IBOM MEDICAL JOURNAL
Vol.18 No.2 | April - June, 2025 | Pages 224 - 230
www.ibommedicaljournal.org

Polycyclic aromatic hydrocarbons and heavy metals in some Nigerian commercial meats: a public health concern?

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Abstract

Background: Various chemical compounds enter food during meat production, processing, and storage. With increasing urbanization and industrialization, environmental pollution is also rising, posing a public health concern.
Objectives: This study determined the concentrations of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in commonly consumed commercial meats obtained from different sources in Calabar, Nigeria.
Method: The six samples investigated in this study are roadside grilled ram meat (suya), hotel suya, grilled pork, fried pork, grilled catfish and smoked catfish. PAH levels were determined using gas chromatography, while heavy metal concentrations were analysed using atomic absorption spectrophotometry.
Results: The grilled meats had significantly higher contents of most of the PAHs with Flouranthene having the highest concentration (19.04±0.03 µg/kg) in grilled pork. Also notable was the exceptionally high value (49.53±0.04 µg/kg) recorded by grilled catfish for Benzo[e]Anthracene (BeA) while on the other hand, it was not detected in fried pork. Both Pyrene and BeA were not detected in smoked catfish but were significantly found in other samples. The heavy metals were found in minimal concentrations with mercury not being detected at all in any of the six samples. Notably, most of the PAH levels detected were below the European Food Safety Authority's (EFSA) maximum permissible limit of 35 µg/kg for total PAHs in food.
Conclusion: To prevent undesirable health outcomes that long term/excessive consumption these meats may pose due to their PAH and heavy metal contents, mild to moderate consumption should be advised as well as healthier preparation methods such as air frying.

Keywords: food safety, PAH, Heavy metals, commercial meat, public health.

Introduction

There are 17 Sustainable Development Goals (SDGs) and at least three of them are focused on food security, food safety and better health conditions; these are SDG 2 (Zero hunger), SDG 3 (Good health and wellbeing) and SDG 12 (Responsible consumption and production)[1]. This shows how important the issue of food consumption is in the maintenance of health and prevention of disease. Food safety has to do with the handling, preparing, and storing of food in order to reduce the risk of contamination and food borne diseases among consumers. Several factors influence the production of safe food, from inputs to processing and packaging. These factors include agricultural practices, worker behaviour, the failure to implement preventive measures during food processing and preparation, the use of chemical substances, exposure to environmental contaminants, poor handling and storage methods. Meat has been a significant component of human diets for thousands of years, providing essential nutrients and contributing to

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DOI: 10.61386/imj.v18i2.656

overall health and well-being. Meat is a rich source of high-quality protein, essential amino acids, vitamins, and minerals, making it a valuable dietary component[2]. The iron in meat is essential for the production of haemoglobin, the protein in red blood cells that carries oxygen throughout the body[3]. Apart from iron, meat is rich in many essential micronutrients that play various roles in tissue growth and immune system boosting.

Some key concerns regarding meat food safety include spoilage, microbial and chemical contamination, adulteration, and improper storage. Ensuring meat is produced and processed in a hygienic environment is essential for maintaining quality and safety. Chemical contamination, unlike microbial contamination, is not usually detected by examining these sensory indicators like discoloration and bad odour, hence the need for laboratory assessment of some of these meat products in order to ascertain the safety of consumers – especially those who do so on a regular basis. Consequently, this study focused on evaluating the PAH levels and heavy metal concentrations of some frequently consumed meat and fish products prepared using different cooking methods such as grilling, frying and smoking. The samples studied were hotel suya, roadside suya, grilled pork, fried pork, grilled catfish (Clarias gariepinus) and smoked catfish. Furthermore, the American Meat Science Association (AMSA) defines meat as red meat (beef, pork, and lamb), poultry, fish/seafood, and meat from other managed species[4]. Meat is skeletal muscle and its associated tissues derived from mammalian, avian, reptilian, amphibian, and aquatic species commonly harvested for human consumption[5]. Cultural factors such as traditions, customs, and taboos, play a significant role in determining the types of meat consumed[6]. For instance, in the Northern part of the country, ram and cow meat are popularly consumed, while in the South, fish, goat and poultry meat are mainly consumed. Despite the general increase in meat consumption, concerns about food safety and quality persist from a commercial perspective. Changing consumer demands are shaping the meat market due to evolving attitudes toward diet and a growing awareness of healthy living[7].

