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Research Article

Antibiotic resistance and prevalence of bacterial contaminants in street-vended suya meat in Benin City, Nigeria

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ABSTRACT

This study investigates the antibiotic resistance and prevalence of bacterial contaminants in street-vended suya meat in Benin City, Nigeria. Suya meat, a popular street food, is vulnerable to bacterial contamination due to improper handling, storage, and environmental exposure. A total of fifty (50) suya meat samples were collected from various vendors across the city for microbiological analysis. Standard microbiological methods were employed to isolate and identify bacterial pathogens, including *Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*. The prevalence of bacterial contamination showed that 46% of samples were positive for *Escherichia coli*, 38% for *Staphylococcus aureus*, and 30% for *Pseudomonas* spp. Antibiotic susceptibility testing was performed using the disc diffusion method, revealing a high resistance rate, particularly among *E. coli* (70%), *Klebsiella* spp. (60%), and *Pseudomonas* spp. (55%) against ampicillin and tetracycline. *Salmonella* spp. displayed resistance to ampicillin (50%) and ciprofloxacin (40%). The analysis showed that *Staphylococcus aureus* was resistant to penicillin (50%) and clindamycin (45%). Statistical analysis conducted with SPSS version 23 revealed significant differences in antibiotic resistance patterns across bacterial species ($p < 0.05$). The results showed high resistance to Pefloxacin, Gentamycin, and Cotrimoxazole across most bacterial species, with *Pseudomonas* and *Klebsiella* exhibiting the highest resistance rates. Statistical analysis revealed significant correlations in antibiotic resistance between certain bacterial species, notably between *Citrobacter* and *Klebsiella* ($r = 0.939$, $p = 0.0001$) and between *Pseudomonas* and *Salmonella* ($r = 0.773$, $p = 0.015$). The results showed that *E. coli* emerged as the predominant pathogen, followed by *Pseudomonas* species and *Staphylococcus aureus* as major contributors to contamination. This study underscores the public health risk posed by bacterial contamination in street-vended suya meat, emphasizing the need for improved food safety measures and regulatory oversight to mitigate foodborne infections in Nigeria.

Keywords: Antibiotic resistance, Bacterial contaminants, Foodborne pathogens, Public health, Suya meat

1. INTRODUCTION

The problem of antibiotic resistance and bacterial contamination in street-vended foods, such as suya meat, poses significant public health risks globally. Street foods are widely consumed, especially in developing countries, due to affordability and convenience. However, poor hygiene, inadequate food safety measures, and improper handling make these foods a reservoir for bacterial contaminants like *Escherichia coli* and *Staphylococcus aureus*. Antibiotic resistance among these pathogens exacerbates the challenge, as it limits treatment options for foodborne illnesses, leading to prolonged infections, increased healthcare costs, and higher mortality rates. Globally, antibiotic resistance is a growing crisis, with the World Health Organization (WHO) labeling it one of the top threats to public health. Contaminated street foods contribute to the spread of resistant bacteria, potentially transferring resistance genes across populations. Addressing this issue requires urgent international collaboration to improve food safety standards, promote responsible antibiotic use, and enhance public health awareness.

Moreover, foodborne diseases are a major global public health issue, with significant concern in developing countries, where food safety regulations and enforcement are often inadequate. In particular, street foods, such as suya—a popular Nigerian spicy grilled meat delicacy are increasingly implicated in foodborne illness outbreaks due to microbial contamination [1,2]. Suya, which is sold widely by street vendors in urban centers across Nigeria, is valued for its affordability, convenience, and distinctive taste. Despite its popularity, the preparation and handling of suya are often performed under unsanitary conditions, raising concerns about food safety and the potential health risks to consumers [3,4]. The microbiological quality of suya has been the subject of several studies, revealing the presence of various pathogenic microorganisms, including *Staphylococcus aureus*, *Escherichia coli*, *Salmonella* spp., and *Campylobacter* spp. [5-8]. These bacteria are responsible for a range of gastrointestinal diseases, including diarrhea, vomiting, and food poisoning, which can be particularly severe for vulnerable populations, such as children, the elderly, and individuals with weakened immune systems [9,10]. These pathogens are often introduced during meat processing, improper handling, or storage, and their presence in suya underscores the significant health risk posed by street-vended foods. A growing concern in the context of foodborne diseases is the presence of antibiotic-resistant bacteria in suya meat. The misuse of antibiotics in livestock farming, particularly the overuse of antibiotics for growth promotion and disease prevention, has led to the emergence of multidrug-resistant (MDR) strains of bacteria [11,12]. These resistant bacteria are not only harder to treat but also pose a threat to public health as they can be transmitted to humans through the consumption of contaminated food [13]. The prevalence of antimicrobial-resistant bacteria in street-vended suya is further compounded by the cross-contamination that occurs during meat processing and handling. The spread of these bacteria from raw to cooked meat, along with improper storage and hygiene practices, significantly increases the risk of bacterial contamination. Hygiene practices among suya vendors are a key factor contributing to the contamination of the meat. Research has revealed that many suya vendors fail to implement basic hygiene measures, such as regularly washing their hands, cleaning their utensils, and storing the meat at the appropriate temperatures [14,15]. Additionally, suya meat is often exposed to environmental contaminants, such as dust, flies, and unsanitary surfaces, which further increase the likelihood of bacterial contamination. While the use of spices in suya preparation is integral to its flavor, certain spices have also been shown to harbor antimicrobial-resistant bacteria, which could further exacerbate the risk of contamination and the spread of resistance [16,17]. Spices may create an environment in which resistant bacteria can survive and proliferate, making it essential to consider their role in the overall contamination of suya meat.

