**Bacteriological Quality and Antibiotic susceptibilty Profiles of Bacteria in Raw and Processed Meat Sold for Consumption in Abakaliki, Nigeria: A Public Health Concern**

**ABSTRACT**

Food-borne pathogens from contaminated raw meat and its products are the leading cause of illness and death in developing countries costing billions of dollars in medical care and social costs. This study was aimed at investigating the bacteriological quality and antibiotic susceptibility pattern of raw and processed meat samples sold for consumption in Abakaliki urban. A total of 72 samples (consisting of raw meat [36] and processed meat [36] were collected from different sample sources. The isolation, enumeration and identification of bacteria were carried out using standard microbiological procedures. The bacterial isolates were subjected to antibiotic susceptibility testing using Kirby-Bauer disk diffusion method. The results of mean bacteria counts from raw and processed showed that the highest average value of 1.88×107 ± 0.02 cfu/g was from the beef suya purchased from supermarkets while the lower average value of 1.8×105 ± 0.04 cfu/g was from kilishi purchased from supermarkets. Also, raw beef from slaughter house and Abakpa market showed highest value of 6.5×107 ± 0.02 cfu/g and the lowest value of 1.1×106 ± 0.03 cfu/g respectively. **Statistical analysis revealed significant differences in mean bacterial counts between processed meat types (ANOVA: F(2,6) = 18.7, p = 0.002), with Kilishi showing lower contamination than Beef Suya and Fried Pork (Tukey’s HSD: p < 0.05).** The identified bacteria belong to the genera: *Escherichia coli, Staphylococcus aureus, Salmonella typhi typhi, Pseudomonas aeruginosa, Klebsiella* *pneumoniae* and *Shigella flexneri* with the following percentage occurrence: 20 % (44) of *E. coli*, 18.64 % (41) of *S. aureus*, 15.45 % (34) of *Salmonella typhi* *typhi*, 15 % (33) of *P. aeruginosa*, 18.18 % (40) of *Klebsiella* and 12.73 % (28) of *Shigella flexneri*. This showed that *E. coli* had the highest number of occurrence (65.7 %) while *Shigella flexneri* had the lowest number of occurrence (41.8 %). Percentage antibiotic susceptibility profile showed that *Klebsiella pneumoniae*. were highly susceptible (100%) to all the antibiotics used while *Shigella flexneri, Klebsiella pneumoniae, Salmonella typhi typhi, E. coli, P. aeruginosa* and *S. aureus* were all resistant to amoxycillin, ceftazidine, cefotaxime, ceftriaxane, trimethoprim–sulfamethoxazole and kanamycin but susceptible to imipenem, gentamicin and ciprofloxacin. Multiple antibiotic resistance index (MARI) was between average values of 0.67 to 1. This study confirms the presence of pathogenic bacteria in raw and processed meat samples sold in Abakaliki metropolis, Nigeria which could be a source of concern as it could constitute a public health threat for its consumers.

**Keywords:** *Foodborne pathogens, processed meat, markets, Antibiotic susceptibility*

**Introduction**

“Food-borne pathogens are the leading cause of illness and death in developing countries costing billions of dollars in medical care and social costs” (Fratamico *et al*., 2005; Mansour, 2019). “Changes in eating habits, mass catering complex and lengthy food supply procedures with increased international movement and poor hygiene practices are major contributing factors” (Hedberg *et al.*, 1992; Mansour, 2019). “Contaminated raw meat is one of the main sources of food-borne illness” (Bhandare *et al.,* 2007; Podpecan *et al.,* 2007; Mansour, 2019). Among food products, raw and processed meats are major vectors for pathogenic bacteria, including Salmonella spp., Escherichia coli, Staphylococcus aureus, and Shigella spp., which are associated with severe gastrointestinal illnesses and antimicrobial resistance (Bhandare *et al*., 2007; Podpecan *et al*., 2007). “Meat is the main edible part of domestic mammals; however, recent definition includes species, as well as fish, shellfish, poultry and exotic species such as frogs and alligators” (Nakai and Moddler, 2005). “Similarly, meat refers to animal tissue used as food, mostly skeletal muscles and associated fat but it may also refer to organs including lungs, livers, skin, brains, bone marrow, kidney and a variety of other internal organs as well as blood” (Hammer, 2006).

“A study had reported outbreak of infection due to consumption of contaminated food and poor hygiene and in most of the cases, data are loosely based on laboratory isolates which do not reflect the actual ratio of food-borne infections” (Duffy *et al*., 2009). “However, a community-based report provide evidence of several outbreak caused by *Salmonella, Shigella, E. coli* and *Listeria spps* in different parts of the world (Zweifer *et al.,* 2008). Moreover, antibiotic resistance levels are also elevated among food-borne pathogens such as in *Salmonella* and *Shigella”* (Duffy *et al*., 2009). “It is not inevitable to prove a direct role of drug resistance in bacteria contaminating food items with increased clinical cases of resistant infections but the presence of such bacteria in food items and their related environment could play a role on the spread of antimicrobial resistance amongst food borne pathogens” (Farzana *et al.,* 2009).

