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Assessment of the Microbiological Quality of Artisanal Sausages Sold by Street Vendors in the City of Kisangani, Dr Congo

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Abstract

Food products sold on public streets may be contaminated and cause foodborne illnesses, posing a serious challenge to food safety and public health. To assess the microbiological quality of artisanal sausages sold on the streets of Kisangani, twenty sausage samples ten samples per vendor type were collected from two types of vendors: street vendors and food stalls. Total aerobic mesophilic flora (TAMF), fecal coliforms (FC), Staphylococcus aureus, and Salmonella spp. were the primary microorganisms tested for. The microbiological quality of the samples was assessed based on quality standards. Antibiotic susceptibility testing of potentially pathogenic strains to commonly used antibiotics in Kisangani was conducted to study antibiotic resistance. Microbiological analyses revealed that the sausages were contaminated with spoilage flora (FMAT), indicators of fecal contamination (fecal coliforms), as well as bacteria responsible for foodborne illnesses that are potentially pathogenic (S. aureus and Salmonella sp.). This contamination depends on processing hygiene and is likely the result of the meat-to-sausage processing stage, prior to sale during the packaging of the sausages into bags, during sale while the product is on display, and due to improper storage conditions. Staff handling and selling the sausages, the equipment used, and the environment could likely be sources of contamination due to poor hygiene. It was found that sausages collected from street vendors were more contaminated than those collected from grocery stores ($p=0.02$). In accordance with quality standards, 100% of the samples collected from street vendors were classified as unfit for consumption, compared to 33.3% of the samples from grocery stores that were classified as unfit. With the exception of their susceptibility to ceftriaxone, the S. aureus and Salmonella sp. strains isolated from sausages were all found to be resistant to the other antibiotics tested. Finally, strict hygiene measures must be reinforced in the sector to improve food safety and public health for the population that consumes these sausages.

Keywords: Microbiological Quality, Sausages, Street Vendors, Food, Kisangani.

1. INTRODUCTION

Contaminated and unsafe food poses a major threat to human health and national economies. Food safety plays a crucial role in ensuring that food remains safe throughout the entire food supply chain, from production and harvesting to processing, storage, distribution, preparation, and consumption. It is estimated that approximately 420,000 people worldwide die each year after consuming contaminated food, with children under the age of five bearing 40% of the burden of foodborne diseases. Furthermore, an estimated 600 million cases of foodborne illnesses occur annually, disproportionately affecting vulnerable and marginalized populations, particularly women, children, people living in conflict settings, and migrants (WHO, 2018).

Food quality has become a major concern for consumers worldwide. In recent decades, several food safety crises, including bovine spongiform encephalopathy (BSE), scrapie, and dioxin-contaminated poultry, have heightened consumer awareness and increased the demand for safe food products (Zayukua *et al.,* 2019). To meet these expectations, food products must undergo rigorous hygienic quality control before being placed on the market (AFSSA, 2008; Gounadaki *et al.,* 2008). Food safety is a shared responsibility involving governments,

producers, and consumers. Everyone has a role to play, from farm to table, in ensuring that food is safe and does not pose a risk to human health (WHO, 2018).

Foodborne diseases are generally infectious or toxic in nature and are caused by bacteria, viruses, parasites, or chemical substances that enter the human body through contaminated food or water. These hazards are often invisible to the naked eye. Recent studies have shown that most diseases affecting populations in developing countries are associated with foodborne intoxications. Street-vended foods are also recognized as important sources of diseases commonly referred to as "dirty hands diseases," including cholera, bacillary dysentery, amoebic dysentery, typhoid fever, salmonellosis, and others (Makengo, 2002; Oliveira & de São João, 2019). Likewise, several gastrointestinal disorders, such as colitis, dysentery, gastritis, and diarrhea, result from the consumption of contaminated foods sold on public streets. Among the major foodborne pathogens involved are *Listeria monocytogenes*, *Campylobacter jejuni*, *Yersinia enterocolitica*, *Aeromonas hydrophila*, *Clostridium perfringens*, *Salmonella* spp., *Staphylococcus aureus*, and fecal coliforms, particularly *Escherichia coli* (Dickson, 2004; Seck, 2007; Aijuka *et al.,* 2018; Diassana, 2018).

