Research article

Dietary Exposure to Polycyclic Aromatic Hydrocarbons and the Probabilistic Health Risk Assessment of Eating Roasted Yams (*Dioscorea Species*) by African Population

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Abstract

The roasting of food is one of the oldest food preparation and preservation technologies. Although roasted foods have been associated with potential health hazards, this processing method is still used in many foods. This study was carried out to ascertain the health risks of ingesting white (*Dioscorea rotundata*), and bitter yam (*Dioscorea dumetorum*) roasted with firewood, charcoal, and charcoal augmented with PET bottles. The PAH content in all the roasted yam samples was identified and analyzed using gas chromatography-mass spectroscopy (GC-MS). A total of 8 PAHs were identified in both yam species; however, bitter yam roasted with augmented charcoal contained 9 PAHs. The total EDI showed that bitter yam roasted with augmented charcoal (6.59E-1) had the highest PAH content while white yam roasted with only charcoal contained the lowest (1.27E-1). The hazard quotients and indexes revealed that bitter yam had the highest HQ in all the roasting methods except for napathalene, fluoranthene and benzo (a) pyrene in samples roasted with charcoal. The HI for both species in all the roasting methods was above 1 (>1), while firewood produced the highest HI. Benzo (a) anthracene was the most potent PAH identified across the yam species and the roasting techniques. The evaluated ILCR showed that dibenzo (a, h) anthracene identified in white yam smoked with charcoal had the highest tendency to cause cancer (6.38E-1) while the least PAH was acenaphthylene (3.35E-6) which was seen in bitter yam roasted with charcoal. Therefore, it is necessary to inform the consumers of the possible health implications associated with consuming roasted yams and especially yam roasted with augmented charcoal.

Keywords

Dioscorea sp.;
PAHs;
roasting;
accumulation;
risk assessment

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1. Introduction

The exponential increase in population has caused a boom in the industrial and urban sectors. This boom in the urban and industrial sectors inevitably led to a spike in different forms of pollution in the environment in a quest to meet the people's needs and demand [1, 2]. The quest to feed the growing population has opened up ways to maximize agricultural yield via the use of agrochemicals [3]. It has also led to improved food processing and preservation techniques such as roasting, barbecuing, and packaging to achieve this purpose. Some of these activities contribute immensely to contaminating and polluting ready-to-eat foods. Recently, awareness of food contamination (biological and chemical) and caloric value have been on the rise [4]. For instance, lead poisoning associated with food ingestion led to hundreds of child morbidity in Nigeria in 2010 [5]. The contamination of food and food materials during preparation by polycyclic aromatic hydrocarbons (PAHs) has contributed to the onset and development of oncogenes and mutagens [6]. The presence of PAHs in food samples poses a threat to human health and awareness of this problem has continued to grow. Food preparation (drying, smoking, cooking, grilling, frying, roasting, and baking) is usually considered the leading cause of PAH contamination in foods [7]. Barbecuing with charcoal plus wood chips resulted in the formation of benzo (a) pyrene in most foods; and for beef burgers only, barbecuing over charcoal (without the use of wood chips) gave the highest levels of polycyclic aromatic hydrocarbons (PAHs) [8].

Yam (*Dioscorea* genus) is a staple carbohydrate frequently consumed in Nigeria. Nigeria is one of the major producers of yams in Africa. It is one of Africa's most important tropical root crops after cassava and sweet potatoes [9]. There are different types of yams usually consumed in Nigeria, and they include the *Dioscorea rotundata* (white yam), also known as sweet yam; *Dioscorea dumetorum* (bitter yam), locally known as Una in the Igbo language; and *Dioscorea alata* (water yam), locally known as Abala in the Igbo language. The white yam is consumed more than the bitter yam [10]. White yam is consumed in different forms: pasted, boiled, fried, and roasted. Yam can be made into flour and reconditioned with hot water to form amala (commonly called swallow), which is ingested with soup [11]. Bitter yam is usually considered a food for adults and a preferred food for consumption by people with diabetes [10]. Roasting yam is an old method of food processing in Nigerian states. It is one of the street-side affordable foods. It is easily obtained from people who roast plantain for beans and roasted plantain, typical are typical dishes in Nigeria's western and southern parts. Most diabetics prefer roasted bitter yam to white yam since that is the preferred type of yam (*Dioscorea sp*.) for them. A significant cause for concern is using items such as nylons, plastics, and PET bottles to augment the burning of wood or charcoal during roasting. Nigeria, an oil-producing country but still suffers from a scarcity of refined oil products such as kerosene, and some of these products are used to ignite the fire for roasting. Because of the lack of kerosene, most street food vendors and families who cannot afford to buy kerosene find ways to augment the burning of charcoal or firewood during roasting. This may exacerbate or contribute to adding PAHs to the roasted food items. The adverse effects of PAHs on human health depend on the exposure length, route of exposure, and concentration of PAHs. The effects are also dependent on the toxicity equivalence of the PAHs. Other factors can be the exposed individual's age and pre-existing health status.