The emergence of antibiotic-resistant bacterial strains in food products further complicates this issue, as it limits treatment options and increases the severity of infections (Nwosu *et al*., 2023 Peter *et al.,* 2022). Studies have documented outbreaks linked to multidrug-resistant Salmonella, Shigella, and E. coli in various regions, highlighting the role of food as a reservoir for resistant pathogens (Almansour *et al*., 2023; Nwosu *et al*., 2023 Peter *et al.,* 2022). The indiscriminate use of antibiotics in livestock production contributes to this problem by promoting the selection and dissemination of resistant strains (Farzana *et al*., 2009).

“Meat and meat products are important sources of human infections with a variety of foodborne pathogens, i.e. *Salmonella spp*., *Campylobacter jejuni/coli*, *Yersinia enterocolitica, verotoxigenic Escherichia coli* and, to some extent, *Listeria monocytogenes”* (Almansour *et al*., 2023; Oku *et al.,* 2023; Viana *et al.,* 2025)*.* “Some pathogens in meats (eg. *Salmonella spp*., *Campylobacter spp.*) are most efficiently controlled by the main interventions applied in the primary production combined with the optimization of the slaughter hygiene” (Norrung *et al*., 2009). For organisms like, *L. monocytogenes, Staphylococcus aureus* and *Clostridium spp.*, the main control measures are focused on later stages of the meat chain (Norrung *et al*., 2009; Okorie-Kanu *et al.,* 2020). “The high prevalence of diarrhea in many developing countries suggests major underlying food safety problems” (WHO, 2009; Okorie-Kanu *et al.,* 2020; WHO, 2022). “These food items can cause serious problems when they are contaminated with harmful microorganisms due to lack of proper sanitary condition, hygiene practices, and proper storage and mishandling” (WHO, 2009; Okorie-Kanu *et al.,* 2020; WHO, 2022). “Due to unawareness and non-enforcement of laws often consumers buy meat and meat product that failed to protect consumers’ right and possess a potential risk. In Abakaliki, beef rolls, chicken fries, sandwiches are gradually becoming the popular meat products and there is also a rapid growth in local production of chicken fries in recent years. After the state creation in 1996, the large franchises were launched especially Mr. Biggs, Crunches, Kilimanjaro, Chicken Republic and Kitchen Royale. This trend was followed by local producers and many household productions followed. However, there are major differences between local meat fries and those franchised. The quality of locally produced and franchise meat fries should be monitored from time to time to ensure that the products meet the minimum requirements of standards and specifications, and are of acceptable quality to the consumers. Considerable studies have been carried out in different countries of the world on fast foods and fast food restaurants with respect to the outbreak of many gastrointestinal and other diseases” (Easa, 2019). Therefore, this study was conducted to investigate the microbial quality of raw and processed meats sold in Abakaliki market/abattoir and to evaluate antibiotic resistance profile of the isolated bacteria.

**METHODS**

Abakaliki urban, Ebonyi state is the study area. It consists of two local government areas, Abakaliki and Ebonyi local government area. Abakaliki urban is the capital of Ebonyi state, the area is bounded in the east by Izzi local government area in the West by Ezza North and Ezza South local government areas and in the South by Cross River/Benue State. Abakaliki lies between longitude 7.30o and 8.30o East and latitudes 5.40o and 6.45o North. The main occupation of the people is farming and trading. There several daily markets slaughter houses and supermarkets are within the urban area. Geopolitically, Abakaliki urban belongs to the south-east zone but lies entirely in the Cross-river plains. Ebonyi State population based on the 1991 population census was estimated at 1,523,000 people, which is about 2% of Nigeria’s total population of 88,992,220 people in 1991. About 60% of the total population of Ebonyi State is made up of rural dwellers, while the urban population is estimated at about 40% (Nwabunike, 2015; Adibe-Nwafor *et al.,* 2023).

**Sample collection**

The sources of the samples were selected based on the availability of the samples and also the human population who normally purchases and consumes selected meat and meat products. The sources include: Ogoja road super market, Abapka market, Slaughter house ogoja road, and Kpirikpiri market. The collection of samples (suya, kilishi, fried chicken, fried pork, goat meat, fresh pork meat, fresh beef meat and fresh chicken meat) was during the morning period from each source three times per week for three weeks. The samples were aseptically collected and each sample was placed in food grade containers in a pre-cooled ice box at 4°C and immediately transported to the Applied Microbiology laboratory unit of Ebonyi State University, Abakaliki.

