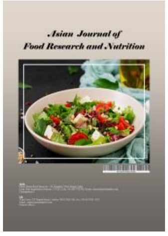

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Polycyclic Aromatic Hydrocarbons, PAHs Contamination Levels and Health Risks in Foods Consumed in Nigeria: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rate of increase in the number of cancer patients in Nigeria is alarming and calls for constant investigations into polycyclic aromatic hydrocarbons, PAHs and other pollutants. PAHs can be explained as a set of organic compounds which are generated and dispersed into the atmosphere as a result of incomplete combustion of organic materials such as crude oil, coal, wood, and are carcinogenic and genotoxic in nature. They are generally found in various components of the natural environment such as foods, soil, air, water This study aimed at developing a comprehensive report on PAH pollution and its human health risks recorded in the Nigeria. Fifteen studies were selected on PAHs contamination levels and health risk

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assessment in the following food categories: grains and grain products; seafoods; protein foods; leafy and fruit vegetables. The selected studies were reviewed based on the following information: authors, year of publication, aim of study, area of study, period of sampling, type(s) and number of samples collected, analytical technique, number and concentrations of PAHs identified, risk assessment and potential sources (in some of them) of PAH pollution in the study area. The margin of exposure, MOE adopted by the European food security authority, EFSA Scientific Committee and based on the bench mark dose lower confidence limit for a 10% increase in the number of tumour bearing animals compared to control animals ($BMDL_{10}$) was used for risk assessment of genotoxic and carcinogenic substances. The values of MOE (calculated by dividing the lowest $BMDL_{10}$ values with the estimates of dietary exposure to benzo[*a*]pyrene (0.07), PAH2 (0.17), PAH4 (0.34) and PAH8 (0.49)) obtained in the reviewed studies were mainly higher than 10,000. This according to EFSA indicate low concern for human health and considered low priority for risk management actions. While few recorded MOE values less than 10,000 indicating concern for human health. Some reviewed studies reported mean values of PAHs low than the permissible limit by some regulatory bodies while some reported higher values. It is recommended that prompt action should be taken by the Policy makers and stakeholders to ensure human health protection and also future studies should focus on PAH pollution in fruits, vegetables, farmlands, soils, water, ambient air and the human health risks involved in each case

Keywords: Polycyclic aromatic hydrocarbons; food; contaminations; health risk; review.

1. INTRODUCTION

Polycyclic aromatic hydrocarbons (PAH) include all organic compounds with two or more fused aromatic rings made up of mainly carbon and hydrogen atoms. They are generated and dispersed quotidianly into the environment during incomplete combustion of organic materials [1,2,3]. The major sources of PAHs are the exhaust of motor vehicles, petroleum refineries, heating in power plants, combustion of refuse, deposition from sewage, oil/gasoline spills, tobacco smoke, barbeque smoke, and coke production.

There are over 100 PAH congeners (including parent PAHs and alkylated derivatives) identified in the environment. The United States Environmental Protection Agency [4] has established that 16 of them are priority pollutants due to the health risks they pose to human being. They are chrysene, (Chy) acenaphthylene, (Ace) acenaphthene, (Acph) phenanthrene, (Ph) anthracene, (AnT) fluoranthene, (Flu) fluorene,(Fl) pyrene,(Pyr) naphthalene, (NaP) benzo[*b*]fluoranthene, (BbF) benzo[*k*]fluoranthene, (BkF) benzo[*a*]pyrene, (BaP)benzo[*a*]anthracene, (BaA) dibenz[*a,h*]anthracene,(DahA) benzo[*g,h,i*]perylene, (BghiP) and indeno[*1,2,3-cd*]pyrene (IndP) [4].

The properties of PAHs are determined by the number of rings and their molecular mass [5]. PAH congeners that possess four or more rings are described as high molecular weight (HMW) PAHs and they include fluoranthene, pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene, benzo[g,h,i]perylene. While congeners with two or three benzene rings are described as low molecular weight (LMW) and they include naphthalene, acenaphthylene, acenaphthene, fluorine, phenathrene and anthracene [5,2,3]. Heavy PAHs are more stable and toxic than the light PAHs [6]. Benzo(*a*)pyrene [B(a)P], a well-known PAH congener, is used to represent PAHs as it is considered by the International Agency for Research on Cancer [7] as a known carcinogen and suggested its use as a marker of occurrence and effect of the carcinogenic PAHs.

