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Research article

Health Risk Assessment of PAHs in Processed Fish and Roasted Bovine Skin in Benin City, Nigeria

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Abstract
Polycyclic aromatic hydrocarbons (PAHs) are environmental contaminants with potential health risks, particularly in food. This study assessed the PAH levels present in processed bovine skin (kpomo) and grilled fish and their related health risks. Ten (10) kpomo and 10 grilled fish samples were collected from different vendors and analysed using gas chromatography-mass spectrometry. Health risk assessments were carried out based on estimated daily intake (EDI), hazard quotient (HQ), hazard index (HI), and cancer risk index (CR). Results showed that fluoranthene was the only PAH detected in kpomo samples, with concentrations ranging from 0.039 mg/kg to 0.125 mg/kg. In grilled fish samples, PAH levels ranged from 0.012 mg/kg (Benzo(b)fluoranthene) to 0.764 mg/kg (Indeno(1,2,3)perylene), with only two samples showing contamination. HQ and HI values indicated minimal non-carcinogenic risks for most food samples; however, children exposed to certain fish samples (ZE) had an HI > 1, suggesting potential adverse health effects. The cancer risk assessment showed generally low carcinogenic risks, except for a sole processed fish sample (ZE), where HI values exceeded 1×10^{-3} for children. These findings revealed the need for continued monitoring of PAHs in food products, improved processing techniques, and stricter food safety regulations to minimize health risks, particularly for vulnerable human populations.

Keywords: Bovine skin, cancer risk index, Estimated daily intake, Grilled fish, Non-carcinogenic health risk

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are chemical moieties known to comprise of multiple aromatic rings, created from the incomplete combustion of organic materials like wood, coal, oil as well as gas (Gaurav *et al*., 2021; Adesina, 2022). PAHs are a well documented public health concern due to their carcinogenic attributes (Barbosa Jr *et al*., 2023). In Nigeria, roasted bovine skin ("kpomo") and grilled fish are widely consumed, but traditional smoking and grilling methods can lead to PAH accumulation, and as such pose public health risks (Iwu *et al*., 2024). PAHs are known to enter food through environmental contamination and processing techniques, including grilling and smoking (Reizer *et al*., 2022). Certain PAHs, such as benzo[a]pyrene and dibenzo[a,h]anthracene, have been described as probable or possible anthropogenic carcinogens by the International Agency for Research on Cancer (IARC) (Sahin *et al*., 2020; Aamir *et al*., 2021).

Roasting and grilling are known to expose food to combustion byproducts, leading to PAH deposition (Duedahl-Olesen and Ionas, 2022). Traditional roasting of kpomo often utilize firewood, which can generate high PAH levels. Similarly, grilling fish over an open flame can result in PAH formation, depending on temperature, duration of heat exposure as well as fat content. Studies have revealed that food borne PAH concentrations vary based on cooking methods, smoking duration, and fuel type (Deeduah and Iwuoha, 2021; Khalili *et al*., 2023).

These variations highlight the need for controlled cooking techniques to minimize PAH exposure. It has been opined that there is a paucity of data with respect to PAH contamination and related health risks for foods prepared using traditional cooking practices exemplified by grilling and roasting over hot charcoal (Ejeomo *et al.*, 2025). The dearth of relevant information with regards to PAH contamination and related health risk(s) is particularly acute with respect to a variety of grilled meals and barbecued foods been consumed by individuals residing in Benin city and other urban settlements in Edo State, Southern Nigeria.

Human health risk assessment usually categorizes PAH exposure into non-carcinogenic and carcinogenic risks (Lee and Choi, 2023). Non-carcinogenic risks are assessed using reference doses (RfD) and hazard quotients (HQ), where HQ values exceeding 1 indicate potential health concerns (Oni *et al*., 2022). Carcinogenic risk assessment is utilized in estimating lifetime cancer probability, using slope factors to ascertain acceptable exposure limits (Lee and Choi, 2023). Regulatory bodies utilize these respective assessments as a baseline data when establishing safety guidelines and pollution control measures (Taghizadeh *et al*., 2022).

