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Review paper

Health hazards associated with ready-to-eat-meat in Nigeria: A call for public concern and critical interventions

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A b s t r a c t: Scientific investigations on the type of ready-to-eat (RTE) meat popularly called Suya and sold in Nigeria are generating scientific and public concern due to microbial and chemical hazards associated with the products. This review evaluated the safety profile of Nigerian RTE meats, with special focus on Suya as a potential source of microbial, heavy metal and polycyclic aromatic hydrocarbon (PAH) food hazards. Assessments of outcomes of research articles on safety of RTE meat published from 1984 to 2019 were carried out using electronic databases and key word searches. Research outcomes were categorised into six sections representing the six geopolitical zones (South-south, South-east, South-west, North-east, North-west and North-central) of Nigeria. Virtually all research findings in various zones revealed microbial, heavy metal or PAH levels on RTE meat were higher than permitted limits and acceptable standards. The unhygienic activities of most meat slaughterers (sources of raw meat), processors (who prepare and package RTE meat) and vendors (involved in display and hawking processes) are major contributing factors to microbial and chemical hazards. To this end, adequate safety and sanitary measures are suggested and other essentials should be implemented by designated authorities and relevant stakeholders to ensure the menace posed by unhygienic RTE meat is curtailed drastically.

Keywords: *RTE meat, safety, microbiological contamination, chemical contamination, Nigeria.*

Introduction

Meat refers to animals' flesh (skeletal muscles) and other parts such as fats, liver kidney, heart, lung, brain, intestine, and connective tissue that serve as food (*Olayinka and Sani*, 2014). Worldwide, including in Africa and Nigeria, meat is considered a rich source of protein and essential micronutrients that are needed for growth and good health for people in various socio-demographic categories, including the young, old, rich and poor (*Olayinka and Sani*, 2014). The majority of the Nigerian populace depends on livestock for food and livelihood (*Elelu et al.*, 2019). Meat requires adequate preservation due to its short shelf life (*Olaoye et al.*, 2016). On the other hand, meat has essential nutrients that support microbial growth and metabolism when adequate preservation and hygiene is not maintained (*May et al.*, 2003; *Eke et al.*, 2013; *Nwakanma et al.*, 2015).

Globally, it has been assessed that about 600 million (1 in 10) persons annually are predisposed to foodborne disease, resulting in about 420,000 deaths every year and foodborne diseases consume about US$ 3.6 billion yearly (*Ezirigwe*, 2018; *WHO*, 2015). From the World Health Organization (WHO) assessment, about 200,000 deaths annually due to diarrhoea result from food poisoning (*Afolabi and Odubanjo*, 2015*; WHO*, 2019).

Nigeria is the most densely populated nation in Africa, with a population of about 185 million distributed over 250 ethnic groups (*WHO*, 2019). The greater

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proportion, 52% of the populace, resides in rural areas while 48% reside in the cities (*Akinlua*, 2015). The country has six geopolitical zones, North-west (NW), North-east (NE), North-central (NC), South-west (SW), South-east (SE) and South-south (SS), which are distributed over 36 states (*Akinlua et al.*, 2015).

In Nigeria, waterborne diseases such as diarrhoea, typhoid and cholera resulting from food poisoning are a major public health concern. The Nigerian Federal Ministry of Health reported roughly 90,000 cases of food poisoning in 2007 (*Osakue et al.*, 2016). This is substantiated by the increasing human population, rural-urban migration and industrialisation, environmental pollution, poverty (*Osakue et al.*, 2016) and over-reliance on ready-to-eat (RTE) food, due to individuals' busy schedules and lack of time to properly prepare their meals. This is supported by an increase in the number of outlets selling RTE food in various locations (*Izah et al.*, 2017). In the interest of saving money for a rainy day, most of the populace, including travellers, school children and low-income earners, patronise RTE food vendors, but pay scarce attention to safety issues, quality and hygiene (*Ezirigwe*, 2018).

Presently, the nutritional standard of most RTE meat, especially Suya, is low due to poor handling conditions leading to contamination with air microbiota, other microorganisms and chemicals in excess of safe limits during butchering, processing, packaging and vending (*Osakue*, 2016).

Studies by authors in various locations in Nigeria have revealed that heavy metals, polycyclic hydrocarbons (PAHs) and microorganisms are major sources of contaminants on RTE Suya meat, and this is of public health significance in initiating reductions of foodborne diseases (*Nwakanma et al.*, 2015*; Folorunso et al.*, 2018).

To this end, this review attempts to provide an update on the safety status of RTE meat sold in Nigeria. The outcome of this review will provide useful information to the general public and health institutions on the risks associated with the intake of bacteria- and heavy metal-contaminated Suya meat. Also, improved strategies to prepare hygienic Suya for human consumption and avoid the public health menace of highly contaminated product are suggested.

Methodology

The study constitutes a literature survey of the microbial, heavy metal and PAH contamination of RTE meat sold in various geographic zones in Nigeria published in scientific journals between 1984 to June 2019. Electronic databases (Google scholar, Pubmed, Science direct, and Medline) were accessed using the following search terms; Suya, ready to eat meat, heavy metal contamination of Nigeria Suya meat, bacterial contamination of Suya meat. Manual searches of reference lists from papers downloaded on these related topics were also performed to uncover additional related studies missed by the search engines. The last search was carried out on 28 December, 2019. Probable health implications of microbial and heavy metal contamination and measures to prevent contamination were also searched for using search engines. Relevant measures to curtail contamination and improve the quality of RTE meat in Nigeria are suggested.

Description of RTE meat

RTE meat can be described as well-prepared animal tissue which does not require further preparation before consumption (*Okoli et al.*, 2018). RTE meats can be formulated to be street delicacies prepared from boneless or entire beef, lamb or pork meat with added spices, salts, flavours and vegetables followed by roasting under charcoal fire (*Eke et al 2013; Olaoye et al.*, 2016). In Nigeria, these meats occur in various forms: skewer meat or Suya (tsire, boneless, spiced and barbequed), kilishi (dried meat similar to Suya but un-spiced), pork as well as chicken and goat meat (chevon) (*Fasoyiro 2012; Shamsuddeen and Puma*, 2016). Besides the aforementioned, kanda (Igbo) and tinko (Yoruba), which are dried and unspiced meats obtained from carcasses of rejected or dead animals (buffalo, donkey, cattle etc.), though not used in RTE meats, are widely consumed in Africa (*Adeyeye 2016; Ribah et al.*, 2018). Balangu guru, Kilishi, balangu, kundi, Jirga, ndako and dambunama are Hausa names for processed smoked, roasted or dried meats eaten in Northern Nigeria (*Ogbonna et al 2012; Yusuf et al.*, 2012*; Folorunso*, 2018). RTE meats serve as good sources of proteins, vitamins and minerals for growth, repair and maintenance of tissue cells (*Nwakanma et al.*, 2015*; Adeyeye*, 2016).

Suya, the most popular RTE meat in Nigeria

Suya mostly prepared from beef (or bovine meat) is the most commonly sought after RTE meat in every geographic location in Nigeria, including rural and urban areas. The history of Nigerian Suya meat can be traced to the Hausa/Fulani people of Northern Nigeria and other neighbouring countries, including Cameroon, Niger and Sudan (*Garba et al.*,

2017), where 80% of Nigerian cattle rearing occurs and is a major source of their livelihood (*Ogbonna et al.*, 2012*; Egbebi and Muhammad 2016, Falegan et al.*, 2017).

