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Levels and Health Risk of Polycyclic Aromatic Hydrocarbons in Cassava (*Manihot esculenta*) Cultivated in Oil-Polluted Areas of Bayelsa State, Nigeria

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ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are carcinogenic pollutants that accumulate in food crops grown in oil-polluted areas. This study determined PAH concentrations in cassava from Gbarantoru (oil-impacted) and Yenagoa (control), Bayelsa State, Nigeria, using GC-MS. Results showed that benzo[a]pyrene was highest in Yenagoa (3.73 ppm) and Gbarantoru (2.79 ppm), compared to the EFSA limit of 0.002 ppm. Chrysene was 2.99 ppm in Yenagoa and 1.64 ppm in Gbarantoru, while benzo[k]fluoranthene reached 2.51 ppm and 0.51 ppm respectively. Indeno [1,2,3-cd] pyrene (0.57 ppm Yenagoa; 0.20 ppm Gbarantoru) and dibenz[a,h]anthracene (0.49 ppm; 0.22 ppm) were also elevated. Health risk assessment revealed Hazard Quotients (HQ) >1 for benzo[a]pyrene (6.64), chrysene (3.90), and benzo[k]fluoranthene (2.76). Cancer risk (CR) values exceeded USEPA's acceptable threshold (1×10^{-4}), with benzo[a]pyrene (1.45×10^{-2}) and dibenz[a,h]anthracene (1.37×10^{-3}) posing the greatest carcinogenic risks. These findings confirm that cassava consumers in Bayelsa face significant dietary exposure to PAHs.

Keywords: Polycyclic aromatic hydrocarbons, cassava, dietary exposure, Niger Delta, cancer risk

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are hydrophobic organic compounds generated from incomplete combustion of fossil fuels, biomass burning, and oil refining (Anyakora & Coker, 2007; Ravindra et al., 2008). They are of global concern because of their persistence, bioaccumulation potential, and strong toxicological effects, including carcinogenicity and mutagenicity (IARC, 2010; Abdel-Shafy & Mansour, 2016). In oil-producing regions such as the Niger Delta, extensive gas flaring and oil spills contribute to elevated PAH loads in soils and crops (Nriagu et al., 2016; Ana et al., 2019).

Cassava (*Manihot esculenta*) is the most consumed staple in Nigeria, contributing over 50% of daily caloric intake in some communities (FAO, 2018; Eze et al., 2020). Its cultivation in oil-polluted soils

increases the risk of hydrocarbon uptake into edible tubers. Studies have demonstrated that root crops readily absorb persistent organic pollutants, making cassava a potential dietary pathway of PAH exposure (Obueh & Odesiri-Eruteyan, 2016; Wu et al., 2019). Chronic ingestion of PAHs, particularly benzo[a]pyrene, has been linked to oxidative stress, DNA damage, and gastrointestinal and hepatic cancers (Phillips, 1999; Boström et al., 2002; EFSA, 2008).

Although PAHs have been widely reported in fish, shellfish, and drinking water in Nigeria (Okonkwo et al., 2015; Chukwu et al., 2019), few studies have examined their occurrence in staple crops. Cassava, despite its significance, remains understudied. Moreover, risk assessments quantifying human health risks from cassava consumption in oil-producing communities are scarce (Enuneku et al., 2018).

This study investigated PAH concentrations in cassava from Gbarantoru (oil-polluted site) and Yenagoa (control site), Bayelsa State. Gas chromatography–mass spectrometry (GC-MS) was used for quantification. Health risks were evaluated using Hazard Quotients (HQ) for non-carcinogenic effects and Cancer Risk (CR) indices for carcinogenic outcomes, following USEPA protocols (USEPA, 2011). Findings provide baseline data on PAH contamination in cassava and highlight implications for food safety, public health, and environmental management in the Niger Delta.

MATERIALS AND METHODS

Study Area

This study was carried out in Bayelsa State, Nigeria, using cassava tubers obtained from Gbarantoru, a community severely impacted by petroleum activities, and Yenagoa, the state capital considered as the reference site. Gbarantoru is located in an oil-producing region where gas flaring, oil spills, and artisanal refining are common, while Yenagoa is less impacted but still influenced by regional atmospheric fallout.

Sample Collection and Preparation

Cassava tubers were randomly harvested from five farms in each site. Tubers were cleaned, peeled, chopped, and oven-dried at 60 °C to constant weight. The dried samples were milled into powder, homogenized, and stored in amber glass jars at 4 °C until analysis.

Extraction and Cleanup

Approximately 10 g of cassava powder was subjected to Soxhlet extraction using dichloromethane as solvent for 8 hours. Extracts were concentrated with a rotary evaporator and purified using silica gel column chromatography to remove lipids and interfering compounds.

PAH Analysis

Sixteen priority PAHs were quantified using Gas Chromatography–Mass Spectrometry (GC-MS, Agilent 7890A) equipped with an HP-5MS capillary column. The GC oven was programmed from 70 °C to 300 °C at 10 °C/min. Identification was based on retention times and mass spectra matched against NIST library standards. Calibration was performed using five-point calibration curves with $R^2 > 0.99$.