Given the widespread anthropogenic consumption of kpomo and grilled fish in different parts of Southern Nigeria, the likely presence of PAHs in these foods and the possible health concerns linked with the consumption of these PAH contaminated foods are issues that warrant both preliminary and comprehensive scientific investigations (Adeyeye and Ashaolu, 2022).

Despite the popularity of kpomo and grilled fish especially amongst residents of Benin city, Southern Nigeria, studies on their PAH profiles and related health risks associated with its consumption has remained limited. Evaluating PAH levels in these foods is crucial for understanding health risks associated with the consumption of these foods. This study focused on the assessment of the health risks related with the anthropogenic consumption of kpomo and grilled fish sold in different parts of Benin City, Southern Nigeria. The objectives of this study included; the determination of PAH profiles of the respective food samples as well as the carcinogenic and non-carcinogenic health risks associated with the documented PAH value (s) detected for the respective food samples.

MATERIALS AND METHODS

Sample collection

Bovine skin (kpomo)

A total of ten (10) processed cowhide (Kpomo) samples were purchased from two slaughterhouses and several retail meat shops in the Oluku area of Benin City (6.4541°N, 5.5957°E). The samples were placed in labeled and clean polyethylene bags, kept in coolers containing ice packs, and transported to a Federal Ministry of Environment-accredited environmental laboratory in Otokutu, Warri, Delta State for PAH evaluation.

Grilled fish

Ten (10) grilled fish samples were collected—five each from vendors located in both Oluku and Ekosodin areas of Benin City. Samples were similarly bagged, cooled with ice packs in clean coolers, and transported to a Federal Ministry of Environment-accredited environmental laboratory in Otokutu, Warri, Delta State for PAH evaluation.

Sample preparation and extraction

Extraction process

For each sample, 5 g was extracted in an ultrasonic bath using 10 ml of acetonitrile for 60 minutes. After 10 minutes, the extract was completely filtered to separate the solvent phase.

Clean-up procedure

The PAH extract was cleaned up using CHROMAFIX 400-SA solid-phase extraction cartridges. The cartridges were pre-conditioned with 3 ml of methanol. Then, 1 ml of the sample extract was passed through each cartridge. Elution was performed using methanol, and the eluates were concentrated to 1 ml using a gentle stream of high-purity nitrogen gas.

PAH analysis using GC-MS

Instrumentation

Analysis was conducted using an Agilent 6890 Gas Chromatography-Mass Spectrometry (GC-MS) system equipped with an ion trap detector. A Factor Four HP-5MS capillary column (30 m length, 0.25 mm internal diameter, 0.25 µm film thickness) was used.

Operating conditions

The injector and transfer line temperatures were maintained at 325°C. Helium was used as the carrier gas at a flow rate of 1 ml/min. The GC oven temperature program began at 40°C for 2 minutes, increased to 250°C at 30°C/min, then ramped to 320°C at 10°C/min, and held for 2 minutes. The detector operated in SCAN mode with a scanning range of 70–300 m/z. PAH identification was done by matching mass spectra and retention times with standards.

Target compounds

The 16 polycyclic aromatic hydrocarbons (PAHs) analysed were: Naphthalene, Acenaphthalene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, and Benzo(g,h,i)perylene.

Replicate and units

All analyses were performed in duplicates, and the PAH data were expressed in milligrams per kilogram (mg/kg).

Health risk evaluation

The non-carcinogenic health risk related with the food borne PAH values were determined as follows:

$$EDI = \frac{C\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT}$$

Where: EDI = estimated daily intake; C = concentration of PAH (mg/kg); IR = ingestion rate of meat (kg/day); EF = exposure frequency (days/year); ED = exposure duration (years); BW = bodyweight (kg) and AT = averaging time (days)

$$HQ = \frac{EDI}{RfD}$$

Where: HQ = hazard quotient; EDI = estimated daily intake; RfD = reference dose

$$HI = \sum HQ_i$$

Where: HI = hazard index; HQ = hazard quotient

HQ and HI were rated according to the same scale as follows: Values less than 1 indicated that there was negligible health risk related with the contaminant, while values from 1 and higher indicated a potential health risk due to exposure.

