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Levels and Distribution of Polycyclic Aromatic Hydrocarbons and Associated Human Health Risk in the Consumption of Root, Stalk, Leaf, and Grain of Guinea Corn Plant Cultivated on Gosa dumpsite soil, Abuja, Nigeria

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ABSTRACT: Several studies have shown that the 16 USEPA priority PAHs can be released into the environment through open incineration of municipal solid waste (MSW), primarily through pyrolytic processes associated with the burning of MSW. Consequently, the objective of this paper was to determine the levels and distribution of polycyclic aromatic hydrocarbons (PAHs) and associated human health risk in the consumption of root, stalk, leaf, and grain of guinea corn plant cultivated on Gosa dumpsite soil, Abuja, Nigeria using appropriate standard procedures after QuEChERS extraction and analyzed with GC–MS. High molecular weight (HMW) PAHs were the main compounds detected in parts of the guinea corn (root, stalk, leaf, and grain). The hazard quotient (HQ) linked to ingestion of the grain was 5.2 x 10^{-5} for adults and 2.5 x 10^{-7} for children, due mainly to benzo(g,h,i) perylene (BghiP), the only detected non-carcinogenic PAH. The cancer risk (CR) was 8.7 × 10^{-7} for adults and 8.9× 10^{-7} for children. Adults and children exposed to PAHs in guinea corn grain through consumption are unlikely to experience noncarcinogenic health risks. The probability of both exposed adults and children developing cancer may not exist. However, the distribution of carcinogenic PAHs in the dumpsite calls for urgent attention from relevant regulatory agencies and stakeholders to discourage the cultivation of food crops on polluted soil and to adopt safe waste disposal practices, due to bioaccumulation of PAHs.

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Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds that are environmentally toxic (Hussein *et al*., 2016; Kim *et al*., 2013). They are composed of two or more fused benzene rings and are pervasive due to their recalcitrant nature, owing to their persistence in environmental media (Hussein *et al*., 2016; Kim *et al*., 2013). Of the many polycyclic aromatic hydrocarbons (PAHs), 16 have been identified by the United States Environmental Protection Agency (USEPA) as priority pollutants (Hussar *et al*., 2012). These include naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), anthracene (Ant), fluorene (Fle), phenanthrene (Phe), fluoranthene (Flt), pyrene (Pyr), benz(a)anthracene (BaA), chrysene (Chr), benzo(b)fluoranthene (BbF), benzo(a)pyrene (BaP), benzo(k)fluoranthene (BkF), benzo(g,h,i)perylene (BghiP), indeno(1,2,3-cd)pyrene (Ind), and dibenz(a,h)anthracene (DBahA) (Hussar *et*

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al., 2012). Priority pollutants are characterized by toxicity, prevalence, persistence in the environment, and bioaccumulation potential (USEPA, 2025). For these reasons, priority pollutants are highly monitored and managed. Seven out of the 16 USEPA priority PAHs have been classified as known carcinogens: BaP, BbF, BkF, Chr, Ind, BaA, and DBahA (USEPA, 1993). Polycyclic aromatic hydrocarbons are introduced into the environment mainly through incomplete combustion of organic compounds such as fossil fuels, incineration of garbage, biomass, and agricultural waste (Hussein *et al.,* 2016; Lee, 2010). The primary non-combustion process of PAH emission into the environment is oil spills (Fallahi *et al.,* 2023). Gosa dumpsite is an open dumpsite and the largest in Abuja, Nigeria. Solid wastes collected from residential buildings, commercial establishments, offices, and industries within Abuja are disposed of at this site.