Etymologically, the word *sausage* originates from the Latin term *salifia*, referring to minced and salted meat stuffed into casings (Kavira, 2022). Sausages are fresh processed meat products obtained from various types of meat, including veal, lamb, mutton, horse meat, and poultry, and are widely appreciated by consumers. Rich in proteins and minerals, they are considered highly nutritious foods and constitute an important component of a balanced diet (Vivien, 2014). Depending on the manufacturing process, whether industrial or artisanal, sausages may also contain water, sugars, spices, smoke flavoring, and preservatives (Allaoui *et al.,* 2012). However, due to their high nutritional value, meat-based sausages provide an excellent substrate for microbial growth. Microbial contamination may not only deteriorate their sensory qualities (taste, odor, and appearance) but also cause foodborne illnesses, including foodborne intoxications and infectious diseases (Budjulobo, 2010).

Most processed meat products (including cheeses, sausages, and related products) marketed in Kisangani are imported from eastern regions of the Democratic Republic of the Congo, particularly from the cities of Goma (North Kivu Province) and Bunia (Ituri Province), while a smaller proportion originates from Kinshasa in western DRC. These artisanal or traditionally manufactured sausages are sold by street vendors who carry them in plastic bags while walking through public streets. They are also displayed in grocery stores where storage conditions are often inadequate. Furthermore, environmental sanitation remains a major challenge in developing countries, and the city of Kisangani is no exception. Poor sanitary conditions characterize public areas such as markets and other locations where these sausages are sold, thereby increasing the risk of food contamination. Consequently, the population of Kisangani is exposed to significant public health risks associated with street-vended foods, which are generally sold at affordable prices and therefore widely consumed by low-income populations. Although this informal food sector provides accessible food, it also raises serious nutritional, sanitary, and environmental concerns that may compromise food safety. The poor hygienic quality of artisanal sausages sold by street vendors has previously been reported in several African cities (Diouf, 1992; Aissani & Bouzidi, 2019).

The unhygienic conditions under which artisanal sausages are produced, transported, marketed, and stored raise serious concerns regarding their microbiological quality. Under these circumstances, contamination of sausages sold on the streets of Kisangani is highly suspected, particularly because these products are mainly consumed by low-income populations who rely heavily on street foods. Therefore, the objective of this study was to assess the microbiological quality of artisanal meat sausages sold on public streets in Kisangani, Democratic Republic of the Congo. To achieve this objective, the major microbiological indicators of food spoilage and contamination were investigated. These included total aerobic mesophilic flora as an indicator of poor hygienic practices, thermotolerant (fecal) coliforms as indicators of fecal contamination, *Salmonella* spp., and *Staphylococcus aureus*, both of which are potentially pathogenic bacteria responsible for foodborne illnesses (Cardinal, 2003; Nsitu *et al.,* 2023). The bacterial counts obtained were subsequently compared with the microbiological standards required for sausage quality. In addition, considering the growing concern regarding antimicrobial resistance among foodborne bacteria in developing countries (Lambert, 2005; Warda, 2016; Hachemi *et al.,* 2019), the susceptibility of bacterial isolates recovered from these sausages to antibiotics commonly used in Kisangani was also evaluated.

This study contributes to the assessment of the microbiological quality of artisanal sausages marketed on public streets in Kisangani. It aims to alert public health authorities to the health risks associated with contaminated sausages and recommends the implementation of effective hygienic control measures throughout the food supply chain, including processing, production, transportation, marketing, storage, and consumption, in order to improve food safety and protect public health.

2. MATERIALS AND METHODS

2.1. Study Area

This study was conducted in the city of Kisangani, the capital of Tshopo Province in the Democratic Republic of the Congo (DRC). Administratively, Kisangani covers a total area of 1,910 km² and comprises six municipalities: Kisangani, Makiso, Mangobo, Kabondo, Tshopo, and Lubunga (Lomba, 2011).

Sausage samples were collected from public streets surrounding the Central Market, located in Makiso Municipality in the downtown area of Kisangani. The vicinity of this market is characterized by poor environmental sanitation, a high population density, numerous street vendors, and a large number of small grocery stores. Immediately after collection, the samples were transported to the Microbiology Laboratory of the Faculty of Sciences, University of Kisangani, for microbiological analyses and quality assessment.

2.2. Sample Collection

A preliminary survey of the sampling sites was conducted before the beginning of the study. Sample collection was carried out over a three-month period (12 weeks), from 15 February to 15 May 2025.

Artisanal sausages were collected in downtown Kisangani from two categories of vendors: street vendors and grocery stores. Both categories were located along the streets surrounding the Central Market. Street vendors were randomly selected on each sampling day, whereas grocery stores were purposively selected based on their high customer attendance.

A total of 10 street vendors and 10 grocery stores were included in the study.

