Bima Journal of Science and Technology, Vol. 8(4A) Dec, 2024 ISSN: 2536-6041

DOI: 10.56892/bima.v8i4.1146

Determination of PAHS in Soil, Cassava and Processed Cassava Meal (Fufu) from Selected Communities in Ohaji Egbema, Imo State, Nigeria

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ABSTRACT

This study investigates levels of Polycyclic Aromatic Hydrocarbons (PAHs) in soil, cassava tubers from farmlands and processed cassava meal (fufu) in Ohaji/Egbema, Nigeria. Impact of PAHs on soil and cassava portends adverse effect on health of people. Ten different samples of soil, cassava and fufu collected from ten different villages in Ohaji/Egbema Local Government Area, and a positive control from Umuguma, a distant village located in Owerri-West Local Government Area were examined for PAHs contamination using Gas Chromatography (GC) system equipped with Flame Ionization Detector (DC/FID). The results obtained showed the presence of all USEPA Target PAHs in different concentrations in $mgkg^{-1}$. Soil samples observed from Ekwugba and Etekwuru had PAHs concentration at $1.1x\ 10^{-2}$mg/kg; and1.28mg/kg respectively ranging from the least to the highest. Cassava sample from Etekwuru recorded the highest PAHs value of ($1.7x10^{-2}$mg/kg), followed by cassava sample from Asaa with PAHs value of ($9.0x10^{-3}$mg/kg) while cassava from Ekwugba had the least PAHs value of ($1.0x10^{-3}$mg/kg). PAHs level obtained from soil samples had no correlation to that from cassava tubers harvested from such farmlands. From the study, the PAHs levels in most samples were above ATSDR (2021) accepted limit between 0 - 0.1mg/kg. The results as presented in table 3 show that there is no significant difference in the level of PAHs in fufu from Ohaji/Egbema and control location. It is therefore recommended that affected areas should be remediated before being use as farmlands for cultivation of edible crops.

Keywords: Polycyclic Aromatic Hydrocarbons (PAHs), Soil, Cassava Tubers, Gas Chromatography, Processed Cassava Meal (fufu), Ohaji/Egbema.

INTRODUCTION

Egbema/Ohaji is known for bulk supply of processed cassava meals such as fufu and garri sold in major Owerri markets. Meanwhile, a lot of oil exploration activities are carried out within its environments. This oil exploration activities release various pollutants such as PAHs and toxic materials into the farmlands and surrounding water bodies (WHO 2020). Therefore, an investigation to determine the concentration of PAHs in the soil, cassava tubers and processed product (fufu) from such area will be beneficial to public health. Polycyclic aromatic hydrocarbons with two or more fused benzene rings in various structural configurations are classified as highly toxic pollutants; they can cause both acute and chronic effects in the organisms (Narro *et al.,* 2002). Although PAHs are ubiquitous in nature, quantities from synthesis in terrestrial vegetation, microbial synthesis, and volcanic activity are infinitesimal in comparison with those produced from forest, grassland fires and anthropogenic sources (EPA, 2017). Anthropogenic activities associated with significant production of PAHs include deposition especially from spillage of petroleum and petroleum products, coke production in the iron and steel industry, catalytic cracking in the petroleum industry, production of carbon black, coil tar pitch,

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asphalt, heating and power generation, controlled refuse incineration, open burning, and emissions from internal combustion engines used in transportation (Nwaichi *et al*., 2015). PAHs (Polycyclic Aromatic Hydrocarbons) can cause mutation and cancer and also affect endocrine systems. The effects on human health will depend mainly on the amount one is exposed to (or concentration), the innate toxicity of the PAHs and whether exposure occurs via inhalation, ingestion or skin contact, exposure to contaminated soil/dust, and from inhalation of PAH vapours. Two or three aromatic rings, such as the naphthalenes, anthracenes and fluoranthenes tend to be the most acutely toxic, whereas the longer PAHs with four to seven rings, such as benzo(a)fluoranthene, chrysene and pyrene, are not acutely toxic but tend to be more carcinogenic (Emoyan *et al.,* 2020). These compounds tend to bioaccumulate in plants/ food crops (cassava) in polluted farmlands or soil (Okereke-Okonkwo, 2020).

Soil as one of the crucial material on the top surface of the earth serves as a natural medium for the growth of land plants (Emoyan *et al*., 2020).Herbert and Banwart, 2018 reported that this basic component of ecosystems is susceptible to contamination and degradation through accidental or deliberate mismanagement. Due to natural and anthropogenic activities, aggregation of heavy metals, emission from the rapidly expanding industrial areas, disposal of high metal wastes, leaded gasoline and paints, soil can become contaminated (Wuana and Okieimen, 2017). Hydrocarbon pollutants spread through the soil leading to serious pollution problems (Thouand, *et al.,* 1999). Soil and plant have been affected by excessive accumulation of petroleum and other related human activities (Kabata and Pendias, 2018) and thereby constitute major environmental and human health problems (EeLuiAng and Jeffery, 2019).Cassava (*Manihot esculenta Crantz*) is one of the most important crops in Nigeria (Nweke, 2019) and many tropical countries providing a valuable source of calories and is a staple food for about 800 million people in the world (Oyewole, 2002). Processed cassava meal (fufu), is mostly wrapped with white polythene bags during the processing stages and also used as packaging material (Ozen and Floros, 2021).