The EFSA Panel on Contaminants in the Food Chain (CONTAM Panel) concluded that the risk characterisation should be based upon the PAHs for which oral carcinogenicity data were available, i.e. for benzo[*a*]pyrene and the other PAHs that were measured in the two coal tar mixtures used in the carcinogenicity studies of [8]: benz[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*ghi*]perylene, chrysene, dibenz[*a,h*]anthracene and indeno[*1,2,3-cd*]pyrene. The CONTAM Panel concluded that these eight PAHs (PAH8), currently constitute the only possible indicators of the carcinogenic potency of PAHs in food. The sum of benzo[*a*]pyrene, chrysene, benz[*a*]anthracene and benzo[*b*]fluoranthene (PAH4) and the sum of benzo[*a*]pyrene and chrysene (PAH2) were calculated. The use of PAH8 and PAH4 for MOE approach has been established for risk assessment of PAHs in foods [9]. Different types of foods use PAH8, PAH4 and PAH2 for the exposure calculation and estimation of margins of exposure (MOEs) based on the bench mark dose lower confidence limit for a 10% increase in the number of tumour bearing animals compared to control animals ($BMDL_{10}$) [10]. PAHs being carcinogenic and mutagenic in nature are potent immune suppressants and can interfere with the normal function of DNA [11]. Human beings may be exposed to these substances at home, outside or at workplace through inhalation, ingestion or dermal contact. The effects of PAHs are carcinogenicity (biochemical disruption and cell damage, mutations, developmental malformation, tumors and cancer), teratogenic (birth defects, premature delivery, childhood asthma, heart malfunctioning, DNA damage, low IQ) genotoxicity, (harmful effects on skin, body fluid). These were observed after long term PAHs exposure and confirmed by toxicological experiments [12].

The quotidian character of PAHs, their exposure and toxic effects on living organisms in the environment constitute a significant risk to human health and these effects may occur due to short- and long-term exposure to PAHs [13,3]. The two highest contributors to the dietary exposure were cereals and cereal products, and sea food and sea food products. Food can be contaminated by environmental PAHs that are present in air, soil or water, by industrial food processing methods (e.g. heating, drying and smoking processes) and by home food preparation (e.g. grilling and roasting processes).

Several studies reported PAHs contaminations and health risk assessment in some foods commonly consumed in Nigeria – grains and its products, [14,15,16,17] vegetables and vegetable oils,[18,19,20] sea foods [21,22,23] edible mushroom [24], meat [25,26,27], fish [28,29]. Some studies reported PAHs contamination levels lower than the established permissible limit while some higher. For risk assessment, some studies revealed that the values of margin of exposures, MOEs gotten from the indicators exceed 10000 indicating low concern for human health as established by EFSA and are therefore concluded to be of low importance for risk management actions. While some reported that MOEs values recorded for PAH2, PAH4 and PAH8 were below 10000 indicating concern for human health as proposed by EFSA and are regarded very important for risk management actions. This is the right time for the public and researchers to evaluate these studies and create the awareness of PAH pollution and the health effects in Nigeria through review. This present study intends to review and record the extent of PAH contaminations in various foods commonly consumed in Nigeria and the health havocs involved. The data reported by the chosen studies were reviewed and also proffer possible solutions to environmental problems in Nigeria.

2. METHODOLOGY

2.1 Procedures used for Searching and Selecting PAH-related Studies

Studies published from 2013 to 2022 were searched for and selected for review. Twenty published studies were selected for reviewed.

Search process included the following keywords "Polycyclic Aromatic Hydrocarbons contamination and risk assessment in foods consumed in Nigeria". Different studies were selected based on the following classes of foodstuff: PAHs in grains and grain products; PAHs in seafoods; PAHs in protein foods; PAHs in vegetable and vegetable oils. The selected studies were then assessed for relevancy. Concerning studies that were published twice, researchers decided to choose the one that was most recently published with adequate information on identified PAHs.

2.2 Data Extraction

After suitable studies were selected, a set of information describing each study was extracted: authors, year of publication, aim of study, area of study, period of sampling, type(s) and number of samples collected, analytical technique, number and concentrations of PAHs identified, risk assessment and potential sources of PAH pollution in the study area.

2.3 Daily Estimated Intake

Deterministic approach was applied in finding the dietary intakes of the 16 PAHs. This involved multiplying a fixed value for the contaminant concentration in that food with the fixed value of consumption of an individual food. The total exposure was gotten by adding the intakes from all foods, applying this equation:

Estimated daily Intake (EDI) = ∑Consumption rate × Occurrence / Body Weight

2.4 Risk Assessment

Margin of exposure (MOE) as established by the EFSA Scientific Committee in the Opinion related to substances was applied for risk assessment which are both genotoxic and carcinogenic [10]. MOEs were calculated by dividing the lowest $BMDL_{10}$ values among the models with acceptable fits by the mean and high level estimates of dietary exposure to benzo[*a*]pyrene, PAH2, PAH4 and PAH8. The EFSA Scientific Committee established that for high level consumers, MOE values below or close to 10,000 [10] implies a potential concern for consumer health and therefore requires attention for risk management. While the MOE values of 10,000 or higher implies low concern for human health and requires little or no attention for risk management.