Suya meat, popular in Northern Nigeria, has spread in popularity to villages, town and cities in other parts of Nigeria, where Suya is now sold in many outlets (*Inyang et al.*, 2005). This is confirmed by the prevalence of Suya vendors in big cities and small towns, where their busy schedules occur between 12 noon until night (*Ogbu et al.*, 2016).

Suya is purchased by people in the street, clubs, restaurants, fast food outlets, picnics, beaches, hospitality venues, hotels and other institutions (*Ahmadu and Aduwa*, 2015). It is also served in homes, at parties and for ceremonies as substitutes for fish and other forms of meat (*Nwakanma et al.*, 2015*; Okoli et al.*, 2018).

The study by *Ahmadu and Aduwa* (2015) on the economic analysis of Suya production in Benin City, Edo State, Nigeria, revealed that small scale Suya production is a profitable venture, where every naira invested could yield a net return of 58,000 naira. A similar study was also conducted by *Iliyasu et al*. (2013) in Northern Nigeria, where there are growing livestock and human populations. Thus, with the increase in population, it is predictable and evident that demand for Suya will increase.

In Suya preparation, carcass parts used include beef meat, kidney, liver and intestine (*Garba et al.*, 2017). Suya meat is prepared by roasting and spicing boneless portions of edible tissues and muscle tissues of animals, and can be eaten alone or in combination with onions, herbs or vegetables. Grinding peanuts into a powder is the first step in the preparation of Suya. After this stage, the peanut powder is thoroughly mixed with ground pepper, garlic and ginger. Meat is then cut into small sizes or thin sheets and rolled in the peanut-spice mixture. In order for the peanut cake to stick together, the pulverised meat is left standing in the peanut-spice mixture for about 40–60 minutes. Thereafter, the meat portions are pushed onto skewers and brushed with vegetable oil. Skewered meat is barbecued or roasted on a charcoal fire for about fifteen to twenty minutes, depending on the intensity of the fire (*Olaoye et al.*, 2016*; Nwakanma et al.*, 2015*; Onuorah et al.*, 2015*; Konne et al.*, 2018). Drying of boneless tissues during this slow roasting aids the loss of moisture and helps prevent spoilage (*Ogbonna et al 2012; Onuorah et al.*, 2015). After processing, Suya is packaged in aluminium foil, newspaper, cellophane or other materials (*Alonge et al.*, 2017).

Studies on heavy metals, PAHs and microbial contamination in RTE meat in various geo-political zones in Nigeria

This study covers our investigation and findings from the six geo-political zones in Nigeria. As highlighted below, the microbial, heavy metal and PAH contents of RTE meat were investigated in various locations in Nigeria.

South-south Nigeria

This geopolitical zone encompasses six states: Delta, Edo, Bayelsa, Rivers, Akwa-Ibon and Cross River (*Akinlua et al.*, 2015). In a study carried out in Delta State, levels of heavy metals (lead, cadmium and mercury) were studied on Suya procured from Warri, Ughelli and Ozoro (three samples from each location). Cadmium and mercury levels in all the Suya were below the maximum levels permitted by WHO. On the other hand, lead content was higher than expected values in Suya procured from Warri (0.125 mg/kg), but lower in Suya from Ughelli (0.060 mg/kg) and Ozoro (0.085 mg/kg). The authors suggested Suya from the selected locations should be monitored to avoid adverse effects (*Ojebah and Ewhre*, 2015).

A comparative bacteriological analysis of Suya meats, hawked and from barbeque stands, was carried out in Ozoro, Delta State. *Enterobacter aerogenes and Bacillus subtilis* were the most prevalent bacteria isolated, while *Staphylococcus aureus* and *Lactobacter* were the least prevalent in the meats. Hawked Suya were more contaminated with pathogenic bacteria, *Bacillus subtilis Enterobacter aerogenes*, *Staphylococcus aureus, Lactobacter* species and *Escherichia coli* than were Suya meats sold on barbeque stands (*Orogu and Oshilim*, 2017).

In 2018, Akpoghelie identified 16 PAHs on smoked fish and grilled Suya meat procured from open markets in the Effurun, Igbudu, Jugbale, Olomoro, Oleh and Ozoro markets, Delta State. The study revealed the levels of PAHs in smoked fish and grilled Suya meats were significantly higher than PAHs in these products when they had been soaked in boiled water. The author concluded the skin or outer layer of fish could serve to bioaccumulate PAHs. Thus, soaking these foods in boiling water for a few minutes could drastically reduce or eliminate PAHs (*Akpoghelie*, 2018).

Eke et al. (2013) assessed the microbiological status of commercial Suya products in Ekpoma, Esan West local government area, Edo State. A total

of 40 Suya samples were collected from 20 randomly selected Suya spots (two samples from each spot). Six bacteria genera (*Staphylococcus*, *Escherichia coli*, *Klebsiella*, *Enterobacter*, *Bacillus* and *Paracoccus*), two moulds and two yeasts were isolated, with total viable counts ranging from 1.0×10^3 to 4.8×10^3 cfu/g. From the study, Suya sold in Ekpoma were potentially contaminated with microorganisms. Eke and co-workers called for the attention of relevant food regulatory authorities on Suya sold in the study locations.

In another study, the microbiological quality and proximate analyses of RTE fried chicken parts sold in eateries and roadsides in three local government areas (Egor, Oredo, and Ikpoba Okha) in Benin City, Edo State, were determined (*Osakue et al.*, 2016). From the study, 13 genera of bacteria and 7 genera of fungi were isolated, with *Proteus* (9.9%)*, Staphylococcus aureus* (9.9%), *Enterobacter* (8.5%) *and Micrococcus* (8.5%) having the highest prevalences. There was no *E. coli* or other hazardous food-borne pathogens in samples procured from eateries. Although, the highest microbial counts were recorded in meats from Ikpoba Okha, aerobic colony counts of bacteria and fungi in all meats were greater than allowed in the international food standards (which call for $<10^5$ cfu/g). The authors recommended the quality of fried chicken sold in these vending sites be improved (*Osakue et al.*, 2016).

In recent times, *Inobeme et al.* (2018) investigated the heavy metal contents of smoked fresh chicken, beef and goat meats from selected areas in Auchi, Edo State. The study revealed the content of metals, (except lead in smoked fish and iron in all samples) was within the safe limits as recommended by WHO. The authors suggested that meat sellers should be advised of the dangers associated with open smoking of public food.

Suya beef alongside samples of frozen and roasted Atlantic mackerel (*Scomber scombrus,* Scombridae), and plantain (*Musa paradiasca*) were randomly selected from three sales points in Amassoma town, Bayelsa State, and screened for the presence of 15 PAHs (*Amos-Tautua et al.*, 2015). Benzo[*a*]anthracene with mean level of 7.23 µg/g was detected in Suya beef, while a significant amount of benzo[*a*]pyrene (2.41 µg/g) and benzo[*b*] fluoranthene (4.51 µg/g) were found in roasted mackerel fish. PAH was not detected in roasted plantain or in the raw food items. The authors concluded that the levels of PAHs in roasted fish and Suya in Amassoma were above the permissible limits (*Amos-Tautua et al.*, 2015). They also suggested that people should not eat the charred skin of roasted fish, meat or poultry so as to reduce their intake of chemical hazards.