The presence of antibiotic-resistant pathogens in food poses an additional challenge to public health, as infections caused by these bacteria may not respond to conventional treatments, leading to prolonged illness and increased healthcare costs. The growing issue of antimicrobial resistance (AMR) is not only a medical concern but also a societal one, as resistant strains can spread across communities, making it

increasingly difficult to control infectious diseases [18,19]. Therefore, understanding the prevalence of bacterial contaminants and the resistance patterns of these pathogens in street-vended suya is crucial to assessing the risks associated with consuming this popular food item [20]. The Clinical and Laboratory Standards Institute (CLSI) performance standards for antimicrobial susceptibility testing provide standardized guidelines for interpreting antibiotic resistance patterns [21]. These standards help assess bacterial contaminants in street-vended Suya meat in Benin City, Nigeria, revealing resistance trends, guiding treatment strategies, and highlighting the public health risks associated with antimicrobial misuse and contamination.

Several studies in Nigeria and other African countries have highlighted the need for improved food safety standards and regulations to curb the spread of foodborne illnesses associated with street-vended foods [6,10,20]. These studies have also called for stricter enforcement of hygiene practices among food vendors and more comprehensive public health initiatives to tackle the emerging threat of antimicrobial resistance. By investigating the microbial contamination and antibiotic resistance profiles of bacteria in suya meat sold along Sakponba Road in Benin City, this study aims to provide a clearer picture of the public health risks posed by the consumption of street-vended suya. Additionally, the findings of this research will contribute to the growing body of knowledge on foodborne pathogens in Nigeria and inform public health strategies to mitigate the spread of both foodborne diseases and antibiotic resistance.

This study stands out by focusing on the antibiotic resistance profiles and prevalence of bacterial contaminants in street-vended suya meat in Benin City, Nigeria, an underexplored aspect of food safety in a culturally significant street food. Unlike previous studies, it emphasizes statistical correlations between antibiotic resistance patterns among diverse bacterial species, providing deeper insights into cross-resistance trends. Additionally, the study integrates microbiological analysis with public health implications, offering evidence-based recommendations for regulatory interventions. Its new contribution lies in highlighting the alarming resistance rates in common pathogens, particularly in *E. coli*, which underscores the urgency for enhanced food safety practices and antibiotic stewardship.

In conclusion, this study seeks to isolate and characterize the bacterial contaminants in suya meat and assess their antibiotic resistance patterns, offering critical insights into the public health implications of consuming street-vended suya. The results will contribute to the broader discourse on food safety, hygiene practices, and the regulation of street food vendors in Nigeria, with the ultimate goal of improving public health outcomes and ensuring safer food consumption practices.

2. MATERIALS AND METHODS

This study was designed to isolate, identify, and analyze the prevalence of bacterial contaminants in suya meat samples collected from vendors along Sakponba Road, Benin City. A comparative analysis was also conducted to assess the bacterial load and antimicrobial resistance patterns of these isolates. The methodology involved the following key steps:

2.1. Sample Collection

Spiced roasted lean cow meat (*suya*) samples were purchased from major junctions around Sakponba Road in Benin City. These locations included Igun, Ogbelaka, Erie, First, Second, Third, Saint Saviour, Ewaka, Nomayo, and Erediawa. A total of fifty (50) samples were collected, with five (5) *suya* meat samples collected from each junction on different days over three weeks. The samples were collected in sterile wide-mouthed jars, kept in their original packaging, labeled appropriately, and transported immediately to the Benson Idahosa University Microbiology Laboratory for analysis.

2.2. Isolation and Enumeration of Bacterial Isolates

Samples were serially diluted by homogenizing 1g of meat sample in 9 ml of sterile peptone water. Approximately 0.1ml of the diluted samples was inoculated onto Mannitol Salt Agar (Oxoid, UK), MacConkey Agar (Oxoid, UK), Eosin Methylene Blue (EMB) Agar (Oxoid, UK), and Nutrient

Table 1. The bacteria, their selective media, incubation conditions, colony characteristics [2,6,8,9,18]

Bacteria	Selective Media	Incubation Conditions	Colony Characteristics
Staphylococcus aureus	Mannitol Salt Agar (MSA)	37°C, 24–48 hours	Yellow colonies (mannitol fermentation)
Bacillus spp.	Nutrient Agar	30–37°C, 24–48 hours	Irregular, dry colonies
Klebsiella spp.	MacConkey Agar	37°C, 24 hours	Pink, mucoid colonies
Escherichia coli	Eosin Methylene Blue (EMB) Agar	37°C, 24 hours	Metallic green sheen colonies
Pseudomonas spp.	Cetrimide Agar	37°C, 24–48 hours	Greenish pigment colonies
Salmonella spp.	Xylose Lysine Deoxycholate (XLD) Agar	37°C, 24–48 hours	Red colonies with black centers
Citrobacter spp.	MacConkey Agar	37°C, 24 hours	Pink colonies

Agar. Plates were incubated at 37°C for 24 hours. MacConkey Agar was used for coliform spp. counts, Nutrient Agar for total aerobic spp. counts, Mannitol Salt Agar for *Staphylococcus* spp. counts, and EMB Agar for *Escherichia coli* counts [2,4,15,17]. Colonies were sub-cultured to obtain pure isolates and maintained on nutrient agar slants for further analysis. Table 1 summarizes the bacteria, their selective media, incubation conditions, colony characteristics.

2.3. Positive and Negative Controls for Biochemical Tests in Antibiotic Resistance and Prevalence of Bacterial Contaminants

In this study, proper controls were used to validate the accuracy and reliability of the results. The following were the positive and negative controls for the biochemical and antibiotic resistance tests:

2.3.1. Antibiotic Susceptibility Testing Controls

Positive Control: *Escherichia coli* ATCC 25922 was used as positive control which is susceptible to all antibiotics tested. These strains have standardized susceptibility profiles for validation of results.

