African Journal of Research in Medical and Health Sciences
https://doi.org/10.71921/ajrmhs.vol4no1.106

RESEARCH *Open Access*

POLYCYCLIC AROMATIC HYDROCARBONS IN FOOD CROPS GROWN IN HIGH- AND LOW-CRUDE-OIL-PRODUCING COMMUNITIES OF RIVERS STATE, NIGERIA: A COMPARATIVE CROSS-SECTIONAL STUDY

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Abstract

Background: Dietary sources of polycyclic aromatic hydrocarbons (PAH) through food crops grown in polluted soils, prepared/processed through drying, frying, grilling, toasting, roasting, smoking, drinks, and herbivorous animals account for 70% of transmission into the human body, with associated carcinogenic health consequences, compared to non-dietary sources (inhalation and skin contact).

Aim: This study assessed and compared the concentrations of PAHs in food crops grown in high- and low crude oil–producing communities in Rivers State, Nigeria.

Methodology: Food samples were collected from 30 geo-referenced sampling points across 10 communities. Laboratory analysis followed approved APHA and ASTM standard methods. Data were analysed using SPSS version 26, with statistical significance set at $p < 0.05$ and 95% confidence level.

Results: Of the sixteen priority PAH compounds analysed, eight were detected above the laboratory limit of detection (LOD). All detected PAHs had mean concentrations below the European Union regulatory limit for PAHs in food (benzo[a]pyrene equivalent guideline value: 1.0 µg/kg). However, five PAHs had significantly higher mean concentrations in high-oil-producing communities than in the low-oil-producing communities ($p< 0.05$). In descending order of statistical significance, phenanthrene showed the strongest difference ($p=0.003$), followed by acenaphthylene ($p=0.007$), acenaphthene ($p=0.021$), anthracene ($p=0.032$), and fluorene ($p=0.048$). Acenaphthylene recorded the highest mean concentration, while pyrene had the lowest.

Conclusion: Food crops from both study areas were contaminated with PAHs, with significantly higher levels observed in high oil-producing communities, likely due to oil exploration activities and artisanal refining. Strengthened regulatory controls and remediation strategies are recommended to mitigate long-term exposure risks.

Keywords: *Polycyclic Aromatic Hydrocarbons, Food Crops, Oil-Producing, Comparative study*

Cite as*: Luke A, Tobin-West C. Polycyclic Aromatic Hydrocarbons in Food Crops Grown in High- and Low-Crude-Oil-Producing Communities of Rivers State, Nigeria: A Comparative Cross-Sectional Study. AJRMHS. 2026; 4(1):19 - 31*

Introduction

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic chemical compounds composed of multiple aromatic rings. They occur naturally in substances such as coal, crude oil, gas, gasoline, waste materials, tobacco, and wood, and can bind to or form small particles in the atmosphere.[1,2] When released into the environment, these contaminants may originate from natural sources such as forest fires and volcanic emissions, as well as from anthropogenic activities including cigarette smoking, coal combustion, and vehicle exhaust emissions.[3,4]

Most PAHs are colourless, uncharged, non-polar, and planar compounds formed primarily during the incomplete combustion of organic matter, such as in engines, incinerators, and biomass burning.[5] Long-term exposure to these pollutants derived from sources such as crude oil, tar sands, bitumen, coal, gas, and other petroleum products, as well as from the burning of vegetation, biomass fuels, medical waste, and municipal waste, has been associated with various adverse health outcomes.[6,7]

There are two primary routes through which these pollutants enter the human body: dietary exposure (via contaminated food and, indirectly, soil), which accounts for approximately 70% of total human exposure, and non-dietary exposure (via inhalation and dermal contact), which constitutes the remaining proportion.[1,4] Prolonged dietary exposure to these compounds has been linked to carcinogenic, mutagenic, and immunosuppressive effects, necessitating continuous monitoring and surveillance.[1,4]