In Yenagoa city, Bayelsa State, 18 Suya meats from six communities (three meats from each) were assessed for microbiological quality. Although there was no significant difference in microorganisms from the six communities, six bacteria and four moulds were identified: *Aspergillus niger* (39.7%) was the most prevalent, followed by S*taphylococcus aureus* (28.1%), *Mucor* (11.8%) and *Proteus* (9.3%). *Escherichia coli, Bacillus, Micrococcus, Pseudomonas*, *Aspergillus flavus* and *Penicillium* were the other bacteria and fungi isolated (*Kigigha et al.*, 2016).

The bacterial status and antibacterial susceptibility profiles of selected pathogenic bacteria from eight Suya outlets in Bori city, Port Harcourt, River State, was assessed by Amadi and co-workers. The study revealed that RTE Suya meats were contaminated with a variety of bacterial species. Among 10 bacterial species (comprising six gram-positive and four gram-negative bacteria) isolated, *Staphylococcus aureus* and *Escherichia coli* were the most prevalent (*Amadi et al.*, 2015).

Recently, *Dibofori-Orji and ThankGod (2018)* evaluated heavy metals (iron, lead, cadmium, chromium and nickel) in raw and roasted Suya, sold and consumed in Iwofe, Trans Amadi and Port Harcourt city, River State. The study revealed the Suya studied contained lower than the permitted levels of iron (FAO/WHO permitted level for iron), chromium and cadmium (USDA permitted levels of 1.0 mg/kg and 0.5 mg/kg, respectively), levels of lead and nickel significantly exceeded the FAO/WHO permitted levels of 0.2 mg/kg for these metals.

Konne et al. (*2018*) determined the levels of bacterial contamination in 30 Suya samples from six locations in Bonny local government area, River State. The study revealed the Suya were contaminated with various bacteria, including pathogens: *Bacillus cereus* (10, 34%), *Salmonella* (5, 17%), *Staphylococcus aureus* (1, 3.4%)*, Klebsiella* (2, 6.8%), *Enterococcus* (6, 20%) and *Proteus.*

Microbiological analyses of RTE fish sold in three locations, Ozuoba, Rumuokoro and Ada-George in Port Harcourt revealed the total viable counts, *Staphylococcus* counts, and total coliform counts exceeded the acceptable microbiological standard levels. The authors concluded the locations for roasting the fish, the fish handling and vendors' personal hygiene could have contributed to the microbial loads of the roasted fish (*Odu and Ameweiye*, 2013).

Hazard analyses on two street-vended meat products — Suya and fried clam — popular in Akwa Ibom and Cross River States was carried out by visiting several street vending operations. Categories of foods collected were: raw meats, final products just after processing, after reheating and during holding. The study revealed that aerobic plate counts of the foods increased during handling, processing, storage, and reheating when compared to raw meat procured from the abattoir (*Ekanem*, 2000).

Another study evaluated the microbiological safety of 10 duplicates of different parts of fresh beef meat sold in two major markets (Watt and Marian) in Calabar city, Cross River State. High numbers of pathogenic *Klebsiella pneumoniae*, *Salmonella* and *Escherichia coli*, among others, were found in the fresh meats, which could be health risks for food poisoning. They recommended the populace should adequately cook fresh meat before consumption and the National Agency for Food and Drug Administration and Control (NAFDAC) should also ensure strict compliance of RTE meat producers to the food standard (*Ukut*, 2010).

South-east Nigeria

States constituting this zone are Enugu, Imo, Abia, Ebonyi and Ananbra (*Akinlua et al.*, 2015). In 1990, Sokari and Anozie investigated the occurrence of enterotoxin-producing strains of *Staphylococcus aureus* in 530 meat samples randomly selected from itinerant hawkers in traditional markets and some streets in Port Harcourt (Rivers State) and Enugu State. The study revealed the presence of coagulase-positive *Staphylococcus aureus* on 449 (84.7%) of the products, and among these *S. aureus* strains, 243 (54.1%) produced various enterotoxins, the majority of which were detected on fried beef and Suya rather than on fresh beef. The authors suggested the high level of contamination observed could have resulted from cross contamination due to excessive hand contact (*Sokari and Anozie*, 1990).

In 2002, Chukwura and Mojekwu evaluated the microbiological safety profile of Suya meat sold in various Suya spots in Awka urban area, Anambra State. The study revealed the Suya were contaminated with several genera of bacteria (*Bacillus*, *Staphylococcus aureus, S. epidermidis, Proteus*, *Micrococcus* and *Serratia*) and fungi (*Aspergillus flavus, A. niger, A. fumigatus* and *Fusarium*). A Suya meat collected from Tracas Station had the highest total viable count, of 95.5×10^4 cfu/ml while a lower count of 37.5×10 cfu/ml was recorded for Suya from beside the Ubatel Hotel (*Chukwura and Mojekwu*, 2002).

The bacteriological quality of Suya meats randomly selected from five Suya spots (Eke-Awka, Temporary site, Aroma, Okpuno and Ifite Awka) in Anambra State was evaluated. The following bacteria were isolated from Suya meats: *Escherichia coli*, *Staphylococcus aureus*, *Bacillus cereus*, *Klebsiella aerogenes*, *Pseudomonas aeruginosa* and *Streptococcus pyogenes*. The coliform levels were above the approved limits due to unhygienic preparation and handling, indicating that such Suya meats could pose food safety risks to consumers (*Onuorah et al.*, 2015).

In another study, the bacteriological status of 12 roasted Suya meat samples procured from various roadside marketers in Enugu city, Enugu State was investigated. Bacterial isolates were identified as *Staphylococcus aureus* (35%), *Pseudomonas* (35%). *Staphylococcus aureus* (35%) and *Pseudomonas* (35%) were the most commonly isolated organisms followed by *Escherichia coli* (15%) and *Streptococcus* (15%). The sanitary condition of the Suya sold in those locations was below the required standard for human consumption. The authors suggested that handling by butchers and the use of contaminated water and equipment could be major sources of microbial contamination of the Suya meat (*Nwakanma et al.*, 2015).

The application of seasonings/spices and heating/processing methods on the levels of PAHs were evaluated on fried, roasted and cooked meats in Enugu city. Higher molecular weight PAHs were detected at toxic levels benzo[*a*]anthracene, benzo[*a*] pyrene, chryene and pyrene. Although, cadmium, copper, zinc, lead, chromium and iron present were within permissible limits, cooked meats had the least PAHs followed by fried and roasted meat respectively, indicating that the application of seasonings/spices in meat causes significant increases in the heavy metal content (*Okeke et al.*, 2018).

A recent study by *Okoli et al. (2018)*, on the prevalence, toxigenic potential and antimicrobial susceptibility profile of *Staphylococcus* isolated from roasted and spiced RTE beef, pork, chicken and goat meats in Enugu State, revealed that 9.4% of selected meats were contaminated with *Staphylococcus*. Of these, 79.2% were resistant to fusidic acid, but none were resistant to chloramphenicol, ciprofloxacin, linezolid or teicoplanin. Most of the contaminated samples were from open markets and motor parks rather than from a mechanic village.