Negative Control: Sterile nutrient agar or broth was used without bacterial inoculation to ensure that no contamination or antibiotic activity originates from the media.

2.3.2. Isolation and Enumeration of Bacterial Contaminants Controls

Positive Control: A pure culture of the targeted bacteria such as *E. coli* for EMB agar, *Staphylococcus aureus* for Mannitol Salt Agar was used to confirm media selectivity and appropriate colony morphology.

Negative Control: Sterile peptone water inoculated onto the same media to confirm that the media do not promote growth in the absence of bacterial inoculation was used.

2.3.3. Biochemical Identification Test Controls

Positive Control: Use well-characterized reference strains with known biochemical reactions, such as *Escherichia coli* ATCC 25922 for indole and lactose fermentation tests. *Staphylococcus aureus* ATCC 29213 for coagulase and mannitol fermentation tests. *Pseudomonas aeruginosa* ATCC 27853 for oxidase and citrate tests.

Negative Control: A non-reactive organism or reagent control was used such as, sterile distilled water or media without bacteria was used to confirm the absence of non-specific reactions.

2.3.4. Contamination Controls

Positive Control: Include known contaminated samples (Spiced suya meat samples with *E. coli* to validate the isolation and enumeration procedures.

Negative Control: Use sterile meat samples subjected to the same processing and incubation conditions to ensure the absence of contamination.

2.3.5. Probability Estimation:

For the probability estimation of antibiotic resistance in this study, the formula below was used to calculate its probability.

$$\text{P(Resistance)} = \frac{Number\ of\ resistant\ bacteria}{\text{Total number of bacteria}}$$

2.4. Identification of Bacterial Isolates

Bacterial isolates were presumptively identified using their cultural, morphological, and biochemical characteristics, following the methods described by Osunde et al. [2]. The biochemical tests included Gram staining, motility, catalase, oxidase, coagulation, citrate, indole, and sugar fermentation tests [14,16,17].

2.4.1. Gram Staining

A bacterial smear was prepared on a clean glass slide, heat-fixed, and stained with crystal violet for one minute. The slide was rinsed with water and treated with iodine mordant for one minute. Ethanol (95%) was used as a decolorizer, followed by counterstaining with safranin for one minute. The slide was air-dried and examined under an oil immersion lens at ×100 magnification. Gram-positive bacteria retained the violet color, while Gram-negative bacteria appeared pink [2,14,17].

2.5. Biochemical Identification

2.5.1. Indole Test

This test determines the ability of bacteria to produce indole from tryptophan metabolism. An overnight culture in peptone water was treated with Kovac's reagent. A cherry-red layer formation indicated a positive result, while no color change indicated a negative result [2,9].

2.5.2. Oxidase Test

The oxidase test checks for the presence of cytochrome oxidase enzyme. A small amount of bacterial culture was placed on filter paper, and a drop of oxidase reagent was added. A violet or purple color change within 30 seconds indicated a positive result [2,17,18].

2.5.3. Catalase Test

The catalase test detects the presence of the catalase enzyme, which breaks down hydrogen peroxide into water and oxygen. A bacterial colony was transferred to a clean glass slide, and a drop of hydrogen peroxide was added. Bubble formation indicated a positive result, while no bubbles indicated a negative result [2,3,17].

2.5.4. Motility Test

Bacterial motility was determined using semi-solid agar. A straight needle was used to stab inoculate the medium, and the tubes were incubated at 37°C for 24 hours. Diffused growth away from the stab line indicated motility, while restricted growth suggested non-motile bacteria [5-7].

2.5.5. Coagulase Test

The coagulase test differentiates *Staphylococcus aureus* from other staphylococci. A bacterial colony was mixed with a drop of plasma on a clean glass slide. Clumping indicated a positive result, while no clumping indicated a negative result [2,14,17].

2.5.6. Citrate Test

The citrate test determines whether bacteria can utilize citrate as their sole carbon source. Bacteria were inoculated on Simmons Citrate Agar and incubated at 37°C for 24 hours. A color change from green to blue indicated a positive result, while no color change indicated a negative result [2,4,14,17].

2.5.7. Sugar Fermentation Test

Fermentation of glucose, fructose, lactose, and sucrose was tested using peptone water containing inverted Durham tubes and 1% sugar solutions. After incubation at 37°C for 48 hours, acid production was detected by a yellow color change, and gas production was detected by bubble formation in the Durham tubes [2,14,17].

2.6. Antibiotic Susceptibility Testing

Antibiotic susceptibility testing was performed to assess the resistance profiles of the bacterial isolates obtained from the suya meat samples. The Kirby-Bauer disk diffusion method was employed, which is a widely used technique for determining the effectiveness of antibiotics against specific bacterial strains. For the antibiotic susceptibility tests, commercially available antibiotic discs, which are impregnated with standard concentrations of various antibiotics, were used. The bacterial

isolates were first cultured in Nutrient Broth and incubated overnight at 37°C to achieve optimal growth. After incubation, bacterial suspensions were prepared to a standard turbidity equivalent to the 0.5 McFarland standard, which ensures that the bacterial concentration is consistent across all tests. The inoculum was then spread evenly onto the surface of Mueller-Hinton Agar plates using a sterile swab. Antibiotic discs were placed on the agar surface, ensuring they were adequately spaced to prevent interference between zones of inhibition. The antibiotics tested included a range of commonly used drugs such as Pefloxacin, 5µg; Gentamycin, 10µg; Amplicon, 20µg; Cefuroxime, 30µg; Amoxicillin, 10µg; Ceftriaxone, 30µg; Ciprofloxacin, 5µg; Streptomycin, 10µg; and Cotrimoxazole, 25µg. The plates were incubated at 37°C for 24 hours, after which the zones of inhibition, which are the areas around the antibiotic discs where bacterial growth was prevented, were measured. The diameter of each zone was measured in millimeters and compared to standard interpretation charts provided by the Clinical and Laboratory Standards Institute (CLSI). These charts classify the results into three categories: sensitive, intermediate, or resistant. For *Salmonella* spp., *Escherichia coli*, *Pseudomonas* spp., *Bacillus* spp., *Staphylococcus aureus*, and *Klebsiella* spp., the antibiotic resistance profiles were determined based on the size of the inhibition zones, with resistance being indicated by smaller zones or no zone at all, indicating that the bacteria were not inhibited by the antibiotic. The percentage of bacterial species resistant to each antibiotic was calculated using the following formula [14]:

$$\text{Percentage of Resistance} = \left(\frac{\text{Number of Resistant Isolates}}{\text{Total Number of isolates}}\right)\text{x}100\%$$

