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Research article

Microbial Assessment of Mutton Carcasses after Skinning, after Evisceration and at Retail Stages in Tripoli, Libya

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Abstract

Background: Contamination of mutton carcasses during preparation stages at traditional abattoirs varies widely depending on processing conditions, handling practices, equipment hygiene and environmental sanitation. **Aim:** This study evaluated the surface microbial contamination of mutton carcasses at three distinct preparation stages that include post-skinning, post-evisceration, and retail and at four anatomical sites (shoulder, thigh, outer- and inner abdomen) in two traditional abattoirs in Tripoli, Libya. **Methods:** Surface swabs were collected at the three preparation stages using a sterile 10 cm^2 template. Samples were traced across stages using special carcass identifiers. Bacterial enumeration included aerobic plate counts (APC) at 37°C and 4°C, *Enterobacteriaceae* counts *and Staphylococcus* counts. Isolation and identification of *Staphylococcus* spp., fecal-type *Escherichia coli*, *Enterobacteriaceae* spp., *Campylobacter jejune* and *Yersinia enterocolitica* performed using selective media and standard biochemical confirmation protocols. **Results:** Surface microbial contamination was low after skinning, then slightly increased after evisceration and increased markedly at retail stage of all tested anatomical sites. The Abattoir A consistently exhibited higher APC, *Enterobacteriaceae*, and *Staphylococci* counts compared to the abattoir B. All samples were positive for *S. aureus*, *Proteus vulgaris*, *Y. enterocolitica*, fecal *E. coli*. However, *Salmonella* spp. and *C. jejuni* were not detected. **Conclusion:** These findings highlight critical control points during skinning and evisceration and emphasize the need for improved hygiene practices at retail outlets to reduce microbial hazards and safeguard public health.

Keywords: carcass, mutton, microbial contamination, abattoir hygiene, bacterial count, Tripoli

Introduction

Mutton remains staple and popular meat in Libya, where increasing consumption has driven expansion of small and medium scale sheep production systems (Mohamed *et al*., 2019). However, microbial contamination of mutton carcass surfaces is a critical factor influencing meat quality, shelf life and public health (EFSA, 2013). Carcass contamination during slaughter and dressing primarily originates from the animal's hide, gastrointestinal tract, workers' hands, equipment and the processing environment. Common pathogens of concern in mutton and are frequently implicated in foodborne illnesses include *Salmonella* spp., *C. jejuni*, *E. coli*, *L. monocytogenes*, *C. botulinum*, *C. perfringens*, *S. aureus*, *A. hydrophila*, *B. cereus* and *Y. enterocolitica* (Ali & Alsayeqh, 2022; Darwish *et al*., 2022 and 2023). Total aerobic counts and indicator bacteria such as *Enterobacteriaceae* and *Staphylococcus* spp. are widely used to assess hygiene levels during slaughter. Poor sanitation, inadequate staff training, and use of contaminated equipment significantly increase microbial loads on dressed carcasses (Morshdy *et al.*, 2023). Mutton is less frequently associated with food poisoning outbreaks compared to other meats, whereas, improper slaughtering and handling practices can increase the likelihood of pathogen transmission (EFSA, 2022). Moreover, risk factors include dressing techniques (on the ground or on rail systems), carcass inflation, environmental temperature, lack of refrigeration and open-air transport or display conditions can also introduce additional microbial hazards (Verma *et al*., 2022; Hailu, 2023). In Libya, traditional abattoirs vary widely in infrastructure and hygienic standards, contributing to differences in contamination risks across facilities. Some abattoirs have adopted improved slaughter systems, while others continue to rely on traditional methods that may compromise meat safety. Despite the public health relevance, few studies have evaluated the microbial status of mutton carcasses at progressive preparation stages in Tripoli. Therefore, this study was conducted to evaluate the microbial contamination on mutton carcasses at key preparation stages, namely, post skinning, post evisceration and at retail, in two traditional abattoirs in Tripoli, Libya, and to identify critical points requiring improved hygienic control.

Materials and methods

Collection and preparation of samples

A total of 40 mutton carcasses were sampled from two abattoirs in Tripoli, Libya: the abattoir A (dressing on

ground, n=20) and the abattoir B (dressing on the rail system, n=20) at different stages of preparation (directly after skinning (AS), after evisceration (AE), as well as at butcher shop for the same carcasses). Following each stage, surface swabs were collected from shoulder, thigh, outer abdomen and inner abdomen, on each carcass. A sterile 10 cm² template was used at all sites. The swab technique was used at the three stages of carcass preparation. Each swab was immersed in 10 ml 0.1% sterile peptone water (Oxoid CM509) and were rubbed horizontally and vertically according to ISO 17604:2015 guidelines. Samples were transported in icebox to the Food Hygiene Laboratory at the Department of Food Hygiene at the University of Tripoli and analyzed within 2 hours.

Microbial enumeration procedures

The samples were returned to the diluent tube to achieve a 1:1 dilution. Serial ten-fold dilutions were then prepared up to 10^{-6} using 0.1% peptone water. Appropriate sample dilutions were plated on plate count agar (PCA) at 37°C and 4°C, violet red bile glucose (VRBG) agar (*Enterobacteriaceae*) and Baird-Parker agar (*S. aureus*) in duplicate, as shown in table 1. Colony counts were expressed as CFU/cm^2.

Microbial isolation procedures

Suspected colonies of *Enterobacteriaceae* and *S. aureus* were picked up from VRBG agar plates and Baird-Parker agar plates for further identification. While *Y. enterocolitica* and *C. jejuni* were isolated and identified as shown in table 1.

Microbial identification procedures

Presumptive colonies from selective media were further biochemically identified and confirmed using Gram stain, oxidase, catalase, coagulase, IMViC, urease, API 20E and API Staph tests, as described by MacFaddin (2000).

Statistical analysis

Bacterial counts were converted to $\log_{10}$ CFU/cm² prior to analysis. Differences between preparation stages, anatomical sites and abattoirs were evaluated using ANOVA followed by Tukey's post-hoc tests. Differences were considered significant at $p<0.05$. A heatmap was generated using mean $\log_{10}$ values for each site, stage combination to visualize contamination patterns.