The dumpsite is managed by the Abuja Environmental Protection Board (AEPB). The primary method of final disposal of solid waste at Gosa dumpsite is open burning. Incineration of solid waste is a stationary source of polycyclic aromatic hydrocarbons (PAHs) emissions (Li *et al.,* 2001; Palo *et al.,* 1996; Zhao *et al.,* 2008). Study has shown that Gosa dumpsite is polluted with PAHs (Kelle *et al.,* 2026). Similarly, several studies have reported pollution of dumpsite soil with PAHs (Adedosu *et al.,* 2015; Olayinka *et al.,* 2015; Okechukwu *et al.,* 2021). Once PAHs are released via combustion processes, they attach to particulate matter and become airborne. They eventually deposit on soil, surface water, and plants through atmospheric deposition. Because PAHs are persistent, they remain in the environment and bioaccumulate. Soil acts as a sink or reservoir for PAHs (Lu *et al.,* 2011), due to soil organic matter (SOM), which provides surface area and binding sites for adsorption (Ukalska-Jaruga and Smreczak, 2020). In addition to adsorption on plant foliage via atmospheric deposition (Zha, *et al.,* 2018), PAHs in soil can be absorbed by plant roots and translocated to aerial tissues [Patel *et al.,* 2010; Barathan *et al.,* 2024], facilitating entry into the food chain. Many studies have reported accumulation of PAHs in plants through both atmospheric deposition and root absorption from contaminated soil (Okoye *et al.,* 2023; Ailijiang *et al.,* 2022; Wang *et al.,* 2012; Huang *et al.,* 2012). Given the evidence that PAHs can be released from waste incineration and that Gosa dumpsite soil and some other dumpsite soils are polluted with PAHs, plants cultivated within the vicinity of the dumpsite are likely to be polluted with PAHs through atmospheric deposition and root absorption.

This poses a public health concern because of the adverse health implications of PAHs. Consequently, the objective of this study was to determine the levels and distribution of polycyclic aromatic hydrocarbons (PAHs) and associated human health risk in the consumption of root, stalk, leaf, and grain of guinea corn plant cultivated on Gosa dumpsite soil, Abuja, Nigeria.

MATERIALS AND METHOD

Description of the study area: Gosa dumpsite is a fenced open field with a perimeter of 4,000 meters, located along Idu Train Station Road, Idu, Abuja. It is surrounded by three communities: Hulumi, Jiyita, and Paipe. The site lies within the coordinates N09° 01.270’ E007° 19.590’ and N09° 01.173’ E007° 20.510’.

The vegetation consists of savannah grassland and tropical rainforest. The climate is characterized by two distinct seasons: the rainy season and the dry season. The rainy season lasts for six months, from April to October. Annual precipitation ranges between 1,100 mm and 1,600 mm, while the monthly mean temperature varies from 25 °C to 30 °C.

Sample collection and treatment: six samples of guinea corn plants were randomly collected from the dumpsite by gradually uprooting them from the soil in March 2025. The samples were wrapped in aluminum foil, labelled, and taken to the laboratory, where they were immediately separated into root, stalk (stem), and grain using a stainless-steel knife. The plant parts were cleaned with a brush to remove adhering impurities. Each plant part was pooled together to form a composite, chopped (stalk and root), dried at room temperature in a cool, dark section of the laboratory, and homogenized using an electric blender that had been washed with soap and rinsed with deionized water. The homogenized samples were transferred into properly labelled brown glass bottles and stored at 4 °C.

Extraction and analysis of PAHs in sample: polycyclic aromatic hydrocarbons (PAHs) in the guinea corn samples were extracted using the QuEChERS method (Anastassiades *et al.,* 2003; Wang *et al.,* 2018). For each plant part (root, stalk, grain), 3 g was weighed into 15 mL centrifuge tubes and spiked with 10 µL of a 100 µg/mL internal standard mixture. Samples were vortexed, stored at 4 °C for 1 h, then extracted with 2.5 mL acetonitrile, 1 g $MgSO_4$, and 0.25 g NaCl. After vortexing and centrifugation (4000 rpm), the acetonitrile phase was cleaned with $MgSO_4$, PSA, and GCB (6:1:0.5 ratio),

vortexed, centrifuged, and transferred into brown vials at 4 °C. Reagent blanks confirmed PAH levels below detection limits. Quantification was performed using internal standard calibration with six standards (0.5–50 µg/mL) prepared from the 16 US EPA priority PAHs mixture, spiked with deuterated PAHs per EPA Method 8270E. Extracts and standards were analysed in triplicate using GC-MS (Agilent 6890/5973N) with ChemStation software. A 1 µL aliquot was injected in splitless mode at 280 °C on a DB-5ms column (30 m × 0.25 mm, 0.25 µm film). The oven program was: 70 °C (2 min), ramp to 180 °C at 35 °C/min (3 min), then to 300 °C at 12 °C/min (8 min hold). Helium was used at 1.0 mL/min. MS conditions: EI at 70 eV, source 230 °C, transfer line 280 °C, quadrupole 150 °C. Data were acquired in scan mode (50–550 amu).

