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# Investigation of polycyclic aromatic hydrocarbons deposition on selected agricultural products dried in local kitchens and roadsides, Wukari, Nigeria

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## ABSTRACT

*Environmental pollution due to anthropogenic activities and mode of preservation has posed great menace on agricultural products. As a case study, this work was aimed to investigate the levels of heavy metals PAHs (Pyrene, Benzo(a)pyrene, Benzo(b)fluoranthene, Fluoranthene, Indo(1,2,3-cd)pyrene and Dibenzo(a,h)anthracene) depositions on selected agricultural products that are either stored at the rooftop of local Nigerian kitchens, sun-dried by roadsides or sun-dried away from local kitchens and roadsides. The selected agricultural samples (Zea mays, Manihot esculenta, Capsicum annuum, Solanum lycopersicum, Abelmoschus esculentus and Hibiscus sabdariffa) were sourced from Byepyi (Wukari – Jalingo highway), Gindin waya (Wukari – Ibi road) and Kente (Wukari – Kente road). PAHs were determined using gas chromatography-spectrometry (GC-MS). Generally, PAHs depositions on the selected agricultural samples showed higher concentrations in samples stored at rooftop of local kitchens, compared to samples sun-dried by the roadsides and samples sun-dried under control conditions in the three locations. In Byepyi, PAHs such as; Pyrene, Benzo(a)pyrene, Fluoranthene, Indo(1,2,3-cd)pyrene levels were significantly higher ($P \leq 0.05$) in samples stored at rooftops of local kitchens. Slight change in the result trends was observed for Benzo(b)fluoranthene, Dibenzo(a,h)anthracene, which showed higher concentrations for samples sun-dried by roadsides. In Gindin waya, PAHs analytes levels were significantly higher ($P \leq 0.05$) in samples stored at rooftops of local kitchens. In Kente, PAHs such as Pyrene, Benzo(a)pyrene, Benzo(b)fluoranthene and Indo(1,2,3-cd)pyrene, were significantly higher ($P \leq 0.05$) in samples stored at rooftops of local kitchens. Slight change in the trends was observed for Fluoranthene, Dibenzo(a,h)anthracene, which showed higher concentrations for samples sun-dried. The research showed appreciable levels of metallic and PAHs contamination in selected agricultural products, although they were found to be below FAO/WHO permissible limits. Bioaccumulation of these food contaminants in humans could result to serious health problems.*

**Keywords:** GC-MS; Pyrene, Benzo(a)pyrene; Benzo(b)fluoranthene; Fluoranthene; Indo(1,2,3-cd)pyrene; Dibenzo(a,h)anthracene; Kitchens; Roadsides.

## INTRODUCTION

Roadside sun-drying and kitchen rooftop drying of food commodities are indigenous food preservation methods that are popularly used among farmers in Nigeria, most especially among Wukari people. This practice exposes the food to environmental pollutants such as Polyaromatic hydrocarbons (PAHs) from firewood smoke and exhaust fumes of vehicles (Bolade, 2006; Kolawale and Odoh, 2011). Sun-drying is a popular preservation method in Nigeria (Ikwebe *et al*., 2017), and food commodities that are sun-dried include cereal grains, beef, plantain chips, beans, root and tuber crops, pepper, vegetables, and to name a few.

However, through this drying techniques (Roadside sun-drying and kitchen drying), the foodstuff is subject to air pollution through the trace metals and polyaromatic hydrocarbons (PAHs) released from the exhaust pipes of vehicles driving past and from fire wood smoke. Polyaromatic hydrocarbons (PAHs) are products of several thermal processes, such as smoking of agricultural products through burning of organic materials. Industrial plants and automobiles, as well as pollution of water, air, and soil are major contributors of PAHs to foods (Filazi *et al*., 2003). PAHs can move from object to another because of their relatively high chemical stability, therefore, justifying their presence in agricultural products not subjected to smoking.

The research study was targeted at investigating the levels of Polyaromatic hydrocarbons deposition on selected agricultural products in relation to preservation or storage practices amongst farmers/residents of Wukari LGA, Taraba state, Nigeria.

## MATERIAL AND METHODS

### Sample collection

Samples of agricultural products; *Zea mays* (Maize), *Manihot esculenta* (Cassava flakes), *Capsicum annuum* (pepper), *Solanum lycopersicum* (Tomato), *Abelmoschus esculentus* (okra) and *Hibiscus sabdariffa* (Jute plant) were collected from selected kitchen top and roadside sun-drying spots in Wukari. Agricultural products samples that were dried at home in an open field were collected and served as the control. The samples were randomly collected from three different locations; Byepyi village (Along Wukari-Jalingo highway), Gindin waya village (Along Wukari-Ibi highway) and Kente village, in order to ensure representative sampling. The samples were separately kept in black polyethylene bags during transportation to the laboratory for analysis as described by Bolade, (2016).

### Sampling area

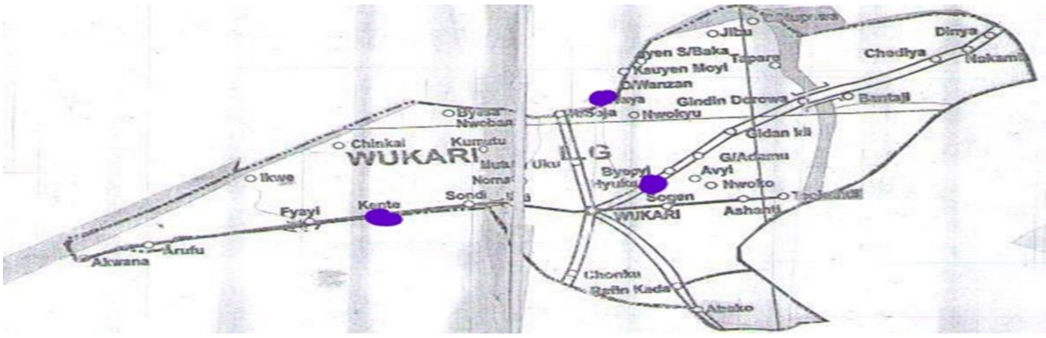


Figure 1: Map showing sampling points designated with blue box (Andrew *et al*., 2017)

### Determination of PAHs in the Samples

Two grammes (2g) of each of the homogenized food samples were thoroughly mixed with anhydrous $Na_2SO_4$ salt to absorb moisture and then extracted with dichloromethane ($CH_2Cl_2$) of analytical grade. The dichloromethane extract was cleaned up by passing it through a column packed with anhydrous $Na_2SO_4$ salt. Rotary evaporator was used to concentrate the resulting extract to give an oily residue; which was again dissolved in 1ml $CH_2Cl_2$ then 1µL was injected into the GC-MS for analysis. The identification of PAHs was based on comparison of the retention times of the peaks with those obtained from standard mixture of PAHs (standards supplied by instrument manufacturer). Quantification was based on external calibrations curves prepared from the standard solution of each of the PAHs (Amos-Tautua *et al*., 2013).

**Statistical analysis**

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS) version 23. The results were expressed as mean ± standard deviation in all parameters and the statistical difference was determined by Analysis of variance (ANOVA) at 95% confidence interval and Duncan multiple comparison test at $p < 0.05$.

## RESULT AND DISCUSSION

**Result of heavy metals and polyaromatic hydrocarbons depositions on agricultural samples**

**Table 1.Result of heavy metals depositions on roadside sundried agricultural samples sourced from Byepyi, Wukari LGA**

Result of heavy metals depositions on roadside sundried agricultural samples sourced from Byepyi (Table 1) revealed the presence of heavy metals depositions in this order: Copper> Iron > Lead > Arsenic > Mercury > Cadmium. There was statistically significant difference ($P \leq 0.05$) across agricultural samples for Lead, Arsenic, Iron and Copper, while there was no statistically significant difference ($p \geq 0.05$) across agricultural samples for Mercury and Cadmium.

Result of polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Byepyi, Wukari LGA

Result of PAHs depositions on roadside sundried agricultural samples sourced from Byepyi (Table 1) revealed the presence of PAHs depositions in this order: Indo(1,2,3cd)pyrene > Dibenzo(a,h)anthracene > Fluoranthene > Pyrene > Benzo(b)fluoranthene > Benzo(a)pyrene. There was statistically significant difference ($p \leq 0.05$) across agricultural samples for Indo(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, Fluoranthene and Pyrene, while there was no statistically significant difference ($p \geq 0.05$) across agricultural samples for Benzo(b)fluoranthene and Benzo(a)pyrene.