Ethical approval

No live animals nor protocols or materials need special approval were used in this study. All sampling and analytical procedures were performed as routinely practiced.

Results

The microbial quality of mutton carcasses was assessed at three critical stages, after-skinning, after-evisceration and upon delivery to butcher shops, by quantifying the average counts of four microbial groups (APC 37°C and 4°C, *Enterobacteriaceae* and *Staphylococci*) across four distinct carcass locations (shoulder, thigh, outer- and inner abdomen). The results consistently demonstrated a significant increase in microbial contamination corresponding to the progression of carcass preparation and subsequent distribution, with the shoulder region generally exhibiting the highest microbial load. The initial microbial load measured immediately after skinning was the lowest, serving as a baseline. The most substantial increase in contamination was observed following the evisceration step, particularly on the inner surface of the abdomen, confirming a loss of hygienic control during this stage. By the time of delivery to butcher shops, the microbial counts reached their highest levels across all assessed sites (Figures 1- 4).

Enumeration of indicator bacteria

The highest $\log_{10}$ CFU/cm^2 values of APC at 37°C were observed at the retail stage for all sites, with the inner abdomen and shoulder regions having the highest contamination (6.3 $\log_{10}$ CFU/cm^2) (Figures 1&4). This high count at the retail stage suggests significant post-processing contamination or temperature abuse. The abattoir A had higher APCs than the abattoir B at all stages. Tukey's post-hoc test showed that APC increased significantly ($p<0.05$) from after-skinning to after-evisceration and from evisceration to retail (Figure 6). APC at 4°C exhibited a similar pattern of APC at 37°C, with the highest values of 5.3 $\log_{10}$ CFU/cm^2 at the butcher stage. The outer abdomen and inner abdomen regions had more psychrophilic growth especially in the abattoir A (Figures 3&4). *Enterobacteriaceae* counts increased gradually with the preparation stages and across all examined carcass regions with the highest counts at the butcher shop reached 5.3 $\log_{10}$ CFU/cm^2 in the abattoir A for shoulder, thigh and inner abdomen sites (Figures 2&4). Mean values were lower in the abattoir B, and this indicated a higher level of hygienic control. Typically, the count of *Enterobacteriaceae* was lower than that of aerobic bacterial counts but showed a similar tendency to increase throughout the preparation stages. *Staphylococcus* spp. was the most prevalent organism at the butcher shop especially in the shoulder and outer abdomen sites. Counts ranged from 2.0-3.5 $\log_{10}$ CFU/cm^2 after skinning and at butcher shop respectively (Figures 1&3).

Overall contamination profile

The heatmap analysis indicated a clear clustering of high microbial load at the later preparation stages, with the abattoir A persistently possessing higher microbial burden in all parameters (Table 2). Such results imply the importance of slaughter hygiene, in particular, during skinning and evisceration, and require enhancement of the hygienic standards of refrigeration and sanitation at retail locations. The microbial evaluation on mutton carcass surfaces revealed significant differences ($p<0.05$) in APC at 4°C and 37°C, *Staphylococci* and *Enterobacteriaceae* across most carcass sites and preparation stages in both abattoirs (Table 3). APC at 37°C showed significant variation between sites and stages, except for the shoulder surface after skinning, indicating that most preparation stage introduced measurable contamination. APC at 4°C exhibited significant differences at all sites, particularly after carcasses were delivered to butcher shops, suggesting ongoing contamination and spoilage risk throughout processing and distribution (Figure 5). *Enterobacteriaceae* counts differed significantly between the outer and inner abdominal surfaces after

Table 1. The investigated bacteria and their enumeration, isolation and identification procedures.

Investigated bacteria	Step	Media	Incubation	Reference
Aerobic Plate Count	Enumeration	Plate Count Agar (Oxoid CM325)	37°C for 24h and 4°C for 10 days	ISO 4833-1:2013
Staphylococci	Enumeration	Baird-Parker Agar (Oxoid CM275)	37°C for 48h	ISO 6888-1:2021
S. aureus (coagulase positive)	Isolation and identification			
Enterobacteriaceae	Enumeration	Violet Red Bile Glucose Agar (Oxoid CM485)	37°C for 24h	ISO 21528-2:2017
	Isolation and identification	Nutrient Agar (Oxoid CM3) slants	37°C for 24h	BAM FDA guidelines (2022)
E. coli (fecal type)	Isolation and identification	MacConkey Broth (Oxoid CM5a) and EC broth (CM 853B)	37°C for 24h and 44.5°C for 24h	ISO 7251:2005
***Salmonella* spp.**	Isolation and identification	Rappaport-Vassiliadis (Oxoid CM669) and Tetrathionate Broths (Oxoid CM29) XLD Agar (Oxoid CM469) and SS Agar (Oxoid CM99)	37°C for 24h	ISO 6579-1:2017
Yersinia enterocolitica	Isolation and identification	Peptone-Sorbitol-Bile Broth (HIMEDIA M1231) and Cefsulodin-Irgasan-Novobiocin Agar (Oxoid CM653 with SR109 supplement)	30°C for 24–48h	ISO 10273:2017
Campylobacter jejune	Isolation and identification	Bolton Broth (Oxoid CM983) with selective supplements under microaerophilic conditions (Campy Gen Oxoid CN35) and Columbia Blood Agar (Oxoid CM331) with Skirrow supplement (Oxoid SR69E)	42°C for 24h and 42°C for 48h	ISO 10272-1:2017