Quality Control and Risk Assessment

Procedural blanks, spiked recoveries, and duplicate analyses were performed to ensure accuracy. Recoveries ranged between 85–105%. Health risk assessment followed USEPA (2011) guidelines. Estimated daily intake (EDI) was calculated from average cassava consumption rates, and Hazard Quotients (HQs) were derived for non-carcinogenic effects. Carcinogenic risk (CR) values were estimated for PAHs with established slope factors, such as benzo[a]pyrene and dibenz[a,h]anthracene.

Risk Assessment

Human health risk assessment followed USEPA (2011) methodology. Daily intake was estimated from cassava consumption rates, and Hazard Quotients (HQs) were computed for non-carcinogenic risks. Cancer Risk (CR) indices were calculated for carcinogenic PAHs such as benzo[a]pyrene. HQ values >1 indicated potential health effects, while CR values exceeding 1×10^{-4} suggested unacceptable lifetime cancer risk.

RESULTS

Table 1 showed that benzo[a]pyrene had the highest concentration in both Yenagoa (3.73 ppm) and Gbarantoru (2.79 ppm), far above the EFSA permissible limit of 0.002 ppm. This indicates severe contamination. Benzo[k]fluoranthene and chrysene were also elevated, ranging from 0.51–2.99 ppm, again surpassing safe thresholds. Indeno[1,2,3-cd] pyrene and dibenz[a,h]anthracene was present in lower concentrations (0.20–0.57 ppm) but still exceeded limits by several folds. Comparatively, PAH levels were consistently higher in Yenagoa than Gbarantoru, though the differences for most compounds were statistically significant ($p < 0.05$). This unexpected trend may suggest regional atmospheric deposition of hydrocarbons beyond oil-polluted farmlands.

Table 1. Concentration of PAHs in cassava from Yenagoa and Gbarantoru

Compound	Yenagoa (ppm)	Gbarantoru (ppm)	EFSA Limit (ppm)	Significance ($p < 0.05$)
Benzo[a]pyrene	3.73 ± 0.15	2.79 ± 0.12	0.002	*
Chrysene	2.99 ± 0.18	1.64 ± 0.09	0.002	*
Benzo[k]fluoranthene	2.51 ± 0.10	0.51 ± 0.05	0.002	*
Indeno[1,2,3-cd]pyrene	0.57 ± 0.08	0.20 ± 0.04	0.002	*
Dibenz[a,h]anthracene	0.49 ± 0.05	0.22 ± 0.03	0.002	*

* = means statistical difference among variables at alpha level $p < 0.05$

Table 2 further revealed high Hazard Quotients (HQs): benzo[a]pyrene (6.64), benzo[k]fluoranthene (2.76), and dibenz[a,h]anthracene (0.64). $HQ > 1$ indicates that consumers are at risk of non-carcinogenic health effects such as liver toxicity. The Cancer Risk (CR) indices for benzo[a]pyrene (1.45×10^{-2}) and dibenz[a,h]anthracene (1.37×10^{-3}) were well above USEPA's acceptable level (1×10^{-4}), suggesting high long-term carcinogenic risk.

Table 2. Health risk indices of PAHs in cassava from Gbarantoru

Compound	Conc. (mg/kg)	RfD (mg/kg/day)	CSF	EDI (mg/kg/day)	HQ	CR
Benzo[a]pyrene	2.79	0.0003	7.3	2.0×10^{-3}	6.64	1.45×10^{-2}
Chrysene	1.64	0.0003	0.29	1.17×10^{-3}	3.90	3.39×10^{-4}
Benzo[k]fluoranthene	0.51	0.0002	0.83	3.64×10^{-4}	2.76	3.02×10^{-4}
Indeno[1,2,3-cd]pyrene	0.20	0.0003	0.41	1.43×10^{-4}	0.48	5.86×10^{-5}
Dibenz[a,h]anthracene	0.22	0.0003	6.3	1.57×10^{-4}	0.64	1.37×10^{-3}

In Fig. 1, Benzo[a]pyrene showed the highest concentrations at both sites (2.79 ppm in Gbarantoru; 3.73 ppm in Yenagoa). Chrysene and benzo[k]fluoranthene were also elevated, especially in Yenagoa, while indeno[1,2,3-cd] pyrene had the lowest levels across both sites. Concentrations in Yenagoa were consistently higher than Gbarantoru for all PAHs, suggesting possible atmospheric deposition and regional transport rather than localized soil contamination.