In another study, the presence and levels of 11 PAHs in Suya alongside other three commonly consumed roasted foods (freshly roasted plantain, yam and fish) in Owerri municipality were assessed. The study revealed that Suya had the second highest level of PAHs (0.0372 mg/kg) after roasted plantain (0.0465 mg/kg) while roasted fish had the lowest level (0.0135 mg/kg). The authors concluded the levels of PAHs detected in the foods were above the WHO permissible limits and could predispose consumers to potential health risks (*Ogbuagu and Ayoade*, 2012).

The level of 10 PAHs in raw cow hide (ponmo) and lean beef (charcoal grilled Suya meats) obtained from Umuahia main market, Abia State were determined. The study revealed a greater concentration of three PAHs in Suya meats due to direct smoking over open-flame charcoal. The authors suggested adequate measures should be put in place to avoid the carcinogenic effect of PAHs from the smoking on consumers (*Ogbonna and Nwaocha*, 2015).

South-west Nigeria

Locations in this zone are Oyo, Osun, Ekiti, Ogun, Ondo, and Lagos States (*Akinlua et al.*, 2015). In 2008, Edema and co-workers carried out an 8-month microbiological safety survey on Suya samples from six Suya spots in South-west Nigeria between November 2005 and June 2006, with a total of 144 samples (24 replicates per sample). The study revealed microbial contamination in processing water, meat processing slabs, utensils, spices and raw meat. *Bacillus cereus*, *Staphylococcus aureus*, *Salmonella* and aflatoxigenic moulds (*Aspergillus flavus* and *Aspergillus parasiticus*) were potential pathogens isolated from utensils and hands of the producers during slicing, staking onto skewers, spicing and holding at ambient temperature (28±2^{o}C). Based on this study, a critical limit for the critical control points was proposed by the authors (*Edema et al.*, 2008).

Samples of raw meat prior to roasting and Tsire-Suya samples were collected from five locations (University of Lagos, Bariga, Allen avenue round about, Ikeja) in Lagos State and were examined for total viable counts, coliform count, *Staphylococcus* count*,* and *Pseudomonas aeruginosa, Bacillus cereus, Staphylococcus aureus* and *Escherichia coli.* From the study, lower bacterial counts were found in Tsire-Suya than in raw meat. Isolated organisms, except *P. aeruginosa*, were susceptible to the spices (*Afromomum melegueta*, *Piper guinense* and *Capsicum frutescence*) used for Suya preparation. The authors opined that the presence of isolates in Tsire-Suya could be due to post-processing contamination or poor processing (*Apata et al.*, 2013).

A comparison of physical, chemical, microbiological and organoleptic characteristics of Suya meats prepared in the laboratory as well as Suya meats from four locations (Yewa, Egba, Remo and Ijebu) in Ogun State were evaluated. The results showed that Suya prepared in the laboratory were more hygienic than Suya from the four other locations (*Iweala et al.*, 2014).

In 2014, Adebiyi and co-workers investigated heavy metal contamination of food, including Suya and drinks in Ota, Ogun State. The study revealed that most roasted food, including Suya were contaminated with nickel at levels above the FAO and WHO tolerable limits (*Adebiyi et al.*, 2008).

As potential bio-indicator of metal exposure, Suya meat and raw meat (serving as a control) sold in the open market, roadsides and motor parks in Lagos, Ile-Ife, Ogbomoso and Ibadan were investigated. Concentrations of iron, zinc, lead, manganese and copper were above the control levels in the raw meat and were above the recommended tolerable upper intake levels as supported by high values of pollution index (PI>1) (*Ologhobo et al.*, 2010).

A study was carried out on different varieties of chicken and beef Suya sourced from three locations in Ibadan city, Oyo State. Varieties studied were raw; spiced; spiced and roasted; leftover, unheated, spiced and roasted Suya from the previous day; as well as leftovers, heated, spiced and roasted Suya from the previous day. Chicken and beef Suya had microbial counts that could pose health risks to consumers. The authors advised of the need to educate Suya vendors in personal hygiene and environmental sanitation practices during their handling of products, as improved practices would prevent cross contamination (*Egbebi and Seidu*, 2011).

In a related study, the microbiological quality (total viable count) of RTE chicken and beef Suya selected from various spots within Oyo town, Oyo State, was investigated. The following bacteria and fungi were isolated from chicken and beef Suya meats: *Bacillus*, *Escherichia*, *Pseudomonas, Staphylococcus, Aspergillus* and *Penicillium*. The authors suggested sterile conditions should be employed in the meat industry to avoid food-borne diseases and infections (*Afolabi and Odubanjo*, 2015).

The quality and safety of 50 sun-dried meat products (kundi) from 10 major markets in Ibadan, Oyo State were assessed by *Adeyeye (2016)* for proximate composition, rancidity indices and the

presence of aflatoxigenic fungi and mycotoxins. Besides high proximal protein content, nine fungal strains, *Aspergillus flavus*, *Aspergillus niger*, *Aspergillus tamarri*, *Fusarium compacticum*, *Fusarium oxysporum*, *Fusarium sacchari*, *Penicillium chrysogenum*, *Penicillium citrinin* and *Penicillium oxalicum* were isolated from the kundi. The majority of kundi were contaminated with mycotoxigenic fungi and mycotoxins. The authors recommended proper monitoring of sun-dried meat sold in major markets in Ibadan.

The microbiological quality of 32 Suya meats sold in four locations within Ado-Ekiti and Akure was studied. Out of 15 genera identified on the products, 8 were bacteria, 4 were moulds and 3 were yeast. *Staphylococcus*, coliforms and *Aspergillus* were the most prevalent. The authors solicited for proper education of processors and consumers on good sanitary practices (*Egbebi and Muhammad*, 2016).

The safety of 20 Suya meats collected from 10 randomly selected Suya spots (two samples at different locations) within Ado Ekiti, Ekiti State, was evaluated. Among the five bacterial genera (*Escherichia coli, Enterobacter*, *Streptococcus*, *Staphylococcus aureus* and *Bacillus*) isolated, *Staphylococcus aureus* was the most prevalent (on 13; 65%), followed by *Streptococcus* (3; 15%), *Bacillus* (2; 10%), *Escherichia coli* and *Enterobacter*. The authors concluded that Suya meats from these study locations were unhygienic and called for the need to instruct Suya vendors on proper sanitation practices and safety hazards associated with improper food handling (*Falegan et al.*, 2017).

Microbiological analysis of 20 skewers of Suya meat obtained from four popular Suya spots in Owo, Ondo State, was carried out. The study revealed *Staphylococcus aureus* and *Pseudomonas* as the most prevalent isolates, followed by *Escherichia coli* and *Streptococcus*. The authors concluded the Suya meats sold in these locations were below the safety standard (*Egbebi and Seidu*, 2011).

The microbiological safety profiles of Suya meats procured from 10 locations, Mushin, Oshodi, Ikorodu, Shomolu, Ketu, Ojota, Surulere, Ikeja, Ebute-meta and Island in Lagos city, were investigated. The following bacteria were isolated: *Escherichia coli*, *Staphylococcus*, *Pseudomonas*, *Clostridium septicum*, *Micrococcus* and *Bacillus alvei* as well as fungi: *Mucor racmosios, Geomyces panorus, Penicillium* and many *Aspergillus*. As concluded by the authors, the presence of these organisms revealed the unhygienic condition of the meat sold in the study locations (*Hassan et al.*, 2014).

