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Review

Assessment of bacterial and fungal contamination in Suya – a public health concern

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ABSTRACT

Ready-to-eat meat products offer numerous benefits, but improper handling can pose severe threats to human health. Due to its short life span, there is a need for adequate handling and preservation to prevent microbial contamination. Suya, a popular ready-to-eat meat product consumed in Nigeria, can be a major source of food poisoning if not processed and handled properly because it can predispose its consumers to pathogenic microorganisms, heavy metals which result from contaminated water and utensils used during processing, and polycyclic aromatic hydrocarbons from the incomplete combustion during roasting of the meat. *Staphylococcus* spp., (95.2%), *Escherichia coli* (90.5%), *Bacillus* sp. (66.7%), *Salmonella* (55%), *Klebsiella* sp. (52.4%) were the most identified bacteria contaminants. While *Aspergillus* spp. (commonly *flavus*, *niger,* and *fumigatus*) were identified in all 11 reports that identified fungal contamination, followed by *Penicillium* spp., (81.8%), *Rhizopus* spp. (63.6%), *Mucor* spp. (54.5%) and *Candida albicans* (45.5%). Infestation by *Taenia sp* (67%), *A. lumbricoides* (50%), *E. histolytica* (41.7%), *G. lamblia* (25%), and Hookworm (16.7%) were also identified. Microbial contaminants were also identified in spices meant to supplement and improve suya's organoleptic and nutritional value. Microbial isolates from suya samples displayed resistance to some commonly used antibiotics, raising concerns about antibiotic resistance development. Suya is one of the unsafe ready-to-eat meat products to consume in Nigeria due to the unhygienic practices during its processing and packaging, such as bare-hand contact, exposure to vehicular emissions, or other environmental contaminants, and packaging in inked papers with contaminants, which makes it unfit for human consumption. This review underscores the importance of identifying and addressing these areas of contamination during suya preparation, production, packaging, and consumption. There is a dire need to educate suya vendors, consumers, and policymakers on food safety and the need for hygienic practices during suya production to safeguard public health.

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1. Introduction

Globally, meat serves as food and is a rich source of essential micronutrients, fats, minerals, and protein that are required for growth and healthy living. Due to its short shelf-life and the essential nutrients which promotes microbial growth, there is a need for

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adequate preservation and proper handling during processing (1–4).

The growth of the fast-food chain has brought about a high demand for ready-to-eat meat products. Ready-to-eat meat products also serve as snacks and delicacies during social events or relaxation. However, the lack of appropriate regulations for fast food ventures poses a significant public health risk. There is a very poor or nonexistent reporting system for food-borne illnesses. Hence, most food-borne illnesses or poisoning go unreported, leaving other unsuspecting consumers to go through the same fate (5).

Ready-to-eat meat products, prepared as kilichi, tsire, or suya, from either beef, poultry, or mutton and spiced with locally sourced condiments (groundnut oil, pepper, ginger, garlic, groundnut cake, salt, and seasoning) are common local market food products across many African countries (1,2,6,7). Suya is often prepared, staked on sticks, spiced, and roasted on hot charcoal (3,8,9).

Earlier reports have identified the presence of pathogenic microorganisms, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) in suya sold and consumed in Nigeria (1,8,10). The introduction of heavy metals might result from water and contaminated utensils used during processing. While PAHs might have been generated during incomplete combustion during the roasting of the suya meat. In an earlier report of PAHs in four commonly roasted food products (suya, plantain, fish, and yam), roasted plantain had the highest concentration of PAHs (0.0465 mg/kg), followed by suya (0.0372 mg/kg), which were above the permissible limits (11). Suya is also listed as one of the unsafe ready-to-eat food products to consume in Nigeria due to the unsanitary environment it is prepared and the unhygienic practices of some of the vendors (12).

Prepared suya is often served with some slices of onions, cabbage, tomatoes, and/or cucumber to improve its nutritional value, organoleptic and antioxidant properties. Most suya vendors who can be seen in various city corners and public places have little or no formal education. Hence, the challenge of knowing about hygienic practices in food handling and sustaining the same (3,13). There is little or no provision for required storage or cooking facilities, utensils sterilization, quality water access, or waste disposal. The vendors are also fond of handling the meat products with bare hands, no hair covering or apron, talking (whereby some might mistakenly spit, sneeze, or cough), and taking money from consumers while processing the food (3). Likewise, it is common practice that consumers also touch suya (spread in an open space) with unwashed hands while making their preferred choice. These food products are often hawked or prepared in unsanitary locations along roadsides or public places where they can be exposed to vehicular emissions, environmental contaminants, or other human activities (4). These and many others are public health concerns about suya's nutritional value and unhygienic standards during its preparation, processing, and packaging (2).