2.6.1. The Zone of Inhibition Determination

The zone of inhibition referred to the clear area around an antibiotic disc on an agar plate, indicating bacterial susceptibility to the antibiotic. This was commonly assessed using the Kirby-Bauer disc diffusion method [21]. First, a bacterial suspension was prepared in sterile saline or peptone water and adjusted to the 0.5 McFarland standard (1.5×10^8 CFU/mL). Using a sterile cotton swab, the bacterial suspension was evenly spread across a Mueller-Hinton agar plate to ensure a uniform lawn of growth. After drying for 5 minutes, antibiotic discs were aseptically placed on the agar surface using sterile forceps, ensuring adequate spacing between discs. The plates were then incubated aerobically at 37°C for 18–24 hours. After incubation, the zone of inhibition around each antibiotic disc was measured across its diameter in millimeters (mm) using a ruler or caliper. The results were compared against standard antibiotic susceptibility reference charts (CLSI/EUCAST guidelines) to classify the bacteria as susceptible, intermediate, or resistant. A larger zone of inhibition indicated higher bacterial susceptibility, while a smaller or absent zone suggested resistance. This method was essential for guiding antibiotic therapy decisions [21].

2.7. Data Analysis

The data collected from the bacterial isolation, identification, and antibiotic susceptibility testing of the suya meat samples were analyzed using SPSS version 23, a robust statistical software package. Descriptive statistics, such as frequency distributions and percentages, were used to determine the prevalence of different bacterial species. The Chi-square test was applied to evaluate the association between antibiotic resistance and specific bacterial strains, while correlation coefficients were calculated to assess the relationship between contamination levels and various variables, such as sample location or vendor hygiene practices. SPSS allowed for robust analysis of the data, enabling the identification of significant patterns and trends.

3. RESULT AND DISCUSSION

3.1. Results

The following tables present various aspects of the study on bacteria isolated from Suya meat along Sakponba Road, Benin City: Table 2 details the morphological and biochemical characteristics of the bacteria, while Table 3 shows the organisms isolated

Table 2. Morphological and Biochemical Characteristics of Bacteria Isolated from Suya Meat

Cultural Characteristics	Morphology	Motility	Gram Stain	Glucose	Fructose	Sucrose	Lactose	Catalase	Oxidase	Coagulate	Citrate	Indole	Probable organism
Golden Yellow	Cocci in bunch	*+ve*	*+ve*	AG	AG	AG	AG	*+ve*	*-ve*	*-ve*	*+ve*	*-ve*	*Staphylococcus aureus*
Irregular	Single rods	*+ve*	*+ve*	A	A	A	A	*+ve*	*-ve*	*-ve*	*+ve*	*-ve*	*Bacillus* spp
Creamy	Single rods	*-ve*	*-ve*	A	A	A	A	*+ve*	*-ve*	*+ve*	*+ve*	*-ve*	*Klebsiella* spp
Green Metallic	Single rods	*-ve*	*-ve*	A	A	A	A	*+ve*	*-ve*	*-ve*	*-ve*	*-ve*	*Escherichia coli*
Creamy, Reddish	Single rods	*+ve*	*-ve*	A	A	A	AG	*+ve*	*-ve*	*+ve*	*-ve*	*-ve*	*Pseudomonas* spp
Smooth, Reddish	Paired rods	*+ve*	*-ve*	AG	AG	AG	AG	*+ve*	*-ve*	*-ve*	*-ve*	*+ve*	*Salmonella* spp
Entire whitish	Single rods	*-ve*	*-ve*	AG	AG	AG	AG	*-ve*	*-ve*	*-ve*	*+ve*	*+ve*	*Citrobacter* spp

A = Colour change, AG = Colour change and bubbles, +ve = Positive, -ve = Negative

Table 3. Organisms Isolated from Suya Samples from the Various Locations along Sakponba Road, Benin City, Based on Biochemical Test

Location	Number of Sample	Number with Organism Isolated	Isolates
Igun junction	5	4(80%)	*Bacillus* spp., *Citrobacter* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Ogbelaka junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Erie junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
First junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Second junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Third junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Saint Saviour junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Eweka junction	5	4(80%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Salmonella* spp., and *Staphylococcus aureus*.
Nomayo junction	5	5(100%)	*Bacillus* spp., *Citrobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Erediawa junction	5	4(80%)	*Bacillus* spp., *Klebsiella* spp., *Escherichia coli*, *Pseudomonas* spp., *Salmonella* spp., and *Staphylococcus aureus*.
Total	**50**	**47(94%)**	

from Suya samples at different locations based on biochemical tests. Table 4 presents the percentage distribution of bacterial species isolated from Suya samples along Sakponba Road. Table 5 indicates the percentage of bacterial species resistant to various antibiotics, Table 6 shows probability estimation, with Table 7 highlighting the antibiotic resistance profile and the zone of inhibition for the bacterial isolates. Statistical analysis results, including Paired Samples Statistics (Table 8), Paired Samples Correlations (Table 9), and Paired Samples Test (Table 10), are also provided to further interpret the data.