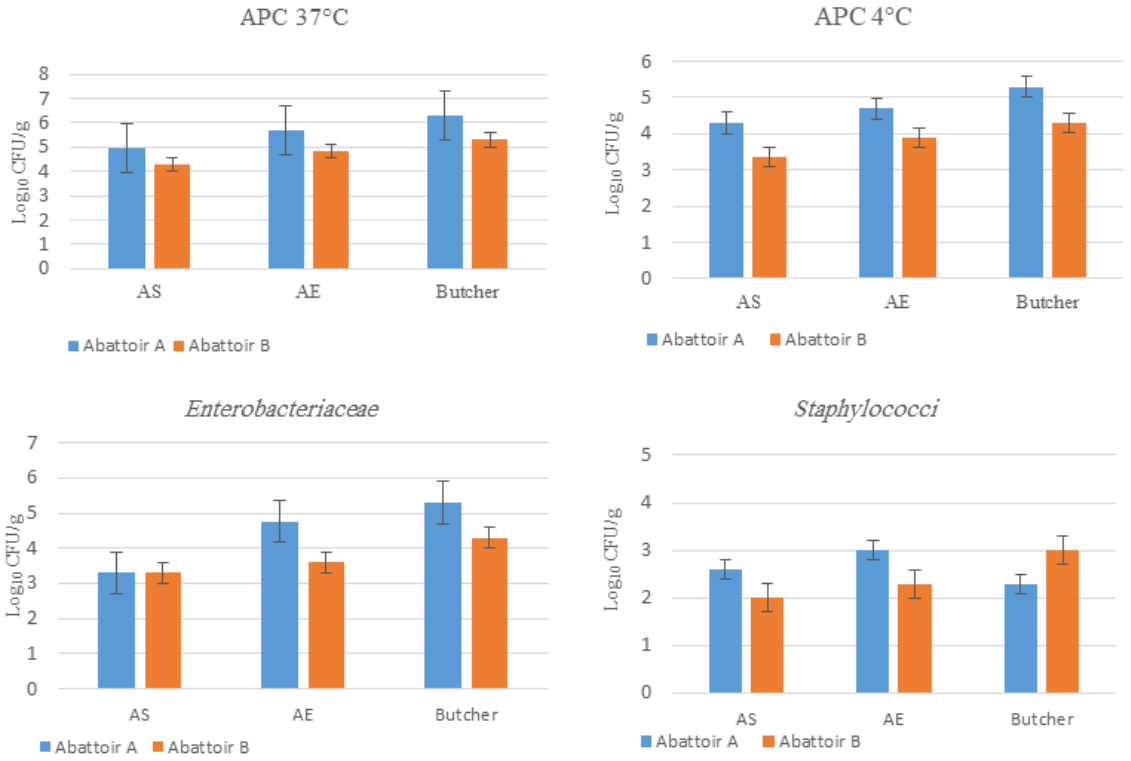


Figure 1. Mean count of surface contamination on shoulder (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

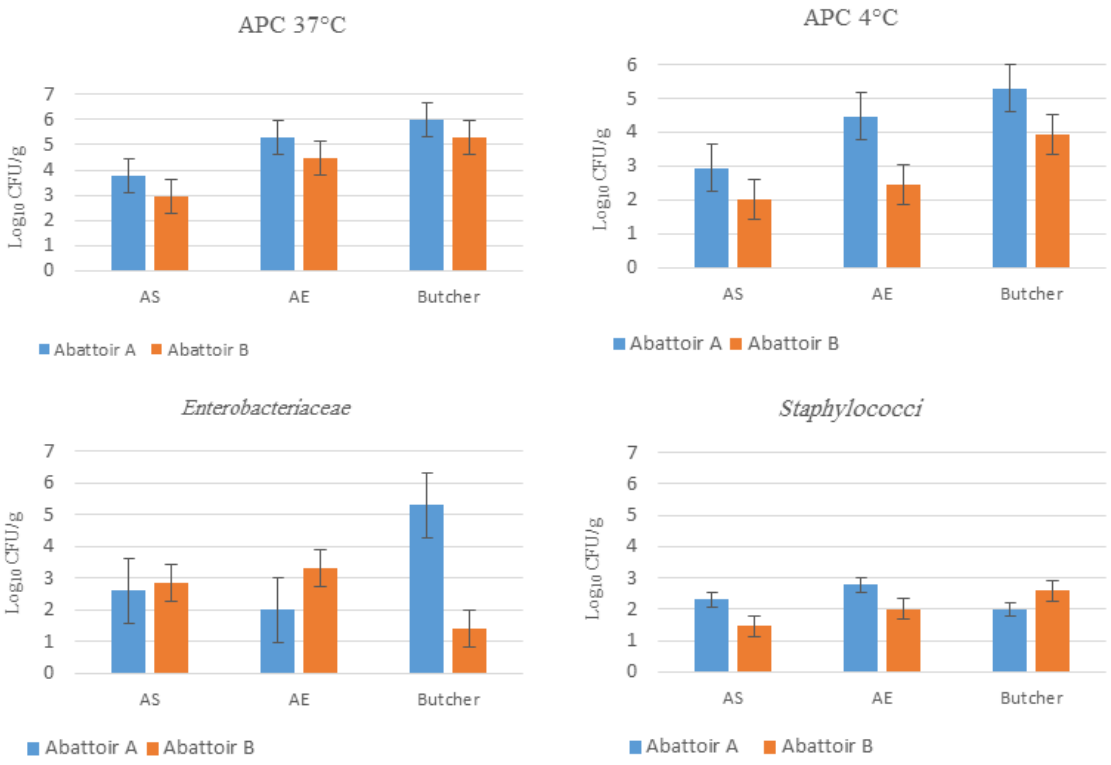


Figure 2. Mean count of surface contamination on thigh (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