Good packaging material for food products must be environmental-friendly, and retain optimal thermal, shelf-life, and organoleptic properties. Suya is often wrapped in inked papers or old newspapers collected from different sources, which are sometimes dirty, dusty, or contaminated by previous exposure to chemicals, insecticides, and/or improper handling (1,2). After purchase, the packaging materials (often newspapers and nylon) are often discarded on the streets as the vendors do not provide waste disposal bins contributing to the looming environmental pollution.

Contamination has been shown to occur at the point of procuring and transporting raw meats, processing, selling, packaging, and storage (14,15). Sadly, the spices (which contribute to the nutritional value) used during the preparation and packaging of suya are also potential sources of contamination (16,17). Hence, identifying and addressing these areas of contamination during suya preparation, production, and consumption is very important. Several studies have examined the microbial contamination in suya and spices used across several states in Nigeria (14–17). This review aims to identify the safety level of suya (and the spices used) sold and consumed across Nigeria. The findings of this review would help to evaluate compliance and to create awareness among regulatory authorities; the National Agency for Food and Drug Administration and Control (NAFDAC) and Standard Organization of Nigeria (SON), policymakers, and most importantly, suya vendors and unsuspecting consumers about this public health concern and suitable means to get the best out of suya production and consumption. Policy briefs can also be generated from the findings of this review to sensitize suya vendors and consumers on ready-to-eat food safety, quality, and hygiene.

2. Materials and Methods

A literature search was conducted in April 2022 on PubMed and Google Scholar using the following search term "Ready-to-eat meat products," "Suya," AND/OR "Kilishi," "Suya spices," "Metagenomics analysis," "Bacterial contamination," "Fungi contamination" and "Nigeria". Exclusion criteria were review papers, preprints, and articles with no full text or that do not meet the study objectives. After evaluation, twenty-seven selected articles representing all six geopolitical zones in Nigeria focusing on microbiological contamination of suya and/or suya spices met the study's inclusion criteria (Supplementary S1). Bacteria and fungi contamination were presented as total bacteria, coliform, and fungi count in cfu/g from each study.

3. Assessment of contamination in Suya

Just as it goes in a Yoruba adage, "What a bird eats, it flies with." Food is essential for human survival as it provides the nutrient required for the optimal functioning of the human body. Increased human population, rural-urban migration, industrialization, increased work demand, limited time for personal food preparation, community and family values, and many other factors have contributed to the increased demand for ready-to-eat or fast-food products (1,3).

3.1. Health benefits of the spices and other fruits sold with suya

Spices are used to supplement food products to improve their nutritional quality and organoleptic properties. Spices have also been shown to have antimicrobial properties, prolonging the shelf-life of food products. Spices used in suya preparation are often composed of ginger, garlic, nutmeg, cayenne pepper, paprika, onion, etc. Proximate analysis of suya spices sold in Ibadan identifies carbohydrate (48.6 %), crude protein (11.4 %), fiber (11.2 %), and ash contents (9.1 %) but low moisture (9.3 %) and fat (11.7 %) contents (17). An earlier report (18) also identified mean percentage of moisture (24 – 48 %), crude protein (24.6 - 46.3 %), fat (8.8 - 17.3 %), carbohydrate (0.1 - 14.6 %), crude fiber (5.3 - 8.8 %), and ash (1.1 - 2.5 %) contents in thirty-six suya samples sold in Kano state, Nigeria.

Suya is also garnished with slices of onions, cucumber, tomatoes, and cabbage (19). Vegetables and fruits are rich sources of vitamins, dietary fiber, minerals, and essential nutrients and thus contribute to suya's nutritional quality. Their antioxidant potential can also assist in mopping up PAHs generated during the roasting of the meat product. Incorporating suya spices and fruits into the diet, along with the lean meat, offers a flavorful and nutritious meal option as well as antimicrobial properties, nutrient-rich meals, low-fat content, improved digestive health, immune support, and nutrient diversity.