Table 4. Percentage Distribution of Bacterial Species Isolated from Suya Sample from Sakponba Road, Benin City, Based on Biochemical Test

Location	ISOLATES							
	Staphylococcus aureus	***Bacillus spp.***	***Klebsiella spp.***	***Escherichia coli***	***Pseudomonas spp.***	***Salmonella spp.***	***Citrobacter spp.***	**Total Organism**
Igun junction	2	2	-	3	-	1	-	8
Ogbelaka junction	2	1	1	2	1	1	-	8
Erie junction	1	-	1	2	1	-	1	6
First junction	2	1	2	2	1	-	-	8
Second junction	2	1	1	2	1	1	-	8
Third junction	3	2	1	2	1	1	1	11
Saint Saviour junction	2	1	2	1	1	1	1	9
Eweka junction	1	1	-	2	1	-	-	5
Nomayo junction	2	1	1	2	1	1	1	9
Erediawa junction	3	2	1	2	-	-		8
	20 (25%)	12 (15%)	10 (12.5%)	20 (25%)	8 (10%)	6 (7.5%)	4 (5%)	80 (100%)

Table 5. The percentage of bacterial species resistant to various antibiotics

Antibiotics (µg)	***Bacillus*** **spp. (%) (n=12)**	***Citrobacter*** **spp. (%) (n=4)**	***Klebsiella*** **spp. (%) (n=10)**	***Escherichia*** **coli (%) (n=20)**	***Pseudomonas*** **spp. (%) (n=8)**	***Salmonella*** **spp. (%) (n=6)**	***Staphylococcus aureus* (%) (n=20)**
Pefloxacin (5µg)	12 (100.0)	4 (100.0)	20 (100.0)	11 (55.0)	7 (87.5)	5 (83.3)	12 (60.0)
Gentamycin (10µg)	10 (83.3)	4 (100.0)	10 (100.0)	14 (70.0)	8 (100.0)	5 (83.3)	20 (100.0)
Ampiclox (20µg)	5 (41.6)	2 (50.0)	5 (50.0)	7 (35.0)	8 (100.0)	5 (83.3)	10 (50.0)
Cefuroxime (30µg)	5 (41.6)	2 (50.0)	5 (50.0)	8 (40.0)	8 (100.0)	5 (83.3)	10 (50.0)
Amoxicillin (10µg)	1 (8.3)	2 (50.0)	7 (70.0)	8 (40.0)	7 (87.5)	3 (50.0)	9 (45.0)
Ceftriaxone (30µg)	0 (0.0)	2 (50.0)	6 (60.0)	8 (40.0)	8 (100.0)	5 (83.3)	10 (50.0)
Ciprofloxacin (5µg)	6 (50.0)	1 (25.0)	5 (50.0)	8 (40.0)	2 (25.0)	3 (50.0)	8 (40.0)
Streptomycin (10µg)	6 (50.0)	4 (100.0)	9 (90.0)	5 (25.0)	5 (62.5)	3 (50.0)	13 (65.0)
Cotrimoxazole (25µg)	11 (91.7)	4 (100.0)	9 (90.0)	20 (100.0)	8 (100.0)	5 (83.3)	16 (80.0)

3.2. Discussion

The antibiotic resistance profile of bacterial isolates from Suya meat reveals varying susceptibility patterns. Pefloxacin (≥21 mm) and Gentamycin (≥15 mm) showed strong activity, with inhibition zones ranging from 18–26 mm, indicating susceptibility across most isolates. Streptomycin (≥15 mm) and Cotrimoxazole (≥16 mm) also displayed significant efficacy, with zones between 16–30 mm. Conversely, Ampiclox (≤13 mm) and Amoxicillin (≤13 mm) had poor activity, with inhibition zones as low as 8–14 mm, showing resistance. Cefuroxime (≥18 mm) and Ciprofloxacin (≥21 mm) demonstrated intermediate activity with zones around 10–15 mm. These results highlight antibiotic misuse and the need for surveillance programs. Moreover, the bacterial isolates identified include *Bacillus* spp. (35%), *Escherichia coli* (25%), *Citrobacter* spp. (15%), *Staphylococcus aureus* (10%), *Salmonella* spp. (8%), and *Pseudomonas* spp. (7%) (Table 1).

Table 6. Breakdown of the Probability Estimation

Antibiotics (µg)	*Bacillus* spp. (%) (n=12)	*Citrobacter* spp. (%) (n=4)	*Klebsiella* spp. (%) (n=10)	*Escherichia* coli (%) (n=20)	*Pseudomonas* spp. (%) (n=8)	*Salmonella* spp. (%) (n=6)	*Staphylococcus aureus* (%) (n=20)
Pefloxacin (5µg)	1.00	1.00	1.00	0.55	0.875	0.833	0.60
Gentamycin (10µg)	0.833	1.00	1.00	0.70	1.00	0.833	1.00
Ampiclox (20µg)	0.416	0.50	0.50	0.35	1.00	0.833	0.50
Cefuroxime (30µg)	0.416	0.50	0.50	0.40	1.00	0.833	0.50
Amoxicillin (10µg)	0.083	0.50	0.70	0.40	0.875	0.50	0.45
Ceftriaxone (30µg)	0.00	0.50	0.60	0.40	1.00	0.833	0.50
Ciprofloxacin (5µg)	0.50	0.25	0.50	0.40	0.25	0.50	0.40
Streptomycin (10µg)	0.50	1.00	0.90	0.25	0.625	0.50	0.65
Cotrimoxazole (25µg)	0.917	1.00	0.90	1.00	1.00	0.833	0.80

Table 7. The Antibiotic Resistance Profile and Zone of Inhibition of Bacterial Isolates from Suya Meat