$$MOE = BMDL_{10} / EDI$$

Where BMDL10 is the benchmark dose lower confidence limit at 10% incidence level. Considering a BMDL10 of 0.07, 0.17, 0.34 and 0.49 all in mg/kg bw per day for BaP, PAH2, PAH4 and PAH8, respectively; EDI is Estimated Daily Intake; where:

BaP = Benzo[a] pyrene
PAH2 = Benzo [a]pyrene and chrysene
PAH4 = Benzo [a]anthracene, benzo[a] pyrene, benzo [b] fluoranthene and chrysene
PAH8 = The sum of eight carcinogenic PAHs: benzo [a] anthracene; benzo [b]fluoranthene; benzo [k] fluoranthene; benzo[g,h,i]perylene; benzo [a]pyrene; chrysene; dibenz[a,h]anthracene; and indeno[1,2,3-C,d] pyrene [9].

2.5 Toxic Equivalency Factor (TEF)

The concentrations of cPAHs obtained were used to find the Total Toxic Equivalence Factor (TTEF) for the analyzed samples. The mathematical expression to determine the toxicity equivalent concentration is given thus:

Total Toxicity Equivalence Concentration (TTEC) or TEQ =∑ Cn × TEFn

Where;

TTEC = Total Toxicity Equivalent Concentration,
TEQ = Total Toxicity Equivalence
Cn = Concentration of the individual cPAH in the mixture
TEFn = Toxic equivalent factor of the individual cPAH associated with its respective mixture [9].

3. RESULTS AND DISCUSSION

3.1 Contamination Levels and Risk Assessment of PAHs in Foods Consumed in Nigeria

3.1.1 Grains and grain products

The study carried out by Odika et al. [14] on risk assessment of polycyclic aromatic hydrocarbons in foreign and local rice consumed in South East Nigeria aimed at determining the quantity of polycyclic aromatic hydrocarbons in foreign and local rice consumed in South East Nigeria; estimating the daily intake amount and the health risks associated with the consumption among adult male and female individuals in South East Nigeria. Eighteen (18) samples which included different types of rice, foreign rice (Indian rice, Royal Stallion, Thailand rice): local rice (Abakaliki, Lafia , Adani.) were purchased from some major markets in Enugu and Anambra states of Nigeria. Extraction of PAHs from the samples was by sonication followed by clean-up. Recovery experiments to optimize PAH extraction from grain samples were carried out. Following a good recovery, the samples were analyzed of sixteen PAHs contamination levels using gas chromatography coupled flame ionization detector. The authors reported contamination of the samples with 16 PAHs but the contamination levels were much lower than the permissible limit 1.0 µg/kg established by EFSA. From the estimated daily intake, total dietary exposure of male was less than that of female indicating that female daily intake of rice is higher.

They also reported that the MOE values gotten for all PAH2, PAH4 and PAH8 were above 10,000 implying low concern for human health as established by EFSA and requires little attention for risk management. The result of their study supplied base values for future monitoring of contamination levels of rice grains and equally revealed the safety of consuming both local and foreign rice obtained from market in South East Nigeria can be ascertained. They recommended that other varieties of foods, should be on regular analysis to ensure their safety with respect to PAHs.

Another study by Odika et al. [15] on health risk of PAHs from wheat (*Tritcum specie*), bambara nut (*Vigna subterranea*) and pigeon peas (*Cajanus cajanifolia*) was reviewed. The study aimed at determining the PAH contamination levels and assessing the health risk of consuming different types of wheat, bambara groundnut and pigeon peas in the Eastern part of Nigeria. Eighteen (18) samples which included different types of wheat, (hard and soft) bambara groundnut, (pure white and mixed white): pigeon peas, **(**white and red) were bought from some major markets in Enugu and Anambra states of Nigeria. They extracted PAHs from the samples using sonication while the analysis of sixteen priority PAHs in the grain samples was by gas chromatography coupled with flame ionization detector, GC-FID. Adult male and female consumers were used to estimate daily intakes while the assessment of health risk was by MOE applying bench mark dose levels for the indicators-BaP, PAH2, PAH4 and PAH8. The three analyzed grains contained the sixteen PAHs but at the level very much lower than 1.0 µg/kg which is the permissible limit established by EFSA for cereals and cereal based products. Estimation of daily intake revealed that adult female individuals are more exposed when compared to their male counterparts. The MOE values gotten from all the indicators were above 10000 implying low concern for human health and required little attention for risk management This study grantees safety of consuming these grains. The data from this study can be used by the legulatory bodies to establish limits for legume grains (bambara groundnut and pigeon peas). The authors recommended that the environmental substances like foods, soil, water and air should be on regular chemical analysis to ensure their safety with respect to PAHs and other hazardous compounds.