These compounds may be present in various food items, including grains, tubers, fruits, and vegetables grown in contaminated soils.[1] They may also contaminate food during processing and preparation methods such as drying, frying, grilling, roasting, toasting, and smoking, particularly when fossil fuels or biomass are combusted at high temperatures or over open flames.[4,8] Additionally, low–molecular-weight (gas-phase) PAHs in the atmosphere, together with high–molecular-weight compounds deposited in soil and water, can enter the food chain through adsorption onto crop surfaces, particularly leafy vegetables, where surface contamination is often more pronounced.[4,9]

Contaminated vegetation may serve as feed for livestock such as grazing herbivores (e.g., cattle) and livestock (pigs), leading to the accumulation of PAHs in animal tissues following ingestion of contaminated plant material and soil particles.[10,11] More than 100 compounds have been identified and are generally classified based on molecular weight. Low–molecular-weight (2–3 ring) PAHs exist primarily in the vapour phase and include compounds such as naphthalene, acenaphthene, acenaphthylene, anthracene, fluorene, and phenanthrene. In contrast, high-molecular-weight (4–6 ring) PAHs are more stable and predominantly associate with particulate matter. These include four-ring compounds (benz[a]anthracene, chrysene, fluoranthene, and pyrene), five-ring compounds (benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, and dibenz[a,h]anthracene), and six-ring compounds (benzo[ghi]perylene and indeno[1,2,3-cd]pyrene).[12,13]

PAHs are primarily generated through pyrolytic processes resulting from the incomplete combustion of organic matter at high temperature and limited oxygen supply. Although both natural and anthropogenic sources contribute to environmental PAH levels, industrial activities remain the predominant source of emissions and substantially increase human exposure to these carcinogenic compounds.[2,14]

According to the Joint Food and Agriculture Organization/World Health Organization (FAO/WHO), the European Food Safety Authority (EFSA), the Scientific Committee on Food (SCF), and the European Commission, four key PAHs commonly identified in food crops are benz[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), and benzo[a]pyrene (BaP). These compounds are recognized for their mutagenic, genotoxic, and carcinogenic properties. Based on classifications by the International Agency for Research on Cancer (IARC), BaP is categorized as a Group 1 carcinogen, while BaA, BbF, and Chr are classified as Group 2B carcinogens.[4,15,16]

Among these, benzo[a]pyrene is the most extensively studied and is often used as a marker for contaminated food substances due to its strong genotoxic potential. It exerts harmful effects through direct interaction with DNA, leading to structural alterations that may initiate carcinogenesis. [17,18]

Elevated concentrations of polycyclic aromatic hydrocarbons (PAHs) in food crops cultivated in crude oil–producing regions may pose significant health risks to exposed populations, particularly in the absence of effective regulatory oversight and environmental remediation. Against this backdrop, this study assessed and compared the concentrations of polycyclic aromatic hydrocarbons in food crops cultivated in high- and low–crude oil–producing communities in Rivers State, Nigeria.

Materials And Methods

Study Area

Rivers State is in the Niger Delta region of Nigeria, with Port Harcourt as its capital. Administratively, it is divided into 23 Local Government Areas (LGAs) and 319 political wards. Five LGAs, Port Harcourt City, Obio/Akpor, Ikwerre, Oyigbo, and Eleme, are classified as urban, while the remaining eighteen are predominantly rural.

The State is bordered to the south by the Atlantic Ocean, to the north by Anambra, Imo, and Abia States, to the east by Akwa Ibom State, and to the west by Bayelsa and Delta States. Much of its coastline lies within the low-lying Niger Delta region, extending from Bonny in the south to Ndoni in the north. The inland areas are characterized by tropical rainforest vegetation, while mangrove swamps dominate the coastal environment.

