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Article

Analysis of PAHs Uptake and Bioaccumulation in Maize (*Zea mays* L.) from Jalingo Dumpsites in Taraba State

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Abstract

This study assessed Polycyclic Aromatic Hydrocarbons (PAHs) uptake and bioaccumulation in maize (*Zea mays* L.) grown on dumpsite soils in Jalingo, Taraba State, Nigeria. The collection of soil samples from three dumpsites and monthly sampled maize stems and leaves over a three-month growth period was performed. Gas Chromatography-Mass Spectrometry (GC-MS) analyzed thirteen PAH compounds, while Transfer Factors (TF) and Bioaccumulation Factors (BAF) evaluated pollutant movement. The results showed a mean total PAH concentration of 0.1008 ± 0.0143 mg/kg in the soil, with benzo[g,h,i]perylene being the highest (0.0715 ± 0.0127 mg/kg). Total PAH levels in both stems and leaves increased progressively from month one to month three. Analysis of variance (ANOVA) and Duncan tests revealed statistically significant variations ($p < 0.05$) for naphthalene, 2-methylnaphthalene, acenaphthene, and fluorene in the leaves, confirming active uptake during plant growth. Crucially, both TF and BAF values exceeded one for several PAHs, especially 2-methylnaphthalene, pyrene, and fluoranthene, proving that maize efficiently extracts and concentrates these toxins from the ground. Ultimately, these findings show that dumpsite farming allows contaminants to enter the food chain, posing potential health risks to local farmers and consumers. To protect public health and the environment, the study highlights a need for regular environmental monitoring, better waste management, and restrictions on growing food crops on contaminated dumpsites. Options are available to shorten the text further, adjust the focus to highlight specific statistical results, or adapt the summary for a different target audience.

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic pollutants composed of multiple aromatic rings. They are formed during the incomplete combustion of organic matter, such as in engines, incinerators, or forest fires. PAHs are uncharged, non-polar, and planar, with many being colorless [1]. Agriculture is the predominant occupation in Taraba State, Nigeria, with a diverse range of farming practices. The state is known for cash crops such as coffee, tea, groundnuts, and cotton, alongside staple crops like maize, rice, sorghum, millet, cassava, and yam. Livestock farming, including cattle, sheep, goats, and poultry, is also significant, particularly on the Mambilla Plateau and along river valleys [2].

They are often known to be persistent and show tendency to persist in the environment with the persistence increasing as the number of rings increase [3]. They are classed as chemical compounds that cause cancer implying carcinogenicity [4,5]). Polycyclic aromatic hydrocarbons (PAHs) study on Nigerian agricultural lands, particularly in the Niger Delta region, have highlighted significant contamination and associated health risks [6].

Pollutant uptake refers to the process by which plants absorb or accumulate pollutant from the soil in which they are growing. Uptake by plants is a critical link in the pathway through which soil contamination can lead to human exposure and potential health risks [7]. Monitoring uptakes help in assessing exposure levels and preventing health issues. Assessing polycyclic aromatic hydrocarbons (PAHs) in dumpsites soils is essential due to their significant implications for environmental health and human safety [8]. Furthermore, PAHs can be taken up by crops and also accumulating therefore posing risks to food safety. Monitoring these contaminants ensures that agricultural products remain within safe consumption limits. In addition, evaluating the levels and effects of pollutants help to assess soil quality and fertility, guiding sustainable agricultural practices [9,10]. This study focused on the level of PAHs in the soil and

the extent of its uptake and accumulation in maize plant, whose products are commonly consumed by both man and animals.

2. Materials and Methods

2.1. Study Location

Jalingo is the capital city of Taraba State in North-Eastern Nigeria. Jalingo Local Government Area (LGA) covers a land area of approximately 195 km² [9]. It lies in the savanna-covered foothills of the Shebshi Mountains, about 25 miles (40 km) southeast of the Benue River. Its coordinates are approximately 8°54′N latitude and 11°22′E longitude. Taraba state shares borders with Bauchi and Gombe states to the North; Benue, Nassarawa, and Plateau states to the West, Adamawa state and Cameroon to the East and South respectively [11,12]. The population of Jalingo has been estimated at about 418,000 in 2018, with more recent estimates around 581,000 as at 2022. The city is ethnically diverse but dominated by the Fulani (60%), with significant minorities including Mumuye, Kuteb, and Kona people [11]. The primary occupation of Jalingo inhabitants is farming, which includes cultivation of food crops and vegetables. Farming dominates the economy with crops like maize, groundnut, rice, yam, sorghum, and vegetables such as tomato, onion, spinach, and sweet pepper [13]. The map of the study area is shown in Figure 1.

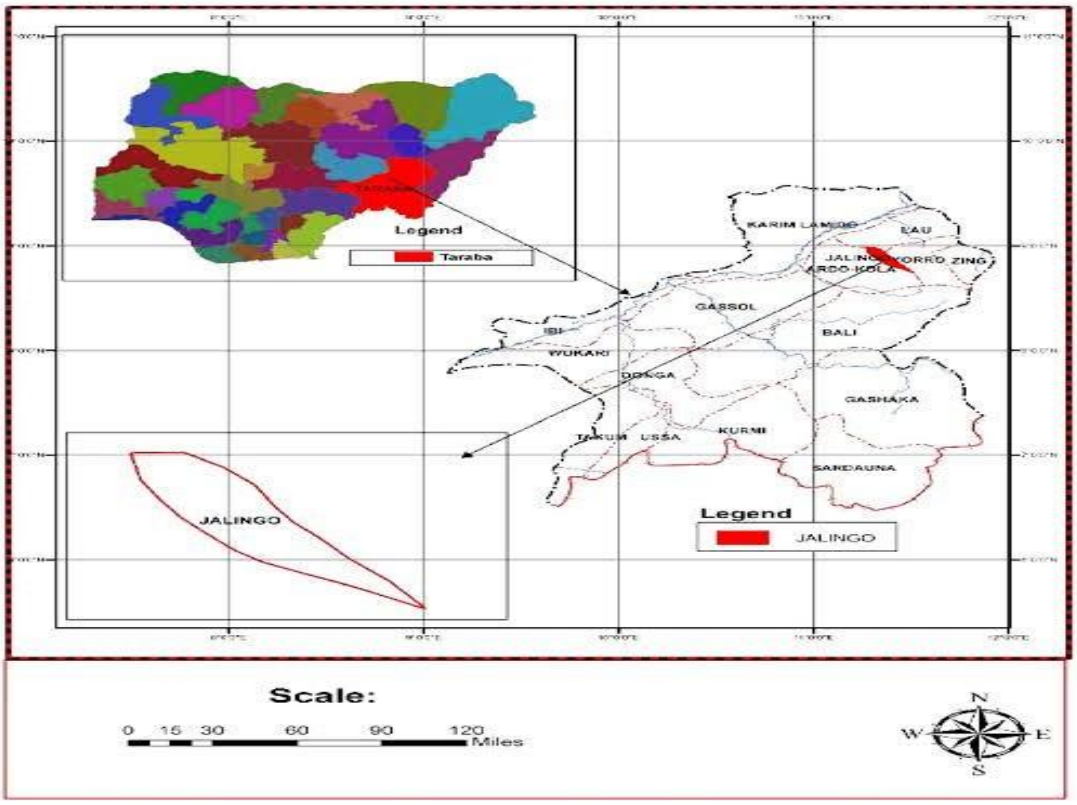


Figure 1. **Map of Taraba State Showing Jalingo Local Government Area** (**Source:[14])**

2.2. Materials and Reagents

Stainless handheld auger, aluminum foil, porcelain mortar and pestle, 2 mm mesh sized sieve, Sonicator (Branson sonifier SFX550), Buchner funnel, beaker, Whatman filter paper, hot plate, Hexane, dichloromethane, alumina (GC grade) as desiccant, conc. H_2SO_4, anhydrous sodium sulfate, HNO_3, perchloric acid, Na_2SO_4, ethyl acetate, acetonitrile, anhydrous magnesium sulphate and distilled water.