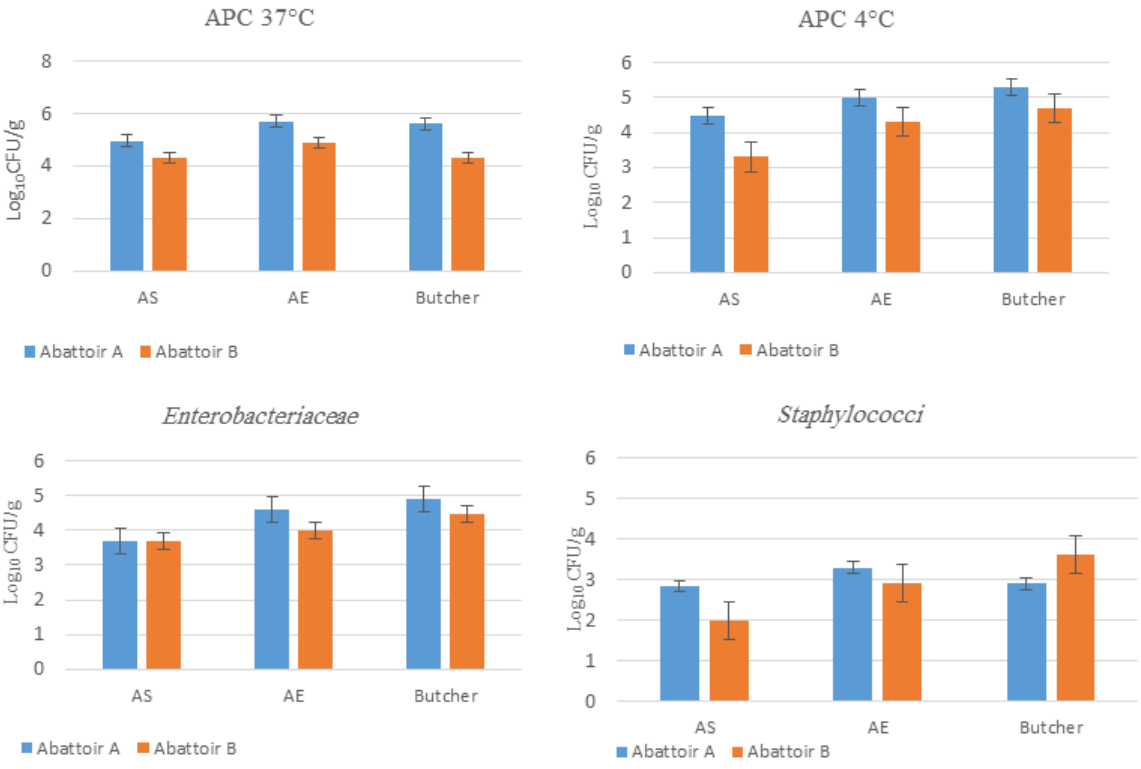


Figure 3. Mean count of surface contamination on outer abdomen (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

evisceration, reflecting fecal contamination risks during gut removal, and continued to vary significantly across all sites after delivery to butcher shops (Figure 7). *Staphylococci* counts also differed significantly across nearly all surface sites, highlighting the strong influence of human handling in microbial transfer (Table 3). Only

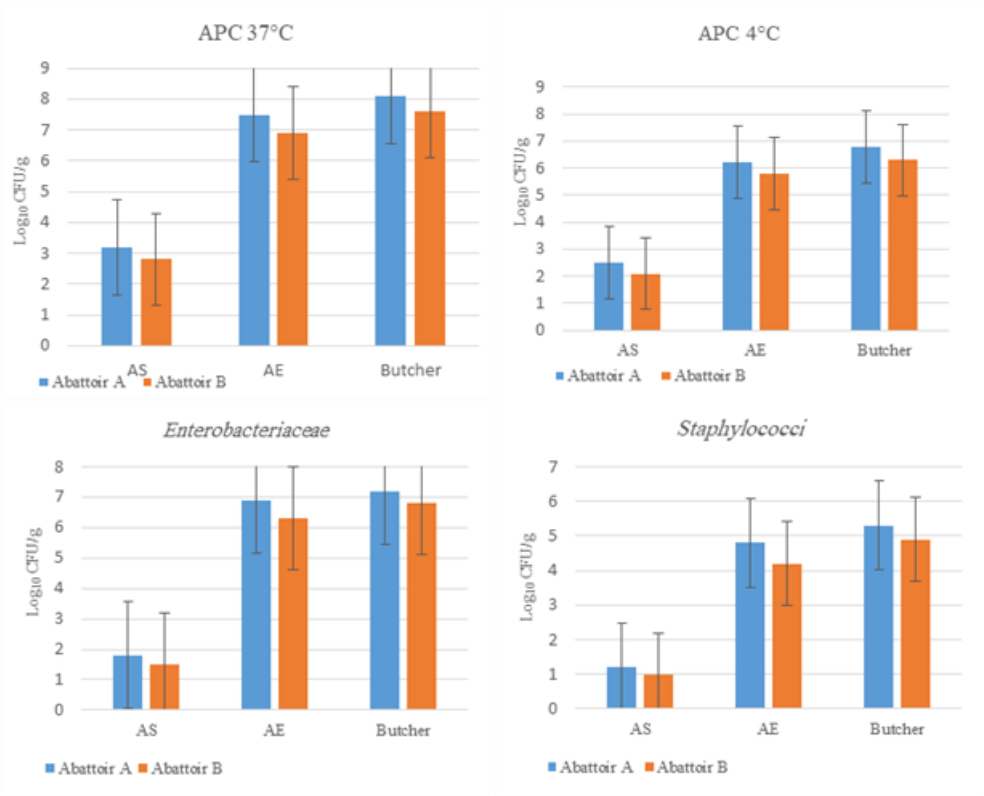


Figure 4. Mean count of surface contamination on inner abdomen (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

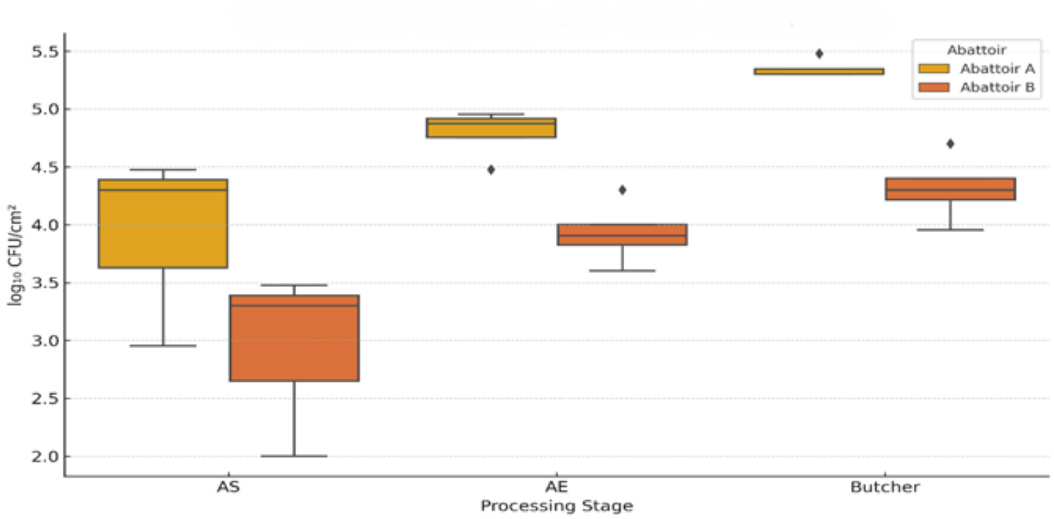


Figure 5. APC mean count at 4°C across stages and abattoirs (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