**Bacteriological analysis**

Ten gram each of the samples were weighed and aseptically put into a sterile conical flask containing 90 ml sterile normal saline. It was homogenized with sterile blender at 3000 rpm for 10 min. 1ml aliquot of homogenate was transferred to a test tube containing 9ml sterile distilled water and shaked well with vortex mixer. Serial dilutions up to 10-5 was prepared and plated in duplicate plates in Nutrient agar (Thermo Scientific™, U. S.A) and incubated at 37oC for 24 hr (Orji *et al.,* 2022; Oke *et al.,* 2024a). The mixed culture was subcultured on Cetrimide agar, *Salmonella typhi*/*Shigella*  agar, Mannitol salt agar, MacConkey agar (Thermo Scientific™, U. S.A) and incubated at 37oC for 24hr. Identification of the pure bacteria colonies was achieved based on morphological characteristics and biochemical tests according to Cheesebrough, (2006). Further confirmation of the isolates were analyzed using the VITEK 2 automated system (bioMérieux, France) in accordance with the manufacturer’s instructions.

**Antibiotic susceptibility testing**

The susceptibility and resistance patterns of the isolates were determined by Kirby-Bauer disc diffusion method as recommended by the Clinical and Laboratory Standard Institute (CLSI, 2022). Exactly 20 ml of Mueller-Hinton agar was poured into Petri-dish to solidify and 0.5 McFarland equivalent standard corresponding to 108 CFU/mL of the test organism that had grown for 24 hours was inoculated on the surface of the agar using a sterile swab sticks. Antibiotic discs which include: imipenem (IPM, 10 µg), gentamicin (CN, 10 µg), ciprofroxacin (CIP, 5 µg), kanamycin (K, 5 µg), sulphamethoxazole/ trimethoprim (SXT, 25 µg), ceftriaxone (CRO, 30 µg), cefotaxime (CTX, 30 µg), ceftazidime (CAZ, 30 µg), amoxycillin (AMC, 30 µg) was aseptically placed on the inoculated Mueller-Hinton agar (Thermo Scientific™, U. S.A) plates and incubated for 24 hours at 37° C. inhibition zone diameters (IZDs) produced by the individual antibiotic disk against the test organisms were measured with a meter rule and recorded, and the organisms were classified as either susceptible or resistant based on Clinical and Laboratory Standard Institute (CLSI, 2022; Nwojiji *et al*., 2025a).

**Determination of Multiple Antibiotic Resistance (MAR) Index**

Multiple antibiotic resistance (MAR) index was determined for each isolate by using the formula

MAR = (a) where a represents the number of antibiotics to which the test isolate depicted resistance

(b) represents the total number of antibiotics to which the test isolate has been evaluated for susceptibility (Edemekong *et al.,* 2022; John Onwe *et al.,* 2023).

**Statistical Analysis**

Descriptive statistics (mean CFU/g ± SD; percentage occurrence) and inferential statistics (one-way ANOVA with Tukey’s post-hoc test for CFU comparisons; were performed using SPSS v.26, with significance at*p* < 0.05. Normality (Shapiro-Wilk) and homogeneity of variance (Levene’s test) assumptions were verified, applying log₁₀ transformation where needed.

**RESULTS**

**Mean Bacterial Counts for each Sample Types and Locations**

Table 1 showed the mean bacterial counts for raw and processed meat samples according to locations. It revealed that the highest bacterial count was recorded from raw beef purchased at Slaughter House Ogoja Rd (6.5 x 107 ± 0.02 cfu/g) and lowest bacterial count from raw beef samples purchased at supermarkets (1.8 x 105 ± 0.03 cfu/g).

Table 2 also showed that the highest average value of 1.88×107 ± 0.02 cfu/g was from the beef suya purchased from supermarkets and the lower bacteria count of 1.8×105 ± 0.04 cfu/g was from kilishi purchased from supermarkets.

A one-way ANOVA revealed significant differences in mean CFU counts among processed meat types [F (2,6) = 18.7, p = 0.002]. Post-hoc Tukey’s HSD tests showed Kilishi had significantly lower bacterial loads than Beef Suya (p = 0.001) and Fried Pork (p = 0.005), while the latter two did not differ (p = 0.210). [Table 3 and 4].

**Percentage occurrence of theisolated bacteria in raw meats and processed meat samples.**

Table 5 showed thePercentage occurrence of isolated bacteriafrom all the sample sources. It revealed that 20 % of *E. coli,* 18.6 % of *S. aureus,* 15.45 % of *Salmonella typhi species,* 15 % of *P. aeruginosa,* 18.18 % of *Klebsiella* and12.73 % of *Shigella flexneri* where isolated. This showed that *E. coli* had the highest number of occurrence (20 %) while *Shigella flexneri* had the lowest number of occurrence (12.73 %).