The aim of this study is to investigate the level of PAHs in soils, cassava and processed cassava meal (fufu) from selected communities in Ohaji/Egbema, Imo state. Achieving this aim, the following objectives were determined; assessment of the level of PAHs in the soil samples from farmlands in Ohaji/Egbema, assessment of the level of PAHs in cassava tubers harvested from the same farmlands in Ohaji/Egbema and ascertaining the level of PAHs in processed fufu wrapped with white Polythene wrappers sold in markets in OhajiEgbema. In the course of this study, it was hypothesized that there is no correlation between levels of PAHs in soil samples from cassava farmlands and cassava roots, and there is no significant difference in the level of PAHs in fufu from Ohaji/Egbema and control location.

MATERIALS AND METHODS

Study Area

The study area was Ohaji/Egbema, an oil rich local Government Area of Imo State, Nigeria. Its headquarters is Mmahu-Egbema with Latitude: 5°18' 12.60" N and Longitude: 6°56' 26.39" E, located in the south-western part of Imo State, Nigeria. It is an area of table agricultural land.

Collection of Samples

In ten different communities at Ohaji/Egbema L.G.A namely Etekwuru, Ekwugba, Umuorji, Ngbara, Oforola, Obokofia, Obiakpu, Agba, Adapalm and Asaa, soil and cassava tuber samples were collected from the same farmlands, stored in polythene and sack bags respectively labeled accordingly and transported to the laboratory for analysis. At each location, soil samples

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were collected at a depth of0 – 30 cm using a soil auger. Control samples were similarly collected from Umuguma, Owerri west. Processed wrapped Fufu were purchased from various markets in the ten different communities and labeled using masking tape according to the area it was collected.

Determination of PAHs in the Soil, Cassava and Fufu Samples

Preparation of Soil and cassava tubers Samples

Soil samples were air-dried under room temperature for 48 hours (2 days) to ensure constant weight, after which, they were homogenized using a ceramic mortar and pestle to obtain finer texture and to remove sticks, pebbles and rock particles(USDA 2017). The air-dried soil samples were then sieved through a 2 mm polythene sieve. Particles larger than 2mm mesh size were discarded. The cassava samples were gently washed under running tap water to remove adhered soil particles, and then washed with sterile water to remove any possible foliar contaminants such as pesticides, fertilizers, dust or mud. The tuber samples were peeled and then cut into small pieces using a stainless knife, and then oven-dried at 60˚C for 3 days to obtain a constant mass. The dried samples were ground using a ceramic mortar and pestle to reduce the dried material to a suitable size for digestion and analysis (Inyang, 2016).

Extraction

Two grams (2g) of the samples were weighed and placed in a glass beaker, 20ml of organic solvent Dichloromethane (DCM) was added to each sample in the beaker. The samples were then stirred with a sterile rod for homogeneity and filtered with the funnel, cotton wool, Silica gel and Sodium Sulphate (cotton wool removes impurities that are visible to the eyes, Silica gel removes impurities that cannot be seen while Sodium sulphate removes moisture from the sample). After filtration, the samples were allowed to concentrate for 1-2 hours before running it through a Gas Chromatography Machine (Greenberg, 2015).

Gas Chromatographic-FID Analysis

The concentrated aromatic fractions were transferred into labeled glass vials with Teflon rubber crimp caps for gas chromatographic analysis. Two microliters of the sample was collected from the beaker using analytical syringe (hypodermic needle) and was injected in the injector compartment of the Gas Chromatography Machine and allowed to run for 25mins. Other GC- FID operating set-up was done according to the instrument's method development as specified in the operating instruction manual Identification and quantification of individual PAHs was based on internal calibration standard containing known concentrations of the 16 PAHs (EPA-16). At a programmed temperature of 60˚C to 180˚C, separation began to occur between the constituents of the vapour partition gas and liquid phases. The sample was automatically detected as it emerges from the column at a constant flow rate by the FID detector whose response is dependent upon the composition of the vapour. The specificity of the 16 PAHs sought for in the samples was confirmed by the presence of transition ions (quantifier and qualifier) as shown by their retention times which corresponded to those of their respective standards. The measured peak area ratio of precursor to quantifier ion was in close agreement with those of the standards. Results were then displayed on the computer system after the process has been completed. The Gas Chromatography uses 3-gases; Air, Helium and Hydrogen. The functions of Air (Oxygen) and Hydrogen is to heat up the machine while Helium is the carrier gas that carries the sample injected. Results obtained were presented as mg kg^{-1} concentration per analyte (Greenberg, 2015).

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Statistical Analysis

The results were expressed as mean ± standard deviation of triplicate determinations, and the test of statistical significance ($p<0.05$) amongst the groups was assessed using one-way analysis of variance (ANOVA).

RESULTS

As shown in figure 1, the level of PAHs in soil samples from Etekwuru recorded highest values (1.28mg/kg) while Ekwugba recorded the least value of ($1.1x10^{-2}$mg/kg) with the range of PAHs within 0.011mg/kg – 1.28mg/kg. According to the Agency for toxic substances and disease registry (ATSDR, 2021), levels of the sum of PAHs between 0 - 0.1mg/kg are considered non-contaminant. Values within the range of 0.1-1.0mg/kg indicate slight contamination, while values within 1.0 -10mg/kg indicates significant contamination. Therefore, Etekwuru soil sample can be considered significantly contaminated since the total PAHs concentration was between 1.0 - 10mg/kg during the sampling period of this study.