Carcinogenic health risk

The carcinogenic health risk associated with PAHs in the samples was the potential for cancer to occur in consumers of kpomo due to dietary exposure to PAHs contaminated meat. This was determined using the formulas below. In the case of this study, the exposure associated with the concentrations of PAHs in the samples were determined as follows:

$$EDI = \frac{C\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT}$$

Where: EDI = estimated daily intake; C = concentration of PAH (mg/kg); IR = ingestion rate of meat (kg/day); EF = exposure frequency (days/year); ED = exposure duration (years); BW = body weight (kg) and AT = averaging time (days)

$$CR = EDI\ x\ CSF$$

Where: EDI = estimated daily intake; CSF = cancer slope factor and CR = cancer risk index

Statistical analysis

The total PAH values of the examined food samples were subjected to non-parametric unpaired student t-test using SPSS version 22 software. The test was conducted at a 95% probability level.

RESULTS AND DISCUSSION

Concentrations of PAHs in the samples

The PAH profiles of the examined kpomo and grilled fish samples are shown in Table 1 and 2, respectively. Only fluoranthene was detected in the kpomo samples. The concentrations of PAHs detected ranged from 0.039mg/kg to 0.125mg/kg. The observed differences between the PAH values for the kpomo and grilled fish samples was significant (*$p<0.05$*).

For grilled fish, the concentrations of PAH ranged from 0.012mg/kg (Benzo(b)fluoranthene) to 0.272mg/kg (fluoranthene) (UF). In sample ZE, the concentrations of PAHs ranged from 0.229mg/kg (Benzo(k)fluoranthene) to 0.764mg/kg (Indo(I,2,3)perylene). No PAHs were detected in any of the other samples.

The study found varying levels of polycyclic aromatic hydrocarbons (PAHs) in the analysed kpomo and fish samples, with contamination detected in only two processed fish samples. Other samples contained no detectable PAHs, suggesting site-specific contamination rather than a widespread issue. These findings align with previous research linking PAH accumulation to localized anthropogenic activities such as combustion processes (Inobeme *et al*., 2018; Ofomata *et al*., 2019; Sojinu *et al*., 2019).

Fluoranthene was the only PAH detected in the kpomo samples and this PAH can enter food through environmental pollution, industrial emissions, and food processing techniques like smoking and roasting (Adeyeye and Ashaolu, 2020; Oko and Okoye, 2020). Compared to studies that reported higher PAH concentrations in smoked or grilled food items (Eklu-Gadegbeku, 2020; Adesina, 2022), the lower values found in this study suggest limited contamination sources or possible PAH degradation during food processing (Deeduah and Iwuoha, 2021).

Studies indicate that PAH distribution is often irregular, with higher concentrations near pollution sources (Alghamdi *et al.,* 2021).

Regulatory comparisons showed that PAH concentrations in this study were below the WHO and USEPA threshold of 1.0 mg/kg for food samples (USEPA, 2019). However, the presence of even low PAH levels would necessitate continued monitoring due to potential long-term health risks.

Table 1: Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) in Kpomo Samples from Oluku Market and Slaughterhouses in Benin City

PAH	M1	M3	M4	M5	M9	PR	S2	S3	S4	S5
Naphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluorene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Phenathrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluoranthene	0.125	0.000	0.000	0.000	0.114	0.000	0.000	0.000	0.000	0.039
Pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(a)anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crysene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(b)Fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(k)Fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(a)pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Indo(1,2,3)perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dibenzo(a,h)anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(g,h,l)perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL PAHs (mg/kg)	0.125	<0.001	<0.001	<0.001	0.114	<0.001	<0.001	<0.001	<0.001	0.039

M1, M9: Kpomo samples collected from shop 1 at Oluku market
M3, M4, M5: Kpomo samples collected from shop 2 at Oluku market
PR, S2, S3, S4 and S5: Kpomo samples collected from respective slaughter houses

Table 2: Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) in Grilled Fish Samples from Uselu and Ekosodin Markets in Benin City