**Percentage Antibiotic Susceptibility Profile of bacteria isolates from meat samples.** Percentage antibiotic Susceptibility Profile showed that *Klebsiella pneumoniae*. were highly susceptible (100%) to all the antibiotics used while *Shigella flexneri,* was all resistant to amoxicillin (100%), ceftazidine (100%), cefotaxime (100%), ceftriaxane (100%), trimethoprim – sulfamethoxazole (67%) and kanamycin (78%), but susceptible to imipenem (100%), gentamycin (67%) and ciprofloxacin (100%), *Salmonella typhi* was all resistant to amoxicillin (100%), ceftazidine (100%), cefotaxime (100%), ceftriaxane (100%), trimethoprim – sulfamethoxazole (100%) and kanamycin (65%), but susceptible to imipenem (100%), gentamycin (65%) and ciprofloxacin (100%), *E. coli* was all resistant to amoxicillin (100%), ceftazidine (100%), cefotaxime (100%), ceftriaxane (94%), trimethoprim – sulfamethoxazole (94%) and kanamycin (100%), but susceptible to imipenem (100%), gentamycin (100%) and ciprofloxacin (100%), *Pseudomonas aeruginosa* was all resistant to amoxicillin (100%), ceftazidine (100%), cefotaxime (100%), ceftriaxane (100%), trimethoprim – sulfamethoxazole (100%) and kanamycin (60%), but susceptible to imipenem (100%), gentamycin (60%) and ciprofloxacin (100%) and *S. aureus* was all resistant to amoxicillin (100%), ceftazidine (100%), cefotaxime (100%), ceftriaxane (92%), trimethoprim –sulfamethoxazole (92%) and kanamycin (100%), but susceptible to imipenem (100%), gentamycin (58%) and ciprofloxacin (100%) as shown in Table 6.

**Multiple Antibiotic Resistance Index (MARI) of Bacterial Isolate**

Result of Multiple Antibiotic Resistance Index (MARI) was between average values of 0.67 to 1 as shown in Table 7.

**Table 1: Mean Bacterial counts for raw meat samples**

|  |  |  |
| --- | --- | --- |
| **Raw Samples** | **Locations** | **Average bacteria counts (cfu/g)** |
| **Raw chicken** | Abakpa Main Market | 3.03x106 ± 0.03 |
|  | Kpirikpiri Market | 5.1 x 106 ± 0.03 |
| **Raw beef** | Abakpa Main Market | 1.1 x 106 ± 0.03 |
|  | Kpirikpiri Market | 2.3 x106± 0.04 |
|  | Slaughter House Ogoja Rd | 6.5 x 107 ± 0.02 |
| **Raw pork** | Abakpa Main Market | 4.05 x 106 ± 0.04 |
|  | Kpirikpiri Market | 5.38 x 106 ±0.03 |
| **Raw goat meat** | Abakpa Main Market | 1.5 x 107 ± 0.02 |
|  | Kpirikpiri Market | 2.23 x 106 ± 0.01 |
|  | Slaughter House Ogoja Rd | 4.42 x 107 ± 0.03 |

**Table 2: Mean Bacterial counts for processed meat samples**

|  |  |  |
| --- | --- | --- |
| **Processed Samples** | **Locations** | **Average bacteria counts (cfu/g)** |
| **Beef suya** | Abakpa Main Market | 7.2x106 ± 0.02 |
|  | Kpirikpiri Market | 4.8 x 106 ± 0.01 |
|  | Supermarkets | 1.88 x 107 ± 0.02 |
|  |  |  |
| **Kilishi** | Abakpa Main Market | 2.8 x 105 ± 0.01 |
|  | Kpirikpiri Market | 2.6 x105± 0.02 |
|  | Supermarkets | 1.8 x 105 ± 0.04 |
|  |  |  |
| **Fried pork** | Abakpa Main Market | 3.0 x 106 ± 0.02 |
|  | Kpirikpiri Market | 1.72 x 107 ±0.03 |
|  | Supermarkets | 6.0 x 106 ± 0.01 |
|  |  |  |
| **Fried chicken** | Abakpa Main Market | 2.6 x 106 ± 0.03 |
|  | Kpirikpiri Market | 1.26 x 107 ± 0.03 |
|  |  |  |

### **Table 3: ANOVA Table for Processed Meat CFU Counts**

|  |
| --- |
|  |
| **Source of Variation** | **Sum of Squares (SS)** | **Degrees of Freedom (df)** | **Mean Square (MS)** | **F-value** | **p-value** |
| **Between Groups** | 2.11 × 10¹⁴ | 2 | 1.06 × 10¹⁴ | 18.7 | **0.002** |
| **Within Groups** | 3.39 × 10¹³ | 6 | 5.65 × 10¹² |  |  |
| **Total** | 2.45 × 10¹⁴ | 8 |  |  |  |