few sites, such as parts of the abdominal surface, showed no significant difference in isolated stages (Figure 8). Together, these findings indicate that contamination accumulates progressively throughout carcass preparation, with the abattoir A exhibiting higher variability and contamination levels due to poor hygiene, floor-level processing and increased manual handling, while the abattoir B suspended processing system resulted in fewer significant differences across sites and stages.

Isolation of some pathogenic bacteria

Fecal indicator organisms (Fecal coliforms and *E. coli*) were ubiquitously detected across all examined surfaces and preparation stages in both investigated abattoirs, confirming widespread fecal contamination. *S. aureus* was the dominant contaminant (up to 50%) in all regions and stages of both abattoirs; its load often increases between the skinning and butcher shop stage. *P. vulgaris* was also frequently observed (up to 60%); its prevalence tends to increase from earlier to later stage. This was

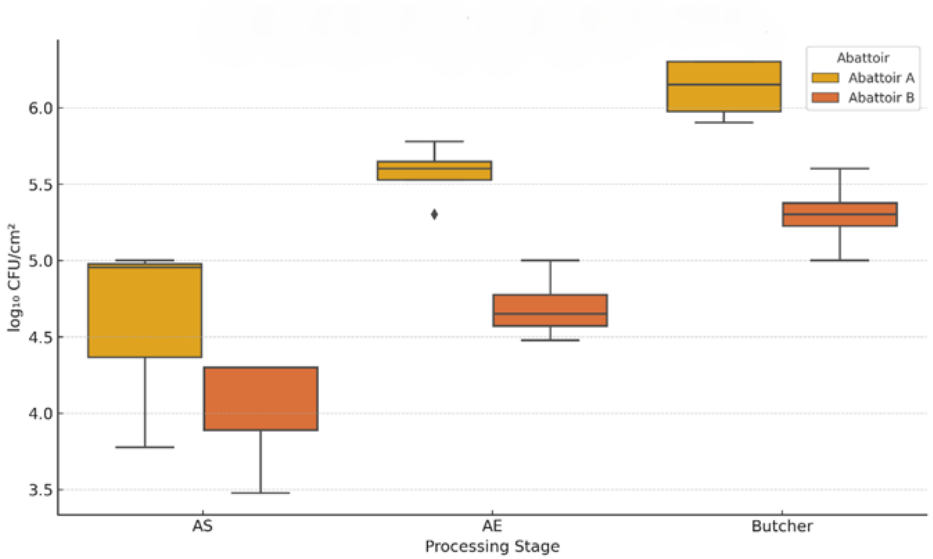


Figure 6. APC mean count at 37°C across stages and abattoirs (log_{10} CFU/cm^2). APC: Aerobic plate count, AS: After skinning, AE: After evisceration.

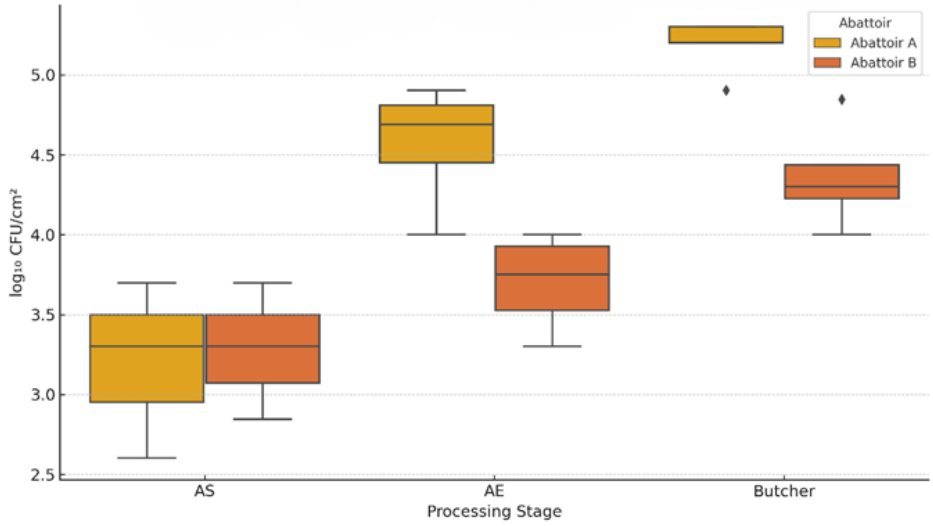


Figure 7. *Enterobacteriaceae* count across stages and abattoirs (log_{10} CFU/cm^2). AS: After skinning, AE: After evisceration.

especially evident on the butcher stage which can be a sign of post-processing contamination. *Y. enterocolitica* and *E. coli* were sporadically found, typically at lower levels (30% and 10%), respectively. Other common isolates included *Enterobacter cloacae*, *E. coli*, *Klebsiella* spp., and *Shigella* spp. Interestingly, *Salmonellae* and *C. jejuni* were not isolated from any site in either abattoir (Tables 4 through 7). The results showed significantly higher contamination levels at the butcher stage, with the abattoir A consistently demonstrating higher bacterial counts than the abattoir B. The inner abdomen region had consistently shown lower bacterial load than the outer abdomen and extremities, mostly due to low external contact. The thigh and shoulder regions generally have a higher level of contamination than the abdomen, suggesting that these areas are either more exposed or difficult to clean during processing.