2.3. Sample Collection and Processing Prior to Analysis

Soil samples were collected from dumpsites in Nyabunkaka, Dinyavo, and Angwan NTA in Jalingo town, Taraba state. The soil samples were randomly collected from three locations of each dumpsite at depths of between 0-10cm from the surface using stainless handheld auger. The samples were then wrapped in aluminum foil and properly preserved until extraction and analysis [15].

Maize seeds were planted on the three different dumpsites soils (A, B and C) then watered morning and evening. After the first month, some part of the maize (stem and leaves were harvested and air dried for 10 days, the dried samples were pulverized using mortar and pestle then sieved with a 25 mm mesh sieve then packaged in an aluminum foil prior to analysis. The same process was repeated for second and third month. The sample codes are given as follows:

- **A ~ Nyabunkaka** [A_1 is stem at first month; A_2 is leaves at first month; A_3 is stem at second month; A_4 is leaves at second month; A_5 is stem at third month; and A_6 is leaves at third month].
- **B ~ Dinyavo** [B_1 is stem at first month; B_2 is leaves at first month; B_3 is stem at second month; B_4 is leaves at second month; B_5 is stem at third month; and B_6 is leaves at third month].
- **C ~ Anguwan NTA** [C_1 is stem at first month; C_2 is leaves at first month; C_3 is stem at second month; C_4 is leaves at second month; C_5 is stem at third month; and C_6 is leaves at third month].

2.4. Extraction of PAHs

Sample extraction was carried using sonication technique for extraction of PAHs based on USEPA method 3550C. Exactly 10g of the samples (soil and plant parts respectively) were put into the centrifuge tube and 50ml of Hexane was then added to it. It was then sonicated for about 10–30 minutes. Centrifuge and supernatant were then decanted. Extraction was repeated 2–3 times and the extracts were then combined. Solvent was reduced using a rotary evaporator to 1 mL and the extract was transferred to a GC vial for analysis [16].

2.5. Analysis of PAHs

Calibrations were obtained with standard solutions of PAH standard mix of concentrations ranging between 200 – 400 µg/l. Linearity was demonstrated by correlations $r^2 \geq 0.999$. The mass spectra were matched against reference databases to identify and quantify individual components. Samples were then analyzed based on USEPA 8270 method. Exactly 1µl of the extract was injected into the Gas chromatograph for quantification of PAHs. The analytes were automatically detected as they emerged from the column by a mass spectrometer detector (MSD). Agilent chemstation software was used for data processing [15].

2.6. Gas Chromatographic Parameters/Conditions

GC-MS Model: Agilent Technologies 7890AGc Gas Chromatography (GC) coupled with Agilent 5975C Mass selective Detector (MSD) (Agilent Technologies, Santa Clara, CA, USA); Chromatographic column: HP-5MS fused-silica capillary column; The injector temperature was maintained at 250°C and operating in split mode with split ratio of 1:10; injection volume :1.0 µL. Ultra-high purity helium (99.99%) was used as the carrier gas at a constant flow rate of 1.0mL/min. The oven temperature program was initiated at 60 °C (held for 2 min) ramped at 10 °C/min to 200 °C (held for 2 min) and finally increased at 5 °C/min to 250 °C, with a final hold time of 10 min (total run time: 44 min) [15].

2.7. Bioaccumulation Factor Determination

Bioaccumulation factor evaluates the net increase of a substance in an organism relative to its environment.

$$BAF = \frac{\Omega_p (mg/kg)}{\upsilon_m (mg/kg)}, \qquad 1 < BAF < 1 \tag{1}$$

where Ω_p is concentration in plant and υ_m is concentration in medium. Also, a BAF value > 1 indicates accumulation, and a BAF value < 1 indicates no accumulation [17].

2.8. Transfer Factor Assessment

The soil-to-plant transfer factor (TF) assesses radionuclide uptake by plants.

$$TF = \frac{\Psi_p (mg/kg)}{\psi_s (mg/kg)}, \qquad 1 < TF < 1 \tag{2}$$

where Ψ_p is activity concentration in plant and ψ_s is activity concentration in soil. Also, a TF value > 1 indicates transfer, and a TF value < 1 indicates limited transfer [17].

2.8. Data Analysis

The one-way Analysis of Variance (ANOVA) F-test was carried out and mean concentration separation was performed using the Duncan Multiple Range Test (DMRT) as post hoc test to ascertain the level of statistical significance across the three months. Statistical analysis of the data was performed using Statistical Package for Social Sciences (SPSS) version 26.0. All statistical tests were performed at 5% significance level ($p < 0.05$).

3. Results and Discussion

Results on the quantification of PAHs in dumpsite soils, PAHs concentration level and distribution in the plant samples, BAF, and TF assessment of the maize are presented. Also, the ANOVA and DMRT results are presented and discussed. The Chromatography plots for all maize samples are presented as well.

3.1. Quantification of PAHs in Dumpsites Soils

The concentrations of 13 PAH compounds detected in maize soil samples (A, B, C) from the study area ranging from 0.0902 to 0.1170 mg/kg with a mean value of 0.1008 ± 0.0143 mg/kg are presented in Table 1. The chromatograms used to determine the concentration of the PAHs in Table 1 can be found in Figure A1- Figure A3 in the appendix. The results from Table 1 shows that the detected PAHs include low molecular weight (LMW) compounds such as naphthalene and acenaphthylene, and high molecular weight (HMW) compounds like benzo[a]anthracene and benzo[g,h,i]perylene. The total PAH concentrations varied among samples, with notable compounds such as pyrene (0.0006±0.0069 mg/kg), fluoranthene (0.0017±0.0058 mg/kg), and benzo[g,h,i]perylene (0.0715 ± 0.0127 mg/kg), accounting for approximately 71% of the total PAH burden. This suggests that combustion-related activities and the indiscriminate burning of municipal wastes at dumpsites are likely major sources of PAHs in the study area.

Table 1. Levels of PAH in Soil Sample

S/N	Sample	Sample A (mg/kg)	Sample B (mg/kg)	Sample C (mg/kg)	Mean ± SD
1.	Naphthalene	0.0047	0.0024	0.0029	0.0033 ± 0.0012
2.	2-Methylnaphthalene	0.0006	0.0007	0.0008	0.0007 ± 0.0001
3.	Acenaphthylene	0.0027	0.0013	0.0013	0.0018 ± 0.0008
4.	Acenaphthene	0.0023	0.0067	0.0047	0.0046 ± 0.0022
5.	Fluorene	0.0003	0.0022	0.0006	0.0010 ± 0.0010
6.	Phenanthrene	0.0014	0.0005	0.0004	0.0008 ± 0.0006
7.	Fluoranthene	0.0042	0.0076	0.0055	0.0058 ± 0.0017
8.	Pyrene	0.0068	0.0064	0.0076	0.0069 ± 0.0006
9.	Benz[a]anthracene	0.0004	0.0017	0.0007	0.0009 ± 0.0007
10.	Benzo[k]fluoranthene	0.0004	0.0005	0.0014	0.0008 ± 0.0006
11.	Benzo[b]fluoranthene	0.0016	0.0009	0.0021	0.0015 ± 0.0006
12.	Dibenz[a,h]anthracene	0.0010	0.0007	0.0018	0.0012 ± 0.0006
13.	Benzo[g,h,i]perylene	0.0687	0.0854	0.0604	0.0715 ± 0.0127
	TOTAL	**0.0951**	**0.1170**	**0.0902**	**0.1008 ± 0.0143**

High molecular weight PAHs like Benzo[a]anthracene, Chrysene, Benzo[k]fluoranthene, Benzo[a]pyrene, and Benzo[g,h,i]perylene are frequently detected and often in higher concentrations. The total PAH concentrations in the soil across the study areas were observed to be within the acceptable limits of the Agency for Toxic Substances and Disease Registry (ATSDR) levels of 1.0 mg/kg for a significantly contaminated site. It was found that the values of PAHs in the soil of the present study were similar to the report presented in a study carried out by Okechukwu *et al.* [18], which had the range of 0.003 to 1.130mg/kg but much lower when compared to results from a study by [19], who reported 5.6491 mg/kg.