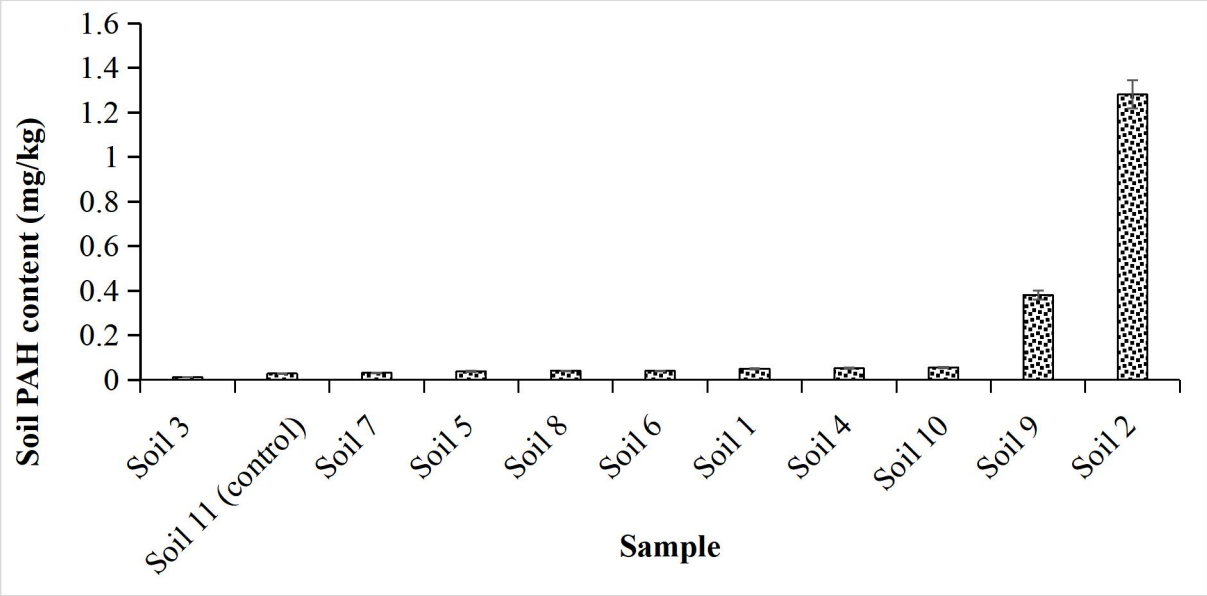

Figure 1: Polycyclic aromatic hydrocarbons (PAHs) levels in soil samples from Ohaaji/Egbema.

Legend: Soil 1 - Ada Palm, Soil 2 - Etekwuru, Soil 3 - Ekwugba, Soil 4 - Umuorji, Soil 5 - Ngbara, Soil 6 - Oforola, Soil 7 - Obokofia, Soil 8 - Obiakpu, Soil 9 - Agba, Soil 10 - Asaa, and Soil 11 - Control soil

In table 1, among the PAHs in the various locations, Naphthalene was not detected in the soil from Umuorji, Ngbara, Oforola, and Obiakwu communities. Also, Acenaphthylene was not detected in soils from Ngbara, Oforola, Obokofia and Obiapku. Among all the various locations, Obokofia soil recorded no fluorine while Ngbara soil had no detection of Acenaphthene. The most persistent four – ringed PAHs among the various locations was Pyrene and found most in the soil sample from Etekwuru with the highest mean value of 0.048mg/kg. Fluoranthene, another four ringed PAHs was the least persistent among the various locations. However, samples from Etekwuru recorded a significant mean value of 0.023mg/kg. Chrysene and Benzo(a)anthracene were the other four ringed PAHs detected in all locations. However, samples from Obokofia, Oforola, Agba, Asaa and Control soils

Bima Journal of Science and Technology, Vol. 8(4A) Dec, 2024 ISSN: 2536-6041

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recorded very insignificant values of Chrysene according to (ATSDR, 2021) standard.Five ringed Benzo(b)fluoranthene was detected in all sample locations but was only significant in Etekwuru with mean value of 0.28mg/kg, followed by Ada plam with mean value of .0.48mg/kg. Benzo(k)fluoranthene was also detected in all locations with Etekwuru recording the highest mean value of 0.19mg/kg, followed by Ekwugba with a mean value of 0.042mg/kg. Control, Obiakpu and Agba recorded the most insignificant mean value. Benzo(a)pyrene was only significantly detected in Etekwuru with a mean value of 0.021mg/kg and Ada palm 0.018mg/kg. The other locations recorded insignificant values.Indeno(1,2,3 – c,d)pyrene was discovered in all sample locations in significant amounts with Asaa recording the highest mean value of 0.44mg/kg, followed by Agba with mean value of 0.33mg/kg. Control sample had the least mean value of 0.001mg/g followed by Obiakpu with 0.002mg/kg. Benzo(g,h,i)perylene, another six ringed PAHs, was discovered in all sample locations with Etekwuru having the highest mean value of 0.13mg/kg, followed by Ada palm with mean value of 0.013mg/kg. Ngbara recorded the least mean value of 0.004mg/kg followed by Obiakpu with 0.0012mg/kg.

Figure 2, depicted that cassava sample from Etekwuru recorded the highest PAHs value of ($1.7x10^{-2}$mg/kg), followed by cassava sample from Asaa with PAHs value of ($9.0x10^{-3}$mg/kg) while cassava from Ekwugba had the least PAHs value of ($1.0x10^{-3}$mg/kg).