Street vendors sold sausages while walking through public areas, carrying them in transparent plastic bags. In grocery stores, the packaged sausages were displayed in glass-door refrigerators.

Sampling was performed weekly, and 10 field visits were conducted during the study period. Two samples were collected during each visit: one from a street vendor and one from a grocery store. Overall, 20 sausage samples were collected, comprising 10 samples from street vendors and 10 samples from grocery stores.

All sampling equipment was thoroughly washed, cleaned, and sterilized before use. Sampling was carried out under aseptic conditions. Hands were disinfected with 90% ethanol before wearing sterile gloves. Samples collected from each type of vendor were first placed in sterile sampling bags, properly labeled, sealed in sterile freezer bags, and then stored in an insulated cooler containing ice packs. The samples were immediately transported to the laboratory for microbiological analyses.

2.3. Microbiological Analyses

2.3.1. Preparation of the Stock Suspension

Under aseptic conditions, 25 g of each sausage sample were accurately weighed using a precision balance and transferred into a sterile container containing 225 mL of sterile peptone water. The mixture was homogenized for 30 seconds to obtain the initial 10^{-1} dilution, referred to as the stock suspension. To allow the recovery of microorganisms that might have been stressed during homogenization, the suspension was allowed to stand for 30 minutes before further processing.

2.3.2. Serial Dilutions

Serial decimal dilutions were prepared from the stock suspension. Sterile test tubes containing 9 mL of sterile physiological saline solution were used.

One milliliter of the stock suspension was transferred into a tube containing 9 mL of saline solution to obtain a 10^{-2} dilution. Subsequently, 1 mL of the 10^{-2} dilution was transferred into another tube containing 9 mL of saline solution to obtain a 10^{-3} dilution. This procedure was repeated successively to prepare 10^{-4} and 10^{-5} dilutions, which were used particularly for the enumeration of total aerobic mesophilic bacteria.

The different dilutions were then inoculated onto appropriate culture media according to the target microorganisms. After inoculation, the culture plates were incubated to allow microbial growth prior to identification and enumeration.

2.3.3. Enumeration of Microorganisms

2.3.3.1. Enumeration of Total Aerobic Mesophilic Flora (TAMF)

Total Aerobic Mesophilic Flora (TAMF) comprises all microorganisms capable of growing on a general-purpose culture medium at 37°C. High TAMF counts generally indicate poor hygienic quality and an increased risk of food spoilage caused by spoilage microorganisms (Raonivalo, 2008).

One milliliter of the selected dilution was aseptically transferred into a sterile Petri dish. Subsequently, 15 mL of molten Plate Count Agar (PCA), cooled to approximately 50°C, was poured into the same Petri dish. PCA is a non-selective culture medium suitable for the growth of a broad range of bacteria.

The inoculum and culture medium were gently mixed and allowed to solidify completely. The Petri dishes were then inverted and incubated at 37°C for 24 h. Colony enumeration was performed on plates containing 30 to 300 colonies, and the results were expressed as colony-forming units per gram (CFU/g).

2.3.3.2. Enumeration of Fecal Coliforms

One milliliter of the selected dilution was transferred into sterile Petri dishes and mixed with 15 mL of molten MacConkey agar. After gentle homogenization, the medium was allowed to solidify. The plates were inverted and incubated at 37°C for 24 h for the enumeration of total coliforms and at 44°C for 24 h for the detection of thermotolerant (fecal) coliforms. Only plates containing 30 to 300 colonies were considered for enumeration, and the results were expressed as CFU/g.

2.3.3.3. Enumeration of Coagulase-Positive Staphylococci

One milliliter of the selected dilution was aseptically transferred into a sterile Petri dish. Subsequently, 15 mL of molten Mannitol Salt Agar (MSA, Chapman medium), cooled to approximately 50°C, was poured into the same Petri dish. Mannitol Salt Agar is a selective medium containing a high concentration of sodium chloride (7.5%), which selectively promotes the growth of staphylococci.

The inoculum and culture medium were gently mixed and allowed to solidify. The Petri dishes were then inverted and incubated at 37°C for 24–48 h. Colony enumeration was performed on plates containing 30–300 colonies. Confirmation of coagulase-positive Staphylococci was based on the free coagulase test, complemented by Gram staining for microscopic confirmation (Joffin & Joffin, 2010; Mekhloufi, 2018).

2.3.3.4. Enumeration of *Salmonella* spp.

One milliliter of the 10^{-1} dilution was inoculated into a test tube containing selenite broth for selective enrichment and incubated at 37°C for 24 h.