North-central Nigeria

Locations and states constituting this geopolitical zone are Federal Capital Territory (FCT), and Niger, Kwara, Nassarawa, Plateau, Kogi, and Benue States (*Akinlua et al.*, 2015). Daminabo and co-workers investigated the microbiological toxicity of 60 kilishi (dried beef cracker) randomly selected from five sale outlets in Abuja city. All bacterial isolates were resistant to cotrimoxazole and streptomycin, while 50% of them were sensitive to ampicillin. All isolates were sensitive to gentamicin while all *E. faecalis* isolates were susceptible to nitrofurantoin. On the other hand, enterococci isolates were resistant to more than one antibiotic. The authors suggested good hygiene practices among kilishi producers so as to eliminate the risk of contamination (*Daminabo et al.*, 2013).

A total of 50 Suya meats from various Suya spots in Abuja were investigated for microbial safety. *Staphylococcus aureus* (54%), *Escherichia coli* (4%), *Salmonella* (26%) and *Bacillus* (16%) were isolated. Total viable counts of bacteria ranged from 4.0×10^8 to 2.2×10^9 cfu/g. At 70°C, *Bacillus* thrived and was more resistant to heat. The authors concluded the presence of these pathogenic bacteria in the Suya calls for serious public concern, because such organisms could result in gastroenteritis and other infections associated with food poisoning (*Amaeze et al.*, 2016).

A microbiological analysis of Suya meats from four locations, Baze University, Kubwa, Lugbe and Maitama within FCT, Abuja, was carried out in 2016. The study revealed the presence of *Escherichia coli*, *Staphylococcus aureus*, *Providencia*, *Bacillus*, and *Pseudomonas aeruginosa* in the meats. Suya meats had significantly (1.5 to 5.9 times) higher total aerobic bacterial counts than did the raw meats. The authors opined that the higher level of contamination could be from the old newspapers used to wrap the Suya meat, contaminated spices, and exposure to airborne (cough, saliva), vector borne (flies) and vehicle borne (kitchen utensils) microbes (*Alonge et al.*, 2017).

Olaoye and co-workers assessed the effects of processing techniques (grilling and roasting techniques) and packaging materials (glass jar, aluminium foil, cling film and paper wrap) on the quality of Suya procured from spots in Tanke Oke-odo, Ilorin, Kwara State. The study revealed the crude protein (41.82%) and fat (9.92%) contents of roasted meats were significantly higher than those of the grilled meats, which were 39.92% and 8.36%, respectively. The authors concluded the roasting method and

storage of samples in glass jars or aluminium foil should be adopted (*Olaoye et al.*, 2016).

In a recent study, Folorunso and co-workers evaluated the microbiological quality of street-vended Suya sold in six major motor parks in Bida city, Niger State. The socio-demographic data revealed five of the vendors never washed their hands before touching raw meat, nine of them preserved their left-over Suya by spreading them in the open air, while 19 of them were not trained on how the product should be processed. High microbial loads were found in all Suya, due to poor hygiene practices by the vendors and as such, these products could constitute a food safety risk for consumers (*Folorunso et al.*, 2018).

A study by Ogbu and co-workers on 20 samples of beef Suya sold in Jos and environs, Plateau State revealed contamination with bacteria and fungi. Bacteria isolated were *Salmonella* (18.84%), *Escherichia coli* (13.04%), *Serratia* (11.59%), *Enterobacter* (10.14%), *Klebsiella* (8.70%), *Staphylococcus* (7.25%) and *Streptococcus* (5.80%). Fungi detected were *Candida albicans* (68.97%), *Aspergillus* (13.79%), *Absidia* (13.79%) and *Cunnighamella* (3.45%). They concluded that beef Suya sold in Jos and its environs were contaminated with bacteria and fungi that could constitute a public health problem (*Ogbu et al.*, 2016).

In another study, 240 Suya meats from four major market locations, low level, high level, Wadata and North Bank in Markurdi city, Benue State were investigated for microbial contaminants. The study revealed that although levels of the organisms (*E. coli*, *S. aureus*, *Salmonella*, *Klebsiella*, *Shigella*, *Penicillium*, *Rhizopus*, yeasts and protozoans) among the selected locations did not vary significantly before and after treatment, the level of indicator organisms harboured by Suya from these locations indicate potential threats to human health. The authors recommended the application of hazard analyses and critical control point (HACCP) programs or International Organization for Standardization (ISO) programs as essential programs (*Manyi et al.*, 2014).

Inyang and co-workers evaluated the bacteriological quality of Suya selected from four locations in Makurdi city. Mean total plate and coliform counts of Suya varied from 3.7×10^5 cfu/g to 2.4×10^6 cfu/g and 1.9×10^2 cfu/g to 1.0×10^3 cfu/g, respectively. Although, total plate count and coliform counts of most Suya were within recommended safe limits, faecal coliform bacteria were isolated from all Suya except that from Wurukum. The authors called for exigent enhancement on the hygienic handling of Suya by processors (*Iyang et al.*, 2005).

North-west Nigeria

The states in this zone are Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa and Kaduna *(Akinlua et al.*, 2015*)*. In a recent study, microbiological analysis of 15 samples of Tsire meat from five spots in Wudil town, Kano State, was carried out. Prevalences of bacterial isolates from the meats were: *Staphylococcus aureus* (43.5%), *Shigella* (21.7%), *Salmonella* (21.7%) and *Escherichia coli* (13.0%), while fungal isolate prevalences were: *Aspergillus niger* (66.7%) and *Penicillium* (33.3%). The authors recommended that appropriate care should be taken during the preparation and handling of Tsire meat (*El-Hassan et al.*, 2018). Microbiological safety analyses of meat samples in Kaura Namoda, Northern Nigeria, were carried out. In the study, six samples were selected weekly over a period of one year from five locations (Sabon-gari area, Motor-park, Market, Academic area, Gulubi area). Fresh meat during the dry season had the highest level of microbial contamination, while samples of kilishi in the rainy season had the highest number of microscopic filamentous fungi. The authors concluded that meats sold in Kaura Namoda are very contaminated, mostly with fungi (*Olayinka and Sani*, 2014).

The lead contents of three commonly consumed Suya meats (beef, chevon and mutton) sold in two major streets in Sokoto city were investigated. Although, the results revealed the presence of lead, with concentrations under the legal limits, the authors recommended every Suya spot should have protective means against atmospheric particulates arising from vehicular traffic in urban regions (*Garba et al.*, 2017).

In another study, the bacterial quality of 216 local fried ground beef products (Dambun nama) sold in different retail outlets around Sokoto city was investigated by *Salihu et al.* (2010). Aerobic mesophiles (100%) were found in all meat samples, followed by faecal coliforms (49.5%) and *E. coli* (36.6%). The authors concluded that the products were not safe for human consumption because the levels of bacteria were above the acceptable limits.

The safety of 116 samples of traditional RTE (38 balangu, 39 kilishi and 39 tsire) meat products from retail outlets in Kebbi and Sokoto States was assessed by *Ribah et al. (2018)* using standard cultural microbiological procedures. From the study, 35/116 (30.17%) meats were contaminated with some of the studied pathogens, with the following prevalences: *Staphylococcus aureus*, 18 (15.51%), *Escherichia coli*, 12 (10.34%) and *Salmonella*, 5 (4.31%). The mean total bacterial count was 23.82×10^6 cfu/g.

Ribah and co-workers recommended that Kebbi and Sokoto State governments should conduct full-scale risk assessment studies on RTE meats.