**Table 1: Polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Byepyi**

| Sample | Parameter (μg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**R** | 0.0631 ± 0.0045$^{c}$ | 0.0073 ± 0.0000$^{a}$ | 0.0046 ± 0.0002$^{a}$ | 0.0296 ± 0.0006$^{b}$ | 0.1232 ± 0.0002$^{d}$ | 0.1153 ± 0.0105$^{d}$ |
| Cassava**R** | 0.0972 ± 0.0002$^{c}$ | 0.0095 ± 0.0002$^{a}$ | 0.0092 ± 0.0001$^{a}$ | 0.0492 ± 0.0008$^{b}$ | 0.1439 ± 0.0003$^{e}$ | 0.1180 ± 0.0034$^{d}$ |
| Okra**R** | 0.0388 ± 0.0009$^{b}$ | 0.0074 ± 0.0016$^{a}$ | 0.0084 ± 0.0006$^{a}$ | 0.0486 ± 0.0008$^{c}$ | 0.1079 ± 0.0008$^{e}$ | 0.0606 ± 0.0042$^{d}$ |
| Tomato**R** | 0.0298 ± 0.0002$^{b}$ | 0.0073 ± 0.0003$^{a}$ | 0.0058 ± 0.0006$^{a}$ | 0.0456 ± 0.0001$^{d}$ | 0.1097 ± 0.0045$^{e}$ | 0.0374 ± 0.0027$^{c}$ |
| Pepper**R** | 0.0096 ± 0.0001$^{b}$ | 0.0047 ± 0.0003$^{a}$ | 0.0036 ± 0.0004$^{a}$ | 0.0385 ± 0.0005$^{c}$ | 0.1027 ± 0.0021$^{e}$ | 0.0858 ± 0.0001$^{d}$ |
| Jute**R** | 0.0399 ± 0.0015$^{b}$ | 0.0042 ± 0.0006$^{a}$ | 0.0058 ± 0.0033$^{a}$ | 0.0501 ± 0.0017$^{c}$ | 0.1062 ± 0.0027$^{e}$ | 0.0616 ± 0.0027$^{d}$ |
| **Average** | **0.0399 ± 0.0012** | **0.0067 ± 0.0005** | **0.0374 ± 0.0009** | **0.0436 ± 0.0008** | **0.1156 ± 0.0018** | **0.0798 ± 0.0039** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). R is sample sundried by the roadside.

**Table 2. Result of polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Byepyi, Wukari L**Result of polyaromatic hydrocarbons (PAHs) depositions on agricultural samples stored at local kitchen roof top sourced from Byepyi (Table 2) revealed the presence of PAHs depositions in this order: Indo(1,2,3-cd) pyrene > Dibenzo(a,h) anthracene > Pyrene > Fluoranthene > Benzo(a)pyrene > Benzo(b)fluoranthene. There was statistically significant difference (p≤0.05) across agricultural samples for Indo(1,2,3-cd) pyrene, Dibenzo(a,h)anthracene, Fluoranthene, Benzo(a)pyrene and Pyrene, while there was no statistically significant difference (p≥0.05) across agricultural samples for Benzo(b)fluoranthene.

**Table 2:** Polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Byepyi

| Sample | Parameter (μg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**K** | 0.0665 ± 0.0003$^{d}$ | 0.0117 ± 0.0017$^{b}$ | 0.0067 ± 0.0001$^{a}$ | 0.0471 ± 0.0011$^{c}$ | 0.1475 ± 0.0008$^{f}$ | 0.1127 ± 0.0023$^{e}$ |
| Cassava**K** | 0.1072 ± 0.0053$^{d}$ | 0.0097 ± 0.0038$^{a}$ | 0.0105 ± 0.0004$^{a}$ | 0.0721 ± 0.0004$^{b}$ | 0.1593 ± 0.0002$^{e}$ | 0.0945 ± 0.0000$^{c}$ |
| Okra**K** | 0.0791 ± 0.0030$^{d}$ | 0.0076 ± 0.0020$^{a}$ | 0.0097 ± 0.0004$^{a}$ | 0.0522 ± 0.0016$^{b}$ | 0.1100 ± 0.0006$^{e}$ | 0.0743 ± 0.0001$^{c}$ |
| Tomato**K** | 0.0634 ± 0.0001$^{c}$ | 0.0071 ± 0.0002$^{a}$ | 0.0075 ± 0.0005$^{a}$ | 0.0618 ± 0.0010$^{c}$ | 0.1071 ± 0.0006$^{d}$ | 0.0389 ± 0.0009$^{b}$ |
| Pepper**K** | 0.0477 ± 0.0023$^{b}$ | 0.0093 ± 0.0003$^{a}$ | 0.0056 ± 0.0008$^{a}$ | 0.0419 ± 0.0004$^{b}$ | 0.1267 ± 0.0078$^{d}$ | 0.0887 ± 0.0010$^{c}$ |
| Jute**K** | 0.0406 ± 0.0013$^{b}$ | 0.0064 ± 0.0011$^{a}$ | 0.0090 ± 0.0001$^{a}$ | 0.0818 ± 0.0006$^{d}$ | 0.1078 ± 0.0052$^{e}$ | 0.0662 ± 0.0018$^{c}$ |
| **Average** | **0.0674 ± 0.0019** | **0.0465 ± 0.0015** | **0.0082 ± 0.0004** | **0.0595 ± 0.0009** | **0.1264 ± 0.0025** | **0.0792 ± 0.0009** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). K is sample stored at the local kitchen rooftop.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in μg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd)pyrene: 0.15, Dibenzo(a,h)anthracene: 0.09.

**Table 3. Result of polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Byepyi, Wukari LGA**

Result of PAHs of agricultural samples dried away from roadside and kitchen roof top sourced from Byepyi (Table 3) revealed the presence of PAHs depositions in this order: Indo(1,2,3-cd) pyrene > Pyrene> Dibenzo(a,h)anthracene > Fluoranthene > Pyrene > Benzo(b)fluoranthene > Benzo(a)pyrene. There was statistically significant difference ($p \leq 0.05$) across agricultural samples for Indo(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, Fluoranthene and Pyrene, while there was no statistically significant difference ($p \geq 0.05$) across agricultural samples for Benzo(a)pyrene.

**Table 3:** Polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Byepyi

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**C** | 0.0235 ± 0.0003[d] | 0.0041 ± 0.0004[a] | 0.0031 ± 0.0002[a] | 0.0077 ± 0.0002[b] | 0.0785 ± 0.0001[e] | 0.0091 ± 0.0010[c] |
| Cassava**C** | 0.0558 ± 0.0001[e] | 0.0052 ± 0.0001[a] | 0.0047 ± 0.0006[a] | 0.0127 ± 0.0001[c] | 0.0522 ± 0.0001[d] | 0.0108 ± 0.0006[b] |
| Okra**C** | 0.0254 ± 0.0009[d] | 0.0021 ± 0.0001[a] | 0.0041 ± 0.0004[b] | 0.0050 ± 0.0001[b] | 0.0849 ± 0.0004[e] | 0.0099 ± 0.0011[c] |
| Tomato**C** | 0.0097 ± 0.0003[d] | 0.0035 ± 0.0004[a] | 0.0030 ± 0.0003[a] | 0.0085 ± 0.0002[c] | 0.0579 ± 0.0005[e] | 0.0056 ± 0.0001[b] |
| Pepper**C** | 0.0081 ± 0.0008[b] | 0.0016 ± 0.0004[a] | 0.0017 ± 0.0000[a] | 0.0085 ± 0.0003[b] | 0.0112 ± 0.0003[c] | 0.0145 ± 0.0003[d] |
| Jute**C** | 0.0104 ± 0.0041[b] | 0.0022 ± 0.0001[a] | 0.0024 ± 0.0001[a] | 0.0042 ± 0.0018[a] | 0.0066 ± 0.0011[ab] | 0.0071 ± 0.0032[ab] |
| **Average** | **0.0222 ± 0.0009** | **0.0031 ± 0.0003** | **0.0032 ± 0.0003** | **0.0078 ± 0.0005** | **0.0486 ± 0.0004** | **0.0095 ± 0.0011** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference ($P \geq 0.05$) while results with different letter of alphabet as superscript within the same column show statistically significant difference ($p \leq 0.05$). C is control sample.