Following enrichment, 1 mL of the culture was transferred into a sterile Petri dish, and molten Salmonella–Shigella (SS) agar was aseptically poured into the plate. After gentle mixing, the medium was allowed to solidify. The plates were inverted and incubated at 37°C for 24–48 h (Savoye, 2011). Plates were incubated upside down to prevent condensation from spreading colonies across the agar surface. Colony enumeration was subsequently performed by direct counting.

2.3.4. Calculation of Microbial Counts

Microbial counts were expressed as colony-forming units per gram (CFU/g) of sausage.

The bacterial load was calculated using the following equation (Martial, 2016):

$$N = \frac{\sum c}{(n1 + 0{,}1 \times n2) \times E} \times fd$$

where:

- **N** = microbial count (CFU/g);
- **ΣC** = total number of colonies counted;
- $\mathbf{n_1}$ = number of plates counted at the first selected dilution;
- $\mathbf{n_2}$ = number of plates counted at the second selected dilution;
- **V** = volume inoculated (mL);
- **d** = dilution factor.

To evaluate the microbiological quality of the samples, the results were compared with microbiological quality standards based on a three-class microbiological criterion (m), classifying samples as satisfactory, acceptable, or unsatisfactory (Gbenou, 2008).

According to these standards, Salmonella must be absent in 25 g of sausage samples, fecal coliform counts must not exceed 5×10^2 CFU/g, Staphylococcus aureus counts must remain below 1×10^2 CFU/g, while the acceptable limit for Total Aerobic Mesophilic Flora (TAMF) is 1×10^5 CFU/g.

Table 1: Microbiological criteria used for the interpretation of results (Source: Gbenou, 2008)

Classification	Total Aerobic Mesophilic Flora (CFU/g)	Enterobacteria (CFU/g)	*Staphylococcus aureus* (CFU/g)	*Salmonella*
Satisfactory (S)	$\leq 10^5$	$\leq 5 \times 10^2$	$\leq 10^2$	Absent
Acceptable (A)	$10^5 < m \leq 10^6$	$5 \times 10^2 < m \leq 5 \times 10^3$	$10^2 < m \leq 10^3$	
Unsatisfactory (U)	$> 10^6$	$> 5 \times 10^3$	$> 10^3$	Present

Values are expressed as CFU/g of sausage, where m represents the acceptable microbiological limit and M the maximum tolerable contamination level (Guiraud & Rosec, 2004).

2.4. Data Processing and Statistical Analysis

Data processing and statistical analyses were performed using RStudio software.

Descriptive statistics, including means, minimum values, and maximum values, were calculated. The percentages of non-compliant samples were also determined.

The student's t-test was used to compare the mean bacterial loads between sausages obtained from the two categories of vendors (street vendors and grocery stores). Differences were considered statistically significant when $p < 0.05$.

2.5. Antibiotic Susceptibility Testing

Antimicrobial susceptibility testing of the bacterial isolates against antibiotics commonly used in Kisangani was performed using the Kirby–Bauer disk diffusion method on Mueller–Hinton agar.

Briefly, antibiotic-impregnated disks were placed onto Mueller–Hinton agar plates previously inoculated with the test organisms. The antibiotics diffused through the agar, creating a concentration gradient that inhibited bacterial growth at concentrations equal to or above the minimum inhibitory concentration (MIC).

Antibacterial activity was assessed by measuring the diameter of the inhibition zone (clear halo surrounding each antibiotic disk) using a millimeter ruler (Singleton, 2005; Monica, 2012). The measured inhibition diameters were interpreted by comparison with the corresponding critical breakpoints.

Table 2: Critical inhibition zone diameters (mm) used for the interpretation of antibiotic susceptibility (John *et al.*, 1979)

Antibiotic	Resistant (mm)	Intermediate (mm)	Susceptible (mm)
Chloramphenicol	≤18	19–22	≥23
Ceftriaxone	≤13	14–20	≥21
Ampicillin	≤13	14–18	≥19
Erythromycin	≤16	17–21	≥22

3. RESULTS

3.1. Bacterial Loads of the Target Microorganisms

The microbiological results obtained from sausages collected from street vendors and grocery stores are presented in the tables below. Table 3 summarizes the minimum, maximum, and mean bacterial counts of the investigated microorganisms, together with the percentage of non-compliant samples.

Table 3. Bacterial counts of artisanal sausages collected from street vendors and grocery stores in Kisangani, Democratic Republic of the Congo. TAMF, Total Aerobic Mesophilic Flora; FC, Fecal Coliforms (44°C); SV, Street Vendors; GS, Grocery Stores; m, acceptable microbiological limit; M, maximum tolerable microbiological limit. Results are expressed as CFU/g.