These compounds are of particular concern due to their known carcinogenicity and mutagenicity [20]. Their persistence in the environment means they can accumulate over time, posing long-term risks. The specific PAH profiles provide initial insights into potential sources. For instance, the presence of both low and high molecular weight PAHs might suggest a combination of petrogenic (e.g., oil spills, petroleum products) and pyrogenic (e.g., incomplete combustion of organic matter from industrial activities, agricultural burning, vehicle emissions) sources [21]. The PAHs are hydrophobic and would tend to adsorb strongly to soil organic matter, potentially accumulating in the rhizosphere and being taken up by crops [17]. The detected concentrations, although relatively low, pose risks due to bioaccumulation and persistence.

3.2. The PAHs Concentration and Distribution in Plant Samples

The presence and levels of thirteen PAHs in both the leaves and stems of maize plants sampled from three Dumpsites (A, B, C) in Jalingo L.G.A are presented in Tables 2 to 7. The results presented in these tables showed that the PAHs detected in the samples include two-ring (such as Naphthalene) to six-ring (like Benzo[g,h,i]perylene) compounds, demonstrating a broad spectrum of PAH contamination. The total PAH concentration in maize stems increased from 0.1117 ± 0.0100 mg/kg at the first month to 0.2730 ± 0.1363 mg/kg in the third month (Table 2 – Table 4). The chromatograms used to determine the concentration of the PAHs in Table 2 to Table 4 are presented in Figure A4 - Figure A12 in the appendix.

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Table 2. Levels of PAHs in stem (First month)

S/N	Samples	A_1(stem) (mg/kg)	B_1(stem) (mg/kg)	C_1(stem) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0034	0.0044	0.0034	0.0037 ± 0.0006
2.	2-Methylnaphthalene	0.0017	0.0023	0.0019	0.0020 ± 0.0003
3.	Acenaphthylene	0.0023	0.0015	0.0008	0.0015 ± 0.0008
4.	Acenaphthene	0.0067	0.0046	0.0065	0.0059 ± 0.0012
5.	Fluorene	0.0032	0.0015	0.0008	0.0018 ± 0.0012
6.	Phenanthrene	0.0015	0.0022	0.0013	0.0017 ± 0.0005
7.	Fluoranthene	0.0086	0.0076	0.0124	0.0095 ± 0.0025
8.	Pyrene	0.0064	0.0164	0.0071	0.0100 ± 0.0056
9.	Benz[a]anthracene	0.0017	0.0059	0.0011	0.0029 ± 0.0026
10.	Benzo[k]fluoranthene	0.0006	0.0016	0.0009	0.0010 ± 0.0005
11.	Benzo[b]fluoranthene	0.0009	0.0021	0.0015	0.0015 ± 0.0006
12.	Dibenz[a,h]anthracene	0.0007	0.0017	0.0032	0.0019 ± 0.0013
13.	Benzo[g,h,i]perylene	0.0854	0.0555	0.0637	0.0682 ± 0.0154
	TOTAL	**0.1231**	**0.1073**	**0.1046**	**0.1117 ± 0.0100**

Table 3. Levels of PAHs in stem (Second month)

S/N	Samples	A_3(stem) (mg/kg)	B_3(stem) (mg/kg)	C_3(stem) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0049	0.0000	0.0038	0.0029 ± 0.0026
2.	2-Methylnaphthalene	0.0026	0.0000	0.0053	0.0026 ± 0.0027
3.	Acenaphthylene	0.0026	0.0037	0.0079	0.0047 ± 0.0028
4.	Acenaphthene	0.0077	0.0055	0.0084	0.0072 ± 0.0015
5.	Fluorene	0.0031	0.0000	0.0028	0.0020 ± 0.0017
6.	Phenanthrene	0.0009	0.0009	0.0029	0.0016 ± 0.0012
7.	Fluoranthene	0.0065	0.0015	0.0172	0.0084 ± 0.0080
8.	Pyrene	0.0032	0.0067	0.0098	0.0066 ± 0.0033
9.	Benz[a]anthracene	0.0024	0.0016	0.0019	0.0020 ± 0.0004
10.	Benzo[k]fluoranthene	0.0005	0.0088	0.0009	0.0034 ± 0.0047
11.	Benzo[b]fluoranthene	0.0008	0.0039	0.0036	0.0028 ± 0.0017
12.	Dibenz[a,h]anthracene	0.0021	0.0093	0.0039	0.0051 ± 0.0038
13.	Benzo[g,h,i]perylene	0.1499	0.0274	0.0699	0.0824 ± 0.0621
	Total	**0.1823**	**0.0693**	**0.1345**	**0.1287 ± 0.0567**

Table 4. Levels of PAHs in stem (Third month)

S/N	Samples	A_5(stem) (mg/kg)	B_5(stem) (mg/kg)	C_5(stem) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0054	0.0075	0.0053	0.0061 ± 0.0012
2.	2-Methylnaphthalene	0.0058	0.0058	0.0046	0.0054 ± 0.0006
3.	Acenaphthylene	0.0037	0.0037	0.0009	0.0028 ± 0.0016
4.	Acenaphthene	0.0082	0.0075	0.0082	0.0080 ± 0.0004
5.	Fluorene	0.0047	0.0031	0.0036	0.0038 ± 0.0008
6.	Phenanthrene	0.0016	0.0074	0.0037	0.0042 ± 0.0029
7.	Fluoranthene	0.0092	0.0168	0.0175	0.0145 ± 0.0046
8.	Pyrene	0.0198	0.0075	0.0243	0.0172 ± 0.0087
9.	Benz[a]anthracene	0.0019	0.0011	0.0048	0.0026 ± 0.0020
10.	Benzo[k]fluoranthene	0.0005	0.0011	0.0008	0.0008 ± 0.0003
11.	Benzo[b]fluoranthene	0.0021	0.0034	0.0037	0.0031 ± 0.0009
12.	Dibenz[a,h]anthracene	0.0012	0.0019	0.0054	0.0028 ± 0.0023
13.	Benzo[g,h,i]perylene	0.1195	0.3699	0.1341	0.2078 ± 0.1405
	TOTAL	**0.1782**	**0.4292**	**0.2116**	**0.2730 ± 0.1363**

Similarly, total PAHs in leaves increased from 0.0720 ± 0.0179 mg/kg in the first month to 0.2350 ± 0.1520 mg/kg in the third month (Table 5 – Table 7). The chromatograms use to determine the concentration of the PAHs in Table 5 to Table 7 can be found in Figure A13 - Figure A21 in the appendix. Benzo[g,h,i]perylene, a high molecular weight (HMW) PAH, consistently shows the highest concentrations across all three months and samples. This indicates a significant

uptake and accumulation of this particular PAH by the maize plants. Its concentration was observed to increase from 0.0682 mg/kg in stem at the first month to 0.2078 mg/kg in the third month while in the leaves, its concentrations increased from 0.0507 mg/kg to 0.1704 mg/kg over the same period. This could be attributed to the fact that as number of rings increase, they tend to persist in the environment they are present in [3]. Its persistence of may be attributed to the hydrophobic nature and its strong affinity for plant lipids.