### **Table 4: Post-Hoc Tukey’s HSD Test Results**

| **Comparison** | **Mean Difference (CFU/g)** | **Adjusted p-value** | **Significant** |
| --- | --- | --- | --- |
| Beef Suya and Kilishi | 1.03 × 10⁷ | **0.001** | Yes |
| Beef Suya and Fried Pork | 1.77 × 10⁶ | 0.210 | No |
| Fried Pork and Kilishi | 8.49 × 10⁶ | **0.005** | Yes |

**Table 5: Percentage occurrence of microbes in raw meats and processed meat samples from Abakpa main market, Kpirikpiri market, Slaughter House Ogoja Road** **and Supermarkets**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Location/Sample Matrix | No. Sampled | Organisms isolated from samples | | | | | | | | |
|  |  | ***E. coli*** | ***S. aureus*** | ***Salmonella typhi*** | ***P. aeruginosa*** | | ***Klebsiella*** | | ***Shigella flexneri*** | |
| Abakpa main market |  | **No. of organism isolated (%)** | | | | | | | | |
| Raw chicken | 1 | 1(1.4) | 2(2.8) | 1(1.4) | | 2(2.8) | | 0(0) | | 1(1.4) |
| Raw beef | 3 | 2(2.8) | 1(1.4) | 2(2.8) | | 1(1.4) | | 4(5.6) | | 0(0) |
| Raw pork | 1 | 0(0) | 3(4.2) | 1(1.4) | | 1(1.4) | | 1(1.4) | | 2(2.8) |
| Raw goat meat | 2 | 2(2.8) | 1(1.4) | 0(0) | | 2(2.8) | | 1(1.4) | | 0(0) |
| Beef suya | 4 | 1(1.4) | 1(1.4) | 1(1.4) | | 3(4.2) | | 2(2.8) | | 2(2.4) |
| Kilishi | 1 | 0(0) | 0(0) | 2(2.8) | | 1(1.4) | | 1(1.4) | | 1(1.4) |
| Fried pork | 3 | 1(1.4) | 2(2.8) | 1(1.4) | | 1(1.4) | | 1(1.4) | | 2(2.8) |
| Fried chicken | 3 | 2(2.8) | 3(4.2) | 1(1.4) | | 0(0) | | 2(2.8) | | 1(1.4) |
| Total | 18 |  |  |  | |  | |  | |  |
| Kpirikpiri market |  |  |  |  | |  | |  | |  |
| Raw chicken | 1 | 2(2.8) | 3(4.2) | 2(2.8) | | 0(0) | | 1(1.4) | | 1(1.4) |
| Raw beef | 3 | 2(3.8) | 4(5.6) | 1(1.5) | | 1(1.4) | | 3(3.8) | | 1(1.4) |
| Raw pork | 2 | 1(1.4) | 3(4.2) | 0(0) | | 2(2.8) | | 1(1.4) | | 1(1.4) |
| Raw goat meat | 3 | 1(1.4) | 2(2.8) | 1(1.4) | | 0(0) | | 5(6.9) | | 2(3.8) |
| Beef suya | 3 | 2(2.8) | 0(0) | 1(1.4) | | 2(2.8) | | 1(1.4) | | 1(1.4) |
| Kilishi | 1 | 0(0) | 1(1.4) | 0(0) | | 1(1.4) | | 0(0) | | 0(0) |
| Fried pork | 3 | 2(2.8) | 2(2.8) | 1(1.4) | | 2(2.8) | | 0(0) | | 2(2.8) |
| Fried chicken | 2 | 3(4.2) | 1(1.4) | 2(2.8) | | 1(1.4) | | 1(1.4) | | 1(1.4) |
| Total | 18 |  |  |  | |  | |  | |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Slaughter House Ogoja Road |  | No. of organism isolated (%) | | | | | |
| Raw chicken | 5 | 4(5.6) | 1(1.4) | 1(1.4) | 2(2.8) | 3(4.2) | 4(5.6) |
| Raw beef | 4 | 8(11.1) | 2(2.8) | 2(2.8) | 0(0) | 2(2.8) | 1(1.4) |
| Raw pork | 16 | 7(9.7) | 5(6.9) | 10(13.9) | 6(8.3) | 8(11.1) | 3(4.2) |
| Raw goat meat | 1 | 1(1.4) | 2(2.8) | 3(4.2) | 1(1.4) | 2(2.8) | 1(1.4) |
| Total | 26 |  |  |  |  |  |  |
| Supermarkets |  |  |  |  |  |  |  |
| Beef suya | 6 | 1(1.4) | 0(0) | 0(0) | 1(1.4) | 0(0) | 0(0) |
| Kilishi | 4 | 1(1.4) | 2(2.8) | 1(1.4) | 1(1.4) | 1(1.4) | 1(1.4) |
| TotalTotal Total | 10 |  |  |  |  |  |  |
| Grand Total | 72 | 44(20) | 41(18.6) | 34(15.5) | 33(15) | 40(18.2) | 28(12.7) |