Echantillons	FMAT		CF (44℃)		Staphylocoques		Salmonelles	
	AMBL	ALMT	AMBL	ALMT	AMBL	ALMT	AMBL	ALMT
E1	$5{,}3.10^6$	$4{,}2.10^6$	$4{,}1.10^3$	$2{,}4.10^3$	$5{,}4.10^2$	$3{,}7.10^2$	$3{,}4.10^2$	$2{,}2.10^2$
E2	$7{,}6.10^6$	$2{,}4.10^6$	$6{,}6.10^3$	$3{,}2.10^2$	$6{,}7.10^2$	$2{,}1.10^2$	$5{,}2.10^2$	$1{,}2.10^2$
E3	$5{,}9.10^6$	$1{,}1.10^6$	$6{,}1.10^2$	$1{,}5.10^3$	$5{,}4.10^2$	$3{,}2.10^2$	$5{,}1.10^2$	$1{,}8.10^2$
E4	$6{,}2.10^6$	$2{,}8.10^6$	$3{,}2.10^3$	$3{,}2.10^3$	$4{,}9.10^2$	$2{,}2.10^2$	$5{,}9.10^2$	$3{,}2.10^2$
E5	$7{,}2.10^6$	$6{,}2.10^6$	$5{,}6.10^3$	$3{,}3.10^2$	$7{,}1.10^2$	$4{,}3.10^2$	$3{,}6.10^2$	$2{,}5.10^2$
E6	$5{,}8.10^6$	$2{,}2.10^6$	$3{,}9.10^3$	$1{,}6.10^2$	$6{,}1.10^2$	$3{,}810^2$	$4{,}1.10^2$	$1{,}2.10^2$
E7	$3{,}9.10^6$	$5{,}4.10^6$	$5{,}2.10^3$	$2{,}5.10^2$	$3{,}9.10^2$	$3{,}1.10^2$	$5{,}5.10^2$	$3{,}1.10^2$
E8	$6{,}1.10^6$	$3{,}6.10^6$	$4{,}7.10^3$	$3{,}2.10^3$	$5{,}3.10^2$	$2{,}4.10^2$	$3{,}2.10^2$	$2{,}2.10^2$
E9	$7{,}1.10^6$	$3{,}9.10^6$	$7{,}3.10^3$	$1{,}2.10^2$	$4{,}2.10^2$	$2{,}6.10^2$	$4{,}2.10^2$	$1{,}4.10^2$
E10	$6{,}4.10^6$	$4{,}4.10^6$	$4{,}9.10^3$	$2{,}2.10^2$	$6{,}2.10^2$	$3{,}2.10^2$	$3{,}7.10^2$	$2{,}1.10^2$
Moyenne	**$6{,}2.10^6$**	**$3{,}6.10^6$** ***	**$5{,}2.10^3$**	**$2{,}4.10^2$** *	**$5{,}5.10^2$**	**$3{,}1.10^2$** **	**$4{,}4.10^2$**	**$2{,}1.10^2$** *
Minimum	**$3{,}9.10^6$**	**$1{,}1.10^6$**	**$3{,}2.10^3$**	**$1{,}2.10^2$**	**$3{,}9.10^2$**	**$2{,}1.10^2$**	**$3{,}2.10^2$**	**$1{,}2.10^2$**
Maximum	**$7{,}6.10^6$**	**$6{,}2.10^6$**	**$7{,}3.10^3$**	**$3{,}3.10^2$**	**$7{,}1.10^2$**	**$4{,}3.10^2$**	**$5{,}9.10^2$**	**$3{,}2.10^2$**
% de non conformité (n=10)	**100%**	**79,78%**	**100%**	**59,66%**	**100%**	**69,86%**	**100%**	**70%**
Normes Microbiologiques	$m=10^5$ $M=10^6$		$m=10^2$ $M=10^3$		$m=10^2$ $M=10^3$		Absence (0/25g d'échantillon)	

Significance levels:

- $p < 0.05$ = significant difference;
- ** $p < 0.01$ = highly significant difference;
- *** $p < 0.001$ = very highly significant difference.