PAH	U1	U5	UF	UG	UH	Z9	ZB	ZC	ZD	ZE
Naphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acenaphthene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluorene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Phenathrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fluoranthene	0.000	0.000	0.272	0.000	0.000	0.000	0.655	0.000	0.000	0.000
Pyrene	0.000	0.000	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(a)anthracene	0.000	0.000	0.219	0.000	0.000	0.000	0.293	0.000	0.000	0.000
Crysene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(b)Fluoranthene	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Benzo(k)Fluoranthene	0.000	0.000	0.000	0.000	0.000	0.000	0.229	0.000	0.000	0.000
Benzo(a)pyrene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Indo(1,2,3)perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.764	0.000	0.000	0.000
Dibenzo(a,h)anthracene	0.000	0.000	0.000	0.000	0.000	0.000	0.397	0.000	0.000	0.000
Benzo(g,h,l)perylene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL PAHs (mg/kg)	<0.001	<0.001	0.530	<0.001	0.000	<0.001	2.339	<0.001	<0.001	<0.001

Z9, ZB, ZC, ZD, ZE: Grilled fish samples collected from different sellers in Ekosodin
U1, U5, UF, UG, UH: Smoked fish samples collected from different sellers in Uselu market

Health risk assessment of kpomo

The non-carcinogenic health risk of kpomo derived fluoranthene to children and adults are shown in Table 3. The hazard quotient of fluoranthene for children in the samples ranged from 0.01247 to 0.03995. These values are less than 1, indicating low potential health risk for each sample. The HI value for fluoranthene in all the samples is also less than 1 (0.08886), indicating low potential health risks.

The hazard quotient of fluoranthene for adults in the samples varied from 0.00134 to 0.00248. These values are less than 1, indicating low potential health risk for each sample. The HI value for fluoranthene in all the samples is also less than 1 (0.00952), also indicative of low potential health risks

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Table 3: Non-Carcinogenic Health Risk Assessment of Fluoranthene Detected in Kpomo Samples for Children and Adults

Concentration (mg/kg)	Children		Adults	
	EDI	HQ	EDI	HQ
0.125	0.00160	0.03995	0.000171	0.00428
0.114	0.00146	0.03644	0.000156	0.00390
0.039	0.000499	0.01247	0.0000534	0.00134
HI		0.08886		0.00952

Health risk assessment of grilled fish

The non-carcinogenic and carcinogenic health risks of the detected PAHs in the fish samples are presented in Table 4 and 5, respectively. The HQ values for PAHs for children and adults from sample UF are less than 1 indicating that there is minimal health risk from exposure to the individual PAHs. The HI value for children is greater than 1 indicating possible adverse health impacts. However, that of adults is less than 1. For sample ZE, the individual HQ values for 4 PAHs in children and 2 PAHs in adults were above 1, indicating potential adverse health impacts. The hazard indices for both children and adults are above 1 which was indicating that there is a high risk of adverse non-carcinogenic health impacts due to ingestion. This trend contrasted with findings reported by Ejeomo *et al*. (2025) which revealed tolerable or lower incremental lifetime cancer risk (ILCR) values with respect to PAH values detected for barbecued fish samples collected from various locations in Warri metropolis, Delta State.

Table 4: Non-carcinogenic risk for the fish borne PAHs

PAH	Children		Adults	
	EDI	HQ	EDI	HQ
		UF		
Fluoranthene	0.000363	0.00907	0.0000389	0.00097
Pyrene	0.0000373	0.00124	0.000004	0.00013
Benzo(a)anthracene	0.000292	0.9733	0.0000313	0.10430
Benzo(b)fluoranthene	0.000016	0.1600	0.00000171	0.01710
		HI = 1.144		HI = 0.123
		ZE		
Fluoranthene	0.000873	0.0218	0.0000936	0.00234
Benzo(a)anthracene	0.000391	1.3020	0.0000419	0.1400
Benzo(k)Fluoranthene	0.000305	3.3930	0.0000327	0.3630
Indo(1,2,3)perylene	0.001019	25.467	0.000109	2.7290
Dibenzo(a,h)anthracene	0.000529	17.644	0.0000567	1.8900
		47.83		5.12