A study of the incidence of extended spectrum β-lactamase producing bacteria and multi-drug resistant strains from 150 Suya meats procured from three spots in Samaru campus, Ahmadu Bello University, Zaria, was undertaken by Adenaike and co-workers. A total of 40 isolated *E. coli* was screened for extended spectrum **β-lactamase** (ESBL) production and confirmed using a double disk synergy test (DDST). The study revealed that 80% of the isolates had multi-drug resistance (MAR) index of 0.2 and above. The authors recommended the hygienic conditions in the preparation of Suya should be improved. Also, in order to enlighten people on proper antibiotic use, public campaign teams should be set up. Addition of antibiotics to animal feed as growth promoters was also recommended to be not used (*Adenaike et al.*, 2013).

In 2014, a study investigated the prevalence of *E. coli* O157 on 182 samples of raw meat, Suya (roasted meat), balangu (barbequed meat), kilishi (spiced sun dried meat) and dambu (shredded fried meat) in four major markets in Zaria city and from a local abattoir. Multiple drug resistance to antimicrobial agents was exhibited by all isolates. The raw meats had an overall *E. coli* O157 prevalence of 2.2%. The authors concluded the presence of this pathogen in meats suggested that consumers could purchase contaminated meat and meat products which would expose them to this foodborne hazard (*Tafida et al.*, 2014).

According to Belo and co-workers, in a study which assessed the level of beef carcass contamination with *Escherichia coli,* including serovar O157, before and after washing with water in North-west state abattoirs, increasing contamination of carcasses was observed during processing. The authors suggested that non-portable water used to wash carcasses might have contributed to contamination in all the abattoirs investigated. Thus, they recommended good hygiene practice and the use of potable water by abattoirs (*Bello et al.*, 2011).

North-east Nigeria

The six states in this geopolitical zone are Bauchi, Yobe, Borno, Gombe, Adamawa and Taraba (*Akinlua et al.*, 2015). Yusulf and co-workers carried out bacteriological analysis of 10 spiced and 10 unspiced 20 balangu (roasted meat) products from five retail outlets in Bauchi city. Prevalences of 14 species of bacteria of public health importance included *Bacillus cereus* (19.6%), *Staphylococcus aureus* (12.5%), *Escherichia coli* (10.7%), *Bacillus alvis* (7.1%)*, Proteus mirabilis* (7.1%) and *Streptococcus faecalis* (7.1%) among others. Average aerobic plate counts (cfu/g) of unspiced balangu were 2.25×10^6, 2.05×10^6, 2.47×10^6, 2.79×10^6 and 2.78×10^6 while those of spiced balangu were 2.66×10^6, 2.36×10^6, 2.69×10^6, 2.85×10^6 and 2.89×10^6 for the five retail outlets. The authors concluded the presence of isolates in meat products could pose gastrointestinal disorders, food poisoning and foodborne diseases (*Yusuf et al.*, 2012).

Microbiological analyses for the presence of methicillin resistant *Staphylococcus aureus* (MRSA) was carried out on 75 samples of processed meat, including 30 skewer meats (tsire), 30 roasted meats (balangu) and 15 dried meats (kilishi*)* from vendors in Gombe, Gombe State. From the study, 13.33% of the isolates were MRSA. The authors recommended that all meat producers and the general public should utilise good hygiene practices to avoid cross contamination of food products (*Shamsuddeen and Puma*, 2016).

Approximately 34 years ago, the microbiological status and moisture content of tsire type Suya retail products in Maiduguri were studied. The study revealed the presence of *Bacillus, Streptococcus, Staphylococcus, Escherichia, Proteus, Pseudomonas* and *Klebsiella.* Tsire products had levels of total bacteria and coliform counts higher than the acceptable limits due to handling at the retail level. At the time of the investigation, the authors opined that it could be difficult to establish and enforce microbiological guidelines for tsire (*Igene and Abulu*, 1984).

In 2012, microbiological and proximate analyses were carried out on Suya meats from five popular markets in Maiduguri city. The result revealed variations in proximate composition of crude protein, crude fat, ash and moisture content in various Suya meats. Microbial counts ranged from log 0.0 to log 8.08 cfu/g. The authors concluded that raw meat and beef Suya sold in Maiduguri were microbiologically unsafe, and improved hygiene was required (*Ogbonna*, 2012).

Health implications of contaminated RTE meat

Foodborne diseases result from intake of foods or drinks contaminated with pathogenic microorganisms (bacteria, fungi, yeasts and moulds) or chemicals (heavy metals and PAHs) *(Ogbu et al.*, 2016*)*. Whenever the level of contaminant surpasses its permitted limit, it becomes harmful to human health (*Kigigha et al.*, 2016). Categories of RTE meat contaminants are highlighted below.

Heavy metal contamination

Heavy metals are those with densities exceeding 5 g/cm^3 (*Inobeme et al.*, 2018). They tend to accumulate in RTE foods and may not undergo proper biodegradation following consumption (*Inobeme et al.*, 2018*; Okeke et al.*, 2018). Repeated ingestion of RTE contaminated with heavy metals from the environment, such as lead, cadmium, mercury and zinc, has various health effects and could result in metal accumulation in human organs, liver, kidney, lung and brain tissue, when the metals are not properly metabolised. This can lead to interaction with cell components, causing depletion of essential nutrients, DNA damage, cell cycle modulation, cancer, reduced immunological function and impaired psycho-social behaviours (*Ojebah and Ewhre 2015; Dibofori-Orji and ThankGod*, 2018). Although zinc is an essential element for human diet for normal growth and development, excess zinc can be hazardous to health, causing nausea and vomiting, epigastric pain, abdominal cramps and diarrhoea. Lead is a major source of heavy metal poisoning which can result in anaemia, calcium and zinc deficiency, encephalopathy seizures and mental retardation. Excessive intake of oxidising chromium can cause, skin inflammation, allergy, lung disorder and lung cancer (*Okeke et al.*, 2018). Iron from nutritional sources is essential for good health, as it serves as the source of haemoglobin iron and catalyst for enzymatic reactions.

PAH contamination

PAHs, which are condensed compounds of linked aromatic rings, are formed when organic material is inadequately incinerated. Sources of PAHs include wood, incense, diesel, tobacco, fuels, gas, coal, oil and biomass as a result of a series of complex chemical reactions (*Farhadian et al.*, 2011*; Ogbonna et al.*, 2012*; Okeke et al.*, 2018).

PAHs can build up during domestic and industrial food processing procedures, e.g. during smoking, barbecuing, drying, roasting, frying and grilling. Inhaled air can also be a source of PAHs (*Ogbuagu and Ayoade*, 2012*; Okeke et al.*, 2018). On the other hand, steaming and boiling introduce hardly any PAHs into processed food (*Ogbuagu and Ayoade*, 2012). PAHs have varying levels of toxicity. Although, some of them have no physiological function or benefits, they can be toxic even at trace amounts (*Inobeme et al.*, 2018). In most cases, lungs, breast, oropharynx, genitourinary and gastrointestinal tracts are organs that trap PAHs. Human and animal studies show exposure to PAHs results in poor foetal development and carcinogenesis due to PAHs binding to DNA and inducing mutations; they are also a cause of colon cancer (*Bastrom et al.*, 2002*; Olabemiro et al.*, 2011). Apart from water, air and soil, food, RTE meat is a notable means by which people intake PAHs (*Inobeme et al.*, 2018).