**Table 4. Result of polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Gindin waya, Wukari LGA**

Result of polyaromatic hydrocarbons (PAHs) depositions on roadside sundried agricultural samples sourced from Gindin waya (Table 4) revealed the presence of PAHs depositions in this order: Fluoranthene > Indo(1,2,3-cd) pyrene> Dibenzo(a,h)anthracene > Pyrene > Benzo(a)pyrene > Benzo(b)fluoranthene. There was statistically significant difference ($p \leq 0.05$) across agricultural samples for all the polyaromatic hydrocarbons analysed; Indo(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene, Benzo(b)fluoranthene and Benzo(a)pyrene.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

**Table 4:** Polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Gindin waya

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**R** | 0.0668 ± 0.0027[f] | 0.0063 ± 0.0001[b] | 0.0030 ± 0.0001[a] | 0.0352 ± 0.0009[c] | 0.0556 ± 0.0000[d] | 0.0628 ± 0.0005[e] |
| Cassava**R** | 0.0694 ± 0.0001[e] | 0.0088 ± 0.0004[b] | 0.0074 ± 0.0006[a] | 0.0361 ± 0.0008[c] | 0.0636 ± 0.0004[d] | 0.0922 ± 0.0007[f] |
| Okra**R** | 0.0331 ± 0.0011[c] | 0.0042 ± 0.0009[a] | 0.0085 ± 0.0004[b] | 0.0507 ± 0.0005[d] | 0.0660 ± 0.0001[e] | 0.0327 ± 0.0001[c] |
| Tomato**R** | 0.0161 ± 0.0018[bc] | 0.0057 ± 0.0001[a] | 0.0047 ± 0.0003[a] | 0.0592 ± 0.0002[d] | 0.0176 ± 0.0008[c] | 0.0151 ± 0.0001[b] |
| Pepper**R** | 0.0130 ± 0.0008[d] | 0.0056 ± 0.0005[b] | 0.0028 ± 0.0006[a] | 0.0433 ± 0.0003[f] | 0.0270 ± 0.0002[e] | 0.0076 ± 0.0004[c] |
| Jute**R** | 0.0140 ± 0.0024[ab] | 0.0073 ± 0.0013[a] | 0.0036 ± 0.0019[a] | 0.0400 ± 0.0074[c] | 0.0302 ± 0.0052[bc] | 0.0288 ± 0.0171[bc] |
| **Average** | **0.0354±0.0015** | **0.0063±0.0006** | **0.0050±0.0007** | **0.0441±0.0017** | **0.0433±0.0011** | **0.0399±0.0032** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). R is sample sundried by the roadside.

**Table 5. Result of polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Gindin waya, Wukari LGA**

Result of Polyaromatic hydrocarbons (PAHs) depositions on agricultural samples stored at local kitchen roof top sourced from Gindin waya (Table 5) revealed the presence of Polyaromatic hydrocarbons (PAHs) depositions in this order: Pyrene > Indo(1,2,3-cd) pyrene > Dibenzo(a,h)anthracene > Fluoranthene > Benzo(a)pyrene > Benzo(b)fluoranthene. There was statistically significant difference (p≤0.05) across agricultural samples for Indo(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, Fluoranthene, Pyrene and Benzo(a)pyrene, while there was no statistically significant difference (p≥0.05) across agricultural samples for Benzo(b)fluoranthene.

**Table 5:** Polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Gindin waya

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**K** | 0.2015 ± 0.0006[e] | 0.0056 ± 0.0002[a] | 0.0063 ± 0.0001[a] | 0.0809 ± 0.0004[d] | 0.0703 ± 0.0002[b] | 0.0797 ± 0.0001[c] |
| Cassava**K** | 0.1200 ± 0.0003[e] | 0.0099 ± 0.0005[b] | 0.0073 ± 0.0002[a] | 0.0376 ± 0.0004[c] | 0.1202 ± 0.0015[e] | 0.0957 ± 0.0003[d] |
| Okra**K** | 0.1704 ± 0.0004[e] | 0.0109 ± 0.0001[a] | 0.0096 ± 0.0003[a] | 0.0659 ± 0.0012[b] | 0.0746 ± 0.0008[c] | 0.0863 ± 0.0001[d] |
| Tomato**K** | 0.1461 ± 0.0016[e] | 0.0095 ± 0.0000[a] | 0.0070 ± 0.0004[a] | 0.0834 ± 0.0001[d] | 0.0544 ± 0.0001[c] | 0.0368 ± 0.0042[b] |
| Pepper**K** | 0.0750 ± 0.0013[e] | 0.0124 ± 0.0003[b] | 0.0063 ± 0.0001[a] | 0.0884 ± 0.0004[f] | 0.0355 ± 0.0002[c] | 0.0510 ± 0.0033[d] |
| Jute**K** | 0.0891 ± 0.0060[e] | 0.0071 ± 0.0018[a] | 0.0040 ± 0.0010[a] | 0.0380 ± 0.0045[b] | 0.0683 ± 0.0016[d] | 0.0505 ± 0.0026[c] |
| **Average** | **0.1212 ± 0.0017** | **0.0092 ± 0.0003** | **0.0068 ± 0.0004** | **0.0657 ± 0.0012** | **0.0706 ± 0.0007** | **0.0667 ± 0.0018** |

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). K is sample stored at the local kitchen rooftop.

**Table 6. Result of polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Gindin waya, Wukari LGA**

Result of polyaromatic hydrocarbons depositions on agricultural samples dried away from roadside and local kitchen roof top sourced from Gindin waya (Table 6) revealed the presence of polyaromatic hydrocarbons (PAHs) depositions in this order: Pyrene > Indo(1,2,3cd)pyrene > Fluoranthene > Dibenzo(a,h)anthracene > Benzo(a)pyrene > Benzo(b)fluoranthene. There was statistically significant difference (p≤0.05) across agricultural samples for Indo(1,2,3-cd)pyrene, Fluoranthene, Dibenzo(a,h)anthracene, Pyrene and Benzo(a)pyrene, while there was no statistically significant difference (p≥0.05) across agricultural samples for Benzo(b)fluoranthene.

**Table 6:** Polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Gindin waya

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**C** | $0.0147 \pm 0.0002^{c}$ | $0.0046 \pm 0.0013^{b}$ | $0.0018 \pm 0.0002^{a}$ | $0.0182 \pm 0.0001^{d}$ | $0.0146 \pm 0.0000^{c}$ | $0.0044 \pm 0.0001^{b}$ |
| Cassava**C** | $0.0618 \pm 0.0005^{e}$ | $0.0038 \pm 0.0001^{a}$ | $0.0034 \pm 0.0001^{a}$ | $0.0249 \pm 0.0003^{d}$ | $0.0171 \pm 0.0001^{c}$ | $0.0079 \pm 0.0003^{b}$ |
| Okra**C** | $0.0670 \pm 0.0004^{e}$ | $0.0010 \pm 0.0001^{a}$ | $0.0047 \pm 0.0008^{b}$ | $0.0098 \pm 0.0004^{c}$ | $0.0118 \pm 0.0001^{d}$ | $0.0039 \pm 0.0001^{b}$ |
| Tomato**C** | $0.0057 \pm 0.0004^{c}$ | $0.0029 \pm 0.0004^{b}$ | $0.0016 \pm 0.0001^{a}$ | $0.0222 \pm 0.0001^{f}$ | $0.0091 \pm 0.0006^{e}$ | $0.0072 \pm 0.0004^{d}$ |
| Pepper**C** | $0.0077 \pm 0.0005^{d}$ | $0.0015 \pm 0.0001^{a}$ | $0.0009 \pm 0.0000^{a}$ | $0.0143 \pm 0.0002^{e}$ | $0.0046 \pm 0.0004^{c}$ | $0.0022 \pm 0.0001^{b}$ |
| Jute**C** | $0.0095 \pm 0.0005^{d}$ | $0.0032 \pm 0.0001^{ab}$ | $0.0015 \pm 0.0002^{a}$ | $0.0075 \pm 0.0001^{c}$ | $0.0047 \pm 0.0006^{b}$ | $0.0085 \pm 0.0016^{cd}$ |
| **Average** | **0.0277 ± 0.0004** | **0.0028 ± 0.0004** | **0.0023 ± 0.0002** | **0.0969 ± 0.0002** | **0.0103 ± 0.0003** | **0.0057 ± 0.0004** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). C is control sample.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

**Table 7. Result of polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Kente, Wukari LGA**

Result of polyaromatic hydrocarbons (PAHs) depositions on roadside sundried agricultural samples sourced from Kente (Table 7) revealed the presence of polyaromatic hydrocarbons (PAHs) depositions in this order: Pyrene > Dibenzo(a,h)anthracene > Fluoranthene > Indo(1,2,3-cd)pyrene > Benzo(b)fluoranthene > Benzo(a)pyrene. There was statistically significant difference ($p \leq 0.05$) across agricultural samples for Indo(1,2,3-cd)pyrene, Dibenzo(a,h)anthracene, Fluoranthene, Benzo(b)fluoranthene and Pyrene, while there was no statistically significant difference ($p \geq 0.05$) across agricultural samples for Benzo(a)pyrene.