The HQ values recorded for both children and adults for all PAHs detected were less than 1×10^{-3} indicating low potential carcinogenic effect due to consumption. However, the HI value for sample ZE was greater than 1×10^{-3} and indicated that there was a likely potential adverse carcinogenic effect in children

Table 5: Carcinogenic risk for the fish borne PAHs

PAH	Children		Adults	
	EDI	HQ	EDI	HQ
		UF		
Benzo(a)anthracene	0.000292	2.92×10^{-5}	0.0000313	3.13×10^{-6}
Benzo(b)fluoranthene	0.000016	1.6×10^{-6}	0.00000171	1.71×10^{-7}
		HI = 3.08×10^{-5}		HI = 3.30×10^{-6}
		ZE		
Benzo(a)anthracene	0.000391	3.91×10^{-5}	0.0000419	4.19×10^{-6}
Benzo(k)Fluoranthene	0.000305	9.16×10^{-6}	0.0000327	9.81×10^{-7}
Indo(1,2,3)perylene	0.001019	1.02×10^{-4}	0.000109	1.09×10^{-5}
Dibenzo(a,h)anthracene	0.000529	5.82×10^{-4}	0.0000567	6.24×10^{-5}
		HI = 2.24×10^{-3}		HI = 7.83×10^{-5}

Health risk assessments indicated that hazard quotient (HQ) values for PAHs in sample UF were below 1 for both adults and children, implying low non-carcinogenic health risks. However, the hazard index (HI) for children exceeded 1, suggesting potential health concerns. The higher HI values in children is in agreement with studies showing their increased susceptibility to PAH exposure due to lower body weight and higher relative intake (Chen *et al.*, 2019; WHO, 2021). Sample ZE posed a greater health risk, with HQ values above 1 for two PAHs in adults and four in children. The overall HI values for both groups exceeded 1, indicating significant non-carcinogenic health risks. The WHO (2021) has warned that long-term PAH exposure may result in immunotoxic and developmental effects, particularly in vulnerable populations.

Carcinogenic risk assessments revealed that whilst individual PAHs had HQ values below 1×10^{-3}, the HI value recorded for sample ZE exceeded this threshold, indicating potential cancer risks, particularly for children. The International Agency for Research on Cancer (IARC) has classified PAHs as probable human carcinogens, with prolonged exposure linked to increased risks of bladder, skin, and lung cancers (IARC, 2019). Chronic exposure, even at low levels, can lead to cumulative adverse health effects over time (Liu *et al.*, 2022). Although fluoranthene is less toxic than benzo[a]pyrene, cumulative PAH exposure remains a concern (Khalili *et al.*, 2023).

The variability in fluoranthene levels across meat samples could be indicative of the influence of processing, storage as well as exposure to PAH contamination sources. Smoking and roasting are known to primarily affect PAH levels in foods prepared using these cooking methods (Adesina, 2020; Adeyeye and Ashaolu, 2020). This trend therein, would invariably bring to the public domain, the twin issues of providing alternative economically affordable cooking techniques or the modification of these practices (roasting and smoking) that can minimize or completely eradicate the occurrence of PAH congeners in these protein-rich foods. Whilst the observed PAH levels in the examined food samples pose minimal immediate health risks, bioaccumulation and long-term exposure effects cannot be ignored. PAHs are known to persist in the environment and human tissues, necessitating routine monitoring to ensure contamination remains within safe limits (WHO, 2021).

CONCLUSION

This study revealed the presence of PAHs, particularly fluoranthene, in kpomo and grilled fish samples from Benin City, with concentrations in some samples posing potential health risks, especially to children. While most samples showed low non-carcinogenic and carcinogenic risk levels, a few, such as sample ZE, exceeded acceptable limits, indicating the need for concern. These findings underscore the potential health risks associated with the routine consumption of these foods with reference to the PAH content of these foods. To safeguard public health, it is recommended that regular monitoring of PAH levels in food items should be conducted and enforced, public awareness on safe food processing should be increased and regulatory agencies must implement and enforce standards for grilling as well as smoking techniques commonly used by local food vendors.