A study by Ihedioha et al. [16] on risk assessment of polycyclic aromatic hydrocarbons in pasta products consumed in Nigeria was evaluated. The study objected to quantitatively determine the PAHs in pastas consumed in Nigeria, estimate the amount of daily intake and the possible risks to consumers. Sixty samples of various types of locally produced and imported pastas were collected in November 2014 from two Abuja and Enugu in Nigeria. Soxhlet extractor was used for extraction using mixture of n-hexane and dichloromethane while sixteen PAHs analysis was by gas chromatography coupled with mass spectrometer, GC-MS. There were detections of PAHs both in the locally produced and imported pasta. The amount of daily intake was done on low and high consumers and MOE was used to assess the risk to consumers. The sum of 16 PAH concentrations obtained in Nigerian type varied from 9 to 800µg/kg while that of imported brands varied from 2 to 7µg/kg. The MOE based on PAH8 for children taking small portion size (average consumers) was less than 10,000 in Nigerian brands while it was a bit higher for children taking big portion size (high consumers). The MOE values of imported type of pastas were above 10,000 for lowly and highly exposed children and adults. Ihedioha et al. [16] reported "a serious concern for consumers of certain Nigerian type of pastas especially for children, and a low concern for consumers (children and adults) of imported type of pastas. They recommended the necessities for setting permissible limits for PAHs in Nigerian foods, regular analysis of Nigerian types of pastas to ensure their safety for human consumption".

There was also a review on a study by Udowelle et al. [17] on health risk assessment and dietary exposure to PAHs, lead and cadmium from bread consumed in Nigeria. The study assessed the dietary exposure and health risk associated with consumption of bread from bakeries in Nigeria. The researchers collected sixty samples of bread from different types of bakeries located in Gusau Zamfara and Port Harcourt Rivers States in Nigeria. Extraction and determination of PAHs were by sonication and GC-FID respectively. From the result of their study, the presence of non-carcinogenic PAHs pyrene (13.72 µg/kg) and genotoxic PAHs (PAH8), benzo[a]anthracene (9.13 µg/ kg) recorded highest concentrations. The total benzo[a]pyrene concentration detected was 6.7 µg/kg in 100% of the analyzed samples. Estimated dietary intake of total PAHs for children varied from 0.004 to 0.063 µg/kg bw. day^{-1}, for adolescents from 0.002 to 0.028 µg/kg day^{-1}, for male from 0.01 to 0.017 µg/kg day^{-1}, for female from 0.002 to 0.027 µg/kg day^{-1} and for seniors from 0.002 to 0.025 µg/kg day^{-1}. Udowelle et al. reported that PAHs concentrations obtained in all bread samples were lower than permissible limit of 1.0 µg/kg for B[a]P set by European regulations for cereal processed foods. The study reported no significant difference between contamination profile of PAHs, Pb and Cd in wood and electric baked bread.

3.1.2 Protein foods

3.1.2.1 Fish

Ekere et al. [28] studied "the levels and risk assessment of polycyclic aromatic hydrocarbons in water and fish of rivers Niger and Benue confluence Lokoja, Kogi State, Central Nigeria. The researchers purchased twenty fish samples namely *Clarias spp* (Catfish) and *Oreochromis spp* (Tilapias) from fishermen at the bank of the river confluence. The extraction was carried out with Sohxlet apparatus using appropriate mixture of acetone and *n*-hexane solvent. Sequel to a good recovery result, which ranged from 99 – 104 %, GC-MS was used to analyze the PAHs in the samples. The values of the limit of detection and quantification varied from 0.0001 to 0.0002 µg/kg and from 0.0003 to 0.0007 µg/kg respectively. The six PAHs detected in water and fish samples were naphthalene(Nap), phenanthrene (Ph), anthracene (Ant), benzo [b] fluoranthene (BbF), benzo [k] fluoranthene (BkF) and benzo [a] pyrene (BaP) at the following concentrations (µg/L) : in water, the detections were in the following ranges : Nap (Not Detected {ND} to 0.543), Ph(ND to 0.083) Ant (ND to 0.083), BbF(0.080 to 0.093), BkF(0,083 to 0.093) and BaP(0.083 to 0.113)". "While in Catfish and Tilapia, the PAHs concentrations (µg/kg) ranges were Nap (2.383 and 1.947), Ph(0.050 and 0.057), Ant(0.057 and 0.057), BbF(0.043 and ND), BkF(0.043 and ND) and BaP(0.050 and ND). From the result of the risk assessment carried out using MOEs approach, it was revealed that there was need for risk management actions. Correlation studies showed no significant difference between PAHs in water and fish, that the PAHs were from the same source. Benzo[a]pyrene concentration values in water and Catfish was high compared to concentration limit of 0.01 µg/L in water by Environment Canada and should be of concern. The researchers recommended that serious attention should be given to waste disposal and improvement measures to taken against indiscriminate dumping of petroleum products and domestic waste in the water and also burning of tyres, organic and petroleum products which are the major sources of these PAHs" [28].