**Table 7:** Polyaromatic hydrocarbon depositions on roadside sundried agricultural samples sourced from Kente

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| Maize**R** | $0.0604 \pm 0.0002^{d}$ | $0.0021 \pm 0.0004^{a}$ | $0.0022 \pm 0.0004^{a}$ | $0.0148 \pm 0.0004^{b}$ | $0.0404 \pm 0.0001^{c}$ | $0.0609 \pm 0.0006^{d}$ |
| Cassava**R** | $0.0859 \pm 0.0032^{e}$ | $0.0035 \pm 0.0008^{a}$ | $0.0059 \pm 0.0003^{a}$ | $0.0278 \pm 0.0076^{c}$ | $0.0173 \pm 0.0004^{b}$ | $0.0570 \pm 0.0010^{d}$ |
| Okra**R** | $0.0483 \pm 0.0029^{d}$ | $0.0014 \pm 0.0004^{a}$ | $0.0029 \pm 0.0008^{ab}$ | $0.0050 \pm 0.0005^{c}$ | $0.0088 \pm 0.0011^{c}$ | $0.0062 \pm 0.0000^{bc}$ |
| Tomato**R** | $0.0550 \pm 0.0009^{c}$ | $0.0054 \pm 0.0005^{a}$ | $0.0054 \pm 0.0007^{a}$ | $0.0812 \pm 0.0006^{d}$ | $0.0121 \pm 0.0002^{b}$ | $0.0084 \pm 0.0034^{ab}$ |
| Pepper**R** | $0.0634 \pm 0.0005^{e}$ | $0.0023 \pm 0.0003^{a}$ | $0.0038 \pm 0.0006^{b}$ | $0.0055 \pm 0.0001^{c}$ | $0.0055 \pm 0.0005^{c}$ | $0.0086 \pm 0.0005^{d}$ |
| Jute**R** | $0.0467 \pm 0.0006^{e}$ | $0.0010 \pm 0.000^{a}$ | $0.0045 \pm 0.0003^{b}$ | $0.0101 \pm 0.0010^{d}$ | $0.0094 \pm 0.0001^{cd}$ | $0.0082 \pm 0.0004^{c}$ |
| **Average** | **0.0600 ± 0.0014** | **0.0026 ± 0.0004** | **0.0041 ± 0.0005** | **0.0241 ± 0.0017** | **0.0156 ± 0.0004** | **0.0249 ± 0.0010** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference ($P \geq 0.05$) while results with different letter of alphabet as superscript within the same column show statistically significant difference ($p \leq 0.05$). R is sample sundried by the roadside.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

**Table 8. Result of polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Kente, Wukari LGA**

Result of polyaromatic hydrocarbons (PAHs) depositions on agricultural samples stored at local kitchen roof top sourced from Kente (Table 8) revealed the presence of PAHs depositions in this order: Pyrene > Indo(1,2,3-cd)pyrene > Dibenzo(a,h)anthracene > Fluoranthene > Benzo(b)fluoranthene > Benzo(a)pyrene. There was statistically significant difference ($p \leq 0.05$) across all agricultural samples for Indo(1,2,3-cd)pyrene, Dibenzo(a,h) anthracene, Fluoranthene, Benzo(b)fluoranthene and Pyrene, while there was no statistically significant difference ($p \geq 0.05$) across all agricultural samples for Benzo(a)pyrene.

**Table 8:** Polyaromatic hydrocarbon depositions on agricultural samples stored at local kitchen rooftop, sourced from Kente

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| MaizeK | $0.0688 \pm 0.0001^{e}$ | $0.0042 \pm 0.0004^{a}$ | $0.0046 \pm 0.0001^{a}$ | $0.0161 \pm 0.0013^{b}$ | $0.0615 \pm 0.0005^{d}$ | $0.0181 \pm 0.0006^{c}$ |
| CassavaK | $0.0957 \pm 0.0004^{f}$ | $0.0052 \pm 0.0001^{a}$ | $0.0071 \pm 0.0009^{b}$ | $0.0298 \pm 0.0013^{c}$ | $0.0459 \pm 0.0004^{d}$ | $0.0571 \pm 0.0001^{e}$ |
| OkraK | $0.0603 \pm 0.0004^{d}$ | $0.0040 \pm 0.0011^{a}$ | $0.0041 \pm 0.0001^{a}$ | $0.0066 \pm 0.0010^{b}$ | $0.0091 \pm 0.0002^{c}$ | $0.0093 \pm 0.0004^{c}$ |
| TomatoK | $0.0588 \pm 0.0000^{e}$ | $0.0024 \pm 0.0001^{a}$ | $0.0045 \pm 0.0006^{b}$ | $0.0125 \pm 0.0006^{d}$ | $0.0126 \pm 0.0003^{d}$ | $0.0080 \pm 0.0007^{c}$ |
| PepperK | $0.0882 \pm 0.0001^{e}$ | $0.0038 \pm 0.0005^{a}$ | $0.0063 \pm 0.0003^{b}$ | $0.0076 \pm 0.0004^{c}$ | $0.0055 \pm 0.0006^{b}$ | $0.0094 \pm 0.0001^{d}$ |
| JuteK | $0.0657 \pm 0.0063^{d}$ | $0.0018 \pm 0.000^{a}$ | $0.0050 \pm 0.0003^{ab}$ | $0.0119 \pm 0.0008^{c}$ | $0.0110 \pm 0.0011^{bc}$ | $0.0098 \pm 0.0006^{bc}$ |
| **Average** | **0.0729 ± 0.0012** | **0.0036 ± 0.0004** | **0.0053 ± 0.0004** | **0.0141 ± 0.0009** | **0.0243 ± 0.0005** | **0.0186 ± 0.0004** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference ($P \geq 0.05$) while results with different letter of alphabet as superscript within the same column show statistically significant difference ($p \leq 0.05$). K is sample stored at the local kitchen rooftop.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

**Table 9. Result of polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Kente, Wukari LGA**

Result of Polyaromatic hydrocarbon (PAHs) depositions on agricultural samples dried away from roadside and local kitchen roof top sourced from Kente (Table 9) revealed the presence of PAHs depositions in this order: Pyrene > Dibenzo(a,h)anthracene > Indo(1,2,3-cd)pyrene > Fluoranthene > Benzo(b)fluoranthene > Benzo(a)pyrene. There was statistically significant difference (P≤0.05) across all agricultural samples for Indo(1,2,3-cd) pyrene, Dibenzo (a, h) anthracene, Fluoranthene, Benzo(b)fluoranthene and Pyrene, while there was no statistically significant difference (p≥0.05) across all agricultural samples for Benzo(a)pyrene.