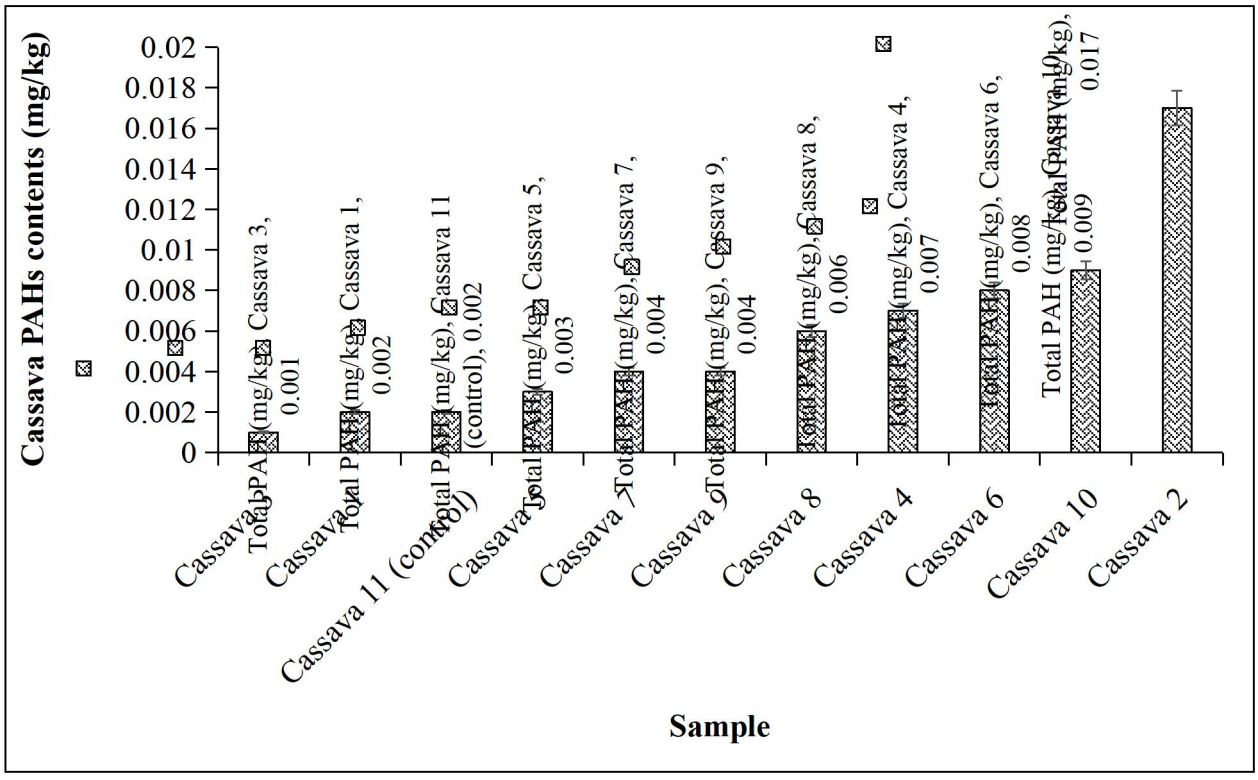

Figure 2: PAHs level in cassava tuber samples from different locations.

Legend: Cassava 1: Ekwugba Village; cassava 2 – Ada palm; cassava 3 - Nbgara; cassava 4 - Obokofia; cassava 5 - Agba; cassava 6 - Obiakpu; cassava 7 - Umuorji; cassva 8 - Oforola; cassava 9 - Asaa; cassava 10 –Etekwuru; Cassava 11- Control.

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Table1: Level of PAHs (mg/kg) in soil samples from different locations in ohaji-egbema.