Research has also highlighted a link between certain food components and the risk of cancer and chronic diseases in humans[8]; hence many informed consumers are reducing their intake of red meat and tilting more towards lean meat (especially poultry) and fish. This is in their bid to stay healthy and reduce the risk of cardiovascular diseases such as hypertension, stroke and myocardial infarction. During food processing, certain products may be formed that, if present in large quantities, could negatively impact health. For instance, cooking specific meats at high temperatures can generate chemicals not found in raw meat, such as PAHs and heterocyclic amines (HCAs), which may increase cancer risk. Additionally, when nitrates and nitrites react with secondary amines, they form nitrosamines, which are mutagens linked to cancer[9]. Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds consisting of two or more fused aromatic rings. They are primarily formed during the incomplete combustion of organic materials such as coal, oil, gas, wood, and garbage[10]. The formation of PAHs during grilling and smoking of food is particularly of concern because these cooking methods are common globally and can significantly increase the levels of PAHs in the final food product. For example, grilling meat/fish over an open flame or charcoal leads to the formation of PAHs as fat drips onto the heat source, creating smoke that deposits PAHs onto the meat surface[11]. This makes food items like suya and grilled fish, which are typically cooked over charcoal grills, a potential source of dietary PAH exposure. The presence of PAHs in food poses significant health risks due to their toxicological properties. Many PAHs are known to be carcinogenic, mutagenic, and teratogenic, posing a threat to human health even at low exposure levels. Regulatory agencies worldwide have established guidelines to limit PAH exposure from food, underscoring the importance of monitoring and controlling these contaminants in the food supply (European Food Safety Authority[12]). Their negative health effects include carcinogenesis, localized skin effects, pulmonary and respiratory problems, genetic reproductive and developmental effects, behavioral, neurotoxic, other organ system effects. Table 1 shows some PAHs and their tolerable limits.

Table 1: Identification of some Polycyclic Aromatic Hydrocarbons

Polycyclic Aromatic hydrocarbon	Molecular Formula	Molecular weight (g/mol)	Boiling point ^{0}C	IARC classification	Tolerable/Safe Limit (ng/kg bw/day)
Benzo(a) pyrene	$C_{20}H_{12}$	252.3	495.0	1	70
Benz(a) anthraecne	$C_{18}H_{12}$	228.3	437.6	2B	70
Chrysene	$C_{18}H_{12}$	228.3	448.0	2B	70
Benzo(b) fluorathene	$C_{20}H_{12}$	252.3	481.0	2B	70

ng/kg bw/day means nanograms per kilogram of body weight per day
Source: IARC[13].

Methodology

This section outlines the methodology used in the collecting and processing the study samples for the laboratory analyses of PAHs and Heavy metal contents of the commercial meats – roadside grilled ram (suya), hotel suya, grilled pork, fried pork, grilled catfish and smoked fish. It covers ethical approval, sampling techniques, sample size, and the procedures followed to ensure the consistency and reliability of the sample collection process.

Ethical Approval: Ethical approval was sought for, and obtained from the Faculty Animal Research Ethics Committee of the Faculty of Basic Medical Sciences, University of Calabar with approval number: 329HND1924.

Sample Collection and Preparation: The suya samples were collected from three hotels and three street vendors across Calabar Metropolis. The grilled pork samples were also randomly purchased from three different roadside sellers while the fried pork samples were bought from three restaurants. The grilled catfish was also purchased at three roadside locations while the smoked catfish were purchased from three different sellers at Beach market, Calabar. The samples were then brought to the Human Nutrition and Dietetics Food laboratory at the University of Calabar, where they were oven-dried and homogenized accordingly before storing them in well-labelled, air-tight Ziploc bags then sent out for analyses.

Analysis of Polycyclic Aromatic Hydrocarbons (PAHs)

The samples were analysed according to the standard procedures outlined in the Association of Official Analytical Chemists method[14] for the determination of PAHs in food matrices. The chemical analysis was carried out at the Central Service Laboratory, National Root Crops Research Institute, Umudike in Abia state, Nigeria.