Enhancing food security and minimizing the effects of food contamination have become of paramount interest in recent times. Evaluating the impact of contaminations with respect to the health risks associated with them has become increasingly pertinent. An important component of assessing health risks for people is to establish the hazard level when those people are exposed to a dangerous substance over time [12]. The United States Environmental Agency has set some modules that can be used to evaluate these risks. Such modules entail determining the bioaccumulation factor calculating the estimated daily intake (EDI), which are used to determine the hazard quotient (HQ), hazard index (HI), and the carcinogenic risks (CR) [13]. The toxic hazard quotient and index (THQ and THI) give an insight on the probability of having health complications from daily consumption of a particular substance or total of a group of importance as the case may be. The cancer risks (CR) as stated by USEPA says that when there is just one case of cancer in a million (1×10^{-6}), hundred thousand (1×10^{-5}) or ten thousand (1×10^{-4}) subjects, then it is considered safe to consume such substance daily in that particular dose; while when there are a case of cancer in a thousand (1×10^{-3}) subjects, it considered unsafe [14]. Therefore, this work was aimed at quantifying PAHs detected in roasted white and bitter yam and evaluating the possible risks of health hazards developed from consuming them.

2. Materials and Methods

2.1 Plant materials

The plant materials used for this study were: *Dioscorea rotundata* (white yam), also known as sweet yam, and *Dioscorea dumetorum* (bitter yam), locally known as Una. Samples were purchased from a farmer at Ogige Market, University of Nigeria, Nsukka, Enugu State, in March 2021.

2.2 Reagents

The reagents used to prepare and extract samples were of analytical grade quality. Anhydrous sodium sulphate, silica gel, dichloromethane, acetone, and glass wool were all purchased from Sigma Aldrich. PAHs mix standard of 16 congeners was purchased from Cerilliant.

2.3 Prepartion of *Dioscorea* sp. samples for roasting

Two yam samples (one tuber from each species) were divided into 9 portions of 250 g per portion. Each group of 9 portions were then sub-divided into three sample groups: (a) the first group comprised *Dioscorea* sp. roasted with firewood and kerosene to aid combustion, (b) the second group comprised *Dioscorea* sp. roasted with charcoal and kerosene to aid combustion, and (c) the last group comprises *Dioscorea* sp. roasted with charcoal and 5 g of plastics added to enhance combustion. The yam samples were laid on a mesh tray above the burning firewood or charcoal.

2.4 Sample preparation for GC-MS analysis

This was done as described in Siddique *et al*. [15]. Potassium hydroxide solution (2M) was mixed with 30 g of yam sample. It was added into 100 mL methanol-water solution in the ratio 9:1 v/v with addition of 2 g of $Na_2S.9H_2O$. The sample was put in a water bath set at 70°C and refluxed for 2 h. A known quantity (100 mL) of *n*-hexane was put in via the condenser and after 15 min, the sample was cooled by introducing cold water (100 mL). The resulting blend was kept in dark overnight, and then concentrated with 60 mL *n*-hexane. The organic layer was later extracted. The extraction was done twice with 30 mL of n-hexane, and the extracted layer dried with anhydrous sodium sulfate and filtered. The *n*-hexane layer was further concentrated to about 2 mL using a rotary evaporator set at 35°C. Column chromatography was used to purify the concentrate. Silica gel was used as the stationary phase while organic solvents used as the mobile phase. Column packing was done by making a slurry of silica gel. The slurry was prepared by introducing 40 mL of *n*-hexane into 20 g of silica gel which was run down the column. When the slurry settled, the sample mixture was added into the column and eluted by passing *n*-hexane (50 mL) through the column, and this was followed by 8 mL of *n*-hexane-dichloromethane (3:1, v/v) mixture. A rotary evaporator was used to concentrate the eluted solvent to approximately 1 mL. It was filtered by passing it through a microporous syringe (0.45 µm) in vials and kept in the refrigerator at -20°C for analysis.

2.5 Analysis of PAHs using GC-MS

The PAHs were quantified using the GC-MS method shown in Siddique *et al*. [15]. The brand of GC-MS used was an Agilent brand (7890B) gas chromatograph with a DB-5MS capillary column (30 m, 0.25 mm ID, 0.25 µm film thickness) that was coupled to a mass spectrometer (5977A). This was used to isolate and identify the PAHs in samples. A known volume of the sample solution (1 µL) was injected in a splitless mode using helium (purity > 99.995%) as the carrier gas that flowed at a rate of 1 mL/min. The GC-MS operating environment for the segregation of PAHs was as follows: the oven temperature was at 80°C for 1 min, with a rate of 25°C/min 260°C/min, and rate 10°C/min to 300°C for 6.3 min. The detector temperature was 150°C, 230°C and 150 °C for ion source, injector and transfer line, respectively.

For quality control, standard procedures were followed strictly in order to guarantee analytical result coherence. This was facilitated by calibrating the instruments correctly before use. To ensure precision and accuracy, the sample analysis were run in triplicates against the standard and blanks. The limit of detection (LOD) ranged from 2.5E-4 to 3.25E-5 µg/g. The percentage recovery ranged from 87 to 116%.

2.6 Health risk assessment

Health risk assessment studies were carried out on *Dioscorea rotundata* (white yam) and *Dioscorea dumetorum* (bitter yam). This was done to ascertain the feasibility of developing health complications from consuming any yam species samples. This was achieved with the aid of the modules provided by USEPA.

2.6.1 Determining the dietary exposure (EDI) to PAHs identified in *Dioscorea* (yam) *species*

EDI was estimated to determine the specific daily consumption of PAHs from the yam samples and relate it to the acceptable, tolerable limits stipulated by USEPA. EDI is expressed in mg/person/day.

$$\mathrm{EDI} = \frac{(DCY \times CPy)}{BW} \tag{1}$$

The daily intake of roasted yam was determined using a food frequency questionnaire according to the method described by Ihedioha and Okoye [16].