REFERENCES

Aamir, M., Yin, S., Liu, Y., Ullah, H., Khan, S. and Liu, W. (2021): Dietary Exposure and Cancer Risk Assessment of the Pakistani Population Exposed to Polycyclic Aromatic Hydrocarbons. *Science of The Total Environment*, 757, 143828. https://doi.org/10.1016/j.scitotenv.2020.143828

Adesina, O. A. (2022): Level of Polycyclic Aromatic Hydrocarbon in Smoked Food Materials from Roadside Barbecue Spots in Western Nigeria and Health Implication. *Polycyclic Aromatic Compounds*, 42(5): 1972-1977. https://doi.org/10.1080/10406638.2020.1821721

Adeyeye, S. A. O. and Ashaolu, T. J. (2022): A Study on Polycyclic Aromatic Hydrocarbon and Heavy Metal Concentrations of Commercial Grilled Meat (Suya) and Smoked Catfish (*Clarias gariepinus* Burchell, 1822) Fish from South-West, Nigeria. *Polycyclic Aromatic Compounds*, 42(6):3281-3290. https://doi.org/10.1080/10406638.2020.1858883

Alghamdi, M.A., Hassan, S.K., Al Sharif, M.Y., Khoder, M.I. and Harrison, R.M. (2021): On the nature of Polycyclic Aromatic Hydrocarbons Associated with Sporting Walkways Dust: Concentrations, Sources and Relative Health Risk. *Science of the Total Environment*, *781*, p.146540.

https://doi.org/10.1016/j.scitotenv.2021.146540

Barbosa Jr, F., Rocha, B. A., Souza, M. C., Bocato, M. Z., Azevedo, L. F., Adeyemi, J. A. and Campiglia, A. D. (2023): Polycyclic Aromatic Hydrocarbons (PAHs): Updated Aspects of their Determination, Kinetics in the Human Body, and Toxicity. *Journal of Toxicology and Environmental Health, Part B*, 26(1): 28-65. https://doi.org/10.1080/10937404.2022.2164390

Chen, X., Yang, L., Myneni, S.C. and Deng, Y. (2019): Leaching of Polycyclic Aromatic Hydrocarbons (PAHs) from Sewage Sludge-derived Biochar. *Chemical Engineering Journal*, 373:840-845. https://doi.org/10.1016/j.cej.2019.05.059

Deeduah, F. and Iwuoha, G. (2021): Genotoxicity and Carcinogenicity of Traditionally Roasted Meat using Indicator Polycyclic Aromatic Hydrocarbons (PAHs), Port Harcourt, Nigeria. *Chemistry International*, 7(3):217-223.

Duedahl-Olesen, L. and Ionas, A. C. (2022): Formation and Mitigation of PAHs in Barbecued Meat–A Review. *Critical Reviews in Food Science and Nutrition*, 62(13), 3553-3568. https://doi.org/10.1080/10408398.2020.1867056.

Ejeomo, C., Oghoje, S. U., Obayagbona, N. O., Celestine, E. and Mabel, A. A. (2025). Effect of Polynuclear Aromatic Hydrocarbons levels in Suya and Barbecue fish on Cancer Risk Index in Warri Metropolis, Southern Nigeria. *Journal of Agriculture, Food and Environment* 6(1): 5-12, https://doi.org/10.47440/JAFE.2025.6102.

Eklu-Gadegbeku, K. (2020): Human Health Risk Assessment of Polycyclic Aromatic Hydrocarbons (PAH) in Smoked Fishes in Togo. *Journal of Agriculture and Environmental Sciences*, *9*(2), 6-13. https://doi.org/10.15640/jaes.v9n2a2

Gaurav, G. K., Mehmood, T., Kumar, M., Cheng, L., Sathishkumar, K., Kumar, A. and Yadav, D. (2021): Review on Polycyclic Aromatic Hydrocarbons (PAHs) Migration from Wastewater. *Journal of contaminant hydrology*, 236, 103715. https://doi.org/10.1016/j.jconhyd.2020.103715.

Inobeme, A., Ajayi, A. I., Mann, A. and Iyaka, Y. A. (2018): Determination of Polycyclic Aromatic Hydrocarbons and Heavy Metal Contents of Barbecue beef, Fish and Chicken. *Food and Environment Safety*, 97: 395 – 403.