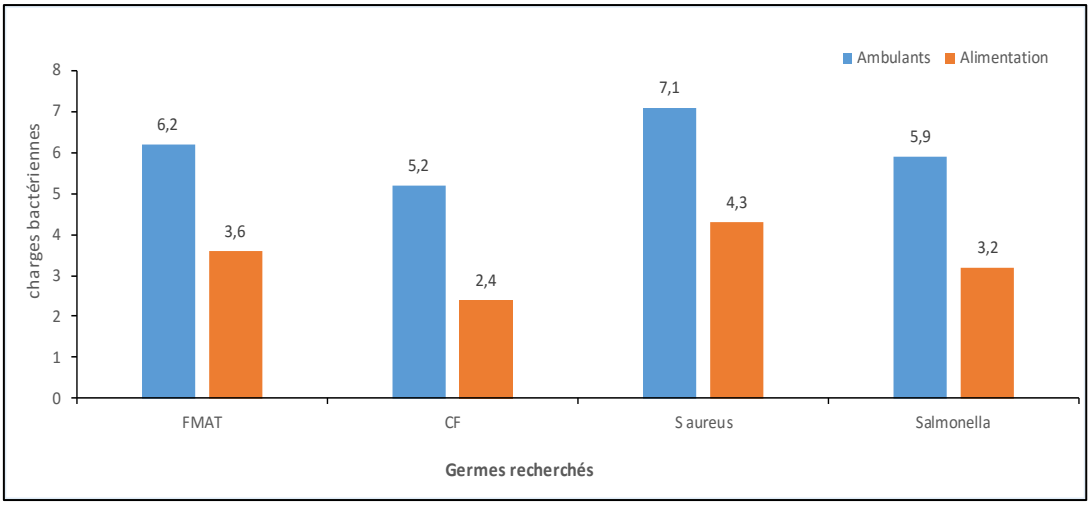

Figure 1: Comparison and variation of bacterial counts between sausages collected from street vendors and grocery stores. TAMF, Total Aerobic Mesophilic Flora; FC, Fecal Coliforms (44°C). Results are expressed as CFU/g

3.2. Microbiological Quality of Sausages

To assess the microbiological quality of the sausage samples, bacterial counts obtained from the two categories of vendors (street vendors and grocery stores) were compared with the microbiological quality standards (Table 1). Samples were classified according to a three-class system (satisfactory, acceptable, and unsatisfactory) for TAMF, fecal coliforms, and *Staphylococcus aureus*, whereas a two-class system (satisfactory or unsatisfactory) was used for *Salmonella* spp.

Based on these microbiological standards, none of the sausage samples collected from street vendors was classified as either satisfactory or acceptable. Consequently, the non-compliance rate reached 100% for all microbiological parameters investigated (TAMF, fecal coliforms, *S. aureus*, and *Salmonella* spp.).

In contrast, among samples collected from grocery stores, 10%, 20%, and 30% were classified as satisfactory for fecal coliforms, *S. aureus*, and *Salmonella* spp., respectively. Furthermore, 20%, 30%, and 10% of the samples were considered acceptable for TAMF, fecal coliforms, and *S. aureus*, respectively.

Although a limited proportion of satisfactory or acceptable samples was observed in grocery stores, the majority of the samples remained microbiologically unsatisfactory, representing 80%, 60%, 70%, and 70% of the samples for TAMF, fecal coliforms, *Staphylococcus aureus*, and *Salmonella* spp., respectively.

Table 4 presents the microbiological quality classification of sausage samples collected from street vendors and grocery stores in Kisangani.

Table 4. Microbiological quality of artisanal sausages sold by street vendors and grocery stores in Kisangani. TAMF, Total Aerobic Mesophilic Flora; FC, Fecal Coliforms (44°C); S. aureus, *Staphylococcus aureus*; n, number of samples; %, percentage of samples.

Site	Qualité des échantillons	Germes recherchés							
		FMAT		CF		*S. aureus*		Salmonelles	
		n	%	n	%	n	%	n	%
Marchands Ambulants	Satisfaisant	0	0	0	0	0	0	0	0
	Acceptable	0	0	0	0	0	0	-	-
	Non satisfaisant	10	100	10	100	10	100	10	100
Alimentations	Satisfaisant	0	0	1	10	2	20	3	30
	Acceptable	2	20	3	30	1	10	-	-
	Non satisfaisant	8	80	6	60	7	70	7	70

3.3. Antibiotic Susceptibility of Bacterial Isolates

The antimicrobial resistance profiles of bacterial isolates recovered from the sausage samples were subsequently investigated. The susceptibility of *Staphylococcus aureus* and *Salmonella* spp. isolates to antibiotics commonly prescribed in Kisangani was evaluated.