Another study by Tongo et al. [29] "on human health risk assessment of PAHs in smoked fish species from markets in Southern Nigeria was reviewed. Four frequently taken smoked fish species from markets in Southern Nigeria were analyzed of sixteen PAHs and assessed of the possible human health risks associated with their consumption. The analyzed fish samples which include *Clarias gariepinus*, *Tilapia zilli*, *Ethmalosa fimbriata*, and *Scomber scombrus* were randomly collected from three major markets Oreogbeni, New Benin and Santana market in Southern, Nigeria". Extraction of PAHs from the samples was carried out based on the method described by Babatunde et al. [30]. The extracts were cleaned up concentrated and analyzed for PAHs using GC-MS. The result of the study showed that the concentrations of PAH4 detected in smoked fish species were respectively (0.45, 0.22, 0.26, 0.47, 0.16) mg/kg for *C. gariepinus, T. zilli, E. fimbriata, and S. scombrus*. The detected concentrations were higher than the established limits of 0.03 mg/kg by the European Union [31] for PAHs in smoked fish and smoked fishery products. From the reported result, taken of these varieties of fish would be of human health concern. The researchers attributed the high values of PAHs in the analyzed samples to the smoking process adopted in course of preparation and preservation. Smoked foods mostly fishes, contain a good number of PAHs, as a result of wood smoke [32] which has been recorded to have high number of PAHs [33]. The human health risk assessment using carcinogenic toxic equivalents (TEQ) approach revealed that the values for all the analyzed fish species were below the estimated screening value (SV) of 3.556 mg/kg. While the estimated cumulative excess cancer risk (ECR) for *E. fimbriata* and *C. gariepinus* and PAH4 index for all the analyzed fish varieties were higher than the accepted values implying potential carcinogenic risk when consumed. The researchers concluded from the result the exposure and potential human health risk from consuming smoked fish from Southern Nigeria. They advised that the fish eaters and sellers should be educated on the safer method to process and preserve fish.

3.1.2.2 Meat

There was also a review of the study by Dan et al [25] "on health risk assessment of polycyclic aromatic hydrocarbons in singed and unsinged *Capra aegagrus* Hircus meat from Uyo Municipal Abattoir in Southern Nigeria. The researchers evaluated the PAHs concentrations in singed and unsinged liver and kidney samples and the accompanied health risks on adult and children population. They applied solvent extraction and used GC-MS to determine PAHs contamination levels in samples and reported that using car tires and condemned plastics to sing *C. aegagrus* hircus could pose the potential carcinogenic risk in humans when consumed. The result showed that the total PAH concentrations for singed liver samples ranged from 44.70-48.23 mg kg^{-1} while that of unsinged liver was 23.53 mg kg^{-1} .Comparably the total PAH concentrations for singed kidney ranged from 66.89 to 71.51 and 34.63 mg kg^{-1} for unsinged kidney sample. The researchers also reported that the values of hazard quotient and index of singed and unsinged samples indicated no substantial non-carcinogenic risk relating to exposure to either individual polycyclic aromatic hydrocarbons or complex PAHs mixture through consumption of liver and kidney of *C. aegagrus* hircus..The result of the study provided reasonable evidence on the need to fully evaluate the risks of PAHs in the singed meat to safeguard the health of the consumers".

Another study on health risk assessment of PAHs in charbroiled meat commonly consumed in Port Harcourt metropolis by Okpara-Akpotu et al. [26] was reviewed. The study aimed at assessing PAHs concentrations in four selected commonly taken charbroiled meats (croaker fish, *Micropogonias undulatus*, chicken, *Gallus gallus domesticus*, pork, *Sus scrofa domesticus*, beef, *Bos Taurus)* and the potential health risks associated with their consumption. The eight samples were bought from various roadside barbeque stands at Mile 4 and Choba in Obio-Akpor local government area in the city of Port Harcourt. The PAHs were extracted from the samples by solvent extraction while the analysis of PAHs was carried out using GC-MS. The result revealed that the levels of PAHs in croaker fish, chicken, pork and beef collected from Mile 4 were significantly lower at $p<0.05$ in comparison to the concentrations of PAH in croaker fish, chicken, pork and beef collected from Choba. The highest mean individual concentration was recorded for Benzo (a) pyrene in croaker fish (0.733±0.015mg/kg) and pork (0.733±0.021mg/kg) from Choba and Mile 4 respectively and were above the maximum permissible limits as recommended by the USEPA. Benzo(a) pyrene levels were significantly higher than European Union(EU) limit of 2.0µg/kg(0.0002mg/kg for meat. Data from the study highlighted a potential health concern for the indigenes of Choba and Mile 4 as the estimated daily intake of PAHs in four commonly consumed charbroiled meats exceeded the permissible daily intake level of 5.0 µg/kg established by EFSA. [9] Moreso, the Hazard Indexes across the study areas were less than one (1) suggesting that no potential adverse health risk may exist. The carcinogenic potency equivalency relating to benzo(a) pyrene B(a)P of charbroiled meats at both study sites exceeded the critical allowable limit for carcinogenic PAHs thus suggesting potential adverse health effect for population at Choba and Mile 4. The researchers with respect to health risk estimated in their study strongly recommended that subsequent dietary intake of the commonly consumed meats around industrial areas or close to the main roads should be discouraged.