Assumptions
a. Ingested dose is equal to the absorbed pollutant dose [17].
b. The average body weight of a Nigerian adult is assumed to be 70 kg.
c. Bitter yam is consumed as much as white yam by the diabetics
EDI = the estimated daily intake or an average daily dose (mg/kg/d) of the PAHs.
DCY = the daily intake of yam (10.38 g/ kg/day) obtained as described by Ihedioha and Okoye [16].
CPY = the concentration of PAHs in yam (mg/kg).
BW = the average Nigerian adult weight (70 kg) [18].

2.6.2 Non-carcinogenic health risk assessment (hazard quotient)

The non-carcinogenic health risk associated with ingesting roasted *Dioscorea rotundata* (white yam) and *Dioscorea dumetorum* (bitter yam) samples was evaluated with the hazard quotient module expressed in mg/kg/day. This was obtained by determining the ratio between the consumed PAHs detected in the yam species and the oral reference dose suggested by USEPA.

Note: A hazard quotient > 1 suggests that there could be health complications from the PAHs in Dioscorea species, while when it is < 1, it is considered safe over a lifetime (USEPA, 2011). This may not mean that the consumers will have health complications directly by consuming these yam species but informs them of the plausible risks associated with consuming them [19].

$$\mathrm{HQ} = \frac{EDI}{RFD} \tag{2}$$

HQ = hazard quotient.
EDI = estimated daily intake of Discorea sp.
RFD = the recommended reference dose.

2.6.3 Hazard index (HI)

The gross risk of being exposed to all the PAHs detected in *Dioscorea* sp. was evaluated by the summation of all the polycyclic aromatic hydrocarbons detected in *Dioscorea* sp. as stipulated by USEPA. Note that when the HI is < 1, it is considered safe to consume these roasted yam species, but when it is >1, it is considered unsafe for consumption over time [20].

$$\mathrm{HI} = \sum_{ip}^{n} HQ \tag{3}$$

n = stands for the number of PAHs present.
i = stands for the individual PAHs.
Hazard index (HI) = HQ (ia) + HQ (ib) + HQ (ic) + HQ (id) --------

2.6.4 Incremental lifetime cancer risk

The cancer risk was evaluated with the aid of the cancer slope factor (CSF). It is obtained by multiplying the CSF with EDI. This CSF of other PAHs is usually dependent on benzo (α) pyrene which is 7.3 mg/kg/day and is obtained by multiplying 7.3 by the toxicity equivalency factors (TEF) of other PAHs. The cancer risk is determined as seen in the equation below. The USEPA stipulated that cancer risks in the range of 1.0×10^{-6} to 1.0×10^{-4} are in the acceptable range or considered to be relatively safe [21], but when it is equal to or less than 1.0×10^{-3}, there may be a risk of developing cancer throughout lifetime consumption. The risk index (RI) is obtained by totaling the cancer risk evaluated for consuming all the PAHs together as detected in *Dioscorea* sp. samples. The aggregation of ILCR is used to determine the risk index (RI).

$$\mathrm{CR} = \mathrm{EDI\ (mg/kg/day)\ x\ CSF\ (mg/kg/day)}^{-1}. \tag{4}$$

EDI = estimated daily intake.
CSF= carncer slope factor.

$$\text{The risk index is given as RI} = \sum_{i=1}^{n} ILCR \tag{5}$$

Here, n stands for the number of PAHs, and I stands for the individual PAHs.

2.6.5 Carcinogenic or mutagenic potency

The carcinogenic or mutagenic potency was calculated by finding the product of the concentration of individual PAH detected in *Dioscorea* sp. samples and its toxicity equivalency factor (TEF) or mutagenic equivalency factor (MEF), respectively. The TEF creates awareness on the rate at which a particular PAH will cause cancer compared to Benzo (α) pyrene [22].

$$B\ (\alpha)\ Pteq = Cip \times TEFi \quad (6)$$

B(α)Pteq = the carcinogenic potency of the PAHs.
Cip = the individual PAH concentration.
TEFi = the toxicity equivalency factor of each PAH.

2.6.6 The toxic equivalency quotient (TEQ) of PAHs

The TEQ is determined by the summation of the product of TEFs of each PAHs and the individual concentration detected in the roasted yam species [22].

$$TEQ1 = \Sigma\ (Cip \times TEFi) \quad \text{or} \quad TEQ1 = \Sigma\ (B\ (\alpha)\ Pteq) \quad (7)$$

TEQ = the toxic equivalency quotient.
Cip = the individual PAH concentration.
TEFi = the toxicity equivalency factor of each PAH.
Σ = the summation of the carcinogenic potency.