Table 5 presents the inhibition zone diameters produced by four antibiotics (ampicillin, ceftriaxone, chloramphenicol, and erythromycin) against *Staphylococcus aureus* and *Salmonella* spp. isolates. The measured inhibition zones were interpreted according to the critical breakpoint values presented in Table 2.

The bacterial isolates exhibited variable susceptibility to the tested antibiotics.

Among the *Staphylococcus aureus* isolates, 50% (SA5, SA6, SA8, SA9, and SA10) were susceptible to ceftriaxone, 30% (SA8, SA9, and SA10) were susceptible to ampicillin, and only 10% (SA6) were susceptible to erythromycin. In addition, 20% of the isolates exhibited intermediate susceptibility to both chloramphenicol and erythromycin.

Nevertheless, the majority of *S. aureus* isolates were resistant to the antibiotics tested, with resistance rates of 80% to chloramphenicol, 70% to both erythromycin and ampicillin, and 50% to ceftriaxone.

Table 5: Inhibition zone diameters (mm) of antibiotics tested against *Staphylococcus aureus* and *Salmonella* spp. isolates recovered from publicly marketed artisanal sausages in Kisangani. SA, *Staphylococcus aureus* isolate; SL, *Salmonella* isolate; R, Resistant; I, Intermediate; S, Susceptible

Isolates	Ceftriaxone	Chloramphenicol	Erythromycin	Ampicillin
SA1	13 (R)	8 (R)	18 (I)	10 (R)
SA2	11 (R)	7 (R)	8 (R)	9 (R)
SA3	13 (R)	5 (R)	6 (R)	11 (R)
SA4	13 (R)	0 (R)	11 (R)	5 (R)
SA5	22 (S)	5 (R)	10 (R)	9 (R)
SA6	21 (S)	0 (R)	22 (S)	13 (R)
SA7	12 (R)	21 (I)	16 (R)	10 (R)
SA8	23 (S)	6 (R)	15 (R)	22 (S)
SA9	21 (S)	7 (R)	10 (R)	19 (S)
SA10	21 (S)	9 (I)	18 (I)	21 (S)
SL1	21 (S)	0 (R)	18 (I)	7 (R)
SL2	13 (R)	0 (R)	18 (I)	0 (R)
SL3	12 (R)	19 (I)	18 (I)	18 (I)
SL4	22 (S)	21 (I)	20 (I)	0 (R)
SL5	14 (I)	0 (R)	9 (R)	8 (R)
SL6	17 (I)	9 (R)	18 (I)	9 (R)
SL7	10 (R)	11 (R)	19 (I)	0 (R)
SL8	21 (S)	12 (R)	21 (R)	7 (R)
SL9	11 (R)	9 (R)	16 (R)	11 (R)
SL10	9 (R)	8 (I)	12 (R)	0 (R)

Regarding *Salmonella* spp., only 30% of the isolates (SL1, SL4, and SL8) were susceptible to ceftriaxone. No isolate was susceptible to chloramphenicol, erythromycin, or ampicillin.

However, 60% of the isolates exhibited intermediate susceptibility to erythromycin, whereas 10% and 30% showed intermediate susceptibility to ampicillin and chloramphenicol, respectively.

Overall, the isolates displayed a high level of antimicrobial resistance, with resistance rates of 90% to ampicillin, 70% to chloramphenicol, 50% to ceftriaxone, and 40% to erythromycin.

Taken together, more than half of all bacterial isolates demonstrated resistance to the antibiotics commonly used in Kisangani. Ceftriaxone was the most effective antibiotic tested, with susceptibility observed in 50% of the *Staphylococcus aureus* isolates and 30% of the *Salmonella* spp. isolates.

4. DISCUSSION

The microbiological analyses revealed that artisanal sausages marketed by street vendors in Kisangani exhibited a high level of microbial contamination. Indeed, this study demonstrated elevated bacterial loads, particularly for Total Aerobic Mesophilic Flora (TAMF), fecal coliforms, coagulase-positive staphylococci, and *Salmonella* spp., all exceeding the recommended microbiological limits. The high prevalence of fecal coliforms, *Salmonella* spp., and coagulase-positive *Staphylococcus aureus* indicates fecal contamination and poor hygienic handling

practices during the processing and marketing of these products.

Fecal coliforms are predominantly represented by *Escherichia coli*, which is exclusively of fecal origin. These bacteria originate from the intestinal tract of humans and animals (Gbenou, 2008). Consequently, their enumeration provides a reliable indicator of hygienic practices during meat handling and of the effectiveness of sanitary measures implemented to reduce the initial microbial contamination (Sow, 2008). Compared with the findings of Allaoui et al. (2012), who reported an average fecal coliform count of 3.57×10^4 CFU/g in traditionally produced sausages from Meknes (Morocco), the bacterial counts obtained in the present study were lower. However, our results were considerably higher than those reported by Cohen et al. (2006), who found an average contamination level of 3.7×10^2 CFU/g in fresh sausages collected from fast-food restaurants in Casablanca, Morocco.

