ that the implementation of GMPs, GHPs and SSOPs in abattoirs during slaughtering and processing aids in contamination reduction and produces high-quality meat. These current study findings align with Codex Alimentarius guidelines, which define GMPs and SSOPs as foundational to effective food safety systems and prerequisites for the successful implementation of HACCP²¹. The European Union mandates all food business operators to develop FSMS based on the PRPs and principles of HACCP as outlined in the European Union 2022/C355 information and notices^{22,23}. The legal instruments align with the international standards, such as the Codex Alimentarius general principles of food hygiene and ISO 22000:2018, which together promote harmonised food safety management practices across various food supply chains^{22,24,25}. In this study, the presence of GMPs and SSOPs reflects an awareness of essential hygiene practices; however, the inconsistent implementation of HACCP across facilities highlights the structural and capacity-related gaps that continue to constrain progress towards comprehensive food safety assurance.

According to Lee *et al.*¹, an effective FSMS is typically a combination of well-established PRPs and a functioning HACCP system. The absence of HACCP in two of the three abattoirs studied may be attributed to inadequate technical expertise, a lack of institutional support, or cost-related limitations, factors commonly observed in food establishments within developing countries^{26–28}. For instance, the listeriosis outbreak in South Africa in 2017, which resulted in multiple deaths and trade restrictions with Zambia, was linked to inadequacies in hygiene and a failure to implement adequate FSMS²⁹. Such incidents emphasise the critical importance of robust FSMS in beef facilities, including both PRPs and HACCP, in mitigating microbiological risks and protecting public health.

The PRPs identified in this present study varied in complexity across the three facilities. Two abattoirs reported comprehensive systems that included not only GMPs and SSOPs but also pest control, staff training, water treatment, quality assurance, and biosecurity protocols. One abattoir, however, implemented a more limited range of PRPs. This variation is significant, as the inadequate or inconsistent application of PRPs can lead to hygiene shortfalls and increased risk of contamination, even in the presence of a formal HACCP plan^{1,20}. These findings are in agreement with those presented by Lee *et al.*¹, which revealed the recall of food products from the market in countries such as Nigeria, the United States, and Europe due to *Salmonella* and *Listeria* contamination. The recalls were attributed to PRP failures rather than failures in HACCP implementation in meat slaughter and food processing plants.

In Zambia, the weak enforcement of hygiene standards and inadequate regulatory oversight have contributed to the delayed adoption of HACCP and a weak FSMS in some slaughter facilities^{14,30,31}. According to Chitakwa *et al.*³¹, the lack of harmonised standards and trained personnel remains a significant challenge in the food processing sector. These findings support the current study's findings that, although baseline PRPs may exist, the absence of HACCP in the majority of the assessed abattoirs indicates a gap in aligning local practices with internationally accepted food safety standards. Therefore, while it is encouraging that foundational FSMS, such as GMPs, GHPs, and SSOPs, are being adopted, the limited uptake of HACCP suggests that abattoirs still face constraints in transitioning to fully integrated food safety systems.

This study measured the performance of FSMS across core control activities, core assurance activities, and food safety outcome functions using mean scores. Core control activities scored 1.86, reflecting an average level of implementation. Core assurance scored 1.78, and food safety performance indicators scored 1.56, both within the basic to average range. These findings suggest that foundational preventive and hygiene measures are in place, but they lack the consistency and robustness necessary for delivering reliable food safety outcomes. The FSMS was observed to be more effective in one of the three abattoirs, and this could be attributed to the inconsistent implementation of some PRPs and HACCP by the other facilities, highlighting structural and capacity-related lapses. These findings align with those of Jeffer *et al.*¹² in Uganda, who reported similarly low

scores in both control and assurance domains within beef supply chains, which were attributed to inadequate sanitation and handling procedures.

Additionally, Osés *et al.*³² noted that FSMS performance in the lamb industry was insufficient to ensure food safety when systems relied solely on basic to average-level activities. This implies that activities that are basic to average may significantly impact the performance of FSMS in beef facilities. The current study identified deficiencies in core control and core assurance activities, as the performance level was low to basic for certain components, including design monitoring, the extent of corrective actions, and defining system requirements. This resonates with the observation made in the study by the Food Agriculture and Organisation¹¹ and Jeffer *et al.*¹² that most African companies had deficiencies in core assurance activities of the FSMS. However, contrary to the present study findings, a Malaysian study on powdered beverage manufacturers reported significantly higher FSMS performance scores among facilities with rigorous certifications such as ISO 22000, as assessed using the FSMS-DI and MAS frameworks³. This emphasises the role of structured systems and external oversight in enhancing FSMS effectiveness. Therefore, this suggests that optimal performance in beef abattoirs in the Lusaka district is achievable when all components of an FSMS, particularly PRPs and HACCP, are fully implemented, leading to above-average scores in FSMS components, such as core control and assurance activities. This is especially critical in the meat industry, where food safety is non-negotiable. Findings from Jeffer *et al.*¹² highlighted that limitations in core control components, such as poor facility sanitation or inadequate raw material control, erode confidence in food safety and limit market access. Similarly, studies on FSMSDI and MAS emphasise that core assurance elements, such as monitoring, verification, and corrective actions, are essential to achieving consistent safety outputs^{3,22,28,33}.