**Table 9:** Polyaromatic hydrocarbon depositions on agricultural samples dried away from roadside and local kitchen rooftop, sourced from Kente

| Sample | Parameter (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h) anthracene |
| MaizeC | 0.0390 ± 0.0006[e] | 0.0012 ± 0.0000[a] | 0.0018 ± 0.0001[a] | 0.0046 ± 0.0003[b] | 0.0131 ± 0.0006[d] | 0.0110 ± 0.0004[c] |
| CassavaC | 0.0485 ± 0.0003[f] | 0.0019 ± 0.0003[a] | 0.0036 ± 0.0000[b] | 0.0054 ± 0.0001[c] | 0.0142 ± 0.0001[d] | 0.0320 ± 0.0011[e] |
| OkraC | 0.0324 ± 0.0002[e] | 0.0005 ± 0.0001[a] | 0.0014 ± 0.0002[b] | 0.0039 ± 0.0006[c] | 0.0076 ± 0.0002[d] | 0.0045 ± 0.0001[c] |
| TomatoC | 0.0459 ± 0.0001[d] | 0.0033 ± 0.0005[a] | 0.0037 ± 0.0004[a] | 0.0132 ± 0.0001[c] | 0.0052 ± 0.0004[b] | 0.0031 ± 0.0001[a] |
| PepperC | 0.0530 ± 0.0004[d] | 0.0014 ± 0.0002[a] | 0.0023 ± 0.0001[b] | 0.0020 ± 0.0004[ab] | 0.0016 ± 0.0004[ab] | 0.0038 ± 0.0001[c] |
| JuteC | 0.0346 ± 0.0075[b] | 0.0011 ± 0.0000[a] | 0.0023 ± 0.0006[a] | 0.0078 ± 0.0004[a] | 0.0031 ± 0.0010[a] | 0.0053 ± 0.0009[a] |
| **Average** | **0.0422 ± 0.0015** | **0.0016 ± 0.0002** | **0.0025 ± 0.0002** | **0.0062 ± 0.0003** | **0.0075 ± 0.0005** | **0.0100 ± 0.0005** |

Results are expressed as mean ± standard deviation of triplet determination. Results with same letter of the alphabet as superscript show no statistically significant difference (P≥0.05) while results with different letter of alphabet as superscript within the same column show statistically significant difference (p≤0.05). C is control sample.

*WHO standards for analyzed parameters (Polyaromatic hydrocarbons) in µg/kg: Pyrene: 0.10, Benzo(a)pyrene: 0.01, Benzo(b)fluoranthene: 0.01, Fluoranthene: 0.07, Indo(1,2,3-cd) pyrene: 0.15, Dibenzo (a, h) anthracene: 0.09.

**Table 10: Summary of polyaromatic hydrocarbons depositions on selected agricultural products from Byepyi, Gindin waya and Kente in Wukari LGA**

The table revealed an increase in PAHs for each sample locations in the order: Gindin Waya<Byepyi<Kente for samples sundried by the roadside and Byepyi<Kente<Gindin Waya for samples stored at local kitchen rooftop.

| | Parameters (µg/kg) | | | | | |
|---|---|---|---|---|---|---|
| Location | Pyrene | Benzo(a) pyrene | Benzo(b) fluoranthene | Fluoranthene | Indo(1,2,3-cd)pyrene | Dibenzo(a,h )anthracene |
| **Byepyi** | | | | | | |
| Sample**R** | 0.0399 ± 0.0012 | 0.0067 ± 0.0005 | 0.0374 ± 0.0009 | 0.0436 ± 0.0008 | 0.1156 ± 0.0018 | 0.0798 ± 0.0039 |
| Sample**K** | 0.0674 ± 0.0019 | 0.046 5± 0.0015 | 0.0082 ± 0.0004 | 0.0595 ± 0.0009 | 0.1264 ± 0.0025 | 0.0792 ± 0.0009 |
| Sample**C** | 0.0222 ± 0.0009 | 0.0031 ± 0.0003 | 0.0032 ± 0.0003 | 0.0078 ± 0.0005 | 0.0486 ± 0.0004 | 0.0095 ± 0.0011 |
| **Gindin waya** | | | | | | |
| Sample**R** | 0.0354 ± 0.0015 | 0.0063 ± 0.0006 | 0.0050 ± 0.0007 | 0.0441 ± 0.0017 | 0.0433 ± 0.0011 | 0.0399 ± 0.0032 |
| Sample**K** | 0.1212 ± 0.0017 | 0.0092 ± 0.0003 | 0.0068 ± 0.0004 | 0.0657 ± 0.0012 | 0.0706 ± 0.0007 | 0.0667 ± 0.0018 |
| Sample**C** | 0.0277 ± 0.0004 | 0.0028 ± 0.0004 | 0.0023 ± 0.0002 | 0.0969 ± 0.0002 | 0.0103 ± 0.0003 | 0.0057 ± 0.0004 |
| **Kente** | | | | | | |
| Sample**R** | 0.0600 ± 0.0014 | 0.0026 ± 0.0004 | 0.0041 ± 0.0005 | 0.0241 ± 0.0017 | 0.0156 ± 0.0004 | 0.0249 ± 0.0010 |
| Sample**K** | 0.0729 ± 0.0012 | 0.0036± 0.0004 | 0.0053 ± 0.0004 | 0.0141 ± 0.0009 | 0.0243 ± 0.0005 | 0.0186 ± 0.0004 |
| Sample**C** | 0.0422 ± 0.0015 | 0.0016 ± 0.0002 | 0.0025 ± 0.0002 | 0.0062 ± 0.0003 | 0.0075 ± 0.0005 | 0.0100 ± 0.0005 |

Generally, agricultural samples from Byepyi showed statistically significant higher concentrations of Benzo(a)pyrene, Benzo(b)fluoranthene, Indo(1,2,3-cd) pyrene and Dibenzo(a, h)anthracene when compared to agricultural samples from Gindin waya and Kente. Agricultural samples from Kente showed statistically higher concentrations of Pyrene and Fluoranthene than agricultural samples from Byepyi and Gindin waya.

Sample**R**: Samples sun-dried by the roadsides

Sample**K**: Samples stored at rooftop of local kitchens

Sample**C**: Samples sun-dried in controlled conditions.

**Discussion**

Polycyclic aromatic hydrocarbons (PAHs) are organic substances that, to a varying degree, resist photolytic, biological and chemical degradation. These substances are also known for their ability to biomagnifies and bioconcentrates under typical environmental conditions, thereby potentially achieving toxicologically relevant concentrations (Muhammad *et al*., 2007). PAHs are ubiquitous in the environment and are common byproducts of combustion processes. PAHs are a natural component of most fossil fuels. Although produced naturally by forest fires and volcanoes, most PAHs in ambient air are the result of man-made processes. Such processes include: burning fuels such as coal, wood, petroleum, petroleum products, or oil, burning refuse, used tires, polypropylene, or polystyrene, coke production, and motor vehicle exhaust (Bando *et al*., 2019). PAHs' higher solubility in lipids facilitates absorption, and their lipid affinity nature helps them to attach to the membrane of cell. The binding produces changes in cell structure and alters the cell normal functions (Sampaio *et al*., 2021). Benzo(a)pyrene is the PAH that is most easily soluble in lipids.

Table 1 showed the results of PAHs depositions in agricultural products sun-dried by the roadside sourced from Byepyi. Cassava and Pepper samples were observed to have the highest and lowest quantity of Pyrene depositions respectively. There was no statistically significant difference ($P \geq 0.05$) observed in the amount of Pyrene depositions in Okra, Tomato, Pepper and Jute samples, also same was observed for Maize and cassava samples. Amount of Pyrene depositions in Okra, Pepper, Jute and Tomato were found to be statistically significantly different ($P \leq 0.05$) to amount of Pyrene depositions in Maize and Cassava samples. A study by Olusola, (2020) revealed high depositions of Benzo(a)pyrene in smoke roadside agricultural products. Benzo(a)pyrene were observed to showed higher and lower depositions in Cassava and Jute samples respectively. No statistical significant difference ($P \geq 0.05$) was observed in the amount of Benzo(a)pyrene depositions in all selected agricultural samples analyzed. Statistically there was no significance difference ($P \geq 0.05$) observed in the quantity of Benzo(b)fluoranthene depositions in the analyzed agricultural samples. Cassava and Pepper samples were found to possess the highest and least amount of Benzo(b)fluoranthene depositions. The amount of fluoranthene was analyzed to show higher depositions in Jute sample and lower depositions in Maize sample. Statistically Maize and Cassava samples are related in the amount of fluoranthene depositions in them. Similarly, Okra, Pepper and Jute samples showed statistical similarities. Fluoranthene depositions in Tomato samples were observed to be statistically significant different ($P \leq 0.05$) when compared to other analyzed agricultural samples. Indo(1,2,3-cd)pyrene was analyzed to be deposited more in Cassava sample than other analyzed samples, with least deposition in Pepper sample. Statistically the amount of Indo(1,2,3-cd)pyrene depositions in Cassava, Okra, Tomato and Jute samples are related but are statistically significantly different ($P \leq 0.05$) with its deposition in Maize sample. Amount of Dibenzo(a,h)anthracene depositions in Maize, Okra, Cassava, Pepper and Jute were found to be statistically related and showed statistical significant difference ($P \leq 0.05$) with the amount of Dibenzo(a,h)anthracene deposition in Tomato sample. Although, the levels of PAHs found in the analyzed agricultural samples sun-dried by the roadside (table 1) sourced from Byepyi showed higher values than the controlled samples (table 13), but are below the FAO/WHO permissible limit.