Among the staphylococci, *Staphylococcus aureus* is considered the most clinically significant species because of its ability to produce enterotoxins responsible for food poisoning (Musole, 2020). It is widely recognized as an indicator of contamination resulting from poor personal hygiene during food handling (Alassane, 1988). Therefore, its enumeration is essential for identifying food products that pose a high risk of foodborne intoxication. Compared with the study conducted by Hery (2015), who reported a mean count of 3×10^4 CFU/g in sausages produced by delicatessen manufacturers in Antananarivo (Madagascar), the contamination levels observed in the present study were substantially higher.

The detection of *Salmonella* spp. is of particular concern because these pathogens should be completely absent from sausages intended for human consumption (Dennaï *et al.,* 2001). Their presence therefore represents a significant public health risk. In contrast to our findings, both Hery (2015) and Allaoui et al. (2012) reported the absence of *Salmonella* spp. in the sausage samples they analyzed.

Regarding the microbiological quality of the sausages, all samples collected from street vendors were classified as unsatisfactory according to the recommended microbiological standards. These findings are consistent with those reported by Kavira (2022), who highlighted that artisanal sausages produced in developing countries are frequently of poor microbiological quality because of excessive fecal contamination, particularly by fecal coliforms and staphylococci, with bacterial loads far exceeding acceptable safety limits.

Although a limited number of samples collected from grocery stores were classified as acceptable, the overall contamination observed in the analyzed samples could mainly be attributed to the use of non-potable water during processing, contaminated equipment, inadequate hygienic practices during production and sale especially among street vendors and insufficient refrigeration during storage in grocery stores. Overall, sausages obtained from street vendors exhibited significantly higher bacterial contamination than those collected from grocery stores. In addition to the above-mentioned contamination sources, Masimango and Kalengayi (1983) emphasized that street food vendors in developing countries frequently operate outside official food safety inspection systems, thereby increasing the risk of microbial contamination.

Most bacterial isolates recovered from the analyzed sausages exhibited resistance to the antibiotics commonly prescribed in Kisangani, with the exception of ceftriaxone, to which a considerable proportion of isolates remained susceptible. In the Democratic Republic of the Congo, recent studies conducted in Kisangani have reported alarming levels of antimicrobial resistance among important bacterial pathogens, including *Escherichia coli, Klebsiella pneumoniae,* and *Staphylococcus aureus* (Lokonga *et al.,* 2024). Similar trends have also been reported in Kinshasa. In developing countries, antimicrobial resistance is exacerbated by the excessive use of antibiotics in livestock production and inadequate hygiene and sanitation practices. Consequently, food products contaminated with bacteria such as *Escherichia coli, Staphylococcus aureus,* and *Salmonella* spp. frequently harbor multidrug-resistant strains, particularly against β-lactam antibiotics and tetracyclines (Arslan & Ozdemir, 2017). Likewise, studies conducted in North Africa have shown that more than 83% of bacterial isolates recovered from sausages were resistant to at least one antibiotic, with particularly high resistance rates to tetracycline and penicillin. Furthermore, *Salmonella* spp., one of the major bacterial agents responsible for foodborne infections, has been reported to exhibit substantial resistance to amoxicillin and tetracycline (Marault *et al.,* 2014).

5. CONCLUSION

This study highlights a high prevalence of contamination of artisanal sausages marketed in Kisangani by foodborne pathogenic bacteria, including *Staphylococcus aureus, Escherichia coli,* and *Salmonella* spp. Publicly sold artisanal sausages, particularly those marketed by street vendors, exhibited unsatisfactory microbiological quality according to the recommended microbiological standards. Furthermore, the majority of the bacterial isolates recovered from these sausages were multidrug-resistant to the antibiotics commonly used in Kisangani. This dual burden of microbial contamination and antimicrobial resistance represents a significant public health concern.

To ensure food safety, urgent measures are required to improve hygienic practices throughout the entire sausage production chain, including processing, transportation, marketing, storage, and handling. In addition, the implementation of effective antimicrobial stewardship programs and rigorous monitoring of antibiotic use is essential to reduce and prevent the emergence and dissemination of antimicrobial-resistant bacteria.

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