Rivers State has a total land area of approximately 11,077 km² and a density of 635.89 persons/km² with an estimated population of 7,326,630 and an annual growth rate of 4.99%. It is one of the most densely populated states in Nigeria. The State is culturally diverse, with major ethnic groups including the Ijaw, Ikwerre, Etche, Ogoni, and Ogba/Egbema peoples. English and Nigerian Pidgin are widely spoken.[19,20]

The State is a major hub of Nigeria's petroleum industry, hosting key facilities such as the country's first petroleum refinery and the Nigeria Liquefied Natural Gas (NLNG) complex, alongside multinational oil companies including Shell, Chevron, Agip, Total, and Elf. In addition to crude oil, other natural resources such as silica, glass sand, and clay are present. Port Harcourt metropolis, comprising Port Harcourt City and Obio/Akpor LGAs, was ranked among Nigeria's leading industrial centres, with a GDP of $21.07 billion and a per capita income of $3,965 as of 2007.[12,13]

Study Design

This study employed a cross-sectional comparative design to assess and compare the concentrations of polycyclic aromatic hydrocarbons in food samples grown in high and low-oil-producing communities in Rivers State, Nigeria.

Operational Definitions of Terms

High crude oil-producing rural communities: Communities with continuous oil exploration and exploitation activities for ≥10 years and located within 500 meters (≈0.3 miles) of gas flaring sites or flow stations.[12,13,21]

Low oil-producing rural communities: Communities with little or no exposure to oil exploration and exploitation activities within the past 10 years and located more than 500 meters (>0.3 miles) from gas flaring sites or flow stations.[12,13,21]

Below Limit of Detection (BLD): This refers to a condition in which the concentration of an analyte in a sample is too low to be reliably detected or distinguished from background noise by the analytical method or instrument used.[22,23]

Limit of Detection (LOD): This is the lowest concentration or quantity of an analyte that can be reliably distinguished from background noise or a blank sample with a specified level of confidence, typically 95%.[23,24]

Sampling Technique

A multistage sampling technique was employed in this study.

Stage 1: Selection of Senatorial Districts

Rivers State was stratified into its three senatorial districts:

- Rivers East: Emohua, Etche, Ikwerre, Obio/Akpor, Ogu/Bolo, Okrika, Omuma, Port Harcourt
- Rivers South-East: Andoni, Eleme, Gokana, Khana, Opobo/Nkoro, Oyigbo, Tai
- Rivers West: Abua/Odual, Ahoada East, Ahoada West, Akuku-Toru, Asari-Toru, Bonny, Degema, Ogba/Egbema/Ndoni

Two senatorial districts (Rivers East and Rivers West) were selected by balloting.

The selected districts were further stratified into:

- High oil-producing LGAs: Akuku-Toru, Asari-Toru, Bonny, Degema, Obio/Akpor, Ogba/Egbema/Ndoni, Port Harcourt
- Low oil-producing LGAs: Abua/Odual, Ahoada East, Ahoada West, Emohua, Etche, Ikwerre, Ogu/Bolo, Okrika, Omuma

Stage 2: Selection of Local Government Areas (LGAs)

From the stratified list, LGAs were selected by balloting to represent both conventional and artisanal oil production activities:

- High oil-producing LGAs: Ogba/Egbema/Ndoni, Emohua
- Low oil-producing LGAs: Ikwerre

Stage 3: Selection of Communities

Five communities were selected from each exposure category:

- High oil-producing communities: Ebocha, Ibaa, Obrikom, Ohali/Usomini/Idu, Okwuzi
- Low oil-producing communities: Ipo, Omuanwa, Omerelu, Ozuoha, Ubima

Stage 4: Selection of Sampling Points

A multistage random sampling approach was employed at the community level. Eligible Local Government Areas (LGAs) and communities within each exposure category were selected using simple random sampling (balloting). Within each selected community, sampling points were stratified based on proximity to pollution sources (i.e., near, intermediate, and distant zones), and one sampling point was randomly selected from each stratum. This stratified random approach ensured representation of varying exposure levels, thereby improving representativeness and minimizing selection bias.