Microbial contamination

Indeed, pathogenic microorganisms have been shown to be associated with ill-prepared, packaged and preserved Suya, because protein, vitamin, fat and phosphorus contents in Suya facilitate their growth (*Onuorah et al.*, 2015*; Okoli et al.*, 2018). It is well documented that microbial loads in raw meat and Suya products tend to increase as long as growth conditions are favourable (*Okoli et al.*, 2018). Also, acidity, pH, temperature, water activity, gas atmosphere, available nutrients and competition with other microbes are factors which can influence microbial multiplication in RTE meat (*Egbebi and Muhammad*, 2016). Climatic conditions in the tropics also favour the persistence and proliferation of most pathogenic microorganisms (*Ekere et al.*, 2018).

After vending or hawking, leftover Suya products are often kept to be sold the following day, thereby providing the opportunity for rancidity and spoilage to occur in the products (*Onuorah et al.*, 2015). Consumption of such products, which may not be properly reheated, could result in foodborne diseases.

In most cases, S*almonella*, *Campylobacter, Listeria monocytogenes, Escherichia coli, Staphylococcus aureus, Clostridium botulinum, Clostridium perfringens, Bacillus cereus, Brucella*, *Vibrio, Yersinia enterocolitica, Streptococcus pyogenes* and *Shigella dysenteriae* among others, are pathogenic microorganisms associated with food poisoning when they are ingested via contaminated RTE meat (*Adeyeye*, 2016). Clearly, it is advisable for proper hygiene to be adopted by producers and consumers of RTE meats.

Signs and symptoms emerging from ingestion of contaminated food include nausea, vomiting, diarrhoea, abdominal cramp, pain, fever, and other clinical manifestations such as bloody diarrhoea, renal failure, sepsis, bacteremia and death (*Okoli et al.*, 2018*; Umar et al.*, 2018). The severity of these signs and symptoms is, however, dependent on the immune status of the individual and on the pathogenic potentials of the ingested organisms (*Okoli et al.*, 2018). Proper cleaning and disinfection should be carried out whenever vomiting occurs in a food handling area (*Umar et al.*, 2018).

In regards to a global concern for the safety of RTE meat products in Nigeria, numerous studies published in scientific journals have been conducted

to evaluate the microbiological status associated with purchase and consumption of RTE meats, including skewered Suya and dried meat.

Means of contamination of RTE meat

Abattoir employees and facilities

Insalubrious practices by some abattoir workers have been reported to cause microbial contamination even before the meat processing stage (*Bello et al.*, 2011). In most abattoirs, cattle carcasses are placed on bare floors or they are washed in water of unproven microbiological quality. Cross contamination of already slaughtered meat could also occur from adjacent raw meat via flies or unclean hands of the handlers (*Ologhobo et al.*, 2010).

Microbial contamination of meat also occurs from the use of contaminated equipment during the bleeding process, and during poor evisceration practices, when meat can be contaminated with gut contents (*Bello et al 2011; Acco*, 2003).

Processing

This is a major factor that predisposes RTE meat to microbial and chemical contamination. Although, it is common for raw meats to have no or low levels of microbial contamination (*Falegan et al.*, 2017), levels can increase with improper processing and handling (*Egbebi and Seidu 2011*). This occurs if the facility or instruments used, including water, raw meat, meat processing slabs, spices and utensils (*Ogbu et al.*, 2016*; Edema et al.*, 2008*; Egbebi and Seidu*, 2011) are of unproven microbiological quality (*Salihu et al.*, 2010). Inadequate municipal water supply can encourage producers to use alternative sources of water that are already contaminated. All these poor hygiene practices are the leading causes of microbial contamination of meat (*Okoli et al.*, 2018). Some meat processors do not subject their raw meat to proper heating because they assume that cooking beyond the stipulated time of about 30 minutes could cause loss of volatile nutrients. Also, some heat resistant toxins may not be completely eliminated during the heating period (*Okoli et al.*, 2018).

Packaging

Materials used to wrap processed RTE meats pose a significant means of contamination (*Eke et al.*, 2013). Most RTE meat vendors use inked paper, cement paper or old and abandoned newspapers which might be considered dirty, dusty and contaminated with insecticides. Importantly, use of packaging material of proven quality and stability would reduce product deterioration and extend the shelf-life of RTE meats (*Umar et al 2018*). Every good packaging material should retain proper thermal, mechanical, and optical properties for foods (*Chin et al.*, 2015).

Post-preparation, handling and vending processes

These processes can constitute public health risks. Occasionally, poor post-preparation handling of the meats can favour contamination of RTE meat with microorganisms from unwashed hands, due to poor personal hygienic practices of vendors (*Acco et al.*, 2003). *Staphylococcus* has been isolated from various body parts (hands, nose, hairs, skin and fingertips) of healthy individuals who purchase RTE meats (*Ogbu et al.*, 2016). RTE meat products can become highly contaminated during hawking processes or exposure to open air to attract potential buyers (*Uzeh et al.*, 2006). This latter exposure has posed an even greater means to contaminate RTE meats with environmental pollutants. Exposure of RTE meat to open air along streets, motor parks and highways could facilitate microbial and chemical contamination from vehicular traffic. Usually, wind currents and contaminated dust can also carry bacterial contaminants, which can be deposited on processed RTE meats (*Okoli et al.*, 2018). Studies have shown the high pH of meat encourages microbial growth, even under standard handling conditions (*Eke et al.*, 2013). Thus, improper storage of RTE meat until the following day by street vendors, which can involve ambient temperature and no proper reheating, could facilitate microbial proliferation (*Olaoye et al.*, 2016). Some vendors do not have the facilities required to reheat their leftover RTE meats (*Acco et al.*, 2003).

Measures to control contamination of RTE meat

With reference to the aforementioned literature, it is becoming increasingly clear that the health risks posed by microbial pathogens and potentially hazardous chemicals in the RTE meat sold in Nigeria cannot be overemphasised. This study has evaluated the safety status of RTE meat, especially Suya, sold in Nigeria. Categorically, there are three major RTE meat contaminants: microorganisms, heavy metals and PAHs. Most studies reviewed provided relevant recommendations to producers, regulatory bodies and consumers on how the quality of RTE meat sold in Nigeria could be improved, as highlighted below.

Advice to RTE meat producers

Suya vendors should be educated on good personal sanitation and hygiene practices in the course of processing and marketing of their products (*Yusuf et al.*, 2012*; Falegan et al.*, 2014*; Egbebi and Seidu*, 2011). Producers should ensure they properly wash their hands with soap and running potable tap water (*Fasoyiro 2012, Konne et al.*, 2018). They should consistently disinfect their facility and any equipment they use to process Suya meats (*Egbebi and Seidu 2011; Konne et al.*, 2018). *Hassan et al. (2014)* recommend Suya meat producers use aseptic techniques. Thus, healthy environment, proper handling, preservation and marketing would minimise microbial, heavy metal and PAH contamination. These steps would help minimise economic losses. Spices should be devoid of potential microbial, heavy metal and PAH contaminants. Processors should properly dispose of any solid and liquid waste acquired during processing to avoid cross contamination and environmental risks (*Fasoyiro*, 2012). *Folorunso et al. (2018)* recommend vendors store leftover Suya in freezers or cold rooms to prevent spoilage.