Extraction of PAHs from Samples

A ten-gram sample was weighed and quantitatively transferred into a 500 mL beaker; 6g sodium sulphate was added and extracted using 300ml n-hexane. The filtrate was concentrated. A 10 mL of acetonitrile was added to the sample and place in a shaker for 2 minutes. An additional 10 mL portion of acetonitrile was added, and the separating funnel closed tightly and placed on a horizontal shaker. It was then set to shake continuously for 30 minutes at 300 rpm/min and finally allowed to stand for 5 minutes to sufficiently separate the phases. A 10 mL of the supernatant was carefully taken and dried over 2 g anhydrous magnesium sulphate through filter paper into 50 mL round bottom flask. This was then concentrated to about 1mL using the rotary evaporator, and made ready for silica clean up step. The extracts were then purified using silica SPE cartridge.

Gas Chromatographic Conditions for PAH Determination

The final extracts were analysed using a Gas Chromatograph-Buck M910 equipped with a Flame Ionization Detector, capable of detecting trace contaminants in the lower µg/kg range. The analysis was conducted using a capillary column coated with VF-5. The injector and detector temperatures were set at 250^{o}C and 280^{o}C, respectively. The oven temperature followed a programmed sequence: 120^{o}C held for 4 minutes, ramped at 10^{o}C/min to 180^{o}C (held for 2 minutes), and finally increased at 5^{o}C/min to 300^{o}C. Helium was used as the carrier gas at a flow rate of 1.0 mL/min, with a detector make-up gas flow of 29 mL/min. The injection volume was 10.0 µL, and the total run time per sample was 43 minutes. Quantification was performed using the external standard method, with an external standard containing 16 PAH compounds (EPA 610 PAH mixture). Serial dilutions of PAH standards determined the method's detection limit, which ranged from 0.0007 to 0.016 µg/kg for PAH compounds. The limit of quantification (LOQ), defined as the detection limit divided by the sampling volume, ranged between 1.8×10^{-7} and 4.10×10^{-5} µg/kg. Recovery efficiency was evaluated by analyzing filters spiked with known concentrations of standard PAH compounds. This method ensured high sensitivity and accuracy in detecting and quantifying contaminants in the samples.

Quantification of PAH Residues

The residue levels of PAH were quantitatively determined by the external standard method using peak area. Measurement was carried out within the linear range of the detector. The peak areas whose retention times coincided with the standards were extrapolated on their corresponding calibration curves to obtain the concentration.

Analysis of Heavy Metal Concentrations

Digestion and Analysis of samples

Analysis for heavy metals were carried out after wet

Table 2: List of important polycyclic aromatic compounds (PAHs) as major food contaminants

Order	PAH	Abbreviation	Chemical formula	CAS number	Molecular mass (g/mol)	Toxic equivalency factor (TEF)	Structure
1	Napthalene	NAP	C10H8	91-20-3	128.17	0.001	
2	Fluorene	FLR	C13H10	86-73-7	166.22	0.001	
3	Anthracene	ANT	C14H10	120-12-7	178.23	0.01	
4	Phenanthrene	PHN	C14H10	85-01-8	178.23	0.001	
5	Fluoranthene	FLT	C16H10	206-44-0	202.26	0.001	
6	Pyrene	PYR	C16H10	129-00-0	202.25	0.001	
7	Benzo[a] anthracene	BAA	C18H12	56-55-3	228	0.1	
8	Chrysene	CHY	C18H12	218-01-9	228	0.001	
9	Benzo[a] pyrene	BAP	C20H12	50-32-8	252	1	
10	Benzo[b] fluoranthene	BBF	C20H12	205-99-2	252	0.1	
11	Benzo[e] pyrene	BEP	C20H12	192-97-2	252.31	–	
12	Benzo[j] fluoranthene	BJF	C20H12	205-82-3	252	–	
13	Benzo[k] fluoranthene	BKF	C20H12	207-08-09	252	0.01	
14	Dibenzo[a,h] anthracene	DBA	C22H14	53-70-3	278	1	
15	Indo[123-cd] pyrene	IP	C22H12	193-39-5	276	0.1	
16	Dibenzo[aL] pyrene	DBP	C24H14	191-30-0	302	–	

Source: Bansal & Kim[15]

digestion using the method of AOAC16. About 0.5g of the samples were treated with 5 ml concentrated nitric acid (HNO_3) and 5 ml of 30 % perchloric acid solution continuously for about 2 hours in an electric heating mantle (HP 220, LITEC Product Inc. Albany, N-Y., USA) until clear solutions were obtained. These were cooled, filtered through Whatman no 45 filter papers and then through < 0.45 millipore filter papers. Filtrates were made up to the 50-ml mark of the volumetric flasks with distilled water and then used to analyse for the individual minerals using Atomic Absorption Spectrophotometer (Buck Scientific AAS Model 210, equipped with single slot burner and air acetylene flame).