Table 1. Reference dose (RD), toxicity equivalent factor (TEF), mutagenic equivalency factor (MEF) and carcinogenic slope factor (CSF) for PAHs [12, 23-25]

PAH compounds	RD (mg/kg/day)	TEF	MEF	CSF (Mg/Kg bw- day-1)
Dibenzo (a-h)anthracene	NA	1	0.29	NA
Benzo (α) pyrene	0.0003	1	1	7.3
Benzo (α) anthracene	NA	0.1	0.08	NA
Benzo (β) fluoranthene	NA	0.1	0.25	NA
Benzo (k) fluoranthene	NA	0.1	0.11	NA
Indeno (1,2,3-c,d) pyrene	NA	0.1	0.31	NA
chrysene	NA	0.1	0.02	NA
Anthracene	0.3	0.01		NA
Benzo (g,h,i) perylene	0.04	0.01	0.19	NA
Acenaphthene	0.06	0.001		NA
Acenaphthylene	0.02	0.001		NA
Fluoranthene	0.04	0.001		NA
Fluorene	0.04	0.001		NA
2-methylnaphthalene	NA	0.001		NA
Naphthalene	0.02	0.001		NA
Phenanthrene	0.3	0.001		NA
Pyrene	0.03	0.001		NA
Xylene	0.2	0.001		

NA - not available

3. Results and Discussion

3.1 Detection and quantification of PAHs in roasted yams (*Dioscorea species)*

Food processing and preparation such as roasting is an ancient practice in African countries. Many findings have been done to ascertain food safety via roasting. Aderibigbe *et al*. [26] studied the quantity of PAHs accumulated in roasted foods such as corn, plantain, suya, yam, and sharwama prepared by street food vendors. The presence of heavy molecular weight PAHs was identified.

In our work, two different species of yams were bought from the Ogige Market, Nsukka, Enugu State, Nigeria, and were roasted and analyzed for the presence and quantity of polycyclic aromatic hydrocarbon compounds. The yam species studied were white yam (*Dioscorea rotundata*) and bitter yam (*Dioscorea dumetorum*), and in all the test samples, different PAH compounds were detected at different concentrations.

The total number of PAHs detected in white and bitter yam roasted with different techniques as seen in Table 2 ranged from 7 to 9. Nine PAHs were detected in the bitter yam roasted with charcoal augmented PET bottles, which was the highest number of PAHs identified in yam species. The PAHs identified in *Dioscorea* species (white yam and bitter yam) roasted with firewood were acenapthylene, naphthalene, fluoranthene, pyrene, dibenzyl (a-h) anthracene, 1-2 benzanthracene, acenaphthene, and benzo (a) pyrene. When the yam samples were roasted with charcoal, the same PAHs were identified with the inclusion of fluorene and the exclusion of acenaphthene and pyrene. After roasting with augmented charcoal, a higher number of heavy PAHs such as benzo (b) fluoranthene, and benzo (K) fluoranthene were detected. This could have been because the plastics included in the roasting could have introduced different kinds of PAHs. These findings align with Nworah *et al*. [8], who tested other roasting methods including nylons on unripe plantain. In contrast, naphthalene and benzo (α) pyrene were not detected as they were detected in those roasted with firewood and charcoal. Roasting yam species with firewood showed that white yam had a total concentration of PAHs of 3.322±0.1 while bitter yam had a concentration of 3.4742±0.1 μg/g. For yam roasting with charcoal, white yam had a total concentration of 1.8589±0.1 μg/g while bitter yam had 1.8044±0.1 μg/g. For yam roasted in charcoal augmented with PET-bottles, the total concentration of PAHs obtained were 3.6633±0.1 μg/g for white yam and 4.4426±0.1 μg/g for bitter yam. For all the yam species roasted, those roasted with charcoal had the least PAH concentration, while those roasted with charcoal augmented with PET-bottle had the highest PAH present. This may have been because the charcoal may have lost most of its organic content and PAHs while burning as wood before being used for yam roasting. Yam samples roasted with firewood may have a high concentration of PAHs because burning firewood usually generates more smoke when compared to augmented charcoal and charcoal. This explanation may be reaffirmed by observation made during roasting with augmented charcoal, which produced yam with a higher concentration of total PAHs than those roasted with just charcoal; it was seen that the process of augmentation with PET-bottles produced an increased rate of smoking [27]. These findings are in line with Olabemiwo [28], who studies PAH levels in roasted maize and plantain. Furthermore, the finding of a higher level of total PAH contaminant in those roasted with augmented charcoal (charcoal + PET) can be attributed to the increased energy and heat during wood combustion as fuel and smoke generation giving rise to more PAHs [29]. The detection of HMW-PAHs such as benzo (b) fluoranthene and benzo (k) fluoranthene in yam roasted with augmented charcoal may be due to the use of PET-bottles to increase heat and flame generation during roasting, which increased smoke generation. Some of these plastics contain PAHs [30] and they are generally used as additives in form of carbon black and extender oils (to increase the flexibility and decrease stiffness of the rubbery polymers) [31]. Bitter yam accumulated more PAH during roasting with firewood and augmented charcoal, while white yam accumulated more PAHs when roasted with charcoal. The sources of PAHs can be peterogenic or pyrogenic and sometimes some food items get contaminated when exposed to petrogenic (crude oil and petroleum products) sources before processing for consumption. Therefore, in order to reaffirm that the PAHs detected in these yams were as a result of roasting, they were subjected to forensic diagnosis (to identify the source of PAHs), usually achieved by using the priority pollutant ratio. The ratio of LMW-PAHs to HMW-PAHs was used to evaluate the origin of PAHs detected, and especially their environmental origins. It was suggested that when LMW-PAHs were abundant, those PAHs detected were of oil origin (petrogenic), whilst when LMW-PAHs were sparse compared to HMW-PAHs, there is every possibility that they were there as a result of incomplete combustion of organic materials (pyrogenic). The source can be evaluated using the priority pollutant ratio by estimating the phenanthrene/anthracene (Ph/An) or fluoranthene/pyrene (Fl/Py) quotient [31]. It has been suggested that a phenanthrene/anthracene quotient of less than 10 (< 10), implies a pyrogenic source, while a ratio above 10 (>10), implies a petrogenic source. Moreover, a (Fl/Py) quotient of less than 1 (<1) implies a petrogenic source, whereas a quotient greater than 1 (>1), it could be pyrogenic origin [31].