PAH (mg/kg)	soil 1	soil 2	soil 3	soil 4	soil 5	soil 6	soil 7	soil 8	soil 9	soil 10	Control soil
Napthalene	0.12 ±0.02^{a}	0.47±0.02^{b}	1.90±0.02^{a}	N D	N D	N D	8.40±0.01^{a}	N D	59.0±0.02^{a}	16.0±0.02^{a}	0.75±0.05^{a}
2-methyl naphthalene	0.48±0.02^{a}	2.9±0.02^{b}	12.0±0.04^{c}		16.0±0.02^{e}	180.0±0.02^{f}	210.0±0.02^{g}	17.0±0.01^{ef}	2.60±0.03^{c}	11.0±0.01^{c}	0.58±0.04^{c}
Acenaphthylene	2.9±0.01^{a}	0.068±0.01^{b}	70.0±0.02^{b}	91.0±0.02^{c}	N D	N D	N D	N D	9.50±0.05^{d}	250.0±0.05^{e}	8.3±0.01^{f}
Fluorene	0.061±0.01^{ac}	0.019±0.01^{b}	0.78±0.04^{c}	0.012±0.02^{c}	11.0±0.02^{d}	2.80±0.02^{c}	N D	0.83±0.01^{ac}	5.10±0.03^{c}	4.6±0.02^{ac}	1.3±0.03^{ab}
Acenaphthene	0.027±0.02^{ab}	0.019±0.02^{a}	0.79±0.03^{ac}	0.010±0.02^{bc}	N D	1.10±0.03^{ac}	0.22±0.01^{bc}	0.96±0.02^{ac}	0.30±0.03^{bc}	3.0±0.01^{ac}	0.52±0.02^{ac}
Phenanthrene	0.016±0.03^{a}	0.0042±0.02^{a}	0.56±0.02^{a}	0.047±0.04^{a}	3.00±0.03^{a}	1.20±0.03^{a}	3.50±0.02^{a}	0.086±0.02^{a}	7.70±0.01^{a}	7.3±0.01^{a}	0.014±0.04^{a}
Anthracene	0.077±0.03^{a}	1.5±0.03^{b}	1.40±0.03^{a}	0.44±0.03^{a}	1.80±0.02^{a}	5.70±0.01^{a}	5.90±0.02^{a}	1.10±0.04^{a}	4.10±0.04^{a}	10.0±0.02^{a}	0.074±0.02^{a}
Fluoranthene	0.095±0.02^{a}	2.3±0.03^{b}	1.80±0.04^{a}	0.021±0.01^{a}	1.90±0.02^{a}	0.17±0.01^{a}	6.60±0.04^{a}	1.1±0.04^{a}	7.20±0.02^{a}	1.50±0.03^{a}	0.98±0.02^{a}
Pyrene	1.6±0.01^{a}	4.8±0.02^{b}	3.40±0.03^{c}	2.50±0.02^{df}	26.0±0.01^{e}	33.0±0.02^{dg}	13.0±0.03^{cf}	7.2±0.05^{h}	180.0±0.04^{cd}	19.0±0.03^{cd}	4.4±0.02^{g}
Benzo (a) anthracene	2.9±0.01^{a}	2.3±0.02^{b}	18.0±0.03^{c}	3.9±0.01^{d}	11.0±0.02^{e}	37.0±0.02^{f}	28.0±0.03^{g}	15.0±0.03^{h}	64.0±0.02^{i}	19.0±0.03^{c}	1.5±0.05^{j}
Chrysene	15.0±0.02^{a}	3.9±0.03^{b}	4.80±0.01^{c}	2.1±0.02^{cd}	0.89±0.01^{c}	3.30±0.01^{c}	26.0±0.04^{cd}	4.7±0.02^{d}	5.00±0.01^{c}	7.2±0.01^{c}	0.39±0.03^{c}
Benzo (b) fluoranthene	0.48±0.02^{a}	2.8±0.03^{b}	6.80±0.03^{c}	0.23±0.02^{c}	0.26±0.03^{c}	1.70±0.01^{c}	7.40±0.04^{c}	2.5±0.02^{ac}	36.0±0.01^{c}	8.9±0.01^{c}	0.59±0.04^{c}
Benzo (k) fluoranthene	0.72±0.03^{a}	19.0±0.02^{b}	42.0±0.02^{cd}	5.4±0.02^{c}	7.50±0.03^{a}	34.0±0.01^{def}	17.0±0.05^{e}	4.4±0.02^{cf}	390.0±0.02^{cf}	200.0±0.02^{a}	5.0±0.05^{cf}
Benzo (k) pyrene	1.8±0.02^{a}	2.1±0.03^{b}	7.40±0.01^{c}	0.70±0.03^{c}	1.40±0.02^{c}	8.70±0.02^{c}	4.30±0.03^{c}	2.8±0.01^{c}	77.0±0.02^{c}	7.0±0.01^{c}	1.8±0.03^{c}
Diben (a,h) anthracene	2.3±0.03^{a}	34.0±0.02^{b}	59.0±0.02^{c}	9.2±0.03^{de}	9.40±0.03^{de}	240.0±0.01^{a}	230.0±0.03^{a}	7.8±0.01^{e}	960.0±0.03^{d}	230.0±0.04^{a}	6.5±0.01^{ce}
Indeno (1,2,3-cd) pyrene	8.6±0.02^{a}	38.0±0.01^{b}	640.0±0.01^{c}	130.0±0.04^{d}	250.0±0.02^{e}	1000.0±0.02^{f}	2100.0±0.05^{g}	120.0±0.02^{h}	33000.0±0.05^{i}	4400.0±0.03^{j}	110.0±0.01^{k}
Benzo(g, h, i) perylene	1.3±0.02^{a}	13.0±0.01^{b}	220.0±0.03^{c}	260.0±0.03^{d}	40.0±0.03^{e}	2400.0±0.03^{f}	430.0±0.01^{g}	120.0±0.02^{h}	3000.0±0.05^{i}	360.0±0.03^{j}	140.0±0.02^{k}

Values are mean ± standard deviation of triplicate determinations. Values with different superscript letter(s) per row are statistically significant ($p<0.05$). ND: non-determinate.

Legend: Soil 1: Adapalm, Soil 2: Etekwuru, Soil 3: Ekwugba, Soil 4: Umuorji, Soil 5: Ngbara, Soil 6: Oforola, Soil 7: Obokofia, Soil 8: Obiakpu, Soil 9: Agba, Soil 10: Asaa.