Discussion

The microbial contamination of mutton carcasses is a significant concern for public health, meat quality and shelf life. Research indicates that contamination primarily occurs during slaughtering and dressing, specifically due to faults in skinning and evisceration, leading to the spread of bacteria from the fleece, blood, and gastrointestinal tract to the dressed surfaces. The current study revealed a progressive increase in bacterial contamination of mutton carcasses from after-skinning to the retail stages, with noticeably higher loads observed post-evisceration and at butcher shops. The present findings indicate that the contamination control efficacy during meat preparation was dependent on specific anatomical regions, and the shoulder and inner abdomen poses the most significant microbial challenge due to potential evisceration contamination. Therefore, critical processing steps such as skinning and evisceration were

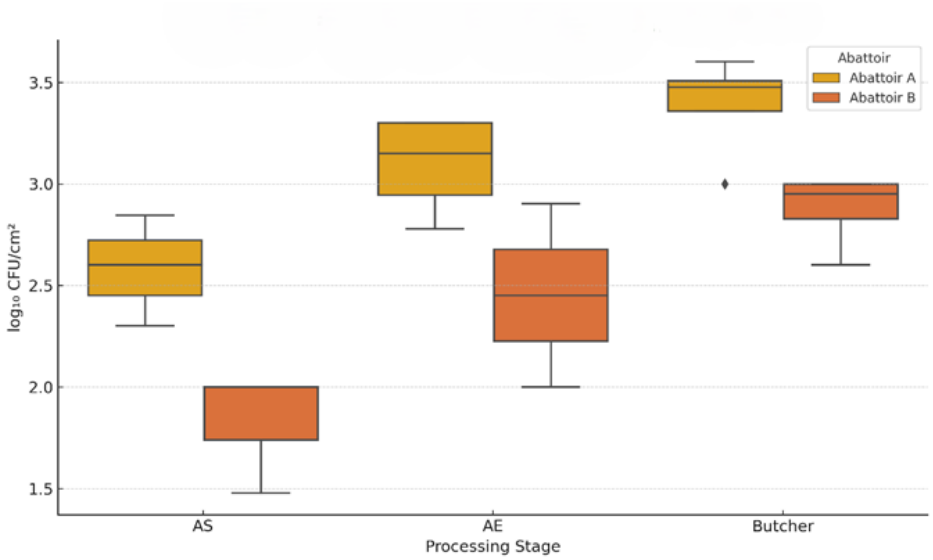
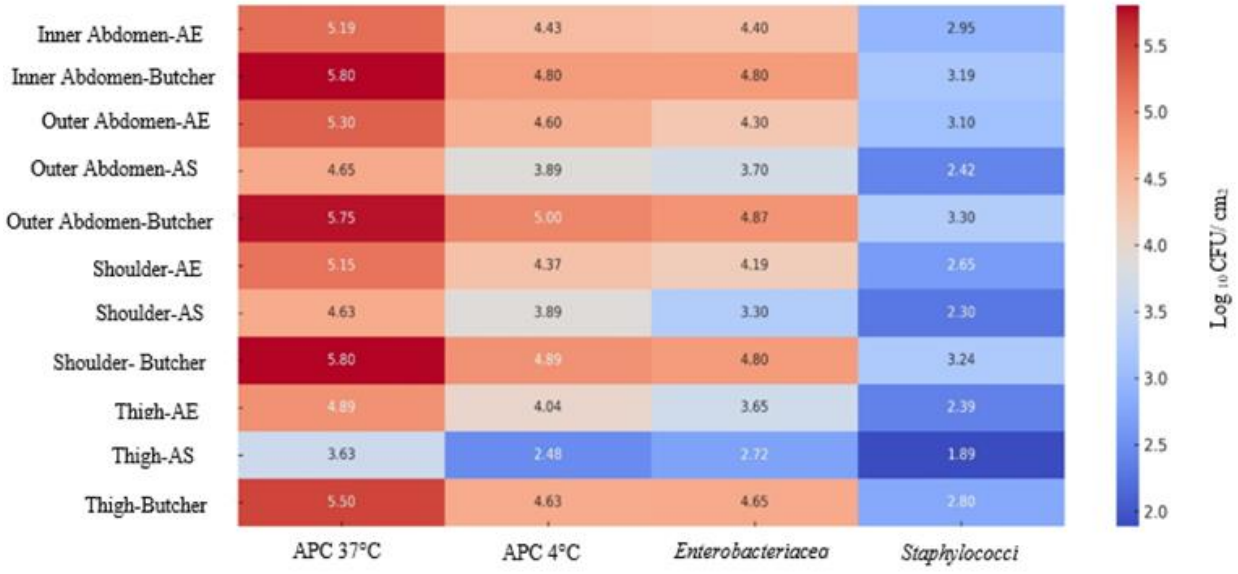


Figure 8. *Staphylococci* count across stages and abattoirs (log_{10} CFU/cm^2). AS: After skinning, AE: After evisceration.

Table 2. Heatmap of mean log_{10} CFU/cm^2 by site and state (all parameters).



crucial in the microbial load reduction, but their effectiveness varies by body region. This is consistent with earlier research showing that slaughtering operations, particularly dressing and evisceration, are crucial points where contamination is introduced (Akinwumi *et al*., 2022; Verma *et al.*, 2022 and Morshdy *et al*., 2023). There were significant differences in microbial counts between the two investigated abattoirs; with the abattoir A consistently exhibited a higher level of contamination. This could be directly attributed to relatively-older techniques and unsanitary conditions, where preparation was conducted on the floor, facilitating contamination from feces or blood which is exacerbated by workers' lack of hygienic awareness. In contrast, the abattoir B maintained better hygiene by hanging carcasses throughout preparation, minimizing floor contact and contamination, a practice known to reduce surface contamination and spoilage by bacteria.

Former report by FAO and WHO (2019) has highlighted that lack of sanitation and improper handling techniques are some of the primary factors leading to meat contamination, especially in traditional or under-equipped slaughterhouses. While, Gill (1998) and Akinwumi *et al.* (2022) found that factors like slaughter line speed, water quality, and time between slaughter steps are also identified to affect microbial loads and possibly cause abattoir differences.

The fecal and handling contamination indicators (*Enterobacteriaceae* and *Staphylococci*) increased significantly by the retail stage, which was evidence of cross-contamination due to the use of equipment, handlers or the environment. This is not an exception; as

Table 3. Variation of microbial counts of mutton carcasses surface at different stages of preparation ($p<0.05$).