Iwu, G. I., Lajide, L., Madu, P. C. and Isah, I. A. (2024): Assessment of Polycyclic Aromatic Hydrocarbon (PAH) Profiles in Heat-processed Meat and Fish: A Study on Health Risk Evaluation. *Discover Food*, 4(1), 46. https://doi.org/10.1007/s44187-024-00116-5

Khalili, F., Shariatifar, N., Dehghani, M. H., Yaghmaeian, K., Nodehi, R. N., Yaseri, M. and Moazzen, M. (2023): Polycyclic Aromatic Hydrocarbons (PAHs) in Meat, Poultry, Fish and Related Product Samples of Iran: A Risk Assessment Study. *Journal of Environmental Health Science and Engineering*, 21(1): 215-224. https://doi.org/10.1007/s40201-023-00854-1

Lee, Y.K., Lee, J.H., Beak, N.G., Kim, K.C. and Han, J.S. (2023): Seasonal and Emission Characteristics of PAHs in the Ambient Air of Industrial Complexes. *Atmosphere*, 15(1), 30. https://doi.org/10.3390/atmos15010030

Liu, M., Cai, M., Duan, M., Chen, M., Lohmann, R., Lin, Y., Liang, J., Ke, H. and Zhang, K. (2022): PAHs in the North Atlantic Ocean and the Arctic Ocean: Spatial Distribution and Water Mass Transport. *Journal of Geophysical Research: Oceans*, 127(6),p.e2021JC018389. https://doi.org/10.1029/2021JC018389

Ofomata, I., Obodoechi, L. O., Obidike, R. I. and Nwanta, J. A. (2019): Presence and Levels of Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in Smoked Fish, Hides and Skin of Slaughter Cattle and Goats in Awka Urban, Nigeria. *International Journal of Current Pharmaceutical Research*, 11:14-17.

Oko, O.J.O. and Okoye, C.B. (2021): Evaluation of Probable Sources and Extent of Beef Contamination by Smoke PAHs (Polycyclic Aromatic Hydrocarbons) in Selected Towns of Northern Nigeria. *European Journal of Earth and Environment*, *8*(1).

Oni, A.A., Babalola, S.O., Adeleye, A.D., Olagunju, T.E., Amama, I.A., Omole, E.O., Adegboye, E. A. and Ohore, O.G. (2022): Non-carcinogenic and Carcinogenic Health Risks Associated with Heavy Metals and Polycyclic Aromatic Hydrocarbons in Well-water Samples from an Automobile Junk Market in Ibadan, SW-Nigeria. *Heliyon*, 8(9). https://doi.org/10.1016/j.heliyon.2022.e10688

Reizer, E., Viskolcz, B. and Fiser, B. (2022): Formation and Growth Mechanisms of Polycyclic Aromatic Hydrocarbons: A Mini-Review. *Chemosphere*, 291, 132793. https://doi.org/10.1016/j.chemosphere.2021.132793

Sahin, S., Ulusoy, H. I., Alemdar, S., Erdogan, S. and Agaoglu, S. (2020): The Presence of Polycyclic Aromatic Hydrocarbons (PAHs) in Grilled Beef, Chicken and Fish by Considering Dietary Exposure and Risk Assessment. *Food Science of Animal Resources*, 40 (5), 675.

Sojinu, O. S., Olofinyokun, L., Idowu, A. O., Mosaku, A. M. and Oguntuase, B. J. (2019): Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Smoked Fish and Meat Samples in Abeokuta. *Journal of Chemical Society of Nigeria*, 44(1).

Taghizadeh, S.F., Rezaee, R., Boskabady, M., Mashayekhi Sardoo, H. and Karimi, G., (2022). Exploring the Carcinogenic and Non-Carcinogenic risk of Chemicals Present in Vegetable Oils. *International Journal of Environmental Analytical Chemistry*, 102(17):5756-5784. https://doi.org/10.1080/03067319.2020.1803848

World Health Organization (WHO) (2021): Human health effects of polycyclic aromatic hydrocarbons as ambient air pollutants. Retrieved from https://www.who.int/europe/publications/i/item/9789289056533.