The basic to average performance of FSMS noted in the current study could be acceptable for the local market; however, limitations may exist for regional and international trade. This aligns with the findings of a study conducted by Kussaga *et al.*³⁴, which found that export market requirements for fish and meat necessitate the application of HACCP as well as the inclusion of ISO 22000 components. This suggests that the lack of adoption and comprehensive application of FSMS, such as HACCP, in meat facilities like beef abattoirs in Lusaka and Zambia at large may hinder regional and international trade in beef products. Prior to the adoption and implementation of HACCP, beef abattoirs must address the deficiencies observed in the components of FSMS by improving monitoring, corrective actions, and continuous review of hazard control strategies to ensure consistent production of safe beef products.

The present study's microbiological findings from Lusaka beef abattoirs reveal critical hygiene issues within food safety management systems. The absence of *Salmonella* spp. in all samples is positive, indicating compliance with minimal safety standards. In contrast, significant levels of other indicator organisms across carcasses, equipment and operators' hands point to serious hygiene lapses.

S. aureus was the most prevalent organism detected (70%) and occurred consistently across all abattoirs and sampling locations. This widespread distribution is epidemiologically significant because *S. aureus* is commonly associated with human skin, nasal passages, and poor hand hygiene. Its presence on operators' hands, knives, and carcasses suggests repeated transfer through routine handling activities rather than isolated contamination events. These current findings resonate with the study conducted in South Africa, where *S. aureus* were reported in high proportions of beef samples due to poor sanitation and inadequate staff hygiene practices³³. Additionally, Jeffer *et al.*¹² also observed similar outcomes in Uganda, attributing microbial presence in beef processing facilities to insufficient water and sanitation, lack of proper abattoir infrastructure, and minimal staff training.

In contrast, *E. coli* was detected in 54% of samples and showed marked variation across abattoirs and processing stages. As *E. coli* is a widely accepted indicator of faecal contamination, its detection, particularly after evisceration and on food contact surfaces, points to gaps in hygiene practices employed during high-risk operations. The significant association between abattoirs and *E. coli* contamination, confirmed by Fisher's Exact test ($p < 0.05$), suggests that some abattoirs were more effective than others in controlling faecal contamination risks. This finding resonates with studies from Nigeria and Kenya, where variability in *E. coli* prevalence (40% and 15% of meat samples, respectively) between abattoirs was attributed to differences in operator training,

sanitation frequency, and enforcement of standard operating procedures^{35,36} alike to microbial levels observed in Abattoirs A and B in the current study.

The distribution of microorganisms across CSLs provides further insight into where FSMS controls were weakest. The detection of *E. coli* and *S. aureus* on carcasses immediately after skinning and evisceration highlights these stages as critical risk points for contamination. This finding is consistent with the findings reported in similar studies among Zambian abattoirs, which reported high bacterial loads and *E. coli* contamination on carcasses sampled immediately after evisceration and skinning^{14,15,37}. These studies identified the same processing steps as observed in the current study as key control points for carcass hygiene. These processing steps involve extensive manual handling and exposure of internal tissues, making them highly sensitive to lapses in hygiene and equipment sanitation. Comparable observations have been reported in Canada³⁸, Romania³⁹, and South Africa³³, where carcass contamination was most pronounced during dressing and evisceration, even under regulated environments, mainly because of insufficient sanitation routines, poor staff practices, and ineffective cleaning procedures. This indicates a periodic global challenge where the actual microbiological performance of food facilities does not always match documented FSMS frameworks. The consistent detection of *S. aureus* on knives suggests inadequate cleaning and disinfection between carcasses, while the presence of *E. coli* on hands and implements indicates poor handwashing practices or ineffective glove use. These findings agree with Gelbíčová *et al.*⁴⁰, who reported that sanitation failures related to food-contact surfaces were a primary contributor to microbial persistence in meat processing facilities. At the chilling stage, the continued detection of indicator organisms, especially *S. aureus* and, in some abattoirs, *E. coli*, suggests that chilling alone was insufficient to mitigate contamination introduced earlier in the processing chain. This supports existing evidence that chilling does not eliminate contamination but rather preserves the microbiological status of the carcass at the point of entry into cold storage^{33,41}. Therefore, failures at upstream CSLs can directly influence the final microbial quality of beef.

Besides the detection of primary organisms, the current study found the presence of other bacteria, namely *Klebsiella spp.*, *Streptococcus spp.*, and *Shigella spp.*, which provides supplementary insight into the overall hygiene environment within the abattoirs. These organisms were detected at lower frequencies and were not consistently associated with specific abattoirs or processing stages, suggesting sporadic rather than systematic contamination. Their presence nonetheless indicates failures in general sanitation and environmental hygiene, as these bacteria are commonly linked to faecal matter, contaminated water, or inadequate cleaning of contact surfaces^{12,14}. Similarly, findings from Ethiopia⁴² and a scoping study involving 13 Eastern African countries⁴³ reported the contamination of beef with these microbes. Accordingly, their detection highlights the need for strengthened hygiene and sanitation controls to improve FSMS performance in Lusaka beef abattoirs.