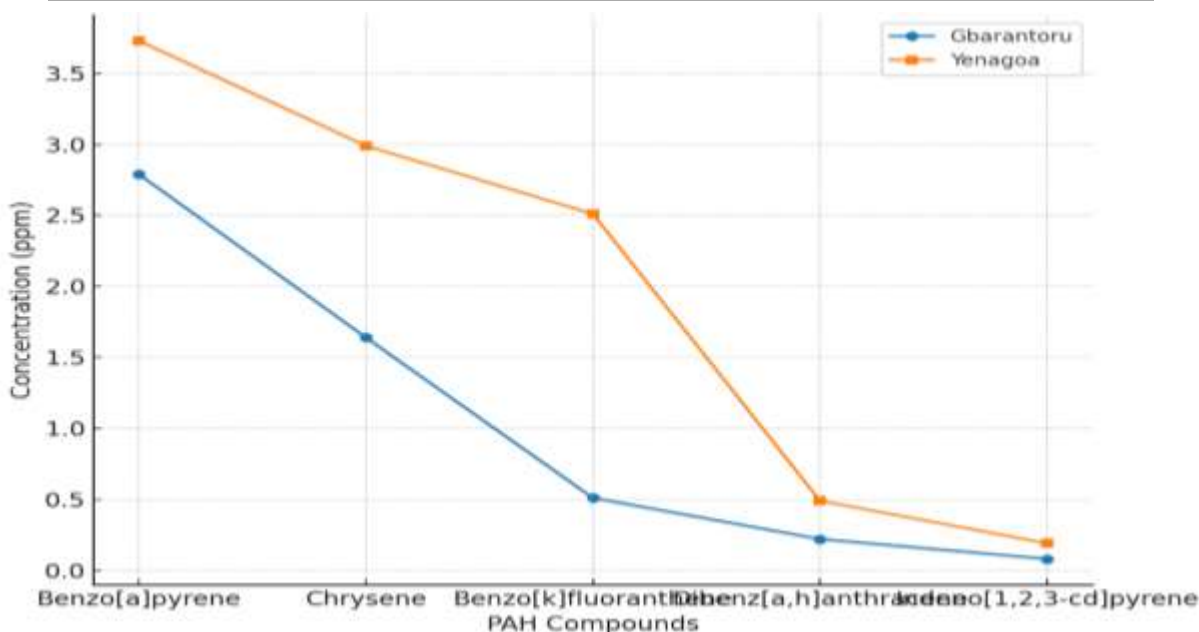


Fig. 1 concentration of PAHs in Cassava from two sites

DISCUSSION

The findings of this study indicate that cassava cultivated in both Gbarantoru and Yenagoa contained PAHs at concentrations significantly above international permissible limits. Benzo[a]pyrene, a Group 1 carcinogen, was most abundant, reaching 3.73 ppm in Yenagoa and 2.79 ppm in Gbarantoru, far exceeding the EFSA limit of 0.002 ppm (EFSA, 2008). Similar exceedances were noted for chrysene, benzo[k]fluoranthene, and dibenz[a,h]anthracene. These results align with previous studies in oil-polluted environments, where food crops accumulated PAHs at hazardous levels (Olawoyin et al., 2012; Alani et al., 2014).

Unexpectedly, higher PAH levels were recorded in Yenagoa (control site). This suggests that contamination may not only result from direct oil pollution but also from regional atmospheric deposition and hydrocarbon fallout from gas flaring (Nriagu et al., 2016; Ana et al., 2019). Similar trends have been reported in other petroleum-producing regions where PAH deposition occurred kilometers away from flaring sites (Zhang et al., 2016).

Risk assessment further highlighted serious health implications. Hazard Quotients for benzo[a]pyrene (6.64), chrysene (3.90), and benzo[k]fluoranthene (2.76) exceeded unity, indicating non-carcinogenic risks (USEPA, 2011). Cancer Risk values for benzo[a]pyrene (1.45×10^{-2}) and dibenz[a,h]anthracene (1.37×10^{-3}) were well above USEPA's threshold of 1×10^{-4} , signaling unacceptable carcinogenic risks. Comparable studies in Asia and South America linked dietary PAH exposure from root crops to gastrointestinal and hepatic cancers (Martínez et al., 2012; Wu et al., 2019).

The predominance of benzo[a]pyrene is particularly concerning. Its metabolic activation to DNA-reactive intermediates is a key mechanism in carcinogenesis (Phillips, 1999; Boström et al., 2002). Chronic ingestion of cassava containing such concentrations could increase the cancer burden in Bayelsa State.

These findings call for urgent interventions, including stricter monitoring of food crops, remediation of contaminated soils, and regulation of gas flaring. Community education on food safety and adoption of phytoremediation techniques could reduce PAH uptake in crops (Enuneku et al., 2018). Overall, cassava is confirmed as a significant dietary exposure pathway to PAHs in oil-producing regions.

CONCLUSION

Cassava cultivated in Bayelsa State contains dangerously high PAHs, including carcinogenic benzo[a]pyrene, at levels thousands of times above global permissible limits. Health risk indices confirm significant risks for both cancer and non-cancer outcomes. Urgent interventions, including environmental remediation, pollution control, and Nigeria-specific food safety standards, are essential to protect human health.

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