3.1.2.3 Mushroom

Study by Igbiri et al. [24] on "PAHs in edible mushrooms from Niger Delta, Nigeria: Carcinogenic and non-carcinogenic health risk assessment carried out in oil-rich Niger Delta. The researchers assessed of PAH concentration levels in wild and cultivated edible varieties of mushroom normally consumed in Niger Delta, Nigeria. Ten mushroom samples were collected in triplicates and extracted of PAHs by sonication. The determination of sixteen PAHs was carried out using GC-MS and risks evaluation were calculated applying MOEs. The result showed that the concentrations of 16 PAHs detected varied from 0.02 mg/kg to 3.37 mg/kg. The dietary intake of 16 PAHs for adults, adolescents and seniors ranged from 0.00 to 0.05 mg/kg/day, 0.00 to 0.06 mg/kg/day and 0.00 – 0.07 mg/kg/day respectively. The BaPeq varied from 0.02 to 2.76 with margin of exposure MOE values of BaP ranging from 3,500,000 to 700,000, 3,500,000 and 3,500,000 to 7,000,000 for adults, adolescents and seniors respectively indicating no health risk concern. The incremental lifetime cancer risk was within the safe range of 1.56×10^{-8} – 1.73×10^{-6} with the highest calculated risk found for wild *Pleurotus ostreatus* mushroom species from the study area. The researchers concluded from the result of the study that mushrooms studied seemed relatively safe for consumption and recommended the need for regular studies on the PAHs concentration levels and health risk assessment in other agricultural produce within the region with a view to determine the extent of contamination and the health risk associated with these natural product consumption by the general population".

A study by Taiwo et al. [27] on the level and health risk assessment of polycyclic aromatic hydrocarbons in protein foods from Lagos and Abeokuta, Southwestern Nigeria was also reviewed. The researchers assessed the levels and health risk of PAHs in protein foods obtained from selected locations in Lagos and Abeokuta. A total of forty eight protein food samples which include meat, cowskin, fish and crayfish (raw and smoked types) were collected in triplicates across the sampling sites. The samples were subjected to chemical analysis of PAHs using standard methods. Data collected were computed using simple descriptive statistics of mean and standard deviation using SPSS version 22.0. The health risk assessment was evaluated for average daily dose (ADD), hazard quotient (HQ), hazard index (HI) and cancer risk (CR) using the United States Environmental Protection Agency model. Results of the study recorded higher ∑PAHs concentrations in protein food samples from Abeokuta than those from Lagos (except smoked cowskin). Indeno[1,2,3-cd]pyrene (96.817 ± 65.922 mg kg^{-1}) was the highest PAH congener measured in protein foodstuffs (raw fish samples from Abeokuta). The ∑CR values of PAHs in Abeokuta smoked fish and crayfish (raw and smoked) samples were above the permissible risk level of 1.0×10^{-4} implying possible risk of developing cancer through consumption of protein foodstuffs. The researchers concluded from the result of their study that PAH levels were generally higher in smoked than raw protein food samples.