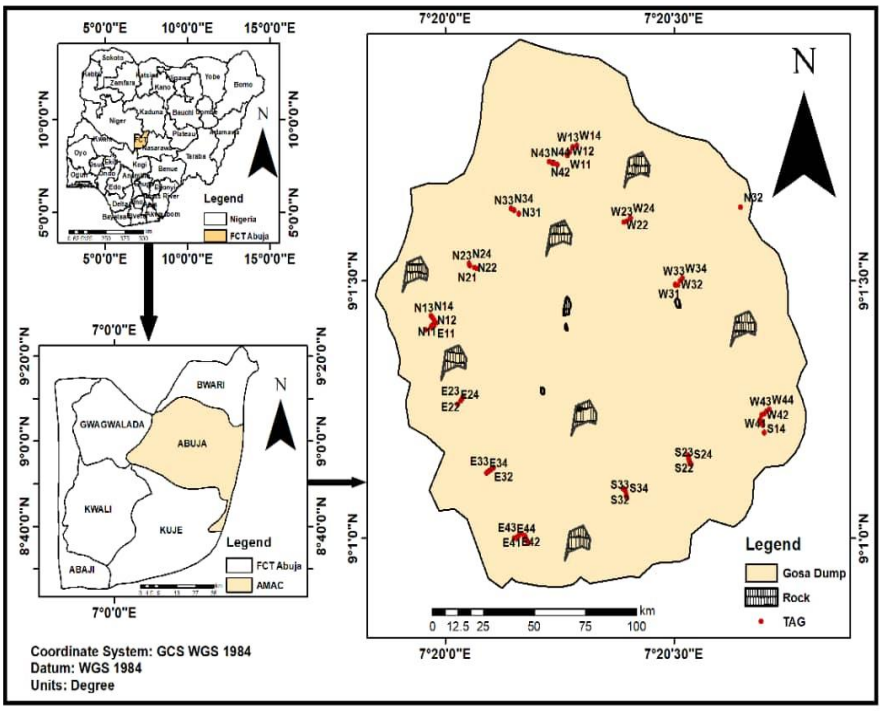


Fig. 1: map of Gosa dumpsite (Source Omada *et al*, 2024)

Method Validation: the analytical method was validated for linearity, sensitivity, accuracy, and precision. Calibration curves for each PAH showed excellent linearity with correlation coefficients (R^2) between 0.991 and 0.999. Sensitivity was assessed using calibration curves, with LOD and LOQ calculated from ten reagent blanks as LOD=3.3σ/S and LOQ=10σ/S, where σ is the standard deviation of background responses and S is the slope of the curve. LODs ranged from 0.04–0.09 µg/kg, while LOQs were 0.12–0.31 µg/kg. Extraction efficiency was tested by spiking 2 g flour of the guinea corn grain with 10 µL of a 100 µg/mL internal standard mixture and 30 µL of a 10 µg/mL PAHs standard mixture, equilibrating at 4 °C for 1 hour, then extracting and cleaning up. Parallel flour of the grain of the guinea corn sample spiked only with internal standard was processed under identical conditions. GC-MS analysis showed recoveries of 90–99%. Precision was evaluated through replicate analyses: intraday precision ranged from 0.30–3.07%, and inter-day precision from 1.20–3.54%. Reagent blanks consistently showed PAHs below detection.

Health Risk Assessment: carcinogenic and non-carcinogenic health risks from human exposure to PAHs in the guinea grain were assessed using health risk equations of the United State Environmental Protection Agency (USEPA, 2015; USEPA 2026) and Agency for Toxic Substance and Disease Registry (ATSDR, 2023). Humans can be exposed to pollutants through ingestion, inhalation, or skin contact. Since guinea corn is widely consumed in foods and drinks, it may serve as a source of PAH exposure. In this study, ingestion was identified as the main pathway for human exposure to PAHs in the samples.