3.2. Microbial contamination

Microbes are ubiquitous and thus can be present just anywhere. The microbial quality of a food product is an index of the degree of safety and hygienic practices adhered to during its preparation (20). Microbial contamination is the leading cause of food poisoning, spoilage, and associated illnesses (17). It has been reported (1) that meat products' microbial contamination often occurs at the abattoir, even before processing and dressing. Where cattle carcasses are laid on untreated surfaces and washed with the available water, which might be unhygienic, improper handling, dirty standards during processing, unsterilized equipment or utensils, and unavailability of standard storage facilities can predispose meat products to microbial contamination (3,5). Storage conditions, temperature, atmospheric conditions, pH, moisture content, and availability of nutrients are factors that promote microbial contamination (21,22). Insufficient heating during suya processing also promotes microbial growth as *E. coli* count, when well heated, was reduced from 3.3×10^6/g in raw suya meat to 3.3×10^4/g in processed suya (23). This corroborates another report (24) where total viable, staphylococcal, and coliform counts were reduced in raw suya meat (before processing) and after processing. The level of parasite contamination is also drastically reduced with adequate heating (8).

The poor hygienic practices of vendors can also be a source of microbial contamination (1,4). In Nigeria, most fast-food joints prepare food under unsanitary and unregulated conditions. Most food vendors handle food and money with bare hands and do not wear aprons or use hair covering during food handling. It is also common to use dirty packaging materials, while some blow air directly into polythene bags used in packaging food products (2). In a study of suya samples gotten from 20 different locations in Jos, Nigeria (5), the highest prevalence of bacterial contamination was reported from places with increased vehicular movement.

Vendors' unhygienic practices and vectors such as flies are culpable in suya .contamination by Salmonella spp. and *Escherichia coli* (2,25). In a comparative study (4), suya hawked by vendors were found to contain more pathogenic bacteria (*Bacillus subtilis*, *Enterobacter* *aerogenes, Escherichia coli, Staphylococcus aureus,* and Lactobacter species) compared to those sold at a spot (*Bacillus subtilis*, *Enterobacter aerogenes*, and *Escherichia coli*). To get buyers' attention, hawked suya are often not covered and are exposed to vehicular emissions, dust particles, flies, and other environmental contaminants (4).

The Public Health Laboratory Service Guidelines adjudged > 10^5 and 10^3 cfu/g as unacceptable limits for Salmonella and *S. aureus*, respectively, in ready-to-eat food products (2,4). From the 21 studies used in this review that reported bacteria contamination, 95.2 % identified contamination with *Staphylococcus spp*., *Escherichia coli* (90.5 %), *Bacillus sp*. (66.7 %), Salmonella (55 %), *Klebsiella sp*. (52.4 %), *Pseudomonas spp*. (42.9 %), *Shigella sp*. (33.33 %), *Streptococcus sp*. (33.33 %), *Proteus sp*. (23.8 %), *Enterobacter sp*. (23.8 %), Micrococcus (9.5 %) and Enterococcus (9.5 %) contamination of suya samples. Serratia, *Providencia sp., Yersinia pestis, Listeria monocytogenes,* Lactobacter, and Lactobacilli were identified (Fig. 1).

The total aerobic bacteria count of suya meat samples was 1.5 – 5.9 times higher than those observed in raw meat samples (25). This corroborates another report whereby *Staphylococcus aureus* contamination was not found in raw suya meat but in processed suya meat (23). In contrast, the least level of contamination was reported in ready-to-eat suya, while the highest microbial contamination was reported in fresh raw meat and hawked suya (26).

Coliform is an index of microbial quality and food safety. Their presence in suya samples depicts contamination via water used during processing or unhygienic practices of vendors (19). *Escherichia coli*, *Salmonella spp., Shigella spp., and Klebsiella spp.* are part of the normal flora found in the intestinal tracts of livestock and warm-blooded animals (13). Their presence in suya samples depicts fecal contamination, which might be due to poor personal hygiene and contaminated water used during slaughtering and preparation (3,19,23,25). *E. coli,* an indicator of fecal contamination, spread majorly through water and is a causative agent of gastroenteritis (3,13,23). Toxin-induced food-borne ailment has been linked to the ingestion of about 1 – 5 micrograms of toxins (27). Hence, microbial load in ready-to-eat meat products above the permissible limit is a health risk and undesirable.