3.1.3 Sea Foods

The study of Dokubo et al [23] on "assessment of PAHs in shellfishes (whelk, oyster and periwinkle) from Kula, Rivers State, Nigeria revealed bioaccumulation of PAHs in the analyzed samples due to anthropogenic activities going on in the study region. The researchers analyzed the samples of PAHs applying the recommended methods by USEPA (1986). The PAHs determination was done using, GC-FID and assessment of health risk was calculated using estimated daily intake (EDI) and margin of exposures (MOEs) approach to characterize risks of PAHs exposure to non cancer (Hazard Index) and excess cancer risk (ECR)". "From the results, BaA had highest concentrations in whelk (0.689±0.003) and periwinkle (0.930±0.001) while naphthalene had highest concentration in oyster (2.000±0.000). The Total concentration of PAHs in µg/kg for whelk, oyster and periwinkle were 1.797±0.013, 3.977 ±0.024 and 1.564±0.017 respectively while the EDI of PAHs (mg/kg/day) through consumption of shell fish varied from $2.00x10^{-4}$ to $6.40x10^{-2}$, $7.0x10^{-4}$ to 1.86 $x10^{-1}$ and 0 to $8.64x10^{-2}$ being higher than oral reference dose (RFD) respectively. The toxic equivalents (TEQs) values of $1.276x10^{-4}$, $1.252x10^{-4}$ and $4.034x10^{-4}$ for whelk, oyster and periwinkle respectively were significantly ($p<0.05$) higher than the screening value (SV) for shellfish ($1.81x10^{-5}$mg/kg). The ECR obtained for whelk was ($3.0x10^{-4}$), oyster ($2.00x10^{-4}$) and periwinkle ($3.24x10^{-4}$), these values were very much higher than USEPA acceptable limit ($1x10^{-4}$). The researchers concluded from the results that bioaccumulation of PAHs in the sea organisms due to anthropogenic activities such as illegal oil refining going on in the study area was a potential health hazard to consumers. Sequel to their findings, the researchers recommended the need for policymakers and other stakeholders to monitor the anthropogenic activities resulting from increased emission of PAHs in the area of study and protect local residents from the ugly health risk of being exposed" [23].

Olayinka et al [22] analyzed "PAHs in sediments and assessed the health risk of consuming fish, crab and shrimps around Atlas Cove, Lagos Nigeria. The study determined the PAHs concentrations in sediments and two species of fish, (*Drepane africana* and *Pomadasys jubelini*), crabs (*Callinectes amnicola*) and shrimps (*Penaeus notialis*) around Atlas Cove jetty Lagos Nigeria. The authors of this study collected forty five samples of sediment from five different locations around Atlas Cove jetty and purchased twelve samples of each fish species, 20 samples of shrimps and crabs from local fishermen at the landing site of the study area. The samples were extracted of PAHs using soxhlet extractor using 1:1 ratio mixture of hexane and dichloromethane. The PAHs analysis was carried out using GC-MS while human health risk was assessed using dietary daily intake and carcinogenic potencies of individual PAH concentrations. The authors detected 17 PAH congeners in sediment samples and ten in biota samples. The total PAHs concentrations recorded in sediment and fish samples varied from 2.15 - 36.46 mg/kg and 11.89 - 71.06 mg/kg respectively. The estimated dietary intake recorded 0.10 - 2.33 mg/kg body weight/day of the organisms while toxic equivalent quotient recorded 0.01 to 0.10 mg/kg and were observed to be higher than the screening values of 0.0014 to 0.0599 mg/kg. The researchers reported that the PAHs concentrations in analyzed sediment and organisms were above the maximum permissible limit of the United State Environmental Protection Agency (USEPA). They inferred from the results obtained that PAHs high concentrations in the organisms was due to bioaccumulation of compounds in their tissues and organs over a period of time. The calculated TEQ values were above the screening values indicating potential health effects. The authors concluded that from the result that most of the detected PAHs were of petrogenic origin, indicating that anthropogenic activities were influencing PAH concentrations in the analyzed organisms".

3.1.4 Vegetables

A study by Okereke et al [19] on distribution and risk assessment of PAHs in vegetables and agricultural soils from two communities in Rivers State, Nigeria was also reviewed. The researchers collected fresh samples of three commonly consumed vegetables: *Telfairia occidentalis (Fluted Pumpkin),* Ocimum grattissimum (Scent leaf), Vernonia amygdalina (Bitter leaf), 3 tubers: Cassava (Manihot esculenta), Cocoyam (Colocasia esculenta), Yam (Dioscorea rotundata) and farm soil samples from farms in Alakahia and Eleme communities. Six samples comprising of three vegetables and three tubers were collected from each site. Soxhlet extractor was used to extract PAHs from the samples using mixed solvents while GC-FID was used to determine PAHs. The result of the study showed detection of 14 and 16 PAHs in the farm soil from Alakahia and Eleme respectively and PAH concentrations at both sites ranged from 0.00 – 47.45 µg/kg. The researchers reported that the total PAH concentrations in the vegetables were generally below the permissible limit of 10ppb established for foods of plant origin. They recommended the need for health concern and continuous monitoring of the PAH levels because of increased anthropogenic activities and vegetable consumption by the people in Alakahia and Eleme. The researchers also reported that carcinogenic Potency equivalent concentration (µg/kg) for vegetables collected from Alakahia ranged from 0.31- 1.51 and that of Eleme ranged from 0.37 - 0.97. These values were above the screening value (0.23) for vegetables, implying that danger involvement in the consumption of such vegetables.