Table 5. Levels of PAHs in leaves (First month)

S/N	Samples	A_2(leaves) (mg/kg)	B_2(leaves) (mg/kg)	C_2(leaves) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0028	0.0026	0.0024	0.0026 ± 0.0002
2.	2-Methylnaphthalene	0.0004	0.0018	0.0007	0.0010 ± 0.0007
3.	Acenaphthylene	0.0002	0.0014	0.0015	0.0010 ± 0.0007
4.	Acenaphthene	0.0013	0.0019	0.0016	0.0016 ± 0.0003
5.	Fluorene	0.0002	0.0012	0.0004	0.0006 ± 0.0005
6.	Phenanthrene	0.0004	0.0013	0.0006	0.0008 ± 0.0005
7.	Fluoranthene	0.0022	0.0117	0.0010	0.0050 ± 0.0059
8.	Pyrene	0.0038	0.0081	0.0032	0.0050 ± 0.0027
9.	Benz[a]anthracene	0.0002	0.0015	0.0004	0.0007 ± 0.0007
10.	Benzo[k]fluoranthene	0.0002	0.0005	0.0007	0.0005 ± 0.0003
11.	Benzo[b]fluoranthene	0.0006	0.0012	0.0015	0.0011 ± 0.0004
12.	Dibenz[a,h]anthracene	0.0007	0.0006	0.0030	0.0014 ± 0.0014
13.	Benzo[g,h,i]perylene	0.0389	0.0525	0.0608	0.0507 ± 0.0111
	Total	**0.0519**	**0.0863**	**0.0778**	**0.0720 ± 0.0179**

PAHs primarily enter plants through two main pathways: root uptake from contaminated soil and foliar deposition from the atmosphere [22]. Based on the presence of both low molecular weight (LMW) PAHs like Naphthalene, Acenaphthene, Fluorene and HMW PAHs such as Fluoranthene, Pyrene, Benzo[g,h,i]perylene, it could suggest that both mechanisms are likely at play. LMW PAHs are generally more volatile and can be more readily absorbed through leaves from the atmosphere, while HMW PAHs, being less volatile and more lipophilic, tend to accumulate in soil and are then taken up by roots, or deposited onto leaves where they are less prone to re-volatilization [23]. There was no consistent pattern of accumulation when comparing the leaves to the stem. This could be attributed to variations in the initial translocation from the roots or accumulation in the vascular tissues. Conversely, in other instances, leaves might show higher concentrations than the stems which could be due to deposition and absorption of this PAHs from the atmosphere on the leaves due to their larger surface area. The variability in leaf and stem concentrations could also depend on the specific PAH, plant species, and environmental conditions [24].

Table 6. Levels of PAHs in leaves (Second month)

S/N	Samples	A_4(leaves) (mg/kg)	B_4(leaves) (mg/kg)	C_4(leaves) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0048	0.0056	0.0037	0.0047 ± 0.0010
2.	2-Methylnaphthalene	0.0018	0.0027	0.0028	0.0024 ± 0.0006
3.	Acenaphthylene	0.0023	0.0025	0.0008	0.0019 ± 0.0009
4.	Acenaphthene	0.0077	0.0047	0.0071	0.0065 ± 0.0016
5.	Fluorene	0.0016	0.0015	0.0016	0.0016 ± 0.0001
6.	Phenanthrene	0.0004	0.0026	0.0015	0.0015 ± 0.0011
7.	Fluoranthene	0.0089	0.0098	0.0182	0.0123 ± 0.0051
8.	Pyrene	0.0076	0.0042	0.0098	0.0072 ± 0.0028
9.	Benz[a]anthracene	0.0019	0.0057	0.0015	0.0030 ± 0.0023
10.	Benzo[k]fluoranthene	0.0014	0.0016	0.0008	0.0013 ± 0.0004
11.	Benzo[b]fluoranthene	0.0021	0.0026	0.0031	0.0026 ± 0.0005
12.	Dibenz[a,h]anthracene	0.0018	0.0015	0.0031	0.0021 ± 0.0009
13.	Benzo[g,h,i]perylene	0.0874	0.3252	0.0681	0.1602 ± 0.1432
	Total	**0.1297**	**0.3702**	**0.1221**	**0.2073 ± 0.1411**

The quantification of these PAHs confirmed that maize plants in the study area indeed took up and accumulated these pollutants from the environment. The observed levels, particularly for known carcinogens like Benzo[a]anthracene, Benzo[b]fluoranthene, and Dibenz[a,h]anthracene, raise concerns about the quality of the dump site soils and the potential for these contaminants to enter the food chain. Naphthalene levels in the leaves generally showed an increase from the first to the third month (0.0028mg/kg < 0.0048mg/kg < 0.0053mg/kg). Similar trends were also observed in stems across different sample locations.

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Table 7. Levels of PAHs in leaves (Third month)

S/N	Samples	A_6(leaves) (mg/kg)	B_6(leaves) (mg/kg)	C_6(leaves) (mg/kg)	Mean ± SD
1.	Naphthalene	0.0053	0.0068	0.0050	0.0057 ± 0.0010
2.	2-Methylnaphthalene	0.0030	0.0056	0.0040	0.0042 ± 0.0013
3.	Acenaphthylene	0.0029	0.0027	0.0083	0.0046 ± 0.0032
4.	Acenaphthene	0.0078	0.0079	0.0085	0.0081 ± 0.0004
5.	Fluorene	0.0040	0.0024	0.0031	0.0032 ± 0.0008
6.	Phenanthrene	0.0009	0.0066	0.0037	0.0037 ± 0.0029
7.	Fluoranthene	0.0072	0.0154	0.0179	0.0135 ± 0.0056
8.	Pyrene	0.0048	0.0072	0.0195	0.0105 ± 0.0079
9.	Benz[a]anthracene	0.0035	0.0075	0.0040	0.0050 ± 0.0022
10.	Benzo[k]fluoranthene	0.0017	0.0002	0.0009	0.0009 ± 0.0008
11.	Benzo[b]fluoranthene	0.0008	0.0028	0.0031	0.0022 ± 0.0013
12.	Dibenz[a,h]anthracene	0.0026	0.0017	0.0046	0.0030 ± 0.0015
13.	Benzo[g,h,i]perylene	0.0929	0.3433	0.0749	0.1704 ± 0.1500
	Total	**0.1374**	**0.4101**	**0.1575**	**0.2350 ± 0.1520**

Similarly, 2-Methylnaphthalene showed a clear increase over time. This observation is in samples A_1 leaf (0.0004mg/kg) to A_3 (0.0018mg/kg) to A_5 (0.0030mg/kg) while Acenaphthene was found to be consistently higher in the later months in the stem in the order (0.0067 mg/kg) < 0.0077mg/kg < 0.0082mg/kg). This temporal increase in PAH levels is consistent with the understanding that plants act as accumulators of environmental pollutants over their life cycle. As plants grow, they are continuously exposed to PAHs from the atmosphere (through foliar deposition) and from the soil (through root uptake) [25]. This finding has significant implications for food safety, as maize consumed at maturity would likely contain higher levels of PAHs.

Table 8. Summary of Statistical Analysis of PAH in Stem

S/No	PAHs	First month	Second month	Third month	F-value	P-value
1	Naphthalene	0.0037±0.0006	0.0029±0.0026	0.0061±0.0012	2.857	0.134
2	2Methylnaphthalene	0.0020±0.0003	0.0026±0.0027	0.0054±0.0006	3.927	0.081
3	Acenaphthylene	0.0015±0.0008	0.0047±0.0028	0.0028±0.0016	2.131	0.200
4	Acenaphthene	0.0059±0.0012	0.0072±0.0015	0.0080±0.0004	2.500	0.162
5	Fluorene	0.0018±0.0012	0.0020±0.0017	0.0038±0.0008	2.124	0.201
6	Phenanthrene	0.0017±0.0005	0.0016±0.0012	0.0042±0.0029	2.020	0.213
7	Fluoranthene	0.0095±0.0025	0.0084±0.0080	0.0145±0.0046	1.031	0.412
8	Pyrene	0.0100±0.0056	0.0066±0.0033	0.0172±0.0087	2.255	0.186
9	Benz[a]anthracene	0.0029±0.0026	0.0020±0.0004	0.0026±0.0020	0.189	0.832
10	Benzo[k]fluoranthene	0.0010±0.0005	0.0034±0.0047	0.0008±0.0003	0.837	0.478
11	Benzo[b]fluoranthene	0.0015±0.0006	0.0028±0.0017	0.0031±0.0009	1.553	0.286
12	Dibenz[a,h]anthracene	0.0019±0.0013	0.0051±0.0038	0.0028±0.0023	1.198	0.365
13	Benzo[g,h,i]perylene	0.0682±0.0155	0.0824±0.0621	0.2078±0.1405	2.228	0.189

Although Table 8 indicate numerical increases in maize stems across the months, the ANOVA results supported by the Duncan tests indicated that these differences were not statistically significant ($p > 0.05$) for all PAHs which could imply that while accumulation occurred, the variations were insufficient to establish significant temporal differences in stem tissues. The absence of significant differences between sampling periods may be due to limited translocation of PAHs into stem tissues. Observations have been reported in contaminated agricultural systems where PAHs accumulate predominantly in roots and leaves while stem concentrations remain comparatively lower [26].