The percentage composition of high molecular weight (HMW) PAHs and low molecular weight (LMW) PAHs detected in the yam species were evaluated, and the results can be seen in Table 3. The composition of rings helps to ascertain the presence of the HMW-PAHs or LMW-PAHs. The ratio also helps to ascertain the origin of PAHs present in the samples, which can be pyrogenic or petrogenic. From the findings, HMW PAHs of four and five rings dominated the LMW PAHs. PAHs with one ring and six rings were not detected. The LMW-PAHs were 37.5 to 40 %. From the findings in this study, the HMW-PAHs were above 60% of the total PAHs detected irrespective of the roasting technique and the yam specie, although those roasted with fired wood had 62.5% of HMW-PAHs. The pollutant priority ratio also showed that the values obtained for those calculated were all above one (> 1) using the Fl/Py quotient. The value obtained for those roasted with firewood were 3.08 for white yam and 2.895 for bitter yam, while those roasted with augmented charcoal were 1.943. Those roasted with firewood had the highest HMW-PAHS, which could be because they were roasted with materials containing more organic content than others. These findings are in tandem with Olabemiwo [28], who found that HMW-PAHS were dominant in roasted maize and plantain.

3.2 Estimated daily intake (EDI) of roasted *Dioscorea* (yam) species

The evaluation of estimated daily intake was done to ascertain if there would be any health complications from ingesting white or bitter yam roasted with firewood, charcoal, or augmented charcoal as seen in Table 4. It was also done to ascertain if the risks would be higher in bitter yam or white yam for each roasting strategy. The EDI for white yam roasted with firewood ranged from 2.04E-2 to 1.10E-1; 3.41E-4 to 2.78E-2 for yam smoked with charcoal, while it ranged from 1.38E-2 to 1.84E-1 for yam roasted with augmented charcoal. As stated above, we can also see that those roasted with augmented charcoal had the highest EDI compared to those roasted with firewood and charcoal. The EDI for bitter yam ranged from 2.79E-2 to 1.00E-1 when roasted with firewood; from 4.59E-4 to 2.07E-2 when smoked with charcoal; it ranged from 1.44E-2 to 1.86E-1 when roasted with augmented charcoal. The EDI of bitter yam also had the same pattern as that of white yam as the bitter yam had the least EDI when roasted with just charcoal, and the highest when roasted with augmented charcoal. Pyrene, acenaphthylene, and benzo (b) fluoranthene were the polycyclic aromatic hydrocarbons that had the lowest EDI in both species roasted with firewood, charcoal, and augmented charcoal. The total EDI evaluation showed that the bitter yam (*Dioscorea dumetorum*) was higher than white yam (*Dioscorea rotundata*). These findings suggested that health issues may result from consuming PAHs in roasted yam. The results also suggested that the least likely PAH to contribute to health issues is pyrene since it was below the reference doses stipulated. Furthermore, the results also indicated that the highest PAH consumed when both *Dioscorea* species were roasted with firewood and charcoal was naphthalene. However, when roasted with

Table 2. Polycyclic aromatic hydrocarbon (PAHs) detected in white yam (*Dioscorea rotundata*) and bitter yam (*Dioscorea dumetorum*) in µg/g

S/N	PAH Compounds	Firewood		Charcoal		Charcoal With PET	
		White	**Bitter yam**	**White yam**	**Bitter yam**	**White yam**	**Bitter yam**
1	Acenaphthylene	0.5059±0.1	0.4850±0.1	0.0023±0.1	0.0031±0.1		
2	fluorene	-		0.1377±0.1	0.1401±0.1	1.2406±0.1	0.4123±0.1
3	Naphthalene	0.7426±0.1	0.6811±0.1	0.6400±0.1	0.6100±0.1	-	-
4	Fluoranthene	0.4253±0.1	0.5463±0.1	0.3926±0.1	0.4127±0.1	0.4611±0.1	1.2541±0.1
5	Phenanthrene	-	-	-	-	0.0000	0.1012±0.1
6	Dibenzyl (a-h) anthracene	0.2342±0.1	0.2532±0.1	0.2809±0.1	0.2120±0.1	0.5900±0.1	0.6211±0.1
7	Benzo (α) anthracene	0.4207±0.1	0.4730±0.1	0.2178±0.1	0.2613±0.1	0.6375±0.1	0.6952±0.1
8	Acenaphthene	0.6495±0.1	0.5889±0.1	-	-	0.2010±0.1	0.2178±0.1
9	Benzo (a) pyrene	0.2068±0.1	0.2580±0.1	0.1876±0.1	0.1652±0.1	-	-
10	Benzo (g_h_i) perylene	-	-	0.0000	0.0000	-	-
11	Benzo (k) Fluoranthene	-	-	-	-	0.4397±0.1	0.3989±0.1
12	Pyrene	0.1377±0.1	0.1887±0.1	-	-	-	0.6452±0.1
13	Benzo (b) Fluoranthene	-	-	-	-	0.0934±0.1	0.0968±0.1
Total		3.3222±0.1	3.4742±0.1	1.8589±0.1	1.8044±0.1	3.6633±0.1	4.4426±0.1

"-" stands for not detected.