Assessment of Non – Carcinogenic Risk: non – carcinogenic risk was estimated using the hazard quotient (HQ) and hazard index (HI) according to

Agency for Toxic Substance and Disease Registry equation (ATSDR, 2025), expressed as;

$$HQ_{ing} = \frac{CDI_{ing}}{R_{fD}} \quad (1)$$

Where,

$$CDI_{ing} = \frac{C\ X\ IR\ X\ ED\ X\ EF}{BW\ X\ AT} \quad (2)$$

C represents the concentration of PAHs in guinea corn grain (mg/L). IR is the daily ingestion rate of guinea corn grain (mg/kg). According to the WHO GEMS/Food Contaminants database (2012), people in Cluster 13 countries (including Nigeria) consume about 330.5 g of cereals per day. ED is the exposure duration: 26 years for adults and 6 years for children. EF is the exposure frequency: 350 days per year for both adults and children. BW is body weight: 80 kg for adults and 15 kg for children. AT is the average time for non-carcinogens: 9,490 days (26 × 365) for adults and 2,190 days (6 × 365) for children. R_{fD} *is* reference dose (mg/kg/day) (USEPA, 2014a). R_{fD} for the non-carcinogenic PAHs is Nap (0.02), Acy (0.06), Ace (0.06), Flu (0.04), Ant (0.3), Phe (0.03), Flt (0.04), Pyr (0.3), BghiP (0.03), (USEPA, 2012). The Hazard Index (HI) represents the aggregate non-carcinogenic health risk derived from the summation of individual Hazard Quotients (HQ). It provides a comprehensive estimate of the potential adverse health effects associated with simultaneous exposure to multiple contaminants and or multiple pathway (USEPA, 2015; USEPA, 2026; ATSDR, 2025; ATSDR, 2023).

$$HI = \Sigma HQ = \quad (3)$$

A hazard quotient < 1 indicates that exposure to pollutants is unlikely to result in non-cancer health effects, whereas an HQ > 1 suggests a potential risk of such health issues. Similarly, a hazard index (HI) < 1 implies that the combined pollutants do not pose a risk of non-carcinogenic adverse health effects, while an HI > 1indicates that the pollutants may have the potential to cause non-carcinogenic health impacts. (USEPA, 2015; USEPA 2026; ATSDR, 2025; ATSDR, 2023).

Carcinogenic Risk: the carcinogenic potential of PAHs in the sample was evaluated using the seven carcinogenic PAHs: BaP, BbF, BkF, Chr, Ind, BaA, and DBahA. To standardize their toxicity, the concentrations of these PAHs were converted into benzo[a]pyrene equivalents (BaPeq) by multiplying each PAH concentration by its corresponding toxic equivalent factor (TEF) (Pan *et al.*, 2015). The cumulative BaPeq ($\sum BaPeq$) of mixture of the PAHs was obtained by applying the equation of Nisbet and LaGoy (1992) (equation 4).

$$\sum BaPeq = \sum C_i x TEF_i \quad (4)$$

Where C_i is the concentration of specific PAHs and TEFs is the correlative toxic equivalency factor. The toxic equivalent factor (TEF) for BaP, BbF, BkF, Chr, Ind, BaA, and DBahA is 1.0, 0.1, 0.01, 0.001, 0.1, 0.1 and 1.0 respectively (USEPA, 2014b). The overall cancer risk (CR) associated with exposure to the PAHs was estimated by applying the equation of USEPA, 2015 and USEPA 2026:

$$CR_{ing} = CDI_{ing} \text{ x } SF \quad (5)$$

In calculating CDI_{ing} using equation 2, C is $\sum BaPeq = \sum C_i x TEF_i$ as described by Pan *et al.*, 2015, AT for carcinogen is 25,550 days (70yr x 365 days) for both adult and children (USEPA, 2014a). SF (ingestion) is cancer slope factor of BaP 7.3 mg/kg/day (Pan *et al.*, 2015; USEPA, 2002). CR value $< 10^{-6}$ (1 in a million-developing cancer) is considered acceptable; values between 10^{-6} to 10^{-4} represents a potential cancer risk, and values > 10^{-4} (1 in 1,000 developing cancer) indicates a high cancer risk (USEPA, 2021).