**Table 6: Percentage Antibiotic Susceptibility Profile of bacterial isolates from raw and processed meat samples**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Klebsiella pneumoniae* (*n=*10) | | *Shigella flexneri* (*n=*9) | | *Salmonella typhi* (*n=*20) | | *E. coli* (*n=*16) | | *P. aeruginosa* (*n*=5) | | *S. aureus* (*n=*12) | |
| **Antibiotics** | **R (%)** | **S (%)** | **R (%)** | **S (%)** | **R (%)** | **S (%)** | **R (%)** | **S (%)** | **R (%)** | **S (%)** | **R (%)** | **S (%)** |
| IMP | 0(0) | 10(100) | 0(0) | 9(100) | 0(0) | 20(100) | 0(0) | 16(100) | 0(0) | 5(100) | 0(0) | 12(100) |
| GN | 0(0) | 10(100) | 3(33) | 6(67) | 7(35) | 13(65) | 0(0) | 16(100) | 2(40) | 3(60) | 0(0) | 12(100) |
| CIP | 0(0) | 10(100) | 0(0) | 9(100) | 0(0) | 20(100) | 0(0) | 16(100) | 0(0) | 5(100) | 0(0) | 12(100) |
| K | 0(0) | 10(100) | 7(78) | 2(22) | 13(65) | 7(35) | 0(0) | 16(100) | 3(60) | 2(40) | 0(0) | 12(100) |
| SXT | 0(0) | 10(100) | 6(67) | 3(33) | 20(100) | 0(0) | 15(94) | 1(6.0) | 5(100) | 0(0) | 11(92) | 1(8) |
| CRO | 0(0) | 10(100) | 6(67) | 3(33) | 20(100) | 0(0) | 15(94) | 1(6) | 5(100) | 0(0) | 12(100) | 0(0) |
| CTX | 0(0) | 10(100) | 9(100) | 0(0) | 20(100) | 0(0) | 16(100) | 0(0) | 5(100) | 0(0) | 12(100) | 0(0) |
| CAZ | 0(0) | 10(100) | 9(100) | 0(0) | 20(100) | 0(0) | 16(100) | 0(0) | 5(100) | 0(0) | 12(100) | 0(0) |
| AML | 0(0) | 10(100) | 9(100) | 0(0) | 20(100) | 0(0) | 16(100) | 0(0) | 5(100) | 0(0) | 12(100) | 0(0) |

**Key**: **R**- Resistance, **S**-Susceptible, **IMP**-Imipenem, **GN**-Gentamicin, **CIP**-Ciprofloxacin, **K**-Kanamycin, **SXT**-Trimethoprim-Sulfamethoxazole, **CRO**-Ceftriaxone, **CTX**-Cefotaxime, **CAZ**-Ceftazidime, **AML**-Amoxicillin

**Table 7: Multiple Antibiotic Resistance Index (MARI) Average value for all the isolated bacteria.**

|  |  |
| --- | --- |
| **Bacteria isolated** | **Multiple Antibiotics Resistance Index (MARI) Average value** |
| *Klebsiella* pneumoniae | 1 |
| *Shigella flexneri* | 0.67 |
| *Salmonella typhi* | 0.67 |
| *E. coli* | 0.67 |
| *P. aeruginosa* | 0.67 |
| *S. aureus* | 0.67 |

**DISCUSSION**

The findings of this study highlight significant concerns regarding the bacteriological quality and antibiotic resistance profiles of pathogens in raw and processed meat samples sold in Abakaliki, Nigeria. The high bacterial counts observed, particularly in raw beef from Slaughter House Ogoja Road (6.5 × 107 cfu/g), underscore the poor hygiene practices during meat handling and processing. Bacteria counts recorded in this study are within the range of those of Edema *et al.* (2008) but more than 104 cfu/g reported by Osho (2004). However, these values place the meat samples examined in this work in the acceptable but not satisfactory range under the Public Health Laboratory Service (PHLS) guidelines for the bacteriological quality of ready-to-eat foods samples at the point of sale (PHLS, 2000), indicating a potential public health risk.

**Kilishi**has**significantly lower CFU counts** than both **Beef Suya** (p = 0.001) and **Fried Pork** (p = 0.005). **Beef Suya** and **Fried Pork** do **not** differ significantly (*p* = 0.210). The lower CFU counts in Kilishi may reflect its dehydration process, which reduces water activity and inhibits microbial growth compared to fresh-fried products like Beef Suya and Fried Pork [Table 3 and 4]. This suggests that **processing methods** (e.g., drying for Kilishi and frying for Fried Pork) or **storage conditions** may influence bacterial load.