Table 3: Wavelength Measurements of Atomic Absorption Spectrophotometer of the Elements

S/No	Elements	Wavelength (Nm)
1	Lead (Pb)	283.3
2	Cadmium (Cd)	228.8
3	Mercury (Hg)	243.0
4	Aluminium (Al)	323.5
5	Arsenic (As)	285.8

Preparation of Standards for Analysis of Minerals

Working standard solutions of the elements were prepared from the stock standard solutions containing 1000 ppm of each element in 2N nitric acid solution. Calibration and measurement of absorbance of each element against a blank at its unique wavelength was done using Atomic Absorption Spectrophotometer (A. Analyst 300, Perkin Elmer, Morwalk, Conn, U.S.A). The calibration curves were prepared separately for each element. Absorbance of each element in the filtrate was read at its wavelength (see Table 3) from the spectrophotometer and its concentration in the samples extrapolated from the standard curve. The concentrations of the elements were determined by extrapolation using standard curves.

Statistical Analysis

The Statistical Package for Social Sciences software (SPSS, version 25.0) was used to carry out all the statistical analyses. The mean concentrations of both PAHs and heavy metals in the samples were statistically analysed. Analysis of variance (ANOVA) was employed to assess differences between sample groups (i.e., hotel suya versus roadside suya, grilled pork versus fried pork, and grilled catfish versus smoked catfish) as well as across sample types. Statistical difference was accepted at $P<0.05$.

Results

PAH concentrations in the sample

Table 4 presents the PAH contents in the six different food samples: suya (roadside), suya (hotel), grilled pork, fried pork, grilled fish and smoked fish. The values are expressed as mean ± SEM, with different superscripts in the same row indicating significant differences ($p < 0.05$) between the samples. It is worthy of note that generally, the six samples significantly differed among themselves for the individual PAHs (i.e. across groups). The Naphthalene content of grilled pork (3.30 ± 0.01 µg/kg) was significantly different from that of fried pork (0.00 ± 0.00). Similarly, roadside suya (5.21 ± 0.01µg/kg) contained significantly higher ($p<0.05$) Naphthalene levels than hotel suya (1.95 ± 0.01 µg/kg). Among fish samples, smoked fish (9.67 ± 0.04) also contained significantly ($p<0.05$) higher Naphthalene compared

Table 4: Concentration of Total Polycyclic Aromatic Hydrocarbons in µg/kg

TPAH	Hotel Suya	Roadside Suya	Fried Pork	Grilled Pork	Smoked fish	Grilled Fish
Napothalene	1.95 ± 0.01^a	5.21 ± 0.01^b	0.00 ± 0.00^a	3.30 ± 0.01^b	9.67 ± 0.04^a	3.38 ± 0.28^b
Acenaphthene	4.64 ± 0.04^a	1.27 ± 0.04^b	5.15 ± 0.01^a	6.24 ± 0.07^b	8.88 ± 0.04^a	4.98 ± 0.01^b
Phenantrene	2.74 ± 0.04^a	7.43 ± 0.01^b	3.89 ± 0.03^a	2.38 ± 0.02^b	3.33 ± 0.06^a	1.04 ± 0.05^b
Fluctone	7.99 ± 0.07^a	5.22 ± 0.07^b	2.40 ± 0.01^a	1.64 ± 0.02^b	2.66 ± 0.02^a	1.96 ± 0.02^b
Flouranthene	9.37 ± 0.01^a	3.49 ± 0.02^b	1.53 ± 0.01^a	19.04 ± 0.03^b	1.84 ± 0.21^a	9.30 ± 0.42^b
Anthracene	2.74 ± 0.01^a	4.89 ± 0.02^b	2.75 ± 0.01^a	2.50 ± 0.00^b	3.24 ± 0.08^a	3.78 ± 0.28^b
Acenaphthylene	2.69 ± 0.02^a	1.95 ± 0.05^b	2.85 ± 0.04^a	1.73 ± 0.05^b	1.64 ± 0.04^a	2.64 ± 0.04^b
Pyrene	2.80 ± 0.01^a	1.85 ± 0.05^b	1.73 ± 0.05^a	2.85 ± 0.04^b	0.00 ± 0.00^a	5.04 ± 0.01^b
Benzo (a) Anthracene	2.49 ± 0.01^a	9.54 ± 0.06^b	1.29 ± 0.02^a	1.43 ± 0.04^b	0.00 ± 0.00^a	4.53 ± 0.04^b
Chrysene	7.42 ± 0.03^a	1.74 ± 0.06^b	3.66 ± 0.02^a	9.04 ± 0.02^b	2.85 ± 0.06^a	9.97 ± 0.02^b
Benzo(e) Anthracene	5.08 ± 0.03^a	1.63 ± 0.05^b	0.00 ± 0.00^a	1.42 ± 0.03^b	5.49 ± 0.01^a	49.53 ± 0.04^b
Benzo(k) Flouranthene	4.58 ± 0.03^a	1.28 ± 0.03^b	1.22 ± 0.05^a	2.04 ± 0.01^b	1.38 ± 0.04^a	2.25 ± 0.35^a
Benzo(a) Pyrene	2.96 ± 0.01^a	5.29 ± 0.02^b	4.17 ± 0.42^a	3.12 ± 0.42^b	6.04 ± 1.39^a	1.24 ± 0.01^b