All fifteen suya samples from three locations in Kano state, Nigeria, were contaminated with *E. coli, Klebsiella sp.,* and *S. aureus* (28). The presence of *Staphylococcus spp.* (normal flora found on human skin and nose), reported in most studies reviewed, depicts contamination due to improper handling (10,13,15,21,25). In a study (29) of suya samples from Ado-Ekiti and Akure, two major state capitals in Nigeria, Staphylococcus spp. were identified in all the suya samples tested. Another report from Ekiti and Kano states that *Staphylococcus aureus* also had the highest percentage occurrence, 65 %, and 43.5 %, respectively (22,30). It was found to be more predominant in suya than in raw meat samples, which

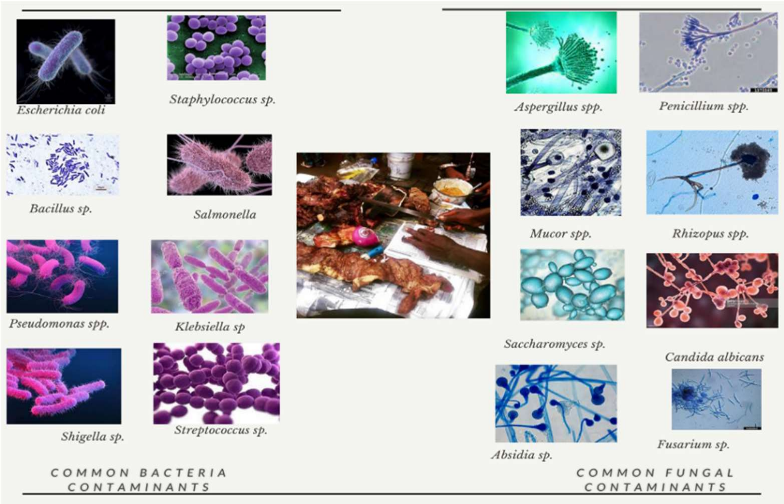

Figure 1. Most prevalent bacterial and fungal contaminants identified in suya samples sold and consumed in Nigeria.

could be attributed to contaminated spices or improper handling during processing (25). The microbial quality of the starting raw meat material can contribute to that of the final product (19). As earlier stated, suya vendors and consumers are fond of handling meat products with bare hands and unsterilized equipment, thereby predisposing the meat products to *Staphylococcus spp.* contamination (22,29). An individual can be exposed to *Staphylococcus spp.* infection by consuming contaminated food products. Toxins produced by the enterotoxigenic strains of *Staphylococcus spp.* can result in toxic shock and/or food poisoning (3,20,21).

Bacillus cereus, commonly found in water and soil, can generate enterotoxins that cause diarrhea and vomiting (10). Contamination with *Bacillus cereus* was identified in all the six selling locations studied in Bonny, Rivers state. *Pseudomonas spp.* found in air or dust particles, soil, and water are the index of environmental contamination (13). Suya samples might get exposed to *Pseudomonas aeruginosa* due to settling dust particles in the environment, inked papers, or nylons used in packaging the meat product (15,25). With a high total viable bacterial count (1.9 - 3.8 x 10^3 cfu/g), *Staphylococcus spp.* (35 %) and *Pseudomonas spp.* (35 %) were the most observed bacteria isolates from 12 suya samples in Enugu, Nigeria (15). Suya's quality varies from one vendor to the other (31). This implies that most microbial contaminants can be well managed if appropriate regulatory and safety measures are implemented.

All 11 studies that reported fungi contamination identified *Aspergillus spp.* (commonly *flavus*, *niger*, and *fumigatus*), while 81.8 % identified *Penicillium spp.*, *Rhizopus spp.* (63.6 %), *Mucor spp.* (54.5 %), *Candida albicans* (45.5 %), *Saccharomyces sp.* (27.3 %), *Fusarium sp.* (27.3 %), *Absidia sp.* (18.2 %), *Rhodotorula sp.* (18.2 %), *Cladosporium sp.* (18.2 %) and *Cunnighamella sp.* (9.1 %). Fungi produce mycotoxins which are deleterious to human health. Chief among them are aflatoxins produced by the *Aspergillus* species (3). Others are fumonisin and ochratoxin A. All the studies recruited in this study that identified fungi in suya samples reported contamination by the *Aspergillus* species (22,31,32). *Aspergillus niger*, *Aspergillus flavus*, and