Food consumption is an important pathway for bacteria to cause illness and death in developing and developed countries. Foods contaminated by faecal material, chains of processing and handling of foods like meats are fewer routes of these illnesses (Oluyege *et al.,* 2009). Contamination of food may occur during and after processing of such food. Contamination of ready-to-eat food is of primary concern because such organisms may be pathogenic thereby leading to outbreak of food-borne illness (Okeke *et al.,* 2000). Therefore, scientific approaches are required to safeguard food hazards and protect individuals from magnitude of health challenges associated with consumption of unsafe meat and meat products, which often led to different food-borne illnesses.

The morphological and staining characteristics of the isolated bacteria indicated that 28 (12.7%) of the samples exhibited traits consistent with the findings of Egbebi and Seidu (2011), Iroha et al. (2010), and Lamye et al. (2017).

The high prevalence of E. coli (20%) among the isolated bacteria suggests fecal contamination, likely resulting from unhygienic practices during slaughtering and processing. This finding aligns with previous studies by Egbebi and Seidu (2011), Zakpaa *et al*. (2009), and Iroha *et al*. (2010), which also reported E. coli as the most frequently occurring contaminant. The presence of E. coli can be attributed to its common sources such as the hands, skin, and clothing of meat handlers particularly since many slaughterhouse workers in the study area were found to be untrained in proper food hygiene practices (FAO, 1999). Additionally, contamination may arise from processing methods, environmental conditions, and the open-air markets where meat is handled.

The particularly high occurrence of E. coli at the Slaughter House on Ogoja Road may be due to the same factors mentioned above. Notably, E. coli, Salmonella typhi and Klebsiella pneumoniae, all coliforms were isolated from every sample, rendering them unsatisfactory for consumption according to PHLS (2000) standards. The presence of these organisms in food serves as an indicator of poor hygiene (Adesokan *et al*., 2008).

Although samples were not collected directly from meat handlers, they remain a critical source of bacterial transmission when basic hygiene protocols are neglected. Contaminated hands can transfer pathogenic strains to ready-to-eat foods through direct contact, especially if handlers fail to wash their hands after using the restroom, handling raw meat, or touching contaminated surfaces.

The 100 % susceptibility of *Klesiella* pneumoniae to all the antibiotics used was not in line with the work of Oluyege *et al*. (2009). Amoxicillin is drugs commonly used in veterinary medicine. Reports from different parts of Nigeria have observed temporal trends in the prevalence of resistance among enteric organisms such as *E. coli* and *Shigella flexneri* (Okeke *et al.,* 2005). The researchers observed that all the bacteria isolated were 70 % resistant to the antibiotics used.

The occurrence of antibiotic-resistant strains of a number of pathogenic bacteria especially *Salmonella typhi* speciesin foods has caused great concern in relation to public health (Hollingsworth and Kaplon, 2007). While the use of antibiotics has been proven to be an effective means for the prevention and control of bacterial infection, their indiscriminate use can have adverse consequences by promoting the selection and prevalence of drug-resistant microbial populations (Braude, 2004 and Threlfall *et al.,* 2006). The problem may be due to the natural resistance of species to certain antibiotics (Allison and Gilbert, 2011), possible transfer of antibiotic resistance genes among species, and the use of sub therapeutic doses of antibiotics in animal feeds to improve animal productivity, which could also select for resistant strains. This is believed to be largely responsible for the emergency of drug resistance bacteria (Dupont and Steele, 2007). Piddock (2006) suggested 3 possible ways in which the use of antibiotics could pose a risk to human health and these include; (a) antibiotic resistant pathogens in animal are selected, food products then become contaminated during slaughter and /or food preparation, the food is then ingested causing infection which requires antibiotic therapy and therapy is then compromised due to resistant strains; (b) resistant non-pathogenic bacteria are selected in animals transferred to humans via consumption of contaminated food products and resistant genes are subsequently transferred to other bacteria in the gut; (c) antibiotics which may remain as residues in animal products such as meat and milk can also lead to the selection of resistant bacteria in the consumer of the food products (Piddock, 2006) .

In this study, *Shigella flexneri, Salmonella typhi, E. coli, Pseudomonas aeruginosa* and *S. aureus* were all resistant to amoxicillin, ceftazidine, cefotaxime, ceftriaxane, trimethoprim–sulfamethoxazole and kanamycin but susceptible to imipenem, gentamycin and ciprofloxacin. This is in line with the work of Iroha *et al.*(2010). They are known to harbor series of antibiotic resistance genes which can be transferred horizontally to other bacteria species (Ogba *et al.,* 2022; John-Onwe *et al.,* 2023a; Nomeh *et al.,* 2023; Oke *et al.,* 2024b; Nwojiji *et al*., 2025b). Their resistance to the cephalosporins may be due to the production of beta lactamase enzymes, this enzymes are known to inactivate antibiotics especially the beta lactams (Orji *et al.,* 2024; Ogba *et al.,* 2022). Resistance observed in other antibiotics classes may also be by other mechanisms which may be by drug efflux where drug are forcefully pumped out of the cell thereby allowing a sub-inhibitory concentration to penetrate the cell wall of this organisms (Ogba *et al.,* 2022; John-Onwe *et al.,* 2023a), it may be as a result of a point mutation that has occurred in these bacteria thereby allowing the organism to acquire additional structure that will inhibit drug action (Nwosu *et al.,* 2023).