Counts	Steps	Abattoir A				Abattoir B			
		Shoulder	Thigh	Abdomen		Shoulder	Thigh	Abdomen	
				Outer	Inner			Outer	Inner
APC at 37°C	**AS**	S*	S*	S*	-	S*	S*	S	-
	AE				S*				NS
	Butcher								
APC at 4°C	**AS**	S	S	S*	-	S	NS	NS	-
	AE				NS				NS
	Butcher								
Enterobacteriaceae	**AS**	S	S*	S	-	S*	NS	NS	-
	AE				NS				NS
	Butcher								
Staphylococci	**AS**	S*	S*	S*	-	S	NS	S*	-
	AE				NS				NS
	Butcher								

APC: Aerobic plate count, AS: After skinning, AE: After evisceration, NS: Not significant, S: Significant, S*: Highly significant.

Table 4. Prevalence of isolated bacteria on shoulder of mutton carcasses surfaces.

Bacteria	Number of Samples / % Positive					
	Abattoir A (n=20)			Abattoir B (n=20)		
	AS	AE	Butcher	AS	AE	Butcher
Fecal Coliform	20/100	20/100	20/100	20/100	20/100	20/100
S. aureus	5/25	6/30	8/40	1/5	6/30	8/40
Y. enterocolitica	ND	1/5	2/10	ND	ND	2/10
Entero. cloaca	1/5	1/5	1/5	ND	ND	ND
Citrobacter spp.	ND	1/5	1/5	ND	ND	ND
Hafnia	ND	ND	ND	ND	2/10	2/10
Providencia spp.	ND	ND	1/5	ND	ND	ND
Serratia spp.	ND	ND	ND	ND	ND	ND
Shigella spp.	ND	1/5	1/5	ND	2/10	2/10
Proteus vulgaris	5/25	6/30	9/45	2/10	6/30	10/50
E. coli	ND	1/5	1/5	ND	ND	2/10
Klebsiella spp.	ND	ND	2/10	ND	2/10	2/10
Salmonellae	ND	ND	ND	ND	ND	ND
Campylo. jejuni	ND	ND	ND	ND	ND	ND

AS: After skinning, AE: After evisceration, ND: Not detected.

EFSA and others have noted that post-slaughter contamination plays a critical role in determining public health risks (Zwirzitz *et al*., 2020; EFSA, 2022). The abundance of psychrotrophs detected, particularly in the samples that had not been refrigerated, highlights the need to maintain cold chains. Verma *et al.* (2022) previously mentioned that inappropriate temperature control helped to sustain and increase the activity of spoilage and pathogenic bacteria during meat distribution.

The microbial contamination of mutton carcasses varied across anatomical regions and between the abattoirs A and B. APC, *Enterobacteriaceae*, and *S. aureus* appeared more frequently in the inner abdomen and shoulder which probably exposed more often to fecal contamination during carcass dressing. This underlines

Table 5. Prevalence of isolated bacteria on thigh of mutton carcasses surfaces.

Bacteria	Number of Positive Samples / % Positive					
	Abattoir A (n=20)			Abattoir B (n=20)		
	AS	AE	Butcher	AS	AE	Butcher
Fecal Coliform	20/100	20/100	20/100	20/100	20/100	20/100
S. aureus	8/40	10/50	10/50	8/40	10/50	10/50
Y. enterocolitica	1/5	2/10	5/25	ND	2/10	4/20
Entero. cloaca	1/5	1/5	1/5	ND	ND	ND
Citrobacter spp.	ND	ND	ND	ND	ND	ND
Hafnia	ND	ND	ND	ND	ND	ND
Providencia spp.	ND	1/5	1/5	ND	ND	ND
Serratia spp.	ND	ND	ND	ND	ND	ND
Proteus vulgaris	3/15	6/30	6/30	6/30	6/30	10/50
Shigella spp.	ND	ND	ND	ND	ND	ND
E. coli	1/5	1/5	1/5	ND	ND	ND
Klebsiella spp.	2/10	2/10	2/10	ND	ND	ND
Salmonellae	ND	ND	ND	ND	ND	ND
Campylo. jejuni	ND	ND	ND	ND	ND	ND

AS: After skinning, AE: After evisceration, ND: Not detected.

Table 6. Prevalence of isolated bacteria on outer abdomen of mutton carcasses surfaces.

Bacteria	Number of Samples / % Positive					
	Abattoir A (n=20)			Abattoir B (n=20)		
	AS	AE	Butcher	AS	AE	Butcher
Fecal Coliform	20/100	20/100	20/100	20/100	20/100	20/100
S. aureus	6/30	9/45	10/50	6/30	9/45	10/50
Y. enterocolitica	3/15	3/15	4/20	2/10	5/25	6/30
Entero. cloaca	ND	1/5	1/5	ND	ND	ND
Citrobacter spp.	ND	ND	ND	ND	2/10	ND
Hafnia	1/5	1/5	1/5	ND	ND	ND
Providencia spp.	ND	ND	ND	ND	ND	ND
Serratia spp.	ND	1/5	1/5	ND	ND	ND
Shigella spp.	ND	1/5	1/5	ND	ND	ND
Proteus vulgaris	5/25	9/45	9/45	4/20	4/20	12/60
E. coli	ND	1/5	1/5	2/10	2/10	2/10
Klebsiella spp.	ND	0	1/5	ND	ND	ND
Salmonellae	ND	ND	ND	ND	ND	ND
Campylo. jejuni	ND	ND	ND	ND	ND	ND

AS: After skinning, AE: After evisceration, ND: Not detected.

the relevance of specific hygiene precautions during processing and in particular areas that are more likely to carry larger microbial loads (Zwirzitz *et al*., 2020; Nakamura *et al*., 2023). However, the microbial counts were lower in the abattoir B in general, which can be attributed to the improved hygiene practices, staff education or sanitation (Zwirzitz *et al*., 2020; Ovuru *et al*., 2024). Although the situation was not that alarming because of low *S. aureus* levels, its presence is still worrisome because of its pathogenicity and potential

Table 7. Prevalence of isolated bacteria on inner abdomen of mutton carcasses surfaces.