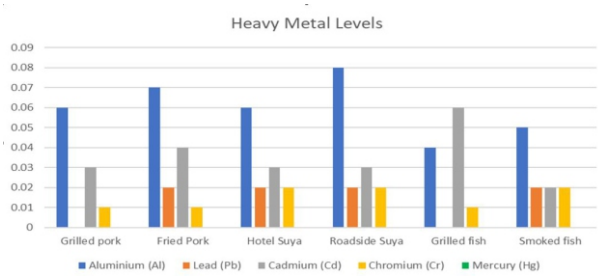
Values are expressed as mean ±SEM, n = 2. Values in the same row with different superscripts are significantly different at $p<0.05$

to grilled fish (3.38 ± 0.28 µg/kg). In most of the cases, the concentrations of the PAHs were significantly higher in the grilled samples than the counterpart. Nevertheless, in the catfish samples, smoked fish (8.88 ± 0.04 µg/kg) recorded significantly higher ($p<0.05$) content of Acenaphthene than that of grilled fish (4.98 ± 0.01 µg/kg). The Fluoranthene content of grilled pork (19.04 ± 0.03 µg/kg) was far higher than that of fried pork (1.53 ± 0.01 µg/kg). Pyrene content of grilled catfish was significantly different from that of smoked catfish, as the later had no detectable levels (0.00). Similarly, smoked fish had no detectable content of Benzo(a)Anthracene but grilled fish contained significantly higher levels (4.53 ± 0.04 µg/kg) than smoked fish. Benzo(e)Anthracene was also not found in fried pork but grilled pork recorded a significant value (1.42 ± 0.03 µg/kg). Notably, grilled fish exhibited exceptionally high Benzo(e)Anthracene content (49.53 ± 0.04 µg/kg), compared to smoked fish (5.49 ± 0.01 µg/kg).

Heavy Metal content of the samples

Figure 1 provides the heavy metals (aluminium, lead, cadmium, chromium & mercury) concentrations of the six samples. All the samples showed no content of mercury. Lead was also not detected in both grilled pork and grilled fish while the other four samples recorded the same value for lead (0.02 ± 0.00 mg/kg). The aluminium contents of grilled pork (0.06 ± 0.00 mg/kg) and fried pork (0.07 ± 0.00 mg/kg) as well as the cadmium contents of grilled pork (0.03 ± 0.00 mg/kg) and fried pork (0.04 ± 0.00 mg/kg) were significantly different ($p<0.05$). Similarly, the aluminium contents of hotel suya (0.06 ± 0.00 mg/kg) and roadside suya (0.07 ± 0.00 mg/kg) samples were significantly different, the cadmium contents of hotel suya (0.03 ± 0.00 mg/kg) and roadside suya (0.03 ± 0.00 mg/kg) samples were also significantly different ($p<0.05$). On a general note, the cadmium, chromium and mercury concentrations of hotel suya and roadside suya were statistically similar ($p>0.05$). Similarly, all six samples had statistically similar ($p>0.05$) content of chromium. Aluminium was the most predominant of all the heavy metals reported in this study with samples showing concentrations ranging from 0.04 ± 0.00 mg/kg (grilled fish) to 0.08 ± 0.00 mg/kg (roadside suya).