RESULTS AND DISCUSSION

The concentrations of the USEPA 16 PAHs in guinea corn samples cultivated in the study area are presented in Table 1. Some of the PAHs, specifically pyrene and the low molecular weight (LMW) PAHs – Nap, Acy, Ace, Fle, Ant, and Phe – were not detected in any part of the guinea corn sample. LMW PAHs exist largely in the gaseous/vapour phase in the atmosphere, compared to high molecular weight (HMW) PAHs, which bind to particulates (Lee, 2010). They are more water-soluble and degrade more quickly in the environment, unlike HMW PAHs (Lee, 2010; Kim *et al.*, 2013; Hussar., 2012). These characteristics of LMW PAHs might have contributed to their being below detection limits in the sample. However, Baba et al. (Baba *et al*., 2022) reported the presence of all 16 USEPA PAHs in guinea corn in their study. In the root of the guinea corn sample, Flt, BaA, Chr, BbF, BkF, BaP, DBahA, Ind, and Bghi were detected, ranging from 0.22–2.24 µg/kg. Chr, BbF, BkF, BaP, DBahA, Ind, and Bghi were detected in the stalk, leaf, and grain of the guinea corn sample, ranging from 0.15–2.82 µg/kg in the stalk, 0.22–2.45 µg/kg in the leaf, and 0.06–0.55 µg/kg in the grain. It is likely that the PAHs were absorbed from the soil through the root of the plant and translocated to its

above-ground parts, since dumpsite soils can be polluted with the 16 PAHs (Adedosu *et al.*, 2015; Olayinka *et al.*, 2015; Okechukwu *et al.*, 2021). Pollution of parts of the guinea corn through atmospheric deposition is also not excluded, as this is a pathway for PAHs into the environment (Zha *et al.*, 2018; Huang *et al.*, 2012). All the PAHs found in the sample are HMW PAHs (4–6 ring PAHs).

HMW PAHs are strongly adsorbed on soil due to soil organic matter (SOM), which provides surface area and binding sites for adsorption (Ukalska-Jaruga and Smreczak, 2020). At low soil pH, SOM develops a positive surface charge. This positive charge enhances the soil's ability to retain polycyclic aromatic hydrocarbons (PAHs) by facilitating electrostatic attractions and hydrogen bonding between functional groups (-NH, -OH, and -COOH) and the PAHs, ultimately increasing PAH adsorption in the soil (Hu *et al.*, 2025). HMW PAHs such as BaP, BbF, BkF, Chr, Ind, BaA, and DBahA are carcinogenic (USEPA, 1993).

Ingestion of food polluted with these carcinogenic PAHs is a public health concern that deserves attention. Cultivation of food crops on polluted soil should be discouraged by relevant regulatory authorities, and environmentally friendly waste disposal methods should be implemented. Guinea corn is a staple cereal food. The grain is prepared and eaten in Nigeria as gruel and thick porridge served with soup. It is also used in making a non-alcoholic beverage called kunu in Nigeria. Guinea corn polluted with PAHs can be a source of exposure to PAHs for consumers. The total concentrations of HMW PAHs and the seven carcinogenic PAHs, ∑HMW PAHs (1.51–6.58 µg/kg) and ∑7 PAHs (1.11–6.18 µg/kg), constituted the major proportion of the PAHs found in the different parts of the sample (Table 1). In terms of the number of rings, ∑5-ring PAHs were the most abundant (0.90–5.46 µg/kg) (Table 1).

Table 3: chronic daily intake (CDI_s, mg/kg/day) of mixture of seven carcinogenic PAHs and cancer risks (CR)

Carcinogenic risk			
Adult		Children	
CDI_s	CR	CDI_s	CR
1.2×10^{-6}	8.7×10^{-6}	6.5×10^{-6}	8.9×10^{-7}

In terms of percentage abundance (Fig. 2 – 5), the most and least abundant PAHs were BaP (35%) and Chr (2%) in the root (Fig. 2), BbF (45%) and BghiP (3%) in the stalk (Fig. 3), BbF (43%) and BkF (3%) in the leaf (Fig. 4), and BkF (36%) and Chr (4%) in the grain (Fig. 5).

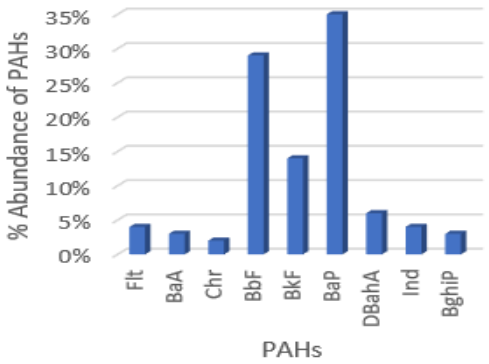


Fig. 1: % abundance of PAHs in guinea

Table 2: chronic daily intake (CDI, mg/kg/day) and hazard quotient (HQ)