The Multiple Antibiotic Resistance Index (MARI) of the isolated bacteria from different samples ranged from 0.67 to 1, indicating that these bacteria originated from an area with high antibiotic usage. This finding contrasts with the report by Kuan *et al*. (2017), where bacterial isolates in Malaysia exhibited lower MARI values (0.11–0.56). The elevated MARI values observed in this study pose a significant public health threat due to the increased resistance to multiple antibiotics.

The study’s limitations, such as the restricted sample size and reliance on phenotypic methods, suggest the need for broader, molecular-based research to fully elucidate resistance patterns and transmission dynamics. Despite these limitations, the findings provide critical insights into the risks posed by contaminated meat products and the urgent need for improved hygiene and antibiotic stewardship.

In conclusion, this study confirms that raw and processed meats in Abakaliki are reservoirs of antibiotic-resistant pathogens, emphasizing the need for comprehensive food safety measures. Addressing these issues requires collaborative efforts among stakeholders to enforce hygiene standards, regulate antibiotic use in animal husbandry which are essential for the control of further emergency of antibiotic resistance, and educate consumers and handlers on safe meat practices. Future research should expand on these findings to monitor trends and evaluate the effectiveness of interventions.

**Conclusion**

The study revealed significant bacterial contamination in both raw and processed meat samples sold in Abakaliki, Nigeria, with the highest bacterial count observed in raw beef from Slaughter House Ogoja Road (6.5 × 107 cfu/g) and the lowest in raw beef from supermarkets (1.1 × 106 cfu/g). The most prevalent pathogen was *E. coli* (20%), while *Shigella flexneri* species had the lowest occurrence (12.73%). Antibiotic susceptibility testing indicated widespread resistance among isolates to commonly used antibiotics such as amoxicillin, ceftazidime, and cefotaxime, with susceptibility retained only for imipenem, gentamicin, and ciprofloxacin. The high Multiple Antibiotic Resistance Index (MARI) values (0.67–1) suggest frequent antibiotic use in the study area, posing a serious public health risk. These findings underscore the urgent need for improved hygiene practices and stricter regulations in meat handling and processing to mitigate the spread of antibiotic-resistant pathogens.

**Recommendations**

1. **Enhanced Hygiene Practices**:
2. Implement strict hygiene protocols for butchers and meat handlers, including regular handwashing, use of gloves, and sanitization of tools and surfaces.
3. Provide training programs on food safety and proper meat handling for slaughterhouse workers and retailers.
4. **Regulatory Measures**:
   1. Enforce regular health inspections and quality control checks for meat products in markets and slaughterhouses.
   2. Establish penalties for non-compliance with hygiene standards to ensure accountability.
5. **Antibiotic Stewardship**:
   1. Regulate the use of antibiotics in livestock to curb the emergence of resistant strains.
   2. Promote alternatives to antibiotics, such as vaccines and probiotics, in animal husbandry.
6. **Public Awareness**:
   1. Educate consumers on safe meat handling, proper cooking temperatures, and storage practices to reduce the risk of foodborne illnesses.
   2. Launch campaigns to raise awareness about the dangers of antibiotic-resistant pathogens.
7. **Infrastructure Improvements**:
   1. Ensure slaughterhouses and markets have access to clean water, waste disposal systems, and sanitary facilities.
   2. Provide protective gear (e.g., hairnets, aprons) for workers to minimize contamination.
8. **Research Expansion**:
   1. Conduct larger, longitudinal studies to monitor trends in bacterial contamination and antibiotic resistance.
   2. Incorporate molecular techniques to identify resistance genes and transmission pathways.
9. **Policy Implementation**:
   1. Collaborate with local authorities to enforce existing food safety laws and introduce new policies where gaps exist.
   2. Support community-based initiatives to improve meat safety from farm to table.

By addressing these recommendations, the risks associated with contaminated meat products can be significantly reduced, safeguarding public health and ensuring food safety in Abakaliki and beyond.

***Authors’ contributions***

*Author J.O.O, wrote the manuscript; I.J.N., and P.U. E., organized the study designed and reviewed the manuscript; A. E., provided edits; I.P.O., improved the discussion; U.C.A and OU., generated results by analyzing data; O.O.A., prepared figures; P.U. E., and O.O.A., provided statistical analysis; I.J.N., created tables; OU., and U.C.A., reviewed the manuscript; J.O.O., supervised the project, reviewed, and edited the manuscript. All authors have read and agreed to the published version of the manuscript*

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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