Selection of Sampling Points

A total of 30 geo-referenced sampling points were selected using a stratified multistage sampling approach. Sampling points were chosen based on population density, active cultivation sites, proximity to oil-related activities (e.g., gas flaring and flow stations), and agricultural relevance. Fifteen sampling points were obtained from high crude-oil-producing communities and fifteen from low crude-oil-producing communities.

Within each exposure group, five communities were selected, and three sampling points were identified per community. Within each community, sampling points were selected using a stratified random approach to capture varying exposure levels (i.e., near, intermediate, and distant from pollution sources). Geographic coordinates of each sampling point were recorded using a GPS device to ensure spatial accuracy and reproducibility.

At each sampling point, farms were delineated into sections, from which sampling locations were randomly selected to reduce selection bias. Where multiple crop stands existed, individual plants were selected using simple random sampling techniques. This multistage randomization approach improved representativeness and reduced sampling bias.

Sample Storage and Transportation

A total of 90 crop samples were harvested, comprising three samples from each crop type, collected from different points within the farmland in each selected community. All samples were placed in labelled zip-lock bags, stored in ice-lined coolers, and transported to the laboratory within 24 hours in accordance with American Public Health Association (APHA) guidelines.[25]

The sampling approach ensured adequate spatial representation across both high and low crude-oil-producing communities, thereby enhancing the generalizability of the findings. It also allowed for a balanced comparison between the two exposure groups, with equal sampling intensity maintained (15 sampling points × 3 crop types = 45 samples per group). The use of multiple sampling points within each community minimized sampling bias and improved the representativeness of the data.

Furthermore, this design enhanced the reliability and precision of PAH concentration estimates by capturing variability across different locations and crop types. The selected sample size is consistent with established practices in environmental and food contamination studies, where multiple samples across spatial gradients and crop varieties are required to adequately account for heterogeneity in contaminant distribution.

Physiochemical Characterization of Food Crops

The staple crops analyzed included cassava (*Manihot esculenta*), pumpkin (*Telfairia occidentalis*), and waterleaf (*Talinum fruticosum* / *Talinum triangulare*). Cassava tubers were sliced, air-dried at room temperature (27°C) for two weeks, ground, and stored in airtight containers until analysis. For the leafy vegetables, 5 g of fresh samples (leaves and stalks) were used for enzyme assays. One gram of each sample was homogenized in 9 mL of distilled water and centrifuged at 1000 rpm for 15 minutes, after which the supernatant was collected for subsequent analysis.

Instrumental Analysis

Samples were analyzed using a gas chromatography–mass spectrometry (GC–MS) system (Shimadzu GC2010 coupled to a QP2010 mass spectrometer). An injection volume of 1 µL was used in splitless mode at 280°C. Chromatographic separation was achieved using an Rtx-5MS capillary column (30 m × 0.25 mm × 0.25 µm), with helium (99.999%) as the carrier gas at a constant flow rate of 1 mL/min. The oven temperature was programmed using a multi-step ramp up to 300°C. Mass spectra were acquired over a scan range of 50–500 m/z using electron ionization at 70 eV. Retention time locking with an internal standard was employed to ensure reproducibility, and compound identification was based on retention times and characteristic mass spectra.

Overall, the QA/QC procedures, including calibration verification, recovery assessment, determination of detection limits, and the use of blank controls, confirmed the reliability, sensitivity, and accuracy of the analytical method for PAH determination in food crops.[26]

Analysed PAHs

Sixteen PAHs were analyzed, including: Acenaphthylene, Acenaphthene, Anthracene, Benz[a]anthracene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[ghi]perylene, Benzo[a]pyrene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno[1,2,3-cd]pyrene, Naphthalene, Phenanthrene, and Pyrene. Results were compared with the World Health Organization (WHO) food safety standards.