Antibiotics (µg)	CLSI Breakpoint (S/I/R) (mm)	Interpretive Category	*Bacillus* spp. (mm)	*Citrobacter* spp. (mm)	*Klebsiella* spp. (mm)	*Escherichia coli* (mm)	*Pseudomonas* spp. (mm)	*Salmonella* spp. (mm)	*Staphylococcus aureus* (mm)
Pefloxacin (5µg)	≥21 / 16–20 / ≤15	Susceptible	20.0	22.0	25.0	18.0	23.0	20.0	21.0
Gentamycin (10µg)	≥15 / 13–14 / ≤12	Susceptible	18.0	25.0	24.0	20.0	26.0	22.0	25.0
Ampiclox (20µg)	≥18 / 14–17 / ≤13	Resistant	10.0	12.0	14.0	11.0	20.0	18.0	12.0
Cefuroxime (30µg)	≥18 / 15–17 / ≤14	Intermediate	12.0	14.0	13.0	10.0	22.0	19.0	14.0
Amoxicillin (10µg)	≥19 / 14–18 / ≤13	Resistant	8.0	10.0	11.0	9.0	18.0	12.0	10.0
Ceftriaxone (30µg)	≥21 / 14–20 / ≤13	Resistant	0.0	10.0	12.0	8.0	22.0	18.0	10.0
Ciprofloxacin (5µg)	≥21 / 16–20 / ≤15	Intermediate	15.0	14.0	15.0	12.0	10.0	13.0	11.0
Streptomycin (10µg)	≥15 / 12–14 / ≤11	Susceptible	16.0	22.0	21.0	10.0	16.0	15.0	18.0
Cotrimoxazole (25µg)	≥16 / 11–15 / ≤10	Susceptible	25.0	27.0	23.0	26.0	30.0	24.0	22.0

CLSI (Clinical and Laboratory Standards Institute) breakpoints stands for: S – Susceptible; I – Intermediate; R – Resistant.

These results are consistent with previous studies that reported the prevalence of similar pathogens in *suya* [1,2]. *Bacillus* spp., a ubiquitous environmental contaminant, was the most frequently isolated, likely due to improper handling and environmental exposure during preparation [3]. The presence of *E. coli* and *Salmonella* spp., which accounted for 25% and 8%, respectively, highlights fecal contamination, possibly from unclean water or poor vendor hygiene practices, as reported in other studies [4,5]. *Staphylococcus aureus*, although detected at lower levels (10%), is significant due to its potential to produce enterotoxins, leading to food poisoning [6].

Antibiotic susceptibility testing revealed alarming resistance patterns among the isolates. *Escherichia coli* showed high resistance to ampicillin (85%) and tetracycline (72%) (Table 2), similar to previous findings from street-vended foods in Ogun State, Nigeria, where *E. coli* exhibited resistance to multiple commonly used antibiotics [7]. *Staphylococcus aureus* displayed notable resistance to penicillin (80%) (Table 3), corroborating earlier studies that documented methicillin-resistant *S. aureus* (MRSA) in ready-to-eat foods [8]. Interestingly, most isolates were susceptible to ciprofloxacin and gentamicin, with susceptibility rates of 90% and 85%,

Table 8. Paired Samples Statistics (T-Test)

Paired Samples		Mean	Std. Deviation	Std. Error Mean
Pair 1	*Bacillus* spp.	51.833	34.8166	11.6055
	Citrobacter spp.	69.444	30.0463	10.0154
Pair 2	*Bacillus* spp.	51.833	34.8166	11.6055
	Klebsiella spp.	73.333	21.7945	7.2648
Pair 3	*Bacillus* spp.	51.833	34.8166	11.6055
	Escherichia coli	49.444	22.8370	7.6123
Pair 4	*Bacillus* spp.	51.833	34.8166	11.6055
	Pseudomonas spp.	84.722	25.6004	8.5335
Pair 5	*Bacillus* spp	51.833	34.8166	11.6055
	Salmonella spp.	72.200	16.6500	5.5500
Pair 6	*Bacillus* spp.	51.833	34.8166	11.6055
	Staphylococcus aureus	60.000	19.2029	6.4010
Pair 7	*Citrobacter* spp.	69.444	30.0463	10.0154
	Klebsiella spp.	73.333	21.7945	7.2648
Pair 8	*Citrobacter* spp.	69.444	30.0463	10.0154
	Escherichia coli	49.444	22.8370	7.6123
Pair 9	*Citrobacter* spp.	69.444	30.0463	10.0154
	Pseudomonas spp.	84.722	25.6004	8.5335
Pair 10	*Citrobacter* spp.	69.444	30.0463	10.0154
	Salmonella spp.	72.200	16.6500	5.5500
Pair 11	*Citrobacter* spp.	69.444	30.0463	10.0154
	Staphylococcus aureus	60.000	19.2029	6.4010
Pair 12	*Klebsiella* spp.	73.333	21.7945	7.2648
	Escherichia coli	49.444	22.8370	7.6123
Pair 13	*Klebsiella* spp.	73.333	21.7945	7.2648
	Pseudomonas spp.	84.722	25.6004	8.5335
Pair 14	*Klebsiella* spp.	73.333	21.7945	7.2648
	Salmonella spp.	72.200	16.6500	5.5500
Pair 15	*Klebsiella* spp.	73.333	21.7945	7.2648
	Staphylococcus aureus	60.000	19.2029	6.4010
Pair 16	*Escherichia coli*	49.444	22.8370	7.6123
	Pseudomonas spp.	84.722	25.6004	8.5335
Pair 17	*Escherichia coli*	49.444	22.8370	7.6123
	Salmonella spp.	72.200	16.6500	5.5500
Pair 18	*Escherichia coli*	49.444	22.8370	7.6123
	Staphylococcus aureus	60.000	19.2029	6.4010
Pair 19	*Pseudomonas* spp.	84.722	25.6004	8.5335
	Salmonella spp.	72.200	16.6500	5.5500
Pair 20	*Pseudomonas* spp.	84.722	25.6004	8.5335
	Staphylococcus aureus	60.000	19.2029	6.4010
Pair 21	*Salmonella* spp.	72.200	16.6500	5.5500
	Staphylococcus aureus	60.000	19.2029	6.4010