Selected agricultural samples stored at local kitchen rooftops sourced from Byepyi showed varying degrees of PAHs depositions but not above safe limit set by FAO/WHO. Pyrene was seen to be highly deposited in Cassava sample and revealed least deposition in Jute sample. Statistical similarities were observed in Pyrene levels of depositions in Maize, Cassava and Okra samples, same was observed for Pepper and jute samples. The Pyrene deposition in Tomato sample statistically significant difference ($P \leq 0.05$) when compared to other selected agricultural samples analyzed. Maize sample was analyzed to show the sample with the highest deposit of Benzo(a)pyrene while Jute sample revealed the least deposit of Benzo(a)pyrene. It was observed that statistically the quantity of Benzo(a)pyrene in Maize sample significantly differ from other analyzed agricultural samples. Benzo(b)fluoranthene concentrations in the selected agricultural samples analyzed showed no statistically significant difference ($P \geq 0.05$). Cassava and Pepper samples showed the highest and least amount of Benzo(b)fluoranthene depositions. Fluoranthene was found to be more deposited in Jute sample than other selected agricultural samples analyzed. The least amount of fluoranthene deposition was seen in Pepper sample. Statistically the concentrations of Indo(1,2,3-cd)pyrene depositions in Cassava, Okra and Jute samples were found to be related, in the same vain indo(1,2,3-cd)pyrene depositions in Tomato and Pepper samples showed close similarities. Higher amount of Indo(1,2,3-cd)pyrene was observed in Cassava sample and the least in Tomato sample. Maize and Tomato samples were analyzed to possess the highest and lowest amount of Dibenzo(a,h)anthracene respectively. Cassava, Okra, Pepper and Jute samples expressed close relationship statistically in there amount of Dibenzo(a,h)anthracene depositions, while they are not statistically in agreement with either of Maize sample or Tomato sample. This research revealed noticeable variations in the quantity of PAHs in all analyzed selected agricultural samples stored at local kitchen rooftops. The amount of PAHs depositions were observed to be higher when compared with results of PAHs analyzed in all selected agricultural samples preserved or stored under controlled conditions (table 3). Despite the noticeable variations in the concentration of PAHs between the experimental samples and controlled samples, the values did not exceed the FAO/WHO safe limit.

In table 4, it was observed that the PAHs analyzed from the selected agricultural samples were found at an appreciable quantity. The table showed results of PAHs of selected agricultural samples sun-dried by the roadsides sourced from Gindin waya (Wukari – Ibi highway). Pyrene depositions analyzed in all selected agricultural samples sun-dried by the roadside showed Cassava and Pepper with the highest and lowest depositions respectively. Jute sample showed statistical similarity with Tomato sample in the amount of Pyrene deposition. Consequently, no statistically significant difference ($P \geq 0.05$) was observed in the concentration of pyrene in Tomato, Okra and Cassava samples. Maize sample showed statistically significant difference ($P \leq 0.05$) in the levels of pyrene depositions with Pepper and other analyzed selected agricultural samples. Benzo(a)pyrene was found to be deposited more in Cassava sample than other analyzed selected agricultural samples, Okra sample showed the least of Benzo(a)pyrene. There was statistical significant difference ($P \leq 0.05$) in the concentration of Benzo(a)pyrene in Maize, Cassava and Tomato samples with Okra, Pepper and Jute samples. Statistically a significant difference ($P \leq 0.05$) was observed in the amount of Benzo(b)fluoranthene in Okra sample when compared to other analyzed agricultural samples. In Tomato sample, fluoranthene levels were found to be highest and expressed the least in Cassava sample. The agricultural samples; Maize, Cassava and Jute were analyzed to be statistically related in the levels of fluoranthene. Similar relationship was observed in the amount of fluoranthene depositions in Okra and Tomato samples. Fluoranthene concentration in Pepper sample showed statistical significant difference ($P \leq 0.05$) with other analyzed selected agricultural samples. Tomato and Jute samples; are statistically related in the levels of Indo(1,2,3-cd)pyrene. The Indo(1,2,3-cd)pyrene levels of depositions showed statistical similarities in Maize and Cassava samples; Okra and Pepper samples, while Tomato sample showed statistically significant difference ($P \leq 0.05$) with all analyzed selected agricultural samples. Okra and Tomato samples were analyzed to possess the highest and least levels of Indo(1,2,3-cd)pyrene depositions. The highest and least levels of Dibenzo(a,h)anthracene depositions in analyzed agricultural samples were observed in Cassava and Pepper samples respectively. Statistical similarities in Dibenzo(a,h)anthracene were observed in Okra, Jute and Pepper samples; Tomato and jute samples, but showed statistically significant difference ($P \leq 0.05$) with Maize or Cassava samples. The amount of PAHs depositions were observed to be higher in selected agricultural samples sun-dried by roadside when compared with results of PAHs analyzed in all selected agricultural samples preserved or stored under controlled conditions (table 6). Despite the noticeable variations in the concentration of PAHs between the experimental samples and controlled samples, the values did not exceed the FAO/WHO safe limit.

A measurable amount of PAHs depositions were seen in all the selected agricultural products analyzed that were preserved or stored at local kitchen rooftops as expressed in table 5. Analysis revealed

Pyrene levels at higher quantity in Maize sample and lowest in Pepper sample. There was no statistically significant difference ($P \geq 0.05$) observed in the amount of Pyrene depositions in all the selected agricultural samples analyzed. Benzo(a)pyrene was found to be higher and lower in Pepper and Jute samples respectively. The levels of Benzo(a)pyrene in Maize, Okra, Tomato and Jute samples showed no statistically significant difference ($P \geq 0.05$) but statistically differ from the deposition levels in Cassava and Pepper samples. Benzo(b)fluoranthene levels of depositions in all selected agricultural samples analyzed showed similarities statistically. Okra and Jute samples were analyzed to possess the highest and least levels of Benzo(b)fluoranthene depositions respectively. In Pepper sample fluoranthene was analyzed to be deposited the most while least deposition of fluoranthene was observed in Cassava sample. Values obtained showed that fluoranthene levels in Maize and Pepper samples are statistically significantly different ($P \leq 0.05$) and consequently varied with fluoranthene levels in Maize and Tomato samples; statistically related and Okra and Jute samples; no statistical significant difference ($P \geq 0.05$). Amount of Indo(1,2,3-cd)pyrene was estimated to be higher in Cassava sample and lower in Pepper sample. Levels of Indo(1,2,3-cd)pyrene in Okra, Tomato and Pepper samples are statistically related and differ statistically with its depositions in Maize or Cassava or Jute samples. Statistical similarities in the levels of Dibenzo(a,h)anthracene depositions in Cassava, Okra and Pepper samples; Maize and Jute samples. Tomato samples showed statistically significant difference ($P \leq 0.05$) in levels of Dibenzo(a,h)anthracene depositions in all other selected agricultural samples analyzed. In our findings, the levels of PAHs depositions on the selected agricultural products sourced from Gindin waya were observed to be higher in crops sun-dried by the roadside (table 4) and those stored at local kitchen rooftops (table 5) than those preserved and stored under controlled conditions (table 6). The samples stored at local kitchen rooftops expressed the highest amount of the PAHs depositions. Despite the noticeable quantity of PAHs analyzed in the selected agricultural samples, none exceeded safe limit set by FAO/WHO.