Aspergillus fumigatus are ubiquitous. Their presence in suya depicts environmental contamination (22). *Aspergillus niger* (66.7 %) and *Penicillium spp.* (33.3 %) were the identified fungal contaminant in suya sold in fifteen suya samples sold in Kano state (22). This corroborates another report where *Aspergillus niger*, *Candida tropicalis*, and *Mucor spp.* were the most identified fungal contaminants in a study of 20 suya samples obtained from ten different locations in Niger state (32). *Aspergillus flavus* and *A. parasiticus*, also identified in the study, produce aflatoxin B1, B2, G1, and G2, which are implicated in food poisoning (32). The International Agency for Research on Cancer has classified aflatoxin as a class 1 carcinogen, i.e., it has the potential to cause cancer. Hence, a serious public health concern.

High moisture content contributes to increased fungal growth in meat products. Fifty-one fungal isolates with a total fungal count of 2.2 – 3.8 x 10^4 sfu/g and high moisture content (24 – 48 %) were identified in a study of thirty-six suya samples sold in Kano (18). The vendor's unhygienic practices, poor storage conditions, and use of contaminated spices and utensils can also predispose suya to fungal contamination (13,32).

Beef infested by *Taenia saginata* can survive the temperatures used during suya preparation and thus can be viable in human consumers (2). In a study of 240 suya samples sold and consumed in Benue state, infestation by *Taenia sp* (67 %), *A. lumbricoides* (50 %), *E. histolytica* (41.7 %), *G. lamblia* (25 %), and Hookworm (16.7 %) were reported, this poses a severe public health concern to unsuspecting consumers (8).

3.3. Spices contamination

Spices with high microbial content can contribute to the microbial load of food products intended to supplement (16,19,26,33). This makes contaminated spices a risk to consumers' health (19). They may become contaminated during harvesting or inadequate storage or preservation, and unhygienic practices of vendors or consumers (33).

Contamination with *Escherichia coli*, *Salmonella spp.*, and *Clostridium perfringens* was reported from a study of 20 spices used during suya production in Kano state (16). There was a staphylococcal count of 1.73x10^7 cfu/g and 1.04x10^5 cfu/g fungal count, beyond the permissible limit. A recent report on twelve suya spices obtained from twelve different locations in Rivers state (34) identified contamination with *Staphylococcus spp.* (44.4%), *Bacillus spp.* (35.2%), *Salmonella spp.* (11.1%), *Enterobacter sp.* (3.7%), *Streptococcus sp.* (3.7%) and *Shigella sp.* (1.9%). *Aspergillus niger, Aspergillus flavus, Aspergillus parasiticus, Aspergillus ochraceus, Fusarium sp., Rhizopus stolonifer,* yeast, and *Trichoderma koningii* were identified in a study of fungal contamination of suya spices gotten from five (5) different locations in Ibadan (17). Save the controls (negative for aflatoxin B1, B2, G1, and G2). All the samples had aflatoxins; aflatoxin G1 was found in 67 % of the samples, while aflatoxin B2 and aflatoxin G2 were found in 33 % of the samples. A lethal dosage (> 20 μg/kg) of aflatoxin B1 was reported from two of the four locations studied (17). The concentration of aflatoxin and microbial contamination differs with location (16,17,34). This points to the absence or non-adherence to regulatory standards to aid hygienic practices during suya processing. The microbial load was significantly decreased when exposed to heat using a microwave oven (from 0 to 60 s) (34). Most of these microbial contaminants are the index of unhygienic practices during meat preparation, suya processing, and preservation, and they are of public health significance. Spice contamination is not only a Nigerian market problem. Like Salmonella, coagulase-positive *Staphylococcus aureus* and *Bacillus cereus* were present in food spices sold and consumed in Turkey though at the permissible limit (33).

3.4 Antibiotic susceptibility of a microbial contaminant in suya

Microbial contamination of suya above permissible limits poses a health hazard risk (35). The use of antibiotics is an appropriate food safety measure after infection. However, resistance to commonly used antibiotics is a growing public health concern that requires concerted effort (35).