In the maize leaves, Table 9 shows significant differences at 5% for four out of the 13 PAHs which includes Naphthalene with p-value of 0.008), 2-Methylnaphthalene with p-value of 0.015, Acenaphthene with p-value of 0.0001, and Fluorene with p-value of 0.004. The significant presence of these four PAHs could be attributed to active accumulation of these compounds in leaves over time. Naphthalene increased from 0.0026 ± 0.0002 mg/kg in the first month to 0.0057 ± 0.0010 mg/kg in the third month. Similarly, 2-Methylnaphthalene increased from 0.0010±0.0007 mg/kg to 0.0042±0.0013 mg/kg, Acenaphthene increased from 0.0016 ± 0.0003 mg/kg to 0.0081 ± 0.0004 mg/kg, and 0.0006±0.0005 mg/kg to 0.0032±0.0008 mg/kg for Fluorene.

The widespread practice of burning crop residues such as maize stalks after harvest and other agricultural wastes to clear land or for nutrient cycling is a major source of PAHs, especially HMW ones, released directly into the soil and atmosphere [27]. Exhaust from diesel-powered tractors and other farm equipment also contributes to the deposition of PAHs in farmland soils [28]. Farmlands located close to roads or urban centers can receive significant atmospheric deposition of PAHs from vehicle exhausts.

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Table 9. Summary of Statistical Analysis of PAH in Leaves

S/N	PAHs	First month	Second month	Third month	F-value	P-value
1.	Naphthalene	0.0026±0.0002[a]	0.0047±0.0010[b]	0.0057±0.0010[b]	11.984	0.008*
2.	2-Methylnaphthalene	0.0010±0.0007[a]	0.0024±0.0006[ab]	0.0042±0.0013[b]	9.191	0.015*
3.	Acenaphthylene	0.0010±0.0007	0.0019±0.0009	0.0046±0.0032	2.784	0.140
4.	Acenaphthene	0.0016±0.0003[a]	0.0065±0.0016[b]	0.0081±0.0004[b]	37.200	0.0001*
5.	Fluorene	0.0006±0.0005[a]	0.0016±0.0001[a]	0.0032±0.0008[b]	16.320	0.004*
6.	Phenanthrene	0.0008±0.0005	0.0015±0.0011	0.0037±0.0029	2.249	0.187
7.	Fluoranthene	0.0050±0.0059	0.0123±0.0051	0.0135±0.0056	2.087	0.205
8.	Pyrene	0.0050±0.0027	0.0072±0.0028	0.0105±0.0079	0.882	0.461
9.	Benz[a]anthracene	0.0007±0.0007	0.0030±0.0023	0.0050±0.0022	3.929	0.081
10.	Benzo[k]fluoranthene	0.0005±0.0003	0.0013±0.0004	0.0009±0.0008	1.817	0.242
11	Benzo[b]fluoranthene	0.0011±0.0004	0.0026±0.0005	0.0022±0.0013	2.720	0.144
12	Dibenz[a,h]anthracene	0.0014±0.0014	0.0021±0.0009	0.0030±0.0015	1.112	0.388
13	Benzo[g,h,i]perylene	0.0507±0.0111	0.1602±0.1432	0.1704±0.1500	0.918	0.449

Asterisk (*) implies significance at 5%. Same superscript letters (a, b) denote no significant mean difference.

The PAHs, even HMW ones, can travel through the atmosphere and deposit onto soils through wet (rain) and dry deposition from regional and even distant sources, contributing to the overall background contamination [18] and [22]. The specific fingerprint of PAHs observed in the Jalingo soil points towards a complex interplay of localized agricultural activities and broader environmental factors, all contributing to the build-up of these persistent organic pollutants.

3.4. Results on BAF and TF Analyses

The BAF and TF values are reported in Tables 10, 11, and 12. The BAF for the different PAHs varied spatially and temporally across locations. Table 10 shows that for sample A, there was no bioaccumulation in the first month but it increases as the time increases to the second and third months where BAF values clearly are greater than one indicating increasing accumulation.

Table 10. PAHs – BAF Across Samples

Month	Sample A	Sample B	Sample C	Mean ± SD
First	0.9500	1.0700	1.2000	1.0733 ± 0.1250
Second	1.3600	3.2000	1.3600	1.9733 ± 1.0623
Third	1.4500	3.5500	1.7500	2.2500 ± 1.1358

However, in sample B and C, there is the presence of accumulation from the first month to the third month because they produced BAF values > 1 with sample B having the highest accumulation in the second and third months with BAF values far greater than 1 and it suggests higher contamination level or increased bioavailability.

Table 11. The TF Results for Maize Stem (Soil to Stem)

S/N	PAHs	First Month	Second Month	Third Month	Mean ± SD
1.	Naphthalene	1.1212	0.8788	1.8485	1.2828 ± 0.5047
2.	2-Methylnaphthalene	20.0000	26.0000	54.0000	33.3333 ± 18.1475
3.	Acenaphthylene	1.8750	5.8750	3.5000	3.7500 ± 2.0117
4.	Acenaphthene	2.6818	3.2727	3.6364	3.1970 ± 0.4818
5.	Fluorene	1.8000	2.0000	3.8000	2.5333 ± 1.1015
6.	Phenanthrene	2.8333	2.6667	7.0000	4.1667 ± 2.4552
7.	Fluoranthene	5.5882	4.9412	8.5294	6.3530 ± 1.9124
8.	Pyrene	16.6670	11.0000	28.6670	18.7780 ± 9.0207
9.	Benz[a]anthracene	3.2222	2.2222	2.8889	2.7778 ± 0.5092
10.	Benzo[k]fluoranthene	1.6667	5.6667	1.3333	2.8889 ± 2.4111
11.	Benzo[b]fluoranthene	2.5000	4.6667	5.1667	4.1111 ± 1.4175
12.	Dibenz[a,h]anthracene	3.1667	8.5000	4.6667	5.4445 ± 2.7504
13.	Benzo[g,h,i]perylene	0.9539	1.1525	2.9063	1.6709 ± 1.0745

The results in Table 11 and Table 12 shows that there is higher TF from soil to the maize stem across the three months compared to the TF from soil to the maize leaves. For example, 2-Methylnaphthalene has across months mean ± SD value of 33.3333 ± 18.1475 for soil-to-stem compared to soil-to-leaves three months mean ± SD value of 25.3333 ± 16.0416. This could be attributed to atmospheric deposition and internal translocation.

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Table 12. The TF Results for Maize Leave (Soil to Leaves)

S/N	PAHs	First Month	Second Month	Third Month	Mean ± SD
1.	Naphthalene	0.7879	1.4242	1.7273	1.3131 ± 0.4795
2.	2-Methylnaphthalene	10.0000	24.0000	42.0000	25.3333 ± 16.0416
3.	Acenaphthylene	1.2500	2.3750	5.7500	3.1250 ± 2.3419
4.	Acenaphthene	0.7273	2.9546	3.6818	2.4546 ± 1.5394
5.	Fluorene	0.6000	1.6000	3.2000	1.8000 ± 1.3115
6.	Phenanthrene	1.3333	2.5000	6.1667	3.3333 ± 2.5222
7.	Fluoranthene	2.9412	7.2353	7.9412	6.0392 ± 2.7061
8.	Pyrene	8.3333	12.0000	17.5000	12.6111 ± 4.6138
9.	Benz[a]anthracene	0.7778	3.3333	5.5556	3.2222 ± 2.3908
10.	Benzo[k]fluoranthene	0.8333	2.1667	1.5000	1.5000 ± 0.6667
11.	Benzo[b]fluoranthene	1.8333	4.3333	3.6667	3.2778 ± 1.2946
12.	Dibenz[a,h]anthracene	2.3333	3.5000	5.0000	3.6111 ± 1.3368
13.	Benzo[g,h,i]perylene	0.7091	2.2406	2.3832	1.7776 ± 0.9281

These findings are consistent with studies by Chen *et al.* [13] and [17] who reported significant PAH uptake by crops grown near dumpsites and urban soils. Transfer factors greater than 1 in some locations indicate enhanced translocation of PAHs from stem to leaf. High bioaccumulation and significant PAH uptake pose potential health risks to farm workers and consumers through dermal contact, inhalation of dust, and ingestion of contaminated maize. Studies by WHO emphasized that prolonged exposure to these contaminants may lead to chronic health issues, including carcinogenic and neurotoxic effects [28].