Figure 1: Heavy metal concentrations of the samples in mg/kg



Discussion

The PAH analysis showed that roadside suya samples generally had higher concentrations of certain PAHs compared to suya from hotels. According to the European Union (EU), maximum allowable limit for Naphthalene in food is set at 10 µg/kg[17], hence the six samples fall below this limit, indicating that they do not pose a significant health risk in terms of Naphthalene exposure. For Benzo(a)anthracene, the EU maximum allowable limit in food is 5 µg/kg[17], hence the roadside suya exceeded this limit while the hotel suya did not – same with the other four samples whose values fell below the limit. This raises concerns about the potential carcinogenic risks associated with frequent consumption of roadside suya, as Benzo(a)anthracene is classified as a known carcinogen by the International Agency for Research on Cancer[13]. A study by Wang et al.[18] found that street food vendors often lack the necessary equipment and techniques to minimize PAH formation, which may explain the higher concentrations observed in this study in the roadside/more exposed meat samples. Although hotel suya may be more controlled in terms of preparation, some PAHs may still accumulate due to specific cooking techniques[19].

The higher levels of benzo(a)pyrene in smoked fish compared to grilled fish, as observed in this study, reflect findings by Dutta et al[20], who identified benzo(a)pyrene as a major carcinogenic PAH formed during smoking. Grilled fish also recorded an exceptionally high concentration of Benzo[e]anthracene (BeA) which was over 10times the concentration of this PAH found in the other samples. BeA is a high molecular weight PAH found in grilled foods, which has potential carcinogenic effects[13]. The BeA content of most of the others were within safe limits (2.0 µg/kg).

Lead (Pb) was detected only in smoked fish, albeit at very low concentrations. This result aligns with the findings of Okafor et al.[21], who noted that smoking could introduce lead into meat and fish products, potentially from the use of contaminated wood or smoking materials. However, the levels detected in this study are below the limits set by regulatory agencies, suggesting that the risk from lead contamination from the smoked fish and other grilled meat is minimal. The World Health Organization (WHO) recommends a limit of 0.1 mg/kg for lead in food products[22]. While the detected levels in the samples were almost (by a difference of 0.01) below this limit, ongoing vigilance is essential due to the cumulative nature of lead toxicity and its association with adverse health outcomes, particularly in vulnerable populations such as children and pregnant women[23].

Despite the low overall concentrations of heavy metals detected in this study, the health risks associated with prolonged consumption of contaminated meat should not be overlooked. While the levels of heavy metals in the samples fall below the safe limits set by international standards, regular consumption of even small amounts can lead to accumulation in the body over time, potentially causing toxicity and adverse health effects[24]. This is especially concerning given that heavy metals have long biological half-lives and can persist in human tissues for extended periods. Alternative food preparation methods such as air frying have been reported to yield healthier foods[25] and hence, their use should be encouraged.

Conclusion and Recommendations

The findings of this research show minimal concentrations of PAHs and heavy metals in many of the meats while some had significant content of these contaminants – even above acceptable limits. Beyond human activities, cooking, processing, and consumption methods can further increase exposure to PAHs and heavy metals. To minimize this risk, effective strategies for chemical contaminant reduction or inhibition should be widely adopted. These strategies should address all potential exposure pathways, including the use of safer cooking techniques, and natural chemical agents like antioxidants. One of the emerging cooking methods is the use of air fryers, which have been shown to reduce the formation of some of these harmful compounds in foods and extract unwanted fat; hence consumers should be encouraged to reduce consumption of these roadside foods and prepare their meat/fish at home using healthier methods, and under controlled as well as more hygienic conditions. The findings underscore the need for further research to better understand the long-term health implications of PAH consumption from different cooking methods. Regular monitoring of commercial food vendors by regulatory bodies will also go a long way to enforce the use of healthy and hygienic cooking methods.

Declaration of conflicting interest: The authors declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding statement: No external funding was received for this research

Informed consent: Not applicable

Data availability statement: Not applicable

Acknowledgement: The author gratefully acknowledges Victoria Fele, Emmanuella Akpidi, and Vivian Okafor for their valuable contributions during the sample collection phase of this study.

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