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As shown below in table 2, Cassava tuber samples from Control, Asaa,Agba, and Obiakpu had no detection of Naphthalene which was the only two ringed PAHs. However, Cassava tuber samples from Ada palm, Etekwuru, Ekwugba, Umuorji, Ngbara, Oforola and Obokofia locations all had detection of Naphthalene with values ranging from 0 - 0.01mg/kg. This was insignificant and therefore non-contaminant according to ATSDR, 2021. There was significant difference among the three ringed PAHs. For 2 – methylnaphthalene, cassava tuber sample from Etekwuru recorded the highest mean value of 0.35mg/kg followed by Asaa sample with 0.12mg/kg, while Cassava samples from Obiakpu and Agba recorded the least mean value of 0.02mg/kg. Acenaphthylene had the highest mean value of 0.35mg/kg from Etekwuru and the least mean value of 0.04mg/kg from Oforola location. Fluorene was also significant, with cassava sample from Asaa, Etekwuru and Obokofia recording mean values of 0.26mg/kg, while Control, Ada palm and Oforola recording the least mean value of 0.06mg/kg. Cassava tuber samples from Ekwubga and Ada palm recorded the least mean value of 0.05mg/kg for acenaphthene while Etekwuru recorded the highest mean value of 0.03mg/kg. Oforola Cassava sample recorded the least mean value of 0.04mg/kg for Phenanthrene with Etekwuru recording the highest mean value of 0.3mg/kg. Fluoranthene was statistically significant ($P<0.05$) in the cassava tuber samples from various locations except for control and Ada palm. Etekwuru sample had the highest mean value of 0.14mg/kg while Ekwugba recorded the least mean value of 0.08mg/kg. Pyrene was also statistically significant, with cassava tuber sample from Asaa recording the highest mean value of 0.65mg/kg and the least mean value of 0.025mg/kg from Ekwugba. Cassava sample from Oforola recorded the highest mean value of 0.9mg/kg for Benzo(a)anthracene while Obiakpu had the least mean value of 0.01mg/kg. Chrysene was also another four ringed PAHs statistically significant in all cassava tuber samples. Umuorji had the highest mean value of 0.33mg/kg while the least mean value of 0.01mg/kg was from Ngbara cassava tuber sample.

From table 3, there was no detection of PAHs constituents in all samples of processed fufu with polythene wrappers purchased from various locations in Ohaji-Egbema.

Table 3: Polycyclic aromatic hydrocarbons (PAHs) contents of processed wrapped fufu samples from different locations in Ohaji-Egbema.

Fufu sample location	PAHs in Fufu (mg/kg)
Ada Palm	<0.001
Etekwuru Village	<0.001
Ekwugba	<0.001
Umuorji	<0.001
Ngbara	<0.001
Oforola	<0.001
Obokofia	<0.001
Obiakpu	<0.001
Agba	<0.001
Asaa	<0.001
Control	<0.001

Bima Journal of Science and Technology, Vol. 8(4A) Dec, 2024 ISSN: 2536-6041

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Table 2: Level of Polycyclic Aromatic Hydrocarbons (mg/kg) in cassava tubers for different location in Ohaji-Egbema

PAHs (mg/kg)	CASSAVA 1	CASSAVA 2	CASSAVA 3	CASSAVA 4	CASSAVA 5	CASSAVA 6	CASSAVA 7	CASSAVA 8	CASSAVA 9	CASSAVA 10	CONTROL
NAPHTHALENE	0.995±0.02^{a}	1.53±0.03^{b}	0.289±0.03^{c}	2.26±.0.20^{d}	0.293±0.02^{c}	0.912±0.04^{a}	0.129±0.022^{c}	ND	ND	ND	ND
2-METHYL NAPHTHALENE	7.37±0.01^{a}	3.5±0.03^{b}	2.07±0.02^{c}	4.88±0.01^{d}	2.94±0.01^{e}	7.61 ± 0.01^{a}	5.41±0.01^{f}	0.247±0.01^{g}	0.221±0.03^{g}	1.28±0.02^{h}	2.51±0.02^{i}
ACENAPHTHYLENE	2.61±0.01^{a}	15.7±0.01^{b}	3.77±0.01^{c}	69.7±0.02^{d}	8.32±0.01^{e}	4.41± 0.02^{f}	81.3±0.01^{g}	5.36±0.02^{h}	6.06±0.03^{i}	0.164±0.01^{j}	2.46±0.02^{k}
FLUORENE	0.695±0.02^{a}	2.66±0.02^{b}	0.156±0.01^{c}	2.36±0.01^{d}	3.09±0.03^{e}	2.86± 0.01^{e}	6.1±0.02^{f}	3.06±0.03^{e}	2.98±0.01^{e}	1.28±0.02^{g}	1.57±0.02^{h}
ACENAPHTHENE	0.528±0.02^{a}	0.393± 0.02^{b}	0.435±0.02^{a}	0.966±0.03 ^{cd}	0.862±0.04^{c}	1.33± 0.01^{eg}	3.29±0.03^{f}	1.13±0.03^{de}	1.55±0.01^{g}	0.277±0.02^{h}	1.09±0.02^{ce}
PHENANTHRENE	7.6±0.015^{a}	3.83±0.02^{b}	2.27±0.01^{c}	0.564±0.02^{d}	0.0588±0.05^{e}	0.0439±0.03^{e}	0.494±0.02^{d}	0.281±0.03^{de}	0.331±0.02^{de}	0.90±0.03^{f}	1.63±0.01^{g}
ANTHRACENE	0.577±0.03^{a}	0.545± 0.04^{b}	0.157±0.02^{c}	6.16±0.01^{d}	2.90±0.03^{e}	21.0± 0.03^{f}	1.50±0.01^{g}	0.0473±0.04^{c}	3.21±0.02^{e}	0.0127±0.01^{c}	3.04±0.02^{e}
FLUORANTHENE	2.16±0.01^{a}	0.140± 0.01^{b}	0.0883±0.04^{c}	0.717±0.03^{d}	0.205±0.03^{ce}	0.599±0.02^{d}	0.852±0.01^{d}	0.476±0.02^{de}	15.0±0.01^{f}	0.0128±0.03^{c}	1.92±0.02^{a}
PYRENE	1.53±0.02^{a}	8.06±0.01^{b}	4.51±0.04^{c}	29.6±0.04^{d}	2.50±0.02^{e}	4.89± 0.02^{f}	7.14±0.03^{g}	2.74±0.01^{e}	8.17±0.04^{h}	6.48±0.02^{i}	19.6±0.03^{j}
BENZO(A) ANTHRANCENE	1.80±0.02^{a}	6.01±0.02^{b}	2.81±0.03^{c}	24.6±0.02^{d}	46.0±0.01^{e}	99.0± 0.04^{f}	2.90±0.05^{c}	1.26±0.01^{g}	1.89±0.04^{a}	4.82±0.03^{h}	8.97±0.04^{i}
CHRYSENE	26.1±0.01^{a}	1.32±0.01^{b}	9.60±0.03^{c}	32.6±0.03^{d}	1.00±0.04^{e}	2.54± 0.02^{f}	7.71±0.02^{g}	1.68±0.02^{h}	3.75±0.05^{i}	1.97±0.02^{j}	2.58±0.03^{f}
BENZO(B)FLUORANTHENE	2.44±0.01^{a}	1.49±0.01^{b}	1.1±0.02^{c}	3.71±0.03^{d}	0.617±0.02^{e}	0.999±0.03^{c}	0.306±0.02^{f}	0.103±0.04^{f}	0.124±0.01^{f}	0.80±0.02^{g}	2.54±0.03^{a}
BENZO(K)FLUORANTHENE	1.45±0.01^{a}	4.44±0.04^{b}	1.7±0.01^{ac}	37.1±0.02^{d}	8.34±0.03^{e}	1.54±0.01^{ac}	3.56±0.03^{f}	6.24±0.01^{g}	4.7±0.02^{h}	0.183±0.01^{c}	3.80±0.02^{f}
BENZO(A) PYRENE	0.556±0.03^{a}	0.602± 0.03^{b}	0.38± 0.03^{ac}	2.11±0.01^{d}	0.401±0.03^{ac}	3.36± 0.01^{e}	0.204±0.02^{c}	0.51±0.02^{ac}	0.407±0.01^{ac}	0.432±0.02^{f}	1.22±0.01^{g}
DIBENZ(A,H)ANTHRACENE	5.41±0.02^{a}	4.54±0.03^{b}	27.2±0.01^{c}	118.0±0.04^{d}	3.50±0.03^{e}	11.7± 0.02^{f}	7.82± 0.01^{g}	30.8±0.02^{h}	1.95±0.02^{i}	1.86±0.03^{j}	3.28±0.03^{e}
INDENO(1, 2, 3-CD) PYRENE	51.7±0.03^{a}	28.0±0.02^{b}	58.6±0.02^{c}	64.2±0.03^{d}	98.1±0.03^{e}	260.0±0.04^{f}	297.0±0.04^{g}	478.0±0.02^{h}	302.0±0.02^{i}	44.6±0.04^{j}	3.92±0.01^{k}
BENZO(G, H, I) PERYLENE	27.7±0.03^{a}	37.6±0.03^{b}	3.36±0.01^{c}	285.0±0.04^{d}	162.0±0.04^{e}	351.0±0.04^{f}	9.27±0.04^{g}	32.3±0.01^{h}	3.96±0.03^{i}	23.7±0.03^{j}	39.2±0.02^{k}
TOTAL PAHs CONCENTRATION	190.0	120.0	120.0	685.0	341.0	793.0	436.0	564.0	395.0	92.9	135