Most of the studies in this review used the disc-diffusion method to ascertain the antibiotic susceptibility of the microbes identified in the suya samples tested. In an antibiogram, for microbes isolated from spices sold in Turkey (33), *Salmonella spp.* was found to be resistant to Vancomycin (100 %), Erythromycin (100 %), and Penicillin G (100 %). Likewise, *Listeria monocytogenes* in the spices were resistant to Nalidixic acid (100 %), Ampicillin/Tetracycline/Penicillin (66.7 %), and Gentamicin/Amoxicillin (33.3 %).

E. coli was resistant to Streptomycin and Chloramphenicol but sensitive to Gentamycin, Ciprofloxacin, Augmentin, Pefloxacin, Septrin, Tarivid, Amoxicillin, and Sparfloxacin (19). In another report (24), *E. coli* isolated from the suya sample sold in Nigeria was also found to be sensitive to Gentamicin but resistant to Ciprofloxacin, Ofloxacin, Erythromycin, and Streptomycin. Meanwhile, *Bacillus cereus* was resistant to Streptomycin but sensitive to other antibiotics. *Staphylococcus aureus* was also resistant to Gentamicin and susceptible to other antibiotics (24). In contrast, *Staphylococcus aureus* was resistant to both Ampiclox and Amoxicillin but sensitive to Gentamicin and other antibiotics tested (19).

Despite different sensitivity rates, all bacteria (*E. coli*, *B. cereus,* and *S. aureus*) isolated save for the *Pseudomonas aeruginosa* were sensitive to the three spices: Afromomum melegueta, Capsicum fructescens, and Piper quineense (24). The use of these spices in suya processing is highly recommended. However, the resistance of *Pseudomonas aeruginosa* to all spices is a great concern due to its role in meat spoilage (24).

All bacteria identified (*S. aureus, Streptococcus spp., Enterobacter spp., Bacillus spp.*, and *E. coli*) were resistant to Retafumurin and Cefotaxime, while half (50%) to Norfloxacin, Ciprofloxacin (25%) and Levofloxacin (10%) (30).

Klebsiella pneumoniae from suya samples were highly resistant to Ampiclox and Erythromycin (35). *Shigella sp.* (60%) and *S. aureus* (30%) had the highest susceptibility profile among all the bacterial isolates from suya (35). Although with varied inhibition profiles, the antibiotics' broad-spectrum activity looks promising (24,33,35). Their usage in addressing microbial contamination after suya consumption is advocated.

Klebsiella spp. and *Pseudomonas spp.* were resistant to only two classes of antibiotics. Others (*E. coli, Enterobacter spp., Shigella spp., Proteus spp.*, and *Bacillus* *spp.*) exhibited multidrug resistance (36). Meanwhile, *E. coli* had the highest prevalence of multidrug resistance phenotype (21.7 %). This corroborates another report where *E. coli* (97.5 %) also demonstrated multidrug resistance (14). There is a dire need for community-based health education against antibiotics abuse, indiscriminate use, and misuse to address the looming antibiotic resistance.

4. Conclusion

The studies reviewed in this analysis have shed light on the microbial contamination of suya, a popular ready-to-eat meat product in Nigeria. However, a significant limitation identified in these studies is the use of standard microbiological methods for microbial identification. While these microbiological methods have advantages in microbial identification, they also come with shortcomings, and more advanced approaches like metagenomics using Next Generation Sequencing or 16S/ITS identification via Sanger sequencing would have been preferable. The metagenomics approach, in particular, would allow for the identification of all microbial communities in the tested samples, not limited to those identified by culture-based methods. This would enable the detection of potentially pathogenic microbes that may be present in the tested samples, providing a more comprehensive understanding of their safety.

Caution must be exercised during spices preparation and suya supplementation to prevent the addition of unwanted microbes into ready-to-eat meat products. To curtail meat contamination, there is a dire need to educate food and suya vendors on hygienic practices pre- and post-production chain (animal care, slaughter, transportation, equipment sterilization, processing, packaging, and storage). Vendors' hygiene and adequate knowledge about environmental sanitation would play a major role in ensuring food safety. The lack of regulatory and aseptic standards in suya preparation and vending accounts for inconsistent product quality variations. Regulatory agencies responsible for food safety should intensify their surveillance efforts to curb unhygienic practices among food vendors and ensure compliance with established standards. By doing so, we can safeguard the health and well-being of the unsuspecting populace and promote a safer and healthier environment for all.

Conflict of interest

The authors declare no conflict of interest.

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