PAHs	Non-Carcinogenic risk			
	Adult		Children	
BghiP	CDI	HQ	CDI	HQ
	1.6×10^{-6}	5.2×10^{-5}	8.4×10^{-6}	2.5×10^{-7}

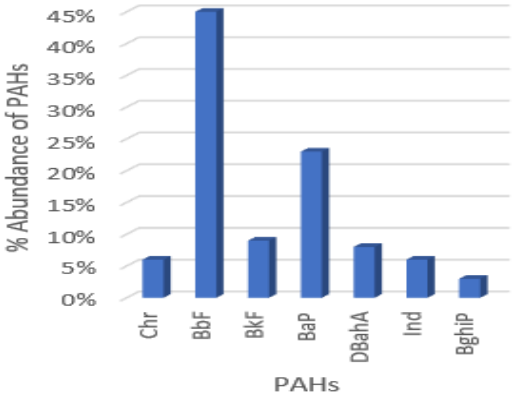


Fig. 2: % abundance of PAHs in guinea corn stalk corn root

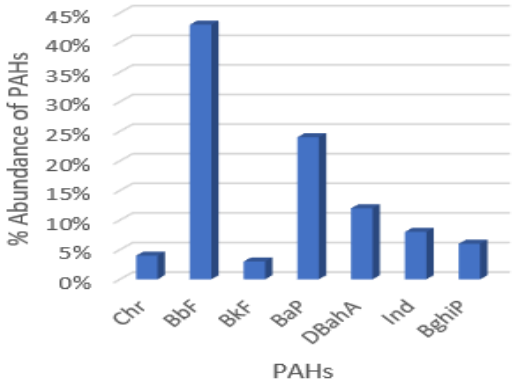


Fig. 3: % abundance of PAHs in guinea corn leaf

The results of the carcinogenic and non-carcinogenic risk assessment are presented in Tables 2 and 3. Only benzo(g,h,i) perylene (BghiP) was detected in the guinea corn grain among the non-carcinogenic PAHs. The hazard quotient (HQ) due to BghiP in the guinea corn grain was 5.2×10^{-5} (less than 1) for adults and 2.5×10^{-7} (less than 1) for children (Table 2). Based

on USEPA and ATSDR thresholds (USEPA, 2015; USEPA, 2026; ATSDR, 2025; ATSDR, 2023), the HQ for adults and children exposed to this PAH suggests that they may not experience non-cancer-related health issues. Though the HQ for both populations may not pose non-cancer health risks, PAHs bioaccumulate due to their persistent nature.

The hazard index (HI) was not computed since only one non-carcinogenic PAH was detected in the grain and there was no multiple exposure pathway. Cancer risk for adults was 8.7×10^{-6} and 8.9×10^{-7} for children (Table 3). These values are within USEPA thresholds of 1×10^{-6} considered safe (USEPA, 2002), suggesting a probability that exposed adults and children may not develop cancer in their lifetime (USEPA, 2002). From the study, cancer risk may be low for both populations, however, the distribution of carcinogenic PAHs in the dumpsite calls for urgent attention from relevant regulatory agencies and stakeholders to discourage the cultivation of food crops on polluted soil and to adopt safe waste disposal practices, due to bioaccumulation of PAHs.