Statistical Analysis

Descriptive statistics (mean ± standard deviation) were used to summarize PAH concentrations. At the bivariate level, differences in mean PAH concentrations between high- and low-oil-producing communities were assessed using independent-samples t-tests after testing for normality. Where normality assumptions were violated, appropriate non-parametric alternatives were considered. While at the multivariate level, the significant variables were set at the probability value ($p<0.05$) and 95% confidence interval and compared with the standard European Union (EU) Regulatory Limits guideline for food substances.

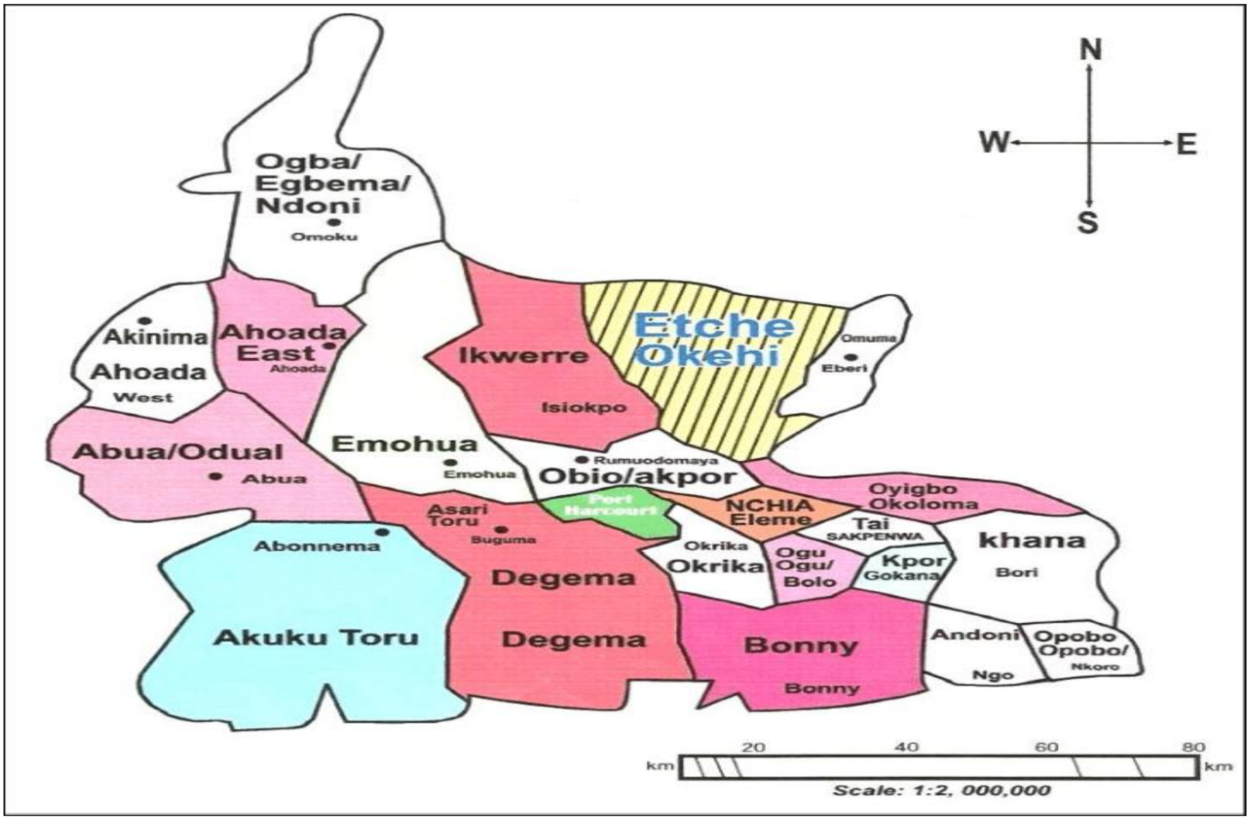

Figure 1: Map of Rivers State showing the Local Government Areas.[27]

Results

The table below shows that of the sixteen priority PAH compounds analysed from food crops grown in the selected study sites, eight were identified. Though the mean concentration of the identified eight PAH compounds was found below the recommended WHO acceptable limit, five out of them were significantly higher in the high oil-producing site compared to the low site. Also, in descending order of significance, phenanthrene was the most significant, while fluorene had the least; phenanthrene ($p=0.003$) > Acenaphthylene ($p=0.007$) > Acenaphthene ($p=0.021$) > Anthracene (0.032) > fluorene ($p=0.048$) (Table 1).