Values are mean ± standard deviation of triplicate determinations. Values with different superscript letter(s) per row are statistically significant ($p<0.05$). ND: non-determinate.

Legend: Cassava 1: Adapalm, Cassava 2: Etekwuru, Cassava 3: Ekwugba, Cassava 4: Umuorji, Cassava 5: Ngbara, Cassava 6: Oforola, Cassava 7: Obokofia, Cassava 8: Obiakpu, Cassava 9: Agba, Cassava 10: Asaa.

DOI: 10.56892/bima.v8i4.1146

DISCUSSION

In the current study, soil sample from Ekwugba community recorded the least value of PAHs at 0.011mg/kg followed by the control soil sample at 0.028mg/kg. These results are similar to those reported by Anegbe and Okieimen, (2016) for soil samples from the surrounding of a petrol station in Benin-city Nigeria. This however can be attributed to the function of heterotrophic organisms which significantly affects the decomposition of hydrocarbons, leading to the low levels of PAHs in the area (Osuji and Nwoye, 2017). Etekwuru soil sample recorded the highest value of PAHs at 1.28mg/kg. There was clearer view as to the specific area that the PAHs were generated as it can be seen that petrogenic activities were more localized at specific locations. For instance, in Etekwuru, there are petrogenic activities within the area such as pollution from oil spillage, effluents from petrochemical companies and unregulated fires. It is reported by Juhasz and Naidu (2020) that soil samples from an industrial site in Welsh had varying Total PAHs concentrations. Soil sample from Etekwuru had a significant amount of Benzo (a) pyrene (0.021mg/kg) which is a PAH of petroleum origin. Benzo (b) fluoranthene which is another marker of PAH source had a mean value of 0.28mg/kg. From a previous study conducted in Soderberg aluminium smelters in Canada, it was discovered that B (b) F degraded slower than most PAHs analyzed and was more stable than other particulate PAHs (Kalf and Van de Plassche, 2015). According to EPA (2023), B (b) F is found in combusted petroleum, plant, garbage and animal materials. It is also found in smoke and soot, and combines with dust particles in the air, carried into water and soil or deposited in plants (Irwin, 2017). Benzo(g,h,i) perylene, a six ringed PAHs, was discovered in high concentration in Etekwuru soil sample with mean value of 0.13mg/kg. B (g,h,i) P is a PAH with origin mainly from combustion source, vehicle exhausts, domestic wood and coal fires, industrial effluents, waste incinerators, natural fires and volcanoes (Inengite, 2020). The presence of the underlisted PAHs in high concentrations shows that petrogenic activities could be the major source of PAHs within some of the study areas (Etekwuru, Ada palm, Ekwugba, Asaa and Agba communities) compared to (Ngbara, Obiakpu, Obokofia, Oforola, Umuorji).