Table 1: concentration (µg/kg) and BaPeq (µg/kg) of 16 USEPA PAHs in guinea corn

PAHs	Guinea cornroot (µg/kg)	Guinea cornstalk (µg/kg)	Guinea cornleaf (µg/kg)	Guinea corn grain (µg/kg)	TEFs	BaPeq (guinea corn root)	BaPeq (guineacornstalk)	BaPeq (guinea cornleaf)	BaPeq (guinea corngrai)
Nap	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Acy	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Ace	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Fle	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Ant	ND	ND	ND	ND	0.01	ND	ND	ND	ND
Phe	ND	ND	ND	ND	0.001	ND	ND	ND	ND
Flt	0.29±0.71	ND	ND	ND	0.001	0.00029	ND	ND	ND
Pyr	ND	ND	ND	ND	0.001	ND	ND	ND	ND
BaA	0.22±0.33	ND	ND	ND	0.1	0.022	ND	ND	ND
Chr	0.14±0.05	0.40±0.03	0.22±0.01	0.06±0.03	0.001	0.00014	0.0004	0.00022	0.00006
BbF	1.90±0.06	2.82±0.01	2.45±0.67	0.07±0.01	0.1	0.19	0.28	0.25	0.007
BkF	0.92±0.11	0.58±0.35	0.18±0.04	0.55±0.07	0.01	0.0092	0.0058	0.024	0.0055
BaP	2.24±0.84	1.46±0.54	1.35±0.41	0.08±0.14	1.0	2.24	1.46	1.35	0.08
DBahA	0.40±0.07	0.55±0.11	0.68±0.45	0.20±0.46	1.0	0.40	0.55	0.68	0.2
Ind	0.25±0.92	0.37±0.05	0.45±0.61	0.15±0.03	0.1	0.025	0.037	0.045	0.015
BghiP	0.22±0.06	0.15±0.88	0.33±0.02	0.40±0.05	0.01	0.0022	0.0015	0.0033	0.004
∑BaPeq	NA	NA	NA	NA	NA	2.88	2.33	2.35	0.311
∑PAHs	6.58	6.33	5.66	1.51	NA	NA	NA	NA	NA
∑7PAHs	6.07	6.18	5.33	1.11	NA	NA	NA	NA	NA
∑LMW PAHs	ND	ND	ND	ND	NA	NA	NA	NA	NA
∑HMW PAHs	6.58	6.33	5.66	1.51	NA	NA	NA	NA	NA
∑2 ring PAHs	ND	ND	ND	ND	NA	NA	NA	NA	NA
∑3 ring PAHs	ND	ND	ND	ND	NA	NA	NA	NA	NA
∑4 ring PAHs	0.65	0.40	0.22	0.06	NA	NA	NA	NA	NA
∑5 ring PAHs	5.46	5.41	4.66	0.90	NA	NA	NA	NA	NA
∑6 ring PAHs	0.65	0.52	0.78	0.55	NA	NA	NA	NA	NA

ND: Not detected, NA: Not applicable, ∑PAHs: Summation of all detected PAHs, ∑7PAHs: Summation of seven carcinogenic PAHs, ∑LMW PAHs: Summation of low molecular weight PAHs, ∑HMW PAHs: Summation of high molecular weight PAHs, ∑2 ring PAHs: Summation of 2 ring PAHs, ∑3 ring PAHs: Summation of 3 ring PAHs, ∑4 ring PAHs: Summation of 4 ring PAHs, ∑4 ring PAHs: Summation of 4 ring PAHs, ∑5 ring PAHs: Summation of 5 ring PAHs, ∑6 ring PAHs: Summation of 6 ring PAHs

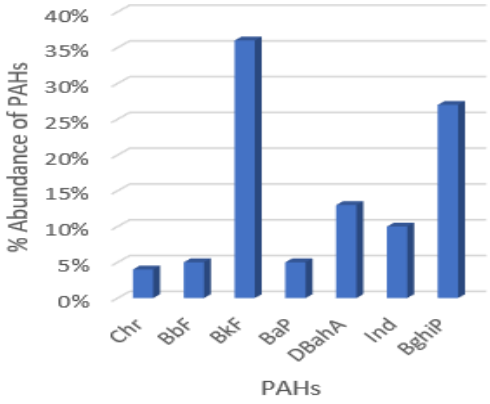


Fig. 5: % abundance of PAHs in guinea corn grain

Conclusion: This study investigated the level, distribution and potential health risks of polycyclic aromatic hydrocarbons (PAHs) in guinea corn cultivated on a municipal dumpsite to evaluate the implications of cultivating food crops on contaminated soils. The findings establish that high-molecular-weight and carcinogenic PAHs predominated in the plant tissues. The health risk assessment indicates no significant non-carcinogenic or carcinogenic risk from grain consumption under the study conditions. Nevertheless, the presence and bioaccumulation of carcinogenic PAHs in the dumpsite environment underscore the need to discourage crop cultivation on polluted soils and strengthen safe waste management practices. These findings are limited to a single study site and crop species. Future research should investigate multiple locations, diverse food crops, seasonal variations, and long-term exposure to provide a broader understanding of PAH bioaccumulation and associated health risks.

DECLARATIONS

Ethical Approval: This study did not involve human participants or animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were conducted responsibly and in accordance with standard academic and institutional guidelines.

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Declaration of Conflict of Interest: The authors declare that there is no known conflict of interest or personal relationships that have influence the work reported in this paper.

Declaration of Data Availability: The data generated in this study are available upon request from the corresponding author.

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