Crops sun-dried by the roadside possess higher tendency to be environmentally polluted. Table 7 showed elevated levels of PAHs depositions in sun-dried selected agricultural samples sourced from Kente village (Wukari – Kente road). Statistical similarities were observed in Pyrene deposition levels in Maize and Okra samples; Cassava, Pepper and Jute samples. Tomato sample was found to be statistically significantly different ($P \leq 0.05$) in there Pyrene deposition levels with other selected agricultural samples analyzed. The highest amount of Benzo(a)pyrene was found in Tomato sample with least amount in Jute sample. No statistical significant difference ($P \geq 0.05$) was observed in Benzo(a)pyrene levels in all selected agricultural products analyzed. Benzo(b)fluoranthene were analyzed in higher quantity in Cassava sample and least in Maize sample. Amount of Benzo(b)fluoranthene depositions in Okra sample showed statistically significant difference ($P \leq 0.05$) with the quantity in Maize, Cassava and Tomato samples; Pepper and Jute with statistical similarities. Fluoranthene depositions were discovered to be more in Tomato sample and least in Pepper sample. Statistical similarities were observed in the amount of Fluoranthene depositions in Tomato and Jute samples; Cassava, Okra and Pepper samples but showed statistically significant difference with Fluoranthene depositions in Maize sample. Maize and Pepper samples showed the Highest and lowest amount of Indo(1,2,3-cd)pyrene depositions respectively. The quantity of Indo(1,2,3-cd)pyrene depositions showed statistical significant similarities among Maize, Okra, Pepper and Jute samples which are statistically significantly different ($P \leq 0.05$) with the amount of Indo(1,2,3-cd) pyrene depositions in Cassava and Tomato samples. Dibenzo(a,h)anthracene levels of depositions were observed to be in higher and lower quantities in Maize and Okra samples respectively. Statistical similarities in Dibenzo(a,h)anthracene was found among Maize, Cassava and Pepper samples; Okra and Tomato samples, both groups showed statistically significant difference ($P \leq 0.05$) with

Dibenzo(a,h)anthracene depositions in Jute sample. Statistical similarities were also observed in dibenzo(a,h)anthracene depositions in Okra and Jute samples.

Selected agricultural samples collected from local kitchen rooftops in Kente village showed varying amount of PAHs depositions in them (table 8). Pyrene levels of depositions in Cassava and Tomato samples were analyzed as the highest and lowest respectively. Maize, Tomato and Pepper samples showed statistically significant similarities ($P \geq 0.05$) in the amount of Pyrene deposition in them. Statistical significant similarities were also observed in the levels of Pyrene depositions in Okra and Jute samples. Cassava sample showed statistically significant difference in Pyrene depositions when compared to all other selected agricultural samples analyzed. Cassava and Jute samples were analyzed to showed the highest and least amount of Benzo(a)pyrene depositions respectively. There was no statistically significant difference observed in the quantity of Benzo(a)pyrene depositions in all analyzed selected agricultural samples. A statistically significant similarities were observed in the amount of Benzo(b)fluoranthene among the Cassava, Tomato and Pepper samples but statistically significantly differ ($P \leq 0.05$) with quantity of Benzo(b)fluoranthene depositions in Maize and Okra samples. The levels of Benzo(b)fluoranthene depositions in Jute samples showed statistically significant similarities ($P \geq 0.05$) with all selected agricultural samples analyzed. Cassava and Okra samples were found to contain highest and least amount of Benzo(b)fluoranthene depositions.

The amount of Fluoranthene levels was analyzed to be higher in Cassava sample and lower in Okra sample with varying quantity of depositions in other selected agricultural samples. Statistically, Maize and Okra samples showed significant similarities, likewise Cassava, Pepper and Jute samples exhibit same characteristics in the amount of Fluoranthene depositions in them. Fluoranthene contamination in Tomato sample showed statistically significant difference ($P \leq 0.05$) with all the selected agricultural samples. Highest and least quantity of Indo(1,2,3-cd)pyrene was observed in Maize and Pepper samples. Amount of Indo(1,2,3-cd)pyrene deposition in Okra showed statistically significant difference ($P \leq 0.05$) with its deposition in Pepper sample; both showed statistical significant similarities ($P \geq 0.05$) with concentration of Indo(1,2,3-cd)pyrene in Jute sample. There was no statistical significance difference ($P \leq 0.05$) in the concentration of Indo(1,2,3-cd)pyrene depositions in Maize, Cassava and Tomato samples but are statistically significantly ($P \leq 0.05$) different with Indo(1,2,3-cd)pyrene depositions in Okra, Pepper and Jute samples. Dibenzo(a,h)anthracene was found in higher concentration in Cassava sample and least concentrated in Tomato sample. The levels of Dibenzo(a,h)anthracene depositions in Maize, Okra, Tomato and Jute samples were observed to be statistically significantly similar, but showed statistically significant difference with its depositions in Cassava sample or Pepper sample. The results of PAHs obtained in this study showed close correlation with several research conducted by Olusola, (2020) and Sampaio *et al*., (2021). Generally, slight increase in PAHs depositions in all selected agricultural samples sun-dried by the roadside (table 7) or stored at local kitchen rooftops (table 8) in comparison to the selected agricultural samples preserved or stored under controlled conditions (table 9) was observed. Despite these elevated levels of PAHs depositions in the analyzed selected agricultural samples, none is above FAO/WHO permissible limit.

Summary of PAHs depositions in selected agricultural samples sourced from Byepyi, Gindin waya and Kente villages (table 10) revealed higher amount of PAHs depositions in samples stored at local kitchen rooftops when compared to its counterpart; sun-dried by roadsides and under controlled conditions. In Byepyi village; Indo(1,2,3-cd)anthracene were analyzed as the highest pollutant, while Benzo(a)pyrene showed the least levels of pollution in the roadside sun-dried selected agricultural samples analyzed. Analysis of PAHs in selected agricultural samples stored at local kitchen rooftops showed Indo(1,2,3-cd)anthracene and Benzo(b)fluoranthene as the highest and least PAHs depositions respectively. Selected agricultural samples sun-dried or stored under controlled conditions showed Indo(1,2,3)pyrene and Benzo(a)pyrene as the highest and lowest PAHs depositions. PAHs levels of depositions in selected agricultural products either sun-dried by roadside or stored at local kitchen rooftops sourced from Byepyi village were observed to showed higher values than those sun-dried under controlled conditions.

PAHs analyzed in selected agricultural samples sourced from Gindin waya village showed: Fluoranthene and Benzo(b)fluoranthene as the highest and lowest PAHs depositions in roadside sun-dried selected agricultural samples; Pyrene and Benzo(b)fluoranthene as the highest and least PAHs depositions in selected agricultural samples stored at local kitchen rooftops. Fluoranthene was also observed to be the highest and Benzo(b)fluoranthene as the least PAHs depositions in selected agricultural samples sun-dried or stored under controlled conditions. Analysis of PAHs were observed to be more concentrated in selected agricultural products sun-dried by roadside or stored at local kitchen rooftops than those sun-dried under controlled conditions. In Kente village, the highest and lowest PAHs depositions analyzed in selected agricultural samples are Pyrene and Benzo(a)pyrene for samples sun-dried by the roadside, stored at local kitchen rooftops and sun-dried under controlled conditions. Samples stored at local kitchen rooftops were found to have more elevated quantity of PAHs depositions than those sun-dried either by the roadside or under controlled conditions. The PAHs analysed in all samples sun-dried by roadside or stored at local kitchen rooftops showed higher values than samples sun-dried under controlled conditions.

## CONCLUSION

The research overall results obtained revealed evidence of Polycyclic aromatic hydrocarbons (PAHs) pollutants depositions on selected agricultural products at varying degrees. The concentration of the PAHs pollutants varied from one agricultural sample to the other and from one road to the other. These could be attributed to the factors such as traffic density, types of wood used in making fire, amount of pollutants in the soil, types of vehicles/motor cycles gas used, quality of road and possibly the ratio of new to old vehicles/motor cycles plying the roads. Although the concentration of PAHs pollutants on the selected agricultural samples in Byepyi, Gindin waya and Kente were generally below FAO/WHO safe limit. Consumption of these agricultural products with reasonable concentration of heavy metals and PAHs levels may result to high level of bioaccumulation in the human system causing related health disorders.

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## REFERENCE

[1] Adebayo, K. S., and Rapheal, O. (**2011**). Survey of heavy metal contaminations of cassava mash and maize corns dried along the highways in some selected states in northern part of Nigeria. *Advances in Applied Science Research*. 2: 561–571.