4. Conclusions

The study successfully achieved its aim of assessing the levels of Polycyclic Aromatic Hydrocarbons (PAHs) uptake by maize plants grown on dumpsite soils in parts of Jalingo, Taraba State. The results confirmed that dumpsite soils contain measurable levels of PAHs resulting from various anthropogenic activities associated with waste disposal and open burning practices. These contaminants were readily taken up by maize plants and accumulated in both stems and leaves throughout the growth period. The predominance of Benzo[g,h,i]perylene among PAHs highlights their environmental persistence and mobility within the soil–plant system. The observed increase in contaminant concentrations over time, coupled with high Transfer Factor and Bioaccumulation Factor values, demonstrates that maize plants possess the capacity to absorb and accumulate pollutants from contaminated dumpsite soils.

The findings further reveal that cultivation of food crops on dumpsite soils may constitute a potential pathway for the transfer of hazardous contaminants into the food chain. Continuous exposure to these pollutants through direct contact, inhalation of contaminated dust, or consumption of contaminated crops may pose adverse health effects to farmers, consumers, and the surrounding population. Therefore, the use of dumpsite soils for agricultural production should be discouraged or carefully regulated and monitored to prevent environmental contamination and protect public health. Based on these critical findings, the following recommendations are proposed:

- Establishment of routine surveillance of PAHs in dumpsite soils and crops to track contamination trends and ensure early intervention.
- Identification and control of key pollutant sources such as industrial discharges, vehicular emissions, and inappropriate fertilizer or pesticide use through stricter environmental regulations and cleaner agricultural practices.
- Promotion of the adoption of safer farming methods, including organic fertilizers, soil remediation techniques, and crop selection to reduce pollutant uptake.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix

Appendix A.1: PAHs Chromatogram Plots

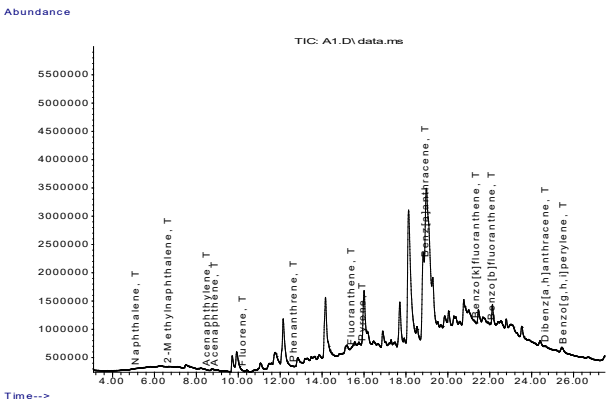


Figure A1. PAHs Chromatogram for soil sample A

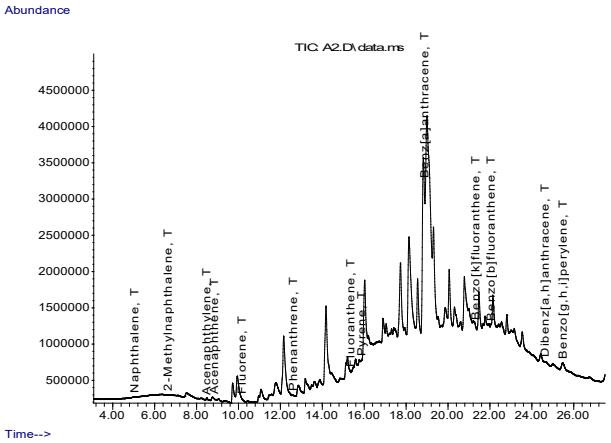


Figure A2. PAHs Chromatogram for soil sample B

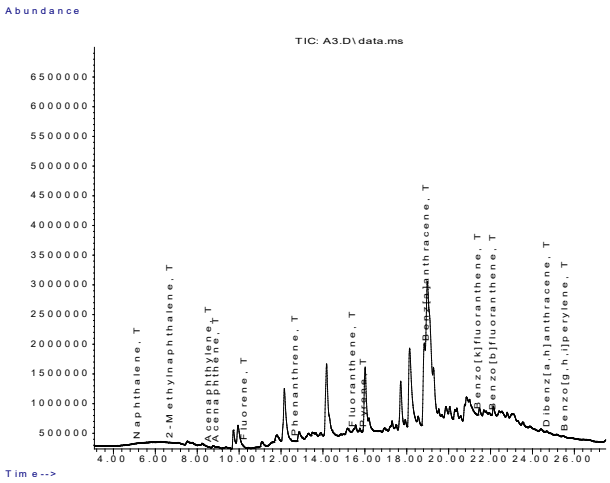


Figure A3. PAHs Chromatogram for soil sample C

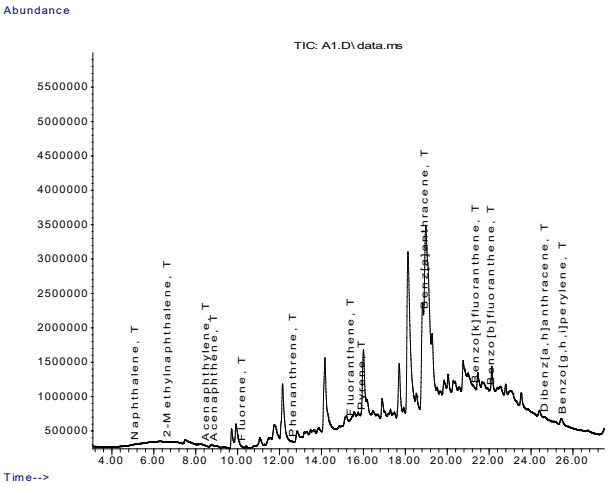


Figure A4. PAHs Chromatogram for stem sample A_1

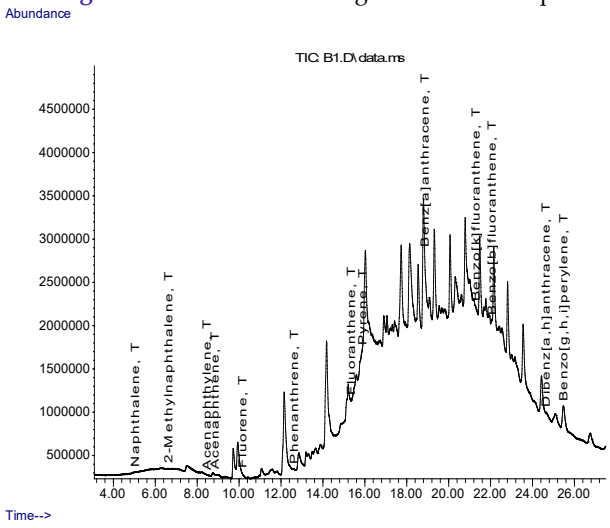


Figure A5. PAHs Chromatogram for stem sample B_1

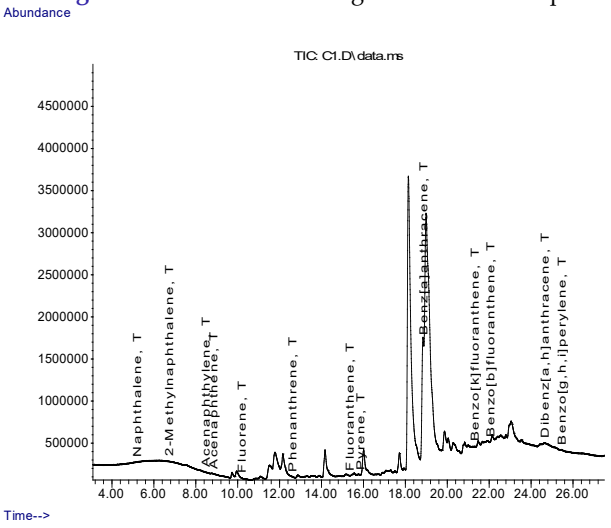


Figure A6. PAHs Chromatogram for stem sample C_1

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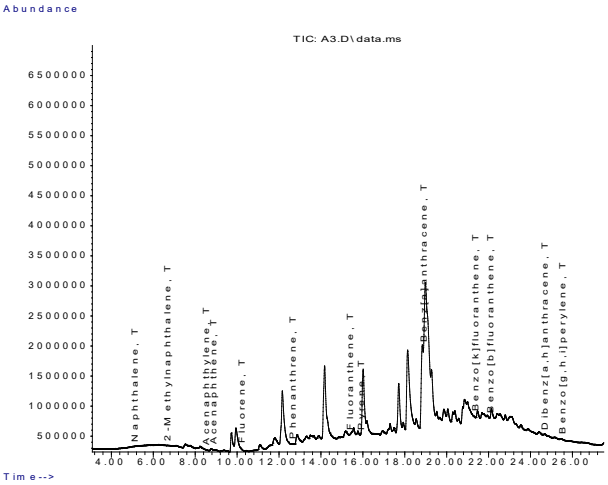