Table 3. The percentage composition of rings present in white yam and bitter yam

Number of Rings	Firewood (%)		Charcoal (%)		Charcoal with PET (%)	
	White yam	**Bitter yam**	**White yam**	**Bitter yam**	**White yam**	**Bitter yam**
1	-	-	-	-		
2	12.5	12.5	20	20	10	10
3	25	25	20	20	30	30
4	37.5	37.5	40	40	30	30
5	25	25	20	20	30	30
6	-	-	-	-	-	-

"-" stands for not present.

Table 4. EDI of PAHs present detected in roasted white and bitter yam

S/N	PAH Compounds	Firewood		Charcoal		Charcoal with PET	
	PAH Compounds	**White**	**Bitter yam**	**White yam**	**Bitter yam**	**White yam**	**Bitter yam**
1	Acenaphthylene	7.50E-2	7.19E-2	3.41E-4	4.59E-4		
2	fluorene	-		2.04E-2	2.07E-2	1.84E-1	6.11E-2
3	Naphthalene	1.10E-1	1.00E-1	9.49E-2	9.04E-2	-	-
4	Fluoranthene	6.30E-2	8.10E-2	5.82E-2	6.11E-2	6.83E-2	1.86E-1
5	Phenanthrene	-	-	-	-	0.0000	1.50E-2
6	Dibenzyl (a-h) anthracene	3.47E-2	3.75E-2	4.16E-2	3.14E-2	8.74E-2	3.13E-2
7	Benzo (α) anthracene	6.23E-2	7.01E-2	3.22E-2	3.87E-2	9.45E-2	1.03E-1
8	Acenaphthene	9.63E-2	8.73E-2	-	-	2.98E-2	3.23E-2
9	Benzo (a) pyrene	3.06E-2	3.82E-2	2.78E-2	2.44E-2	-	-
10	Benzo (g_h_i) perylene	-	-	-	-	-	-
11	Benzo (k) Fluoranthene	-	-	-	-	6.52E-2	5.92E-2
12	Pyrene	2.04E-2	2.79E-2	-	-	-	9.57E-2
13	Benzo (b) Fluoranthene	-	-	-	-	1.38E-2	1.44E-2
Total		**4.92E-1**	**5.15E-1**	**1.27E-1**	**2.6E-1**	**5.4E-1**	**6.59E-1**

"-" stands for not evaluated as the PAH was not detected.

augmented charcoal, it is fluorene that was consumed more for white yam roasted with augmented charcoal and Benzo (α) anthracene for bitter yam. The least consumed PAH in firewood and charcoal roasted yam (*Dioscorea* species) was pyrene and fluorene. The least consumed PAH in augmented charcoal was benzo (b) fluoranthene for white yam and phenanthrene for bitter yam. USEPA established that the higher the number of rings, the higher the tendency to cause health complications. In this order, the bitter yam roasted with augmented charcoal would be the most likely to cause health complications since the most consumed PAH would be benzo (b) fluoranthene. Using the total PAH estimated daily intake, it was also reaffirmed that bitter yam roasted with augmented charcoal would most likely cause health hazards since it had the highest daily intake of total PAHs (6.59E-1). The least health hazard that could be experienced from daily intake of total PAHs would likely come from consumption of white yam roasted with just charcoal as it had the least total EDI (1.27E-1). A sequence of the likelihood to cause health complications would be in the following order: species roasted with augmented charcoal > firewood > charcoal.

3.3 Hazard quotient (HQ) and hazard index (HI) estimation

The HQ and HI were evaluated for both yam species and the results are shown in Table 5. They were determined using the evaluated EDIs to confirm the source of health complications that may arise from consuming these *Dioscorea* species roasted in various ways. The USEPA also stipulated that when the HQ or HI is greater than one (>1), there is a possibility of health compilation that may result from consuming the substance in the food. At the same time, when it is less than one (<1), it may be safe to consume that food with the contaminant in it. Our research showed that the HQ for all the PAHs detected in both white and bitter yam irrespective of the roasting method were greater than 1(>1), except for pyrene detected in samples roasted with firewood. As detected in both yam species roasted with fired wood, pyrene values were 0.0680E+1 and 0.0930E+1 for white and bitter yam, respectively. Pyrene detected in species roasted with augmented charcoal was more than one (>1). Benzo (a) pyrene had the highest HQ in all detected samples, irrespective of the roasting method. The PAH (acenaphthylene) had the lowest HQ in both *Dioscorea* species roasted with charcoal; 1.70E-2 for white yam and 2.30E-2 for bitter yam were observed. The HI for both species in all the roasting methods was above 1 (>1). The HQs determined suggest that the individual PAH may lead to health issues which may emanate from consuming benzo (a) pyrene detected in white yam roasted with firewood. In contrast, the lowest health hazard would arise in white yam via the consumption of acenapthylene. This is in line with Tongo *et al.* [22], who also identified benzo (a) pyrene as the PAH that may cause health hazards. The HI, which is a total of the individual PAH HQs showed that they were all >1 and that consumption of the yam species roasted with firewood would probably lead to health hazards. The least HI was observed to be the white yam species roasted with augmented charcoal and white yam with a value of 0.779E+1. HI may not concur with observations in EDI because of insufficient available data for determining all the HQs for all the identified PAHs detected in all samples.