Another study on the determination of PAHs in some foods from industrialized areas in South Eastern Nigeria: human health risk impact by Onyedikachi et al [18] was reviewed. The analyzedsamples which included; (i) vegetables, i.e. bitter leaf (*Vernonia amygdalina*), water leaf (*Talinum triangulare*) and pumpkin leaf (*Telfairia occidentalis*); (ii) tubers, i.e. yam (*Dioscorea alata*), cocoyam (*Colocasia esculenta*) and cassava (*Manihot esculenta*); (iii) fruits, included orange (*Citrus sinensis*), paw paw (*Carica* papaya), star apple (*Chrysophyllum albidum*); (iv) nuts, i.e. kola nut (*Cola acumulata*), palm kernel nut *(Elaeis guineensis jacq*) and coconut (*Cocos nucifera*) were harvested from farmlands close to the industries (study sites) at Osisioma, Akwuuru, Ishiagu, Ngwo, and Irete. Umudike (a university farmland devoid of industries) was the control for this study. The authors extracted PAHs from the samples using solvent extraction followed by PAHs determination using GC-FID. Recovery test was used to validate the extraction and analytical methods. The result revealed that the mean concentration of PAHs in food samples ranged from below detection limit (< 0.01) to 2.64 ± 0.02, 5.27 ± 0.04, 0.96 ± 0.02, 8.94 ± 0.01 and 1.95 ± 0.06 mg/kg for Star apple collected from Osisioma, pumpkin leaf from Ishiagu, and bitter leaf from Irete, Akwuuru and Ngwo respectively. The authors attributed it to the uptake of PAHs by plant through gaseous and particle bound deposition [34,35]. The result showed that the total PAHs concentrations in most crop samples had highest values 14.49, 36.29, 4.59, 23.36 and 21.8 in mg/kg for *Chyrysophyllum albidum, Telferia occidentalis, Vernonia amygdalina, Talinum triangulare* and *Elaies guinnensis* for Abia (Osisioma), Anambra (Akwuuru), Imo (Irete), Ebonyi (Ishiagu) and Enugu (Ngwo) respectively. The values were higher than the European Union regulatory limit of 0.2 mg/kg d.w. in foods implying possible health risk of exposure to PAHs. The study revealed that vegetables from all the areas accumulated higher levels of PAHs significantly ($p \leq 0.05$) compared to other classes of food crops analyzed. The authors attributed the abundance of PAHs in the analyzed vegetables to their relatively high solubility, volatility and bioavailability [36,37] and also to their large surface area which is in constant contact with air laden with dust and pollutants like PAHs [36]. They also attributed it to the nearness of agricultural lands to the industrial/urban areas where high levels of anthropogenic activities occur that is pollution source [38,39]. For health risk assessment, BaP in analyzed samples from study sites gave values above the DPR intervention limit of 0.01 mg/kg of B(a)P in some foods [39]. The incremental life time cancer risk has a predicted permissible lifetime risks for carcinogens as 10^{-6} (1 in 10,000,000) and 10^{-4} (1 in 10,000) range [40-44]. Values above this range indicate carcinogenic risk [9]. The authors reported the carcinogenic risk values for adults and children to be respectively 1.39 E-06, 1.54 E-06; 3.43 E-06, 3.79 E-06; 6.19 E-07, 6.87 E-07; 1.09 E-06,1.21 E-06; and 9.71 E-07, 1.05 E-06 for Osisioma, Akwuuru, Irete, Ishiagu and Enugu industrial locations. These CR values were within the predicted life time risks for carcinogens for adults and children. The authors reported that adults and children residing at industrial areas in South Eastern Nigeria may be at serious risk due to PAHs intake in foods overtime due to bioaccumulation of this toxic carcinogen and therefore recommended need for immediate action by policy makers and other concerned stakeholders help in establishing regulations in policy decisions and mitigating measures for environment and human health protections.

4. CONCLUSION

The present review study investigated on important information with regard to the occurrence, concentrations, sources (in some of them) and associated potential human health risks of PAHs in the foods consumed in Nigeria using reported results from selected studies. Majority of the selected studies reported PAH pollution occurring in various food consumed in Nigeria. While some studies reported PAHs values being above the permissible limits others reported PAHs values below the limit. From the studies reviewed, majority recorded values of margin of exposure, MOE above 10000 indicating no human health risk concern while few recorded MOE values lower than 10000 indicating human health concern according to EFSA. The PAHs identified in samples from the environments were of both fuel combustion, petrogenic and pyrogenic sources. Researchers recommended mainly on the need for regular studies on the PAHs concentration levels and health risk assessment in other agricultural products and also help of Policymakers and stakeholders to ensure environmental sanity. The reviewers of the present study hereby recommend more reported studies on other PAH groups such as alkylated PAHs and chlorinated PAHs considering their environmental relevance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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