Figure A7. PAHs Chromatogram for stem sample A_3

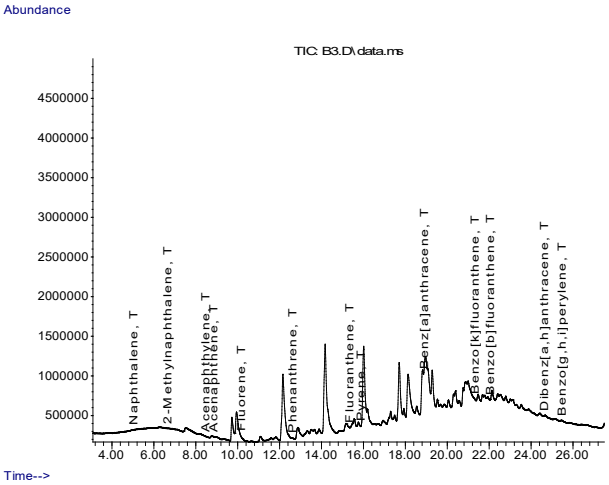


Figure A8. PAHs Chromatogram for stem sample B_3

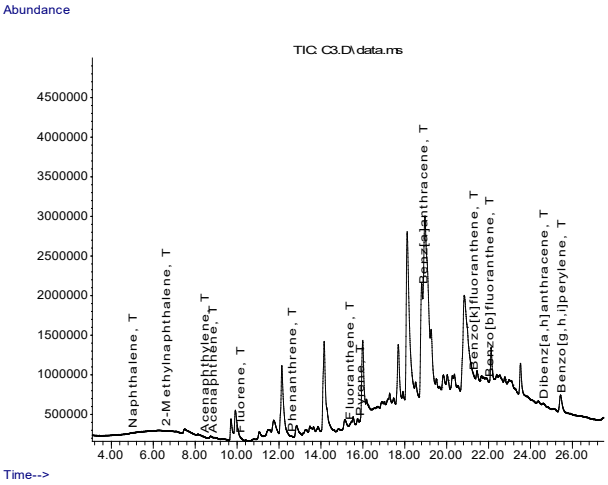


Figure A9. PAHs Chromatogram for stem sample C_3

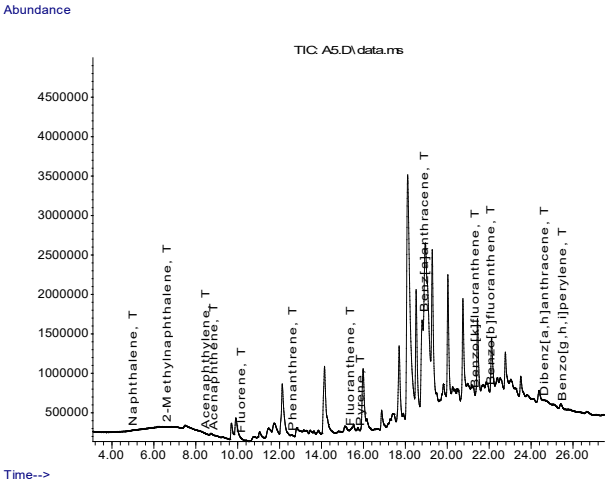


Figure A10. PAHs Chromatogram for stem sample A_5

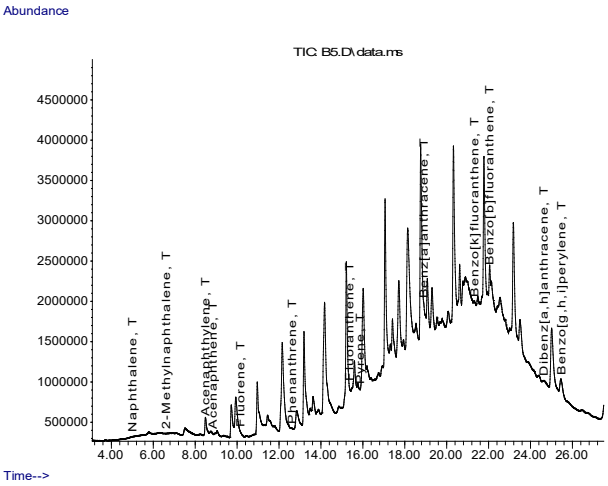


Figure A11. PAHs Chromatogram for stem sample B_5

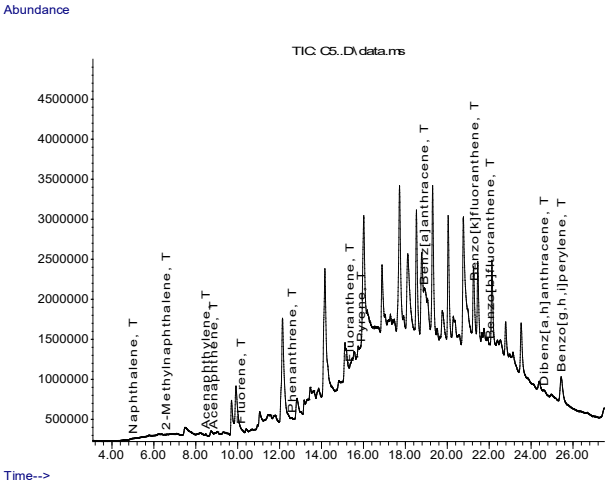


Figure A12. PAHs Chromatogram for stem sample C_5

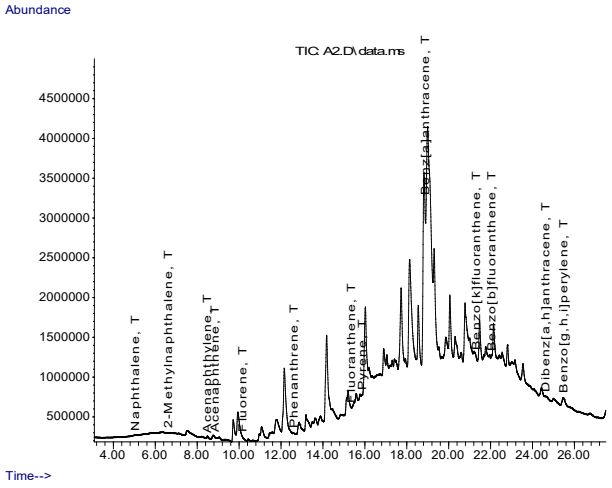


Figure A13. PAHs Chromatogram for leave sample A_2

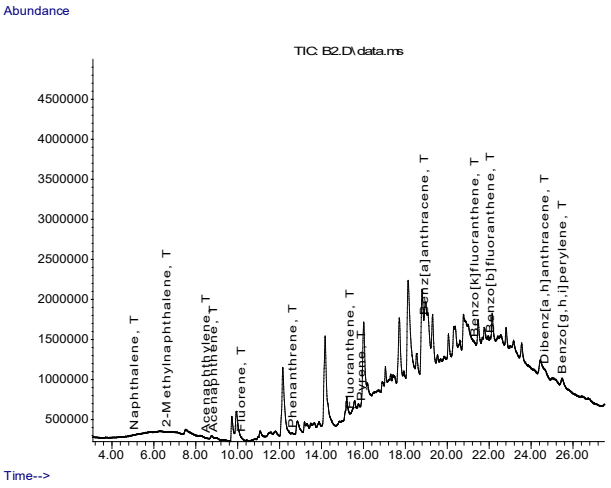


Figure A14. PAHs Chromatogram for leave sample B_2

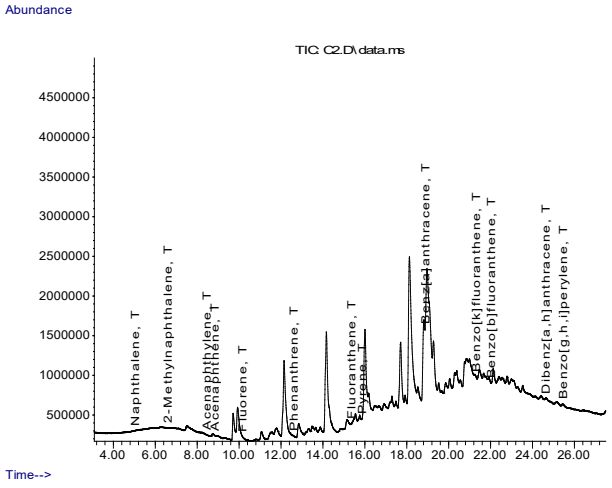


Figure A15 PAHs Chromatogram for leave sample C_2

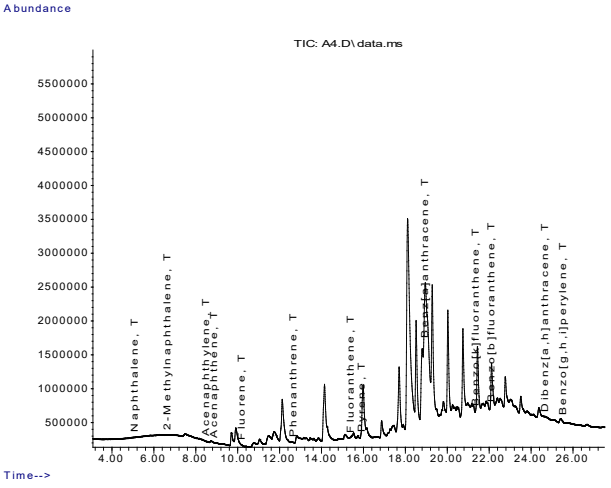


Figure A16. PAHs Chromatogram for leave sample A_4

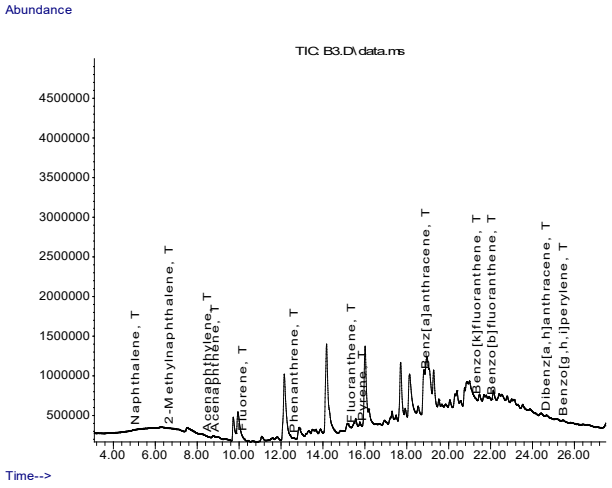


Figure A17. PAHs Chromatogram for leave sample B_4

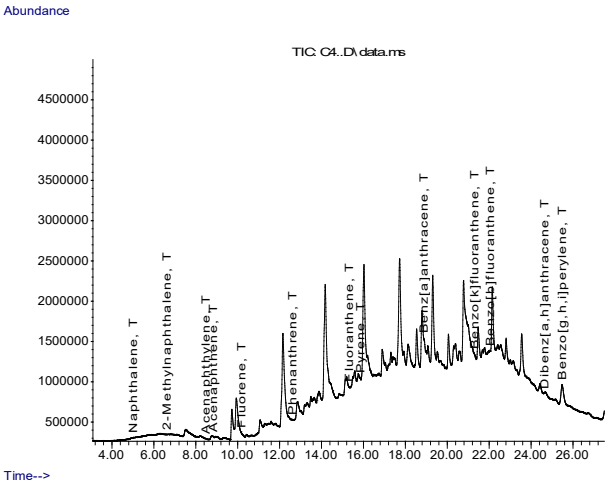


Figure A18. PAHs Chromatogram for leave sample C_4

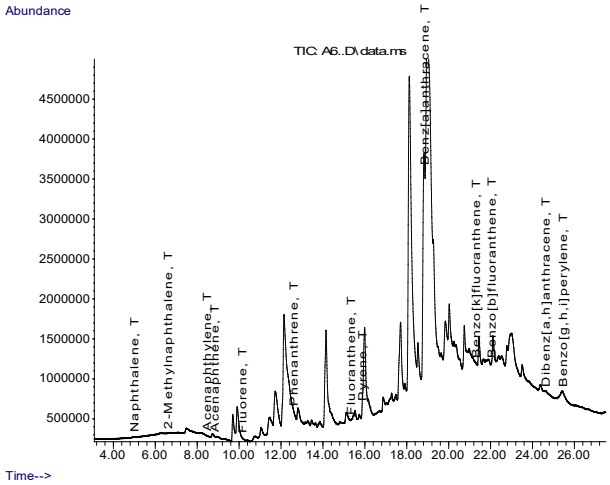


Figure A19. PAHs Chromatogram for leave sample A_6

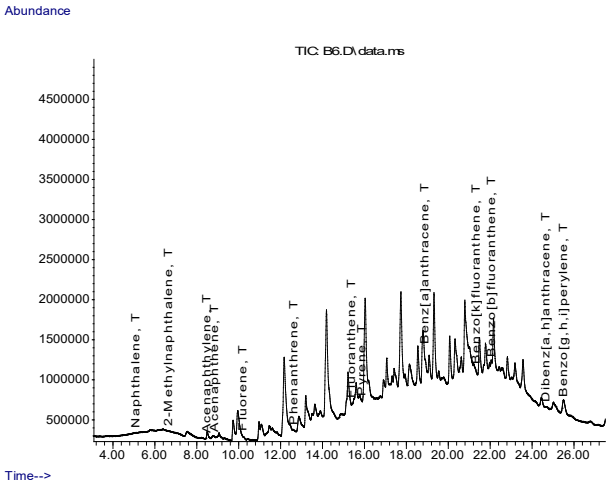


Figure A20. PAHs Chromatogram for leave sample B_6

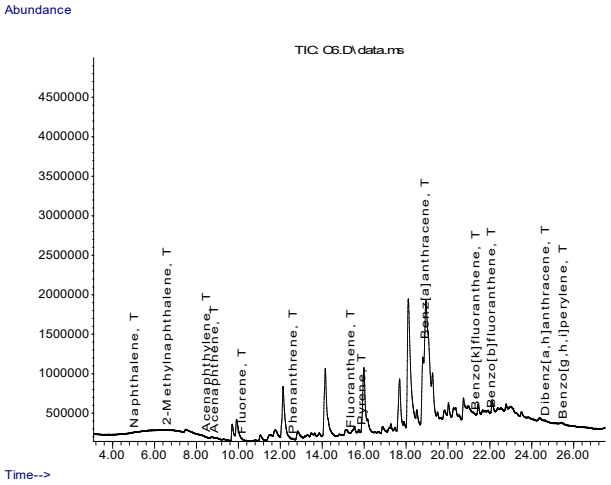


Figure A21. PAHs Chromatogram for leave sample C_6

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