[2] Adejumo, B. A. and Raji, A. O. (**2007**). Technical appraisal of grain storage systems in the Nigerian Sudan Savanna. *Agricultural Engineering International: CIGR Journal*.

[3] Agenin, J.O. (**2002**). Lead in a Nigerian savannah soil under long-term cultivation. *Sci of the Total Env.* 288:1–14.

[4] Akoto, O., Gavor, S., Appah, M.K. and Apau, J. (**2015**). Estimation of human health risk associated with the consumption of pesticide-contaminated vegetables from Kumasi, Ghana. Environ Monit Assess. 187:244.

[5] Alloway, B. J. and Jackson, A. P. (**1999**). Behaviour of trace metals in sludge-amended soils. *Sci Total Environ.* 100:151–176.

[6] Apeh, D.O., Onoja, V.O., Oguche, M., Suleiman, M.S., Bando, C.D., Akubo, F.O. and Negedu, K. (**2020**). Incidence and Dietary Intake of Major Mycotoxins from Staples in Anyigba, Kogi State, Nigeria. *Mycotoxicology*. 6: 1 – 9.

[7] Amos-Tautua, B.M.W., Inengite, A. K., Abasi, C.Y. and Amirize, G.C. (**2013**). Evaluation of polycyclic aromatic hydrocarbons and some heavy metals in roasted food snacks in Amassoma, Niger Delta, Nigeria. *African Journal of Environmental Science and Technology*. 7(10):961-966.

[8] Amusan, A. A., Bada, S. B., and Salami, A. T. (**2003**). Effect of traffic density on heavy metal content of soil and vegetation along roadsides in Osun state, Nigeria. *West African Journal of Applied Ecology*, 4, 107–114.

[ 9] Asogwa, I. S., Okoye, J. I. and Oni, K. (**2017**). Promotion of indigenous food preservation and processing knowledge and the challenge of food security in Africa. *Journal of Food Security.* 5(3):75-87.

[10] Aulakh, A. and Regmi, A. (**2013**). Post-Harvest Food Losses Estimation-Development of Consistent Methodology: Food and Agriculture Organization of the United Nations, Rome Italy 2013.

[11] Bando, C. D., Ikwebe, J., Tutuwa, A. J., Oche, G. S., Odiba, E. O. and David, H. E. (**2019**). Heavy metal and polyaromatic hydrocarbon depositions on local kitchen and roadside sun-dried agricultural products in Nigeria: A public health concern. *International Journal of Advanced Biochemistry Research*. 3(1): 59-65.

[12] Blezinger, S. B. (**2003**). *Animal Health Journal*, Part 1:1 –5.

[13] Bolade, M. K. (**2016**). An investigation into the level of metallic pollutants in roadside-sundried food products from selected areas of Ondo and Osun states, Nigeria. Cogent Food & Agriculture. 2:1-14.

[14] CAC. Evaluation of certain food additives and contaminants. FAO/WHO, Codex Standards, Rome; **2003**.

[15] EU. (**2006**). Commission regulation (EC)NO.1881/2006 *Official Journal of European Union* L364/5.

[16] FAO/WHO. (**2001**). Food additive and contaminants. Joint FAO/ WHO Food Standard Program, ALINORM 01/12A, Codex Alimentarius Commission. The Hague: FAO/WHO. 1–289.

[17] FAO/WHO. (**2002**). Limit test for heavy metals in food additive specifications. Joint FAO/WHO Expert Committee on Food Additives (JECFA) [Internet document]. Retrieved November30,2015,fromhttp://www.fao.org/fileadmin/templates/agns/pdf/jecfa/20020910_Explanat

ory_note_ Heavy_Metals.pdf

[18] FAO/WHO. (**2006**). Evauation of certain food contaminants: sixty-fourth report of the joint FAO/WHO expert committee on food additives. World health organization, Geneva.

[19] Gao, P., da Silva, E., Hou, L., Denslow, N.D., Xiang, P. and Ma, L.Q. (**2018**). Human exposure to polycyclic aromatic hydrocarbons: Metabolomics perspective. *Environ. Int*. 119:466– 477.

[20] Hayma, J. (**2003**). The storage of tropical agricultural products. Agromisa Foundation, Wageningen, STOAS Digigrafi, Wageningen, the Netherlands. 35-74.

[21] Ifegwu, O.C. and Anyakora, C. (**2015**). Polycyclic aromatic hydrocarbons: Part I. Exposure. *In Advances in Clinical Chemistry*, 1st ed.; Elsevier: Amsterdam, The Netherlands. 72(6):277–304.

[22] Ikwebe, J., Ubandoma, A., Tatah, V. S., Abigail, O. A. (**2017**). An Investigation of Nutritional Quality Changes and Microbial Safety of Preserved-Salted Fish of the Benue River. *Biochemistry and Molecular Biology*. 2(5):20-28.

[23] Kolawole, S. A. and Odoh, R. (**2011**). Survey of heavy metal contaminations of cassava mash and maize corns dried along the highways in some selected states in northern part of Nigeria. *Advances in Applied Science Research*. 2(5):561-571.

[24] Lebot, V. (**2009**). Tropical root and tuber crops: Cassava, sweet potato, yams and aroids. Crop Production Science in Agriculture. 17: 77–87.

[25] Ming-Ho, Y. (**2005**). Environmental Toxicology: Biological and Health Effects of Pollutants. Boca Raton, USA: CRC Press LLC. 12(2). ISBN 1-56670-670-2.

[26] Muhammad, A., Saidu, G., Jibril, A. M, Sirajo, A. Z. (**2022**). Assessment of Heavy Metals and Polycyclic Aromatic Hydrocarbons in Agricultural Soils around Kubanni Bridge area, Zaria, Kaduna State, Nigeria. CaJoST. 2: 183-189.

[27] Nogacka, A.M., Gómez-Martin, M., Suárez, A., González-Bernardo, O., Reyes-Gavilán, C.G.and González, S. (**2019**). Xenobiotics formed during food processing: Their relation with the intestinal microbiota and colorectal cancer. Int. J. Mol. Sci. 20:2051.

[28] Olusola A. A. (**2020**). Level of polycyclic aromatic hydrocarbon in smoked food materials from roadside barbeque spots in western Nigeria and health implication. Taylor and Francis group. DOI: 10.1080/10406638.2020.1821721.

[29] Otitoju, O., Otitoju, G. T. O. and Boyi, R. (**2017**). Risk assessment of agricultural farmland: A case study of Wukari, Taraba state Nigeria. *Journal of Pharmacognosy and Phytochemistry.* 7(1):2110-2113.

[30] Sampaio, G.R., Guizellini, G.M., da Silva, S.A., de Almeida, A.P., Pinaffi-Langley, A.C.C., Rogero, M.M., de Camargo, A.C. and Torres, E.A.F.S. (**2021**). Polycyclic Aromatic Hydrocarbons in Foods: Biological Effects, Legislation, Occurrence, Analytical Methods, and Strategies to Reduce Their Formation. *Int. J. Mol. Sci*. 6010.

[31] Sundamari, M. and Ranganathan, T. T. (**2003**). Indigenous agricultural practices for sustainable farming. Agrobios (India). Jodhpur, India.

[32] Thamaga-Chitja, J. M., Hendriks, S. L., Ortmann, G. F. and Green, M. (**2004**). Impact of maize

storage on rural household food security in Northern Kwazulu-Natal. *Journal of Family Ecology and Consumer Sciences*. 32:8-15.

[33] United Nations Conference on Trade and Development. (**2011**). Unctad press. Unctad Organization.

[34] United Nations Environmental Protection. Global Program of Action. **2004**.

[35] United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. (**2007**). Toxicological Profile for Lead.

[36] United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. (**2008**). Toxicological Profile for Cadmium.

[37] United States Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. (2005). 1–397.

[38] WHO/FAO. Joint WHO/FAO food standard programme codex Alimentarius Commission 13th Session, **2007**.

[39] Yongyong, G., Kusheng, W., Xia. H. and Xijin, X. (**2011**). Sources, Distribution, and Toxicity of Polycyclic Aromatic Hydrocarbons. Advancement of the science. 73:9.

[40] Young, R.N. (**2005**). Assessment Information System.