The small range in the concentration of the measured PAHs can be linked to the fact that soil samples in all sampling locations had the same pollution source. Benzo(k)fluoranthene, Dibenz(a,h)anthracene, Indeno(1,2,3-c,d)pyrene and Benzo(g,h,i)perylene were significantly present in all soil samples. This was made possible due to their relatively low volatility, making them settle on soil surfaces through gravitational settling and deposition (Al-Hadad, 2015). The significant special nonuniformity of the concentration of PAHs is an inference that across each sampling location, the concentration of the individual PAHs is significant enough to make a difference (Nam *et al*., 2020). Soil sample from Etekwuru recorded the highest concentration of Benzo (g,h,i)perylene, and this is due to diffusion and subsequent deposition (Srogi, 2020). The least concentration of Benzo(g,h,i)perylene was recorded from Ngbara soil sample. This however, can be attributed to leaching, volatilization, dispersion by wind and bioaccumulation by plants (Li, Li and Chen, 2018). The fate of PAHs in the soil is largely dependent on the organic matter, textural class and moisture content of the soil. In general, soil sample from Etekwuru recorded the highest concentration of PAHs. This can be attributed to high organic carbon content, high sand composition and high moisture content (Abbas and Adeniyi, 2021).

In a recent study by Alexandrine *et al.,* 2022, the high concentration of Benzo (a) pyrene in cassava tuber samples from selected farmlands except Ekwugba, mainly could be attributed to emissions from oil exploration

DOI: 10.56892/bima.v8i4.1146

activities and industrial wastes. B (a) P which is a usual marker of carcinogenic levels of PAHs in the environment poses great risk to human exposure (IARC, 2019). On the other hand, the presence of three-four ring PAHs (which are of both pyrogenic and phytogenic sources) are mostly found in combusted vegetation, coal, leaves, grasses and wood (Pulster *et al*., 2019). PAHs with relative low concentrations in this study could be ascribed to the high vapour pressure and higher volatility which causes them to be resuspended into the atmosphere (Okoli *et al.,*2019).These result was similar to a report by (Okereke *et al.,*2016) on vegetable and tuber samples from Eleme and Alakahia Communities in Rivers State.

This has shown that the sources of PAHs in the cassava tuber samples within the entire study area were from mixed sources (petrogenic, pyrogenic and phytogenic sources). Presence of these PAHs in cassava tubers insinuates that cultivating and harvesting cassava tuber remains a major interior source of PAHs amongst residents of Ohaji-Egbema. Intake of cassava tuber with high level PAHs may lead to adverse health effects such as mental retardation, asthma, DNA mutation, cancer, reproductive defects and heart disease among others (IARC, 2019).

Analysis of PAHs Content in Processed Wrapped Fufu Samples Purchased from Various Locations in Ohaji-Egbema.

The analysis from table 3 showed no detection of the various PAHs constituents in all samples of fufu purchased from the various locations in Ohaji-Egbema. Studies by Yousefi *et al*., 2019 revealed that microorganisms, mainly Bacteria, could have the capacity to bind to PAHs, thereby eliminating PAHs during the fermentation process. Bacteria such as *Lactobacillus plantarum, Streptococcus faecium* and *Leuconostoc mesenteroides* are mainly responsible for the rapid acidification that characterizes cassava fermentation and degradation of PAHs pollutants (Ma and Zhai, 2021). During the aerobic degradation of PAH by these bacteria, there was cleavage of the aromatic ring by oxygen which works as the final electron acceptor and co-substrate for hydroxylation. Also, bacteria uses oxygenase facilitated metabolism (comprising of monooxygenase and dioxygenase enzymes) to perform anaerobic PAH degradation. Hydroxylation of the aromatic ring through dioxygenase enzymes and formation of the cis-dihydrodiol, which was completely oxidized to diol intermediates with the help of dehydrogenase enzymes, was the first step in the aerobic degradation of PAHs during fermentation. Finally, the diol intermediates are broken through the action of intra diol or extra diol ring-breaking dioxygenases using ortho-cleavage or meta-cleavage pathway, leading to the final formation of tricarboxylic acid (TCA) (Mallick *et al.,* 2021).

CONCLUSION

In the selected study areas in OhajiEgbema, PAHs were found present in the soil used for cultivation of cassava at varying concentration. It is evident from this study that most farmlands in Ohaji-Ebema are contaminated with PAHs when compared to the control site. Presence of varying levels of PAHs in the soil and cultivated cassava crop within the area portends great hazards to the soil and the crop consumers. However, there is no significant difference in the level of PAHs in fufu from Ohaji/Egbema and control location.

Recommendation

Assessing cassava for health risk under the current study, proper fermentation of cassava tubers should be practiced by Fufu producers as it helps to reduce PAHs level and detoxify toxic compounds. Government should enforce a law to curb the cultivation of edible crops around polluted areas and also create awareness to educate the public on the

DOI: 10.56892/bima.v8i4.1146

health effect of PAHs ingestion and its bioaccumulation.

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