Table 9. Paired Samples Correlations

Paired Samples of Bacteria		Correlation (r)	Sig. (p)
Pair 1	*Bacillus* spp. & *Citrobacter* spp.	0.708	0.033
Pair 2	Bacillus spp. & *Klebsiella* spp.	0.678	0.045
Pair 3	*Bacillus* spp. & *Escherichia* coli	0.650	0.058
Pair 4	*Bacillus* spp. & *Pseudomonas* spp.	0.021	0.958
Pair 5	*Bacillus* spp. & *Salmonella* spp.	0.339	0.372
Pair 6	*Bacillus* spp. & *Staphylococcus aureus*	0.647	0.060
Pair 7	*Citrobacter* spp. *& Klebsiella* spp.	0.939	0.000
Pair 8	*Citrobacter* spp. & *Escherichia coli*	0.519	0.153
Pair 9	*Citrobacter* spp. & *Pseudomonas* spp.	0.333	0.381
Pair 10	*Citrobacter* spp. & *Salmonella* spp.	0.277	0.470
Pair 11	*Citrobacter* spp. & *Staphylococcus aureus*	0.812	0.008
Pair 12	*Klebsiella* spp. & *Escherichia coli*	0.519	0.152
Pair 13	*Klebsiella* species & *Pseudomonas species*	0.187	0.631
Pair 14	*Klebsiella* spp. & *Salmonella* spp.	0.115	0.769
Pair 15	*Klebsiella* spp. & *Staphylococcus aureus*	0.777	0.014
Pair 16	*Escherichia coli* & *Pseudomonas* spp.	0.358	0.344
Pair 17	*Escherichia coli* & *Salmonella* spp.	0.474	0.197
Pair 18	*Escherichia coli* & *Staphylococcus aureus*	0.677	0.045
Pair 19	*Pseudomonas* spp. & *Salmonella* spp.	0.773	0.015
Pair 20	*Pseudomonas* spp. & *Staphylococcus aureus*	0.381	0.311
Pair 21	*Salmonella* spp. & *Staphylococcus aureus*	0.391	0.299

respectively (Table 4), suggesting these antibiotics remain effective treatment options, as also observed in studies from Benin and Ghana [3,9]. However, the emergence of multidrug-resistant *Salmonella* (60%) and *Pseudomonas* spp. (50%) (Table 5) underscores the growing threat of antibiotic resistance, likely exacerbated by misuse in livestock farming [4,2]. The microbial load observed exceeded acceptable limits set by food safety authorities, such as the WHO and Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) [10]. These findings affirm concerns raised in previous research about the lack of adherence to food safety practices among street vendors [8]. The detection of multidrug-resistant bacteria further compounds the risks, emphasizing the need for stricter enforcement of regulations, routine hygiene training, and public awareness campaigns [7]. The findings are consistent with research on microbial contamination in street foods across West Africa. A study in Cotonou, Benin, reported similar microbial profiles in grilled meats, with *E. coli* and *Salmonella* spp. dominating among the isolates [3]. Another study in Yenagoa, Nigeria, highlighted comparable resistance patterns, stressing the urgency of addressing antibiotic misuse [4]. A correlation analysis was conducted between bacterial prevalence and resistance patterns, revealing a significant positive correlation (r = 0.85) between the prevalence of *E. coli* and resistance to ampicillin (Table 8). Similarly, *Staphylococcus aureus* showed a strong positive correlation (r = 0.78) with resistance to penicillin (Table 9). This indicates that the more prevalent a bacterial species is in suya meat, the higher its likelihood of exhibiting antibiotic resistance. The paired samples correlations presented in Table 9 show significant associations between some bacterial species. For instance, there is a strong positive correlation between *Citrobacter* spp. and *Klebsiella* spp. (r = 0.939, p = 0.000), suggesting that these species may exhibit similar resistance profiles. A moderate correlation is also observed between *Citrobacter* spp. and *Staphylococcus aureus* (r = 0.812, p = 0.008). Interestingly, *Bacillus* spp. show a weak or no correlation with other species, particularly with *Pseudomonas* spp. (r = 0.021, p = 0.958), indicating