Table 1: Comparison of the concentration of polyaromatic hydrocarbons in food crops grown in high and low-oil-producing sites.

Variable	High Sites Mean (95% CI)	Std	Low Sites Mean (95% CI)	Std	t	p-value	EU Regulatory LOD (µg/kg)
Naphthalene	0.004 (0.0014–0.0066)	0.008	0.000 (0.000–0.000)	0.000	1.871	0.072	0.01
Acenaphthylene	0.009 0.0064–0.0116)	0.009	0.001 (-0.0002–0.0022)	0.004	2.896	0.007*	0.01
Acenaphthene	0.007 (0.0044–0.0096)	0.009	0.001 (-0.0002–0.0022)	0.004	2.443	0.021*	0.01
Fluorene	0.005 (0.0024–0.0076)	0.008	0.001 (-0.0001–0.0021)	0.003	2.071	0.048*	0.01
Phenanthrene	0.007 (0.0044–0.0096)	0.009	0.000 (0.000–0.000)	0.000	3.214	0.003*	0.01
Anthracene	0.005 (0.0024–0.0076)	0.009	0.000 (0.000–0.000)	0.000	2.256	0.032*	0.01
Fluoranthene	0.002 (0.0002–0.0038)	0.006	0.000 (0.000–0.000)	0.000	1.382	0.178	0.01
Pyrene	0.001 (-0.0005–0.0025)	0.005	0.000 (0.000–0.000)	0.000	1.000	0.326	0.01
Chrysene	BDL	BDL	BDL	BDL			
Benz[a]anthracene	BDL	BDL	BDL	BDL			
Benzo[b]fluoranthene	BDL	BDL	BDL	BDL			
Benzo[k]fluoranthene	BDL	BDL	BDL	BDL			
Benzo(g,h,i)perylene	BDL	BDL	BDL	BDL			
Benzo[a]pyrene	BDL	BDL	BDL	BDL			
Dibenz[a,h]anthracene	BDL	BDL	BDL	BDL			
Indeno[1,2,3-cd] pyrene	BDL	BDL	BDL	BDL			

*Statistical significance; BDL (Below Limit of Detection); LOD (Limit of Detection)

Discussion

The present study revealed that, in descending order of concentration, five PAH metabolites (phenanthrene > acenaphthylene > acenaphthene > anthracene > fluorene) were significantly higher in high-oil-producing communities compared to the low-oil-producing site. However, the mean concentrations of these PAH compounds in food crops from both study areas remained below the World Health Organization (WHO) regulatory safety limit. This finding is consistent with a similar cross-sectional study conducted in Ughelli South LGA of Delta State, which reported that six PAH metabolites (benzo[a]anthracene, chrysene, benzo[b]fluoranthene, indeno[1,3-cd]pyrene, dibenz[a,h]anthracene, and benzo[k]fluoranthene) detected in cassava tubers from high oil-impacted (Ekore and Uduvwoku) and non-oil-impacted (Okpe-Olomu) communities were below the recommended WHO permissible limits. However, benzo[a]pyrene was reported to be marginally above the permissible limit in that study. Notably, several of the identified PAHs, including benzo[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[k]fluoranthene, are classified as potentially carcinogenic and have been associated with an increased risk of cancer even at low exposure levels.[28]