Bacteria	Number of Samples / % Positive					
	Abattoir A (n=20)			Abattoir B (n=20)		
	AS	AE	Butcher	AS	AE	Butcher
Fecal Coliform	-	20/100	20/100	-	20/100	20/100
S. aureus	-	5/25	10/50	-	9/45	10/50
Y. enterocolitica	-	ND	1/5	-	2/10	5/25
Entero. cloaca		ND	1/5		ND	ND
Citrobacter spp.		ND	ND		2/10	ND
Hafnia		ND	ND		ND	ND
Providencia spp.		ND	ND		ND	ND
Serratia spp.	-	ND	ND	-	ND	ND
Shigella spp.	-	1/5	1/5	-	ND	ND
Proteus vulgaris		4/20	11/55		4/20	8/40
E. coli	-	ND	1/5	-	2/10	2/10
Klebsiella spp.	-	ND	ND	-	ND	ND
Salmonellae	-	ND	ND	-	ND	ND
Campylo. jejuni	-	ND	ND	-	ND	ND

AS: After skinning, AE: After evisceration, ND: Not detected.

resistance to antimicrobials (Ovuru *et al*., 2024). With the help of consistent monitoring of microbes and specific sanitation measures, the quality and safety of meat are guaranteed (Gill, 1998; Ovuru *et al*., 2024). The counts of *S. aureus* were the least common among the three microbial groups examined. This pathogen had been found in all carcass regions such as shoulder, thigh, outer abdomen and inner abdomen with very low levels often approaching zero after skinning and evisceration procedures. Inner abdomen showed a slightly elevated *S. aureus* counts compared to the rest of the regions, the results were significantly lower than APC or *Enterobacteriaceae*. This finding is in contrary to the studies by Abbasi *et al*., (2021) and Odetokun *et al*., (2023) who found that *S. aureus* was the most prevalent (up to 50%), indicating its well-reported importance as a significant foodborne pathogen in meat products. Its persisting at growing rates up to the stage of the butcher, points to the possibility of cross-contamination helped by insufficient hygiene in handling and processing (Das *et al*., 2019; Alkuraythi and Alkhulaifi, 2024). The fact that this pathogen is capable of producing enterotoxins further highlights the public health risk associated with its presence in raw meat (Nunes Nascimento *et al*., 2025; Xing *et al*., 2025). According to these investigations of meat contamination, the incidence of *P. vulgaris*, which can reach 60% in some samples, is consistent with growing concerns regarding this species as foodborne pathogens harboring virulence genes (Mohammed & Al-Deri, 2024). This emphasizes how important it is to raise specific awareness and take preventative measures among meat handlers in order to avoid zoonotic illnesses. The intermittent, yet, existing contamination with *Y. enterocolitica*, known intestinal disease caused by the interaction of poor cooking and bad hygiene, is indicative of the dangers of improper cooking and hygiene as reported in the current risk analysis (Najjar Asiabani *et al*., 2021). *Salmonellae* and *C. jejuni* were not detected in any samples of both investigated abattoirs, yet the possibility of their presence, especially at low levels, cannot be dismissed, as contaminated meat poses an infection risk if eaten raw, undercooked, or if cross-contamination occurs during preparation (Aljasir and Allam, 2025).

The variability in prevalence across sites suggests that contamination control should focus on both evisceration and final handling steps to reduce these pathogens' load. The presence of *E. coli*, including potentially pathogenic strains, underlines the threat of fecal contamination at slaughter (Aworh *et al*., 2021). This emphasizes the critical importance of strict sanitary protocols during skinning and eviscerating, which are known as critical

control points to reduce and minimize carcass contamination (Rani *et al*., 2023). Other isolated *Enterobacteriaceae* contribute to the hazard profile. *Proteus* spp. are associated with food spoilage, putrefactive odor, and gastroenteritis, often linked to surface floor contamination. *Klebsiella* spp. particularly *K. pneumoniae*, are responsible for lobar pneumonia and, along with *Citrobacter* spp., have been implicated in foodborne gastroenteritis outbreaks. *Shigella* is primarily a human disease but can be transmitted through food contaminated by human carriers, causing severe diarrheal illness (Crețu *et al*., 2025). The ubiquitous presence of these pathogens emphasizes the urgent need for improved hygiene practices to break the cycle of contamination from the animal, the environment and human handling.

Conclusion

This study concludes that mutton carcass surfaces are significantly and continuously subjected to microbial contamination originating from various sources during skinning, evisceration, and transportation. The resulting bacterial counts directly reflect the hygienic measures adopted during carcass preparation and handling. Specifically, there was an overall significant difference ($p<0.05$) in microbial counts between the abattoir A and the abattoir B, confirming that hygiene level is location-dependent. While the abattoir B showed no overall significant difference in microbial counts between preparation steps, wide variations were observed in the abattoir A, highlighting its inconsistent and inadequate practices. These findings confirm that variations in facility management and worker compliance strongly influence microbial safety outcomes. Interventions should focus on better dressing practices, efficient refrigeration and close observation of high-risk areas like the inner abdomen in order to reduce these hazards. Regular training of abattoir personnel, enforcement of standardized hygiene protocols and continuous microbial surveillance are necessary to minimize cross contamination. Process control will be further improved by using best practices customized for each abattoir operation and upgrading infrastructure. The consistently higher counts of APC, *Enterobacteriaceae*, and *S. aureus* in the inner abdomen and shoulder demonstrate these regions as critical sites for bacterial endurance and cross-contamination. Overall, the current research underlines a growing evidence that foodborne pathogens in mutton remain a significant public health concern. Reinforcing hygienic measures across slaughtering, evisceration, and butchering, combined with continuous monitoring and preventive training, is essential to guarantee meat safety, protecting consumer health and fulfilling the demands of modern food safety standards.

Author contributions

Hesham T. Naas conceived and designed the study, supervised the project and collected the samples. Hanan L. Eshamah and Hesham T. Naas performed the experiments, analyzed the data, interpreted the results and equally wrote and reviewed the manuscript.

Conflict of interest

The authors declare no conflicts of interest with respect to the publication of this paper.

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