The MAS applied in this present study revealed concerning microbial quality challenges in beef abattoirs. Abattoir A was rated as "poor," with the highest microbial load across sampling points. This could be attributed to either non-functional PRPs or irregular implementation of hygiene procedures. Abattoir B, scoring "moderate," showed relatively better performance, which is likely attributed to more consistent sanitation routines or higher staff compliance. Abattoir C, which fell into the "poor to moderate" category, revealed a mixed pattern, suggesting that although some standards may be in place, they are not uniformly applied. These patterns resonate with the findings by Oses *et al.*³² and Njage *et al.*⁴⁴, who demonstrated that facilities with incomplete verification systems and limited use of microbiological feedback often exhibit fluctuating hygiene outcomes despite having formal FSMS documentation.

It is worth noting that these current study findings confirm that microbiological assessment offers a more accurate measure of FSMS performance than structural audits alone. As observed by Mukuni³⁰, Zambia's heavy reliance on visual inspection in meat facilities may overlook microbial risks that can only be captured through laboratory-based surveillance. Therefore, integrating the FSMS Diagnostic Instrument with microbial profiling tools, such as the MAS, is crucial for identifying weaknesses, guiding interventions, and benchmarking the real-world outcomes of FSMS implementation^{3,12}.

Limitations

This study had several limitations. Only three of the four operational beef abattoirs in Lusaka participated, which may limit the generalizability of the findings beyond the district. Microbiological assessments were restricted to selected pathogens and conducted at a single time point, meaning seasonal or batch-related variations could not be captured. Sampling was limited to five CSLs, potentially missing other contamination sources. Limited funding also prevented molecular confirmation and antimicrobial resistance profiling, which would have strengthened the public health interpretation of the results. Despite these constraints, this study represents the first application of both the FSMS-DI and MAS tools in Zambian beef abattoirs, providing a valuable baseline for FSMS performance and identifying key areas requiring improvement.

Conclusion

This study assessed the effectiveness of food safety management systems in beef abattoirs in Lusaka District and found that, although prerequisite programs were in place, HACCP adoption remained limited. FSMS-DI results showed that core control activities operated at an average level, while core assurance and food safety performance indicators were mostly basic to average, indicating weaknesses in monitoring, verification, and documentation. Microbiological findings confirmed in operational hygiene control at critical points. High detection rates of *S. aureus* (70%) and *E. coli* (54%), particularly at evisceration, chilling, and on contact surfaces such as knives and operators' hands, indicate weaknesses in operational hygiene control at critical points. The detection of additional hygiene and faecal associated organisms, including *Klebsiella* spp., *Streptococcus* spp., and *Shigella* spp., further supports the presence of sanitation failures within specific processing stages. Although *Salmonella* spp. was not detected, suggesting some level of contamination control, the overall microbiological safety profile classified two of the three abattoirs as having poor-to-moderate performance, underscoring the need for strengthened hygiene oversight and targeted FSMS interventions at critical sampling locations. Overall, the study highlights the need for strengthened HACCP integration, improved internal control systems, and enhanced staff training to ensure safer beef production.

Recommendations

This study recommends the following to improve the effectiveness of FSMS in beef abattoirs.

1. Beef abattoirs should ensure that all prerequisite programmes are fully functional and adopt the HACCP system to enhance risk-based control across the beef processing chain.
2. Abattoir management should strengthen control measures at critical control points in the beef value chain, especially at CSLs, such as processing contact surfaces including implements and operator hands where contamination was most frequently detected.
3. Abattoir management should conduct regular and structured training programmes on PRPs for all workers to strengthen operational hygiene and support effective FSMS implementation.
4. Meat inspectors from the Local Authority should provide regular training for abattoir workers and management on hygiene protocols and proper sanitation practices, supported by strict monitoring and penalties for non-compliance.
5. The Lusaka City Council should intensify supervision, conduct routine FSMS performance audits using tools like the FSMS-DI and MAS, and enforce adherence to national and international food safety standards.
6. Future studies should assess the performance of FSMS across a large sample of abattoirs beyond the district, incorporating molecular pathogen profiling to provide a deeper insight into meat safety risks, validate current findings, and guide food safety improvements.

Declarations

Ethics approval

Ethical approval was obtained from Excellence in Research Ethics Committee (ERES) under reference number (Ref: 2024-Dec-012). Additional permission was granted by the University of Zambia, the Lusaka City Council, and the participating abattoirs. All respondents provided informed consent, and confidentiality was upheld throughout the study. No personal identifiers were collected, and abattoirs were anonymised in all reported findings.

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Conflicts of interest

Authors declare no conflict of interest.

Competing interests

Authors declare no competing interests.

Data availability

The datasets supporting the conclusions of this article are made available with restricted access. The datasets are made available upon request with the author through the Science Data Bank Repository, data doi: 10.57760/sciencedb.33279. All data concerning this manuscript is contained within the text.

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