Adebiyi and co-workers recommend that Suya meat vendors should properly cover their products to minimise contamination from dust and vehicles, which are potential sources of heavy metals and airborne contaminants. They also suggest that Suya producers adopt indirect methods of heating Suya, such as microwave ovens (*Adebiyi*, 2008).

Studies in oil producing regions of the Niger Delta have revealed that various industrial activities in metallurgical, petrochemical, petroleum, oil and gas companies, and illegal refining of crude oil (bunkery) are major sources of heavy metals that can contaminate RTE meats (*Dibofori-Orji and Thank-God*, 2018). Thus, producers should take cognizance of these hazards.

In the area of packaging, Olaoye and co-workers recommend glass jars or aluminium foil is used for packaging RTE meats, because they yield better quality and hygiene than paper and other packaging materials, which are considered to be more affordable and economical (*Olaoye et al.*, 2016).

The roles of food safety regulatory organisations and agencies

This is a clarion call to the Federal and State Food Regulatory Authorities/Agencies to wake up to their constitutional tasks of ensuring that RTE meat products getting to consumers' tables are of better quality (*Ologhobo et al.*, 2010). Some of these agencies and organisations include the Federal Ministry of Health, the National Agency for Food and Drug Administration and Control (NAFDAC), the Standards Organization of Nigeria (SON), the National Codex Committee, the Federal Ministry of Agriculture, and state and local governments (*Omotayo and Denloye*, 2002*; Omojokun*, 2013).

There is a need for these agencies to set up local branches and laboratories at strategic locations nationwide to ensure proper monitoring of production, processing, packaging, distribution and vending sites and processes for RTE meats (*Yusuf et al.*, 2012). This can be achieved by periodic sampling and screening of such products for possible contamination (*Yusuf et al.*, 2012). Suya spots should be certified based on standards but not on a monetary basis (*Alonge et al.*, 2017). Suya producers and handlers having open wounds or skin infection should be banned from such services (*Konne et al.*, 2018). Also, sales of RTE meats should be restricted to specified safe locations, as this would aid the meats' sanitary condition (*Yusuf et al.*, 2012). A study carried out by *Orogu and Oshilim (2017)* revealed that hawked Suya meats were more contaminated with pathogenic bacteria than Suya meats sold via barbeque stands. In order to avoid excess contamination of raw meat and the spread of diseases, abattoir staff should ensure that sick animals are isolated from healthy animals for proper treatment (*Yusuf et al.*, 2012). Also, a control mechanism to improve the quality of spices by established, effective methods to decontaminate RTE meat spices is needed (*Odu and Best*, 2016).

Compulsory training and retraining workshops for certified RTE meat handlers should be established. This would aid in verifying the knowledge of processors and vendors. Topics that could be incorporated into such training curriculums include the importance of good hygiene and hand washing, relevance of sanitising work premises, sources, growing conditions, dangers and controls of microorganisms, foodborne diseases, allergies, cross contamination, storage temperature, packaging, fundamentals of HACCP, rapid methods of identifying microorganisms during processing and storage (*Fasoyiro 2012; Folorunso et al.*, 2018).

Possible dangers associated with contaminated RTE meat products should be communicated to producers (*Chin et al.*, 2015). Since RTE meats in oil-producing locations are susceptible to heavy metal contamination (*Dibofori-Orji and Thank-God*, 2018*),* statutory, regulatory laws banning cattle raising, abattoirs and Suya spots in these locations

should be put in place. Better still, such facilities should be sited very far from any environment capable of causing heavy metal discharge or emission.

Advice to consumers and the general public

Through various education programs, consumers should be instructed about the health implication of consuming contaminated RTE meat products (*Yusuf et al.*, 2012). Consumers of Suya and other RTE meats should properly reheat the meats to easily inactivate/kill microorganisms (*Yusuf et al.*, 2012). Suya meat is required to be reheated to about 75°C before consumption (*Konne et al.*, 2018). Consumers should also insist vendors use sterile foil paper or polyethylene to wrap Suya, but reject the use of newsprint, inked paper and cement paper (*Yusuf et al.*, 2012). Consumers should patronise only certified Suya vendors (*Alonge et al.*, 2017). Consumers could further heat process RTE meat products after purchase, which would aid in minimising microbial contamination (*Alonge et al.*, 2017). People in Niger Delta are advised not to consume the charred skin of roasted meat and fish, which can harbour chemical hazards, including PAHs and heavy metals, to a greater extent than the interior edible parts (*Amos-Tautua et al.*, 2015). Also, consumers should soak these charred products in hot water for a few minutes before consuming them, to aid in eliminating PAHs, heavy metals and other toxins (*Akpoghelie*, 2018).

Conclusion

To a large extent, this study has provided a review on hazards associated with RTE meat, particularly Suya meat, sold in Nigeria. The outrageous microbial, PAH and heavy metal contamination observed in RTE Suya meat in many studies was mainly attributed to poor hygiene, packaging, and vending processes. Thus, caution should be exercised by the populace who consume these RTE meat products. Implementation of the above recommendations would greatly minimise the number/spread of foodborne diseases and risks posed by substandard RTE meat in Nigeria.

Zdravstveni rizici povezani sa gotovim mesom za konzumiranje u Nigeriji: Razlog za zabrinutost javnosti i kritične intervencije

Earnest Erhirhie, Chuka Nwosu, Tedwins Emudainohwo, Chidimma Chukwunwejim, Peter Eze, Daniel Ajaghaku

A p s t r a k t: Naučna ispitivanja vrste gotovog mesa (RTE), popularno zvanog Suya, koje se prodaje u Nigeriji, izazivaju naučnu i javnu zabrinutost zbog mikrobioloških i hemijskih opasnosti povezanih sa proizvodima. U ovom pregledu ocenjen je bezbedonosni profil nigerijskog gotovog mesa RTE, sa posebnim naglaskom na Suyu mesu, kao potencijalnom izvoru mikrobiološke opasnosti u hrani, kao i na prisustvo teških metala i policikličnih aromatičnih ugljovodonika (PAH). Rezultati istraživačkih radova o bezbednosti RTE mesa objavljenih od 1984. do 2019. godine su procenjivani korišćenjem elektronskih baza podataka i pretraživanjem ključnih reči. Ishodi istraživanja svrstani su u šest delova koji predstavljaju šest geopolitičkih zona Nigerije (jug-jug, jugoistok, jugozapad, severoistok, severozapad i severno-centralni deo). Praktično svi nalazi istraživanja u različitim zonama otkrili su da su mikrobiološko prisustvo, kao i nivoi teških metala ili PAH u mesu RTE, viši od dozvoljenih granica i prihvatljivih standarda. Nehigijenske aktivnosti većine mesara (izvori sirovog mesa), prerađivača (koji pripremaju i pakuju RTE meso) i prodavaca (koji su uključeni u procese izlaganja) glavni su faktori koji doprinose mikrobiološkim i hemijskim rizicima. U tom cilju, predlažu se odgovarajuće bezbednosne i sanitarne mere, a nadležni organi i relevantne zainteresovane strane trebalo bi da primene druge osnovne stvari kako bi se osiguralo drastično smanjenje rizika od nehigijenskog RTE mesa.

Ključne reči: *RTE meso, bezbednost, mikrobiološka kontaminacija, hemijska kontaminacija, Nigerija.*

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