Table 5. Hazard quotient (HQ) and hazard index (HI) of PAHs present detected in roasted white and bitter yam

	PAH Compounds	**Firewood**		**Charcoal**		**Charcoal with PET**	
S/N	PAH Compounds	White	Bitter yam	White yam	Bitter yam	White yam	Bitter yam
1	Acenaphthylene	0.375E+1	0.359E+1	1.70E-2	2.30E-2		
2	fluorene	-		5.10E-1	5.17E-1	0.460E+1	0.15E+1
3	Naphthalene	0.550E+1	0.500E+1	0.474E+1	0.452E+1	-	-
4	Fluoranthene	0.157E+1	0.202E+1	0.145E+1	0.152E+1	0.170E+1	0.465E+1
5	Phenanthrene	-	-	-	-	0.0000	5.00E-2
6	Dibenzyl (a-h) anthracene	NA	NA	NA	NA	NA	NA
7	Benzo (α) anthracene	NA	NA	NA	NA	NA	NA
8	Acenaphthene	0.160E+1	0.436E+1	-	-	0.149E+1	0.615E+1
9	Benzo (a) pyrene	0.102E+3	0.127E+3	0.926E+2	0.813E+2	-	-
10	Benzo (g_h_i) perylene	-	-	0.0000	0.0000	-	-
11	Benzo (k) Fluoranthene	-	-	-	-	NA	NA
12	Pyrene	0.0680E+1	0.0930E+1	-	-	-	0.319E+1
13	Benzo (β) Fluoranthene	-	-	-	-	NA	NA
Total	**or HI**	**1.15E+2**	**1.429E+2**	**9.931E+1**	**8.788E+1**	**0.779E+1**	**2.104E+1**

"-" stands for not evaluated as the PAH was not detected.

3.4 Carcinogenic potency and toxicity equivalency quotient of PAHs

The carcinogenic potency and toxicity equivalency quotient of PAHs identified in roasted yam species were evaluated using factors provided in Table 1 to ascertain the most potent individual PAH that could lead to cancer, and the toxicity equivalency quotient was done to determine the yam specie or roasting technique that could likely cause cancer, as shown in Table 6. This was done by comparing how potent a particular PAH is when compared with benzo (a) pyrene. The results showed that dibenzo (a, h) anthracene was more potent (2.53E-1) in bitter yam roasted with firewood. At the same time, benzo(a)pyrene was more potent (2.06E-1) in white yam roasted with firewood. Benzo(a)pyrene was the most potent PAH when the yam species were roasted with charcoal, although the benzo (a) pyrene in white yam was more potent (1.87E-1) than that in bitter yam (1.65E-1). Benzo (α) anthracene was the most potent PAH in yam species roasted with augmented charcoal, with bitter yam being the most potent (6.95E-1). Naphthalene was the least potent PAH identified in both white (7.42E-4), and bitter yam (6.81E-4) roasted with firewood; when roasted with charcoal, acenaphthylene was the PAH with the least potency in both white (2.3E-6) and bitter yam (3.1E-6); while when roasted with augmented charcoal, it was fluoranthene (4.61E-4) for white yam and pyrene (6.452E-4) for bitter yam. The least potent PAH is acenaphthylene (2.3E-6), identified in white yam roasted with charcoal, while the most potent PAH was benzo (a) anthracene (6.95E-1) detected in bitter yam roasted with augmented charcoal. This was also in tandem with Tongo *et al*. [22]. It contrasted with the work done by Dokubo and Igwe [24], whose findings showed that benzo (a) pyrene was the most potent PAH. It also contrasted with Ubani *et al*. [25], who obtained benzo (a) pyrene as the most potent PAH. This may be as a result of the concentration levels detected in samples. When the yam species were roasted with firewood, pyrene detected in white yam was the least (1.37E-4) potent PAH detected.

The TEQ determined for white and bitter yam roasted with different techniques showed that bitter yam roasted with augmented charcoal had the highest value (7.40E-1) while white yam roasted with charcoal had the least potency (4.00E-1) as seen in Table 6. The toxicity equivalent quotient (TEQ) is evaluated to ascertain the potency of all the PAHs detected in roasted yam species. The TEQ is usually evaluated by totaling the B (α)Pteq of the identified PAHs in each yam species and roasting technique. The TEQs evaluated were all below one (< 1). This suggests that there may be no calls for alarm in consuming the yams roasted with the different strategies. However, toxicity may arise from consuming yam roasted with augmented charcoal, and most likely from consumption of the bitter yam. The total of the PAHs roasted with charcoal may have the least carcinogenic ability. TEQs were in the order of augmented charcoal > firewood > charcoal. The TEQ study also showed that bitter yam had the highest carcinogenic potency of all the PAHs present, while white yam in charcoal had the lowest. This also reiterates the findings of the carcinogenic potency.