On the contrary, a cross-sectional study conducted in two high-oil-producing communities (Alakahia and Eleme) in Rivers State reported elevated concentrations of PAH compounds in food crops, including leafy vegetables (pumpkin leaf, scent leaf, and bitter leaf) and tubers (cassava, yam, and cocoyam). The PAHs were detected in descending order of concentration as follows: fluoranthene > pyrene > naphthalene. These elevated levels were largely attributed to anthropogenic activities within the communities, including the combustion of wood and fossil fuels, as well as artisanal and conventional refining activities prevalent in the study area.[29] Equally, another cross-sectional study conducted in the Niger Delta region of Nigeria reported that the mean concentration of benzo[b]fluoranthene in food crops (cassava and yam) exceeded the recommended WHO limit. This concentration was significantly higher in two high-oil-producing communities (Akalaolu and Ogale) in Delta State compared to a low-oil-producing community (Nzirimo) in Abia State. Additionally, low levels of other carcinogenic PAH compounds were detected in the oil-producing sites, including benzo[a]pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, indeno[1,3-cd]pyrene, dibenz[a,h]anthracene, and benzo[k]fluoranthene.[30] Likewise, a study conducted in Ohafia, Abia State, Nigeria, a low-oil-producing area in the Niger Delta, reported that mean PAH concentrations in *Telfairia occidentalis* (pumpkin leaves) sold in two major markets were highest in the unwashed samples. Furthermore, concentrations of carcinogenic PAH compounds, including benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, and chrysene, exceeded the recommended regulatory safety limits. The study also indicated that PAH concentrations in these leafy vegetables could be significantly reduced through washing with an aqueous solution of common salt, which was more effective than washing with tap water alone before consumption.[31]

Furthermore, noting that the identified metabolites are precursors of carcinogens, there is a greater likelihood that residents in the high oil-producing communities (Ebocha, Ibaa, Obrikom, Ohali-Usumini/Idu, and Okwuzi) have a higher risk of developing cancers following long-term ingestion of these contaminated food crops as opposed to those in the low oil-producing sites (Ipo, Omerelu, Omuanwa, Ozuaha, and Ubima). This may be attributed to the fact that the former indulge in conventional and artisanal refining activities as opposed to the latter, where mainly storage, transportation and distribution of crude oil and its products are carried out.[32–34]

Strengths of the Study

1. The rigorous multistage sampling technique employed in the study
2. High-quality GC–MS analysis
3. Strong exposure classification
4. Good spatial representation
5. Relevant crop selection

Limitations of the study

1. The cross-sectional nature of the study (no causality)
2. Limited geographic and crop coverage
3. No environmental pathway analysis
4. Potential exposure misclassification
5. No human health risk assessment

Conclusion

The study showed that the sampled food crops grown in both the high and low-oil-producing sites are contaminated with hydrocarbons. Although these pollutants were greater in the high oil-producing communities, perhaps due to continued conventional and artisanal refining activities as opposed to the low oil-producing communities, where refined crude oil and its products are mainly stored, transported and distributed. Thus, long-term consumption of these food crops may predispose residents in the affected communities to deleterious health consequences, particularly cancers.

Recommendation

Regulatory measures should be reinforced to control oil spills in high and low-oil-producing sites where conventional and artisanal refining activities, in addition to the storage, transportation, and distribution of refined crude oil and its products, are carried out. However, the ongoing remediation activities in the Niger Delta region should be facilitated and implemented in all the affected communities.

Acknowledgements

The authors would like to thank all the esteemed gatekeepers/representatives who went the extra mile as tour guards/guides and made frantic efforts to interface with members of the selected communities to understand the importance of the data collection processes and ensure the safety of the researchers. Gatekeepers have also received feedback on the outcome of the study.

Funding: No funding sources

Conflict of interest: None declared.

Ethical approval: Not required.

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Date Submitted: 3rd February 2026

Date Accepted: 16th June 2026

Date Published: 31st July 2026

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