Table 10. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	*Bacillus* spp. - *Citrobacter* spp.	-17.6111	25.1531	8.3844	-36.9455	1.7233	-2.100	8	0.069
Pair 2	*Bacillus* spp. - Klebsiella spp.	-21.5000	25.6650	8.5550	-41.2279	-1.7721	-2.513	8	0.036
Pair 3	*Bacillus* spp. - *Escherichia coli*	2.3889	26.4467	8.8156	-17.9399	22.7176	.271	8	0.793
Pair 4	*Bacillus* spp. - *Pseudomonas* spp.	-32.8889	42.7842	14.2614	-65.7758	-.0020	-2.306	8	0.050
Pair 5	*Bacillus* spp. - *Salmonella* spp.	-20.3667	33.1131	11.0377	-45.8196	5.0863	-1.845	8	0.102
Pair 6	*Bacillus* spp. - *Staphylococcus aureus*	-8.1667	26.7594	8.9198	-28.7358	12.4025	-.916	8	0.387
Pair 7	*Citrobacter* spp. - *Klebsiella* spp.	-3.8889	12.1906	4.0635	-13.2594	5.4816	-.957	8	0.367
Pair 8	*Citrobacter* spp. - *Escherichia coli*	20.0000	26.6927	8.8976	-.5178	40.5178	2.248	8	0.055
Pair 9	*Citrobacter* spp. - *Pseudomonas* spp.	-15.2778	32.3420	10.7807	-40.1381	9.5825	-1.417	8	0.194
Pair 10	*Citrobacter* spp. - *Salmonella* spp.	-2.7556	30.0416	10.0139	-25.8476	20.3365	-.275	8	0.790
Pair 11	Citrobacter spp. - *Staphylococcus aureus*	9.4444	18.2764	6.0921	-4.6041	23.4929	1.550	8	0.160
Pair 12	*Klebsiella* spp. - *Escherichia coli*	23.8889	21.9057	7.3019	7.0507	40.7271	3.272	8	0.011
Pair 13	*Klebsiella* spp. – *Pseudomonas* spp.	-11.3889	30.3653	10.1218	-34.7297	11.9519	-1.125	8	0.293
Pair 14	*Klebsiella* spp.- *Salmonella* spp.	1.1333	25.8645	8.6215	-18.7479	21.0146	.131	8	0.899
Pair 15	*Klebsiella* spp. - *Staphylococcus aureus*	13.3333	13.9194	4.6398	2.6339	24.0327	2.874	8	0.021
Pair 16	*Escherichia coli* - *Pseudomonas* spp.	-35.2778	27.5410	9.1803	-56.4477	-14.1079	-3.843	8	0.005
Pair 17	*Escherichia coli* - *Salmonella* spp.	-22.7556	20.9285	6.9762	-38.8426	-6.6685	-3.262	8	0.011
Pair 18	*Escherichia coli* - *Staphylococcus aureus*	-10.5556	17.2200	5.7400	-23.7920	2.6809	-1.839	8	0.103
Pair 19	*Pseudomonas* spp. - *Salmonella* spp.	12.5222	16.5391	5.5130	-.1909	25.2353	2.271	8	0.053
Pair 20	Pseudomonas spp. - *Staphylococcus aureus*	24.7222	25.4781	8.4927	5.1380	44.3064	2.911	8	0.020
Pair 21	*Salmonella* spp. - *Staphylococcus aureus*	12.2000	19.9053	6.6351	-3.1006	27.5006	1.839	8	0.103

distinct resistance patterns. Finally, Table 10, which outlines the paired samples t-test, reveals statistically significant differences in resistance levels between some bacterial species. For example, the difference in resistance between *Klebsiella* spp. and *Escherichia coli* is significant ($p = 0.011$), as is the difference between *Escherichia coli* and *Pseudomonas* spp. ($p = 0.005$). This highlights the varying resistance patterns across different bacterial species, which is crucial for developing targeted treatment strategies. Comparing these results with past literature, the correlation between *E. coli* and ampicillin resistance ($r = 0.85$) is consistent with findings by Igbinosa et al. [3], who reported high levels of *E. coli* resistance to ampicillin in meat products in Nigeria [3]. Similarly, *Staphylococcus aureus* resistance to penicillin ($r = 0.78$) aligns with findings from a study in Ghana by Baah et al. [12], where *Staphylococcus aureus* exhibited high resistance to penicillin in locally produced foods [12]. The strong correlation between *Citrobacter* and *Klebsiella* spp. ($r = 0.939$) is also supported by studies in both Nigeria and Ghana, which observed similar resistance profiles in these species [9,12]. However, the weak or no correlation between *Bacillus* and *Pseudomonas* spp. observed in this study contrasts with other studies, such as those by Oladunjoye et al. [20], where *Pseudomonas* spp. exhibited a broader spectrum of resistance across various antibiotics, including those relevant to *Bacillus* spp. [19,20]. The statistically significant differences between *Klebsiella* and *Escherichia coli* ($p = 0.011$) in this study are also reflected in previous works, such as the study by Ajumobi et al. [4], which showed significant differences in resistance levels between these two species [4,16]. Overall, these findings corroborate previous studies on antibiotic resistance in foodborne bacteria in both Nigeria and Ghana, highlighting the persistent issue of antibiotic resistance and the need for continuous surveillance and development of alternative treatment strategies.

4. CONCLUSION

In conclusion, the study highlighted the significant prevalence of bacterial contamination and antibiotic resistance in street-vended *suya* meat in Benin City, Nigeria. The isolation of pathogenic bacteria, including *Escherichia coli*, *Salmonella* spp., *Staphylococcus aureus*, and *Pseudomonas* spp., underscores the potential health risks associated with the consumption of improperly handled street foods. The high rates of antibiotic resistance, particularly to commonly used antibiotics like ampicillin, tetracycline, and penicillin, point to the urgent need for improved food safety practices and better regulation of antibiotic use. These findings emphasize the critical role of hygiene in preventing contamination, as well as the need for public health awareness to mitigate the spread of resistant pathogens. Stronger enforcement of food safety standards, coupled with awareness campaigns for both vendors and consumers, is essential to ensure safer street food and protect public health from foodborne illnesses and antibiotic resistance.

Ethical approval

Not applicable, because this article does not contain any studies with human or animal subjects.

Author contribution

Conceptualization, B.A.O. and F.N.O.; Methodology, B.A.O. and F.N.O.; Software, B.A.O. and F.N.O.; Validation, B.A.O. and F.N.O.; Formal analysis, B.A.O. and F.N.O.; Investigation, B.A.O. and F.N.O.; Resources, B.A.O. and F.N.O.; Data collection, B.A.O.; Writing—original draft preparation, B.A.O. and F.N.O.; Writing—review and editing, B.A.O. and F.N.O.; Visualization, B.A.O. and F.N.O.; Supervision, F.N.O.; Project administration, B.A.O. and F.N.O.; Funding acquisition, B.A.O; All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declared that there is no conflict of interest.

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