The risk of developing cancer from a lifetime of consuming roasted white and bitter yam was evaluated, as can be seen in Table 7. The results showed that dibenzo (a, h) anthracene identified in white yam smoked with charcoal had the highest tendency to cause cancer (6.38E-1) while the PAH with the least tendency was acenaphthylene (3.35E-6) which was seen in bitter yam roasted with charcoal. It also showed that consuming white yam and bitter yam roasted with firewood would have benzo (a) anthracene, benzo (a) pyrene and dibenzo (a,h) anthracene lead to cancer over time. They were in the following order benzo (a) pyrene > benzo (a) anthracene > dibenzo (a,h) anthracene. When roasted with firewood, white yam had PAHs with the ability to cause cancer over a lifetime, while roasted with charcoal and augmented charcoal, bitter yam had more PAHs that can cause cancer over time. The risk index evaluation showed that white yam roasted with charcoal had the lowest risk index (3.47E-1) while white yam roasted with augmented charcoal had the highest cancer risk index (7.66E-1). The risk index evaluated showed that those yam samples roasted with

Table 6. Carcinogenic potencies (B(α)Pteq) of PAHs identified in roasted white and bitter yam

S/N	PAH Compounds	Firewood		Charcoal		Charcoal with PET	
		White	Bitter yam	White yam	Bitter yam	White yam	Bitter yam
1	Acenaphthylene	5.05E-4	4.85E-4	2.3E-6	3.1E-6		
2	fluorene	-		1.37E-4	1.40E-4	1.24E-3	4.123E-4
3	Naphthalene	7.42E-4	6.81E-4	6.40E-4	6.10E-4	-	-
4	Fluoranthene	4.25E-4	5.46E-4	3.92E-4	4.12E-4	4.61E-4	1.25E-3
5	Phenanthrene	-	-	-	-	0.0000	1.01E-4
6	Dibenzo (a-h) anthracene	2.34E-1	2.53E-1	2.80E-1	2.12E-1	5.90E-1	6.21E-1
7	Benzo (α) anthracene	4.20E-1	4.73E-1	2.17E-1	2.61E-1	6.37E-1	6.95E-1
8	Acenaphthene	6.49E-4	5.88E-4	-	-	2.01E-4	2.17E-4
9	Benzo (a) pyrene	2.06E-1	2.58E-1	1.87E-1	1.65E-1	-	-
10	Benzo (g_h_i) perylene	-	-	0.0000	0.0000	-	-
11	Benzo (k) Fluoranthene	-	-	-	-	4.39E-2	3.98E-2
12	Pyrene	1.37E-4	1.88E-4	-	-	-	6.452E-4
13	Benzo (b) Fluoranthene	-	-	-	-	9.34E-3	9.68E-3
Total	**TEQ**	**6.19E-1**	**7.24E-1**	**4.00E-1**	**4.20E-1**	**6.90E-1**	**7.40E-1**

"-" stands for not evaluated as the PAH was not detected.

Table 7. Incremental lifetime cancer risk of consuming individual PAHs identified in roasted white and bitter yam

S/N	PAH Compounds	Firewood		Charcoal		Charcoal with PET	
		White	Bitter yam	White yam	Bitter yam	White yam	Bitter yam
1	Acenaphthylene	5.47E-4	5.24E-4	2.49E-6	3.35E-6		
2	fluorene	-		1.48E-4	1.51E-4	1.34E-3	3.25E-5
3	Naphthalene	8.03E-4	7.30E-4	6.92E-4	6.59E-4	-	-
4	Fluoranthene	4.59E-4	5.910E-4	4.24E-4	4.46E-4	4.98E-4	1.32E-3
5	Phenanthrene	-	-	-	-	0.0000	1. 09E-4
6	Dibenzo (a-h) anthracene	2.53E-1	2.73E-1	3.03E-1	2.29E-1	6.38E-1	2.28E-1
7	Benzo (α) anthracene	4.54E-2	5.11E-2	2.35E-2	2.82E-2	6.89E-2	7.51E-2
8	Acenaphthene	7.02E-4	6.37E-4	-	-	2.17E-4	2.35E-4
9	Benzo (a) pyrene	2.23E-1	2.78E-1	2.02E-2	1.78E-1	-	-
10	Benzo (g_h_i) perylene	-	-	0.0000	0.0000	-	-
11	Benzo (k) fluoranthene	-	-	-	-	4.75E-2	4.32E-2
12	Pyrene	1.48E-4	2.03E-4	-	-	-	6.69E-4
13	Benzo (b) fluoranthene	-	-	-	-	1.00E-2	1.05E-2
Total	**or Risk index**	**5.24E-1**	**6.04E-1**	**3.47E-1**	**4.97E-1**	**7.66E-1**	**3.59E-1**

"-" stands for not evaluated as the PAH was not detected.

augmented charcoal had the highest risk index. This risk index shows the possibility of developing cancer by consuming all the PAHs identified in the roasted yam samples.

4. Conclusions

Roasting yam is a practice that Africans may not desert any time soon. However, there were about 9 PAHs detected in the roast yam species investigated in this study. Moreover, the study indicates that there is a risk of health complications including cancer associated with the consumption of roasted yam. The findings also suggest that bitter yams possess more threat than white yam if consumed at the same rate. This work also indicates that roasting with augmenting charcoal seems to be more dangerous than other roasting strategies. Therefore, people who consume roasted yams should be made aware of the possible health predicaments associated with consuming roasted yams, especially those roasted with augmented charcoal. One limitation of the risk assessment was the number of samples used; therefore, future research and assessment of risk should be done with more samples of the species of interest.

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