

Review

A mini cutting-edge review of the levels of polycyclic aromatic hydrocarbons and their health implications in some vegetables in Nigeria

Edidiong Samuel Akwaowo¹ · Abib S. Lawal² · Hillary Onyeka Abugu¹ 

Received: 4 March 2024 / Accepted: 12 November 2024

Published online: 26 November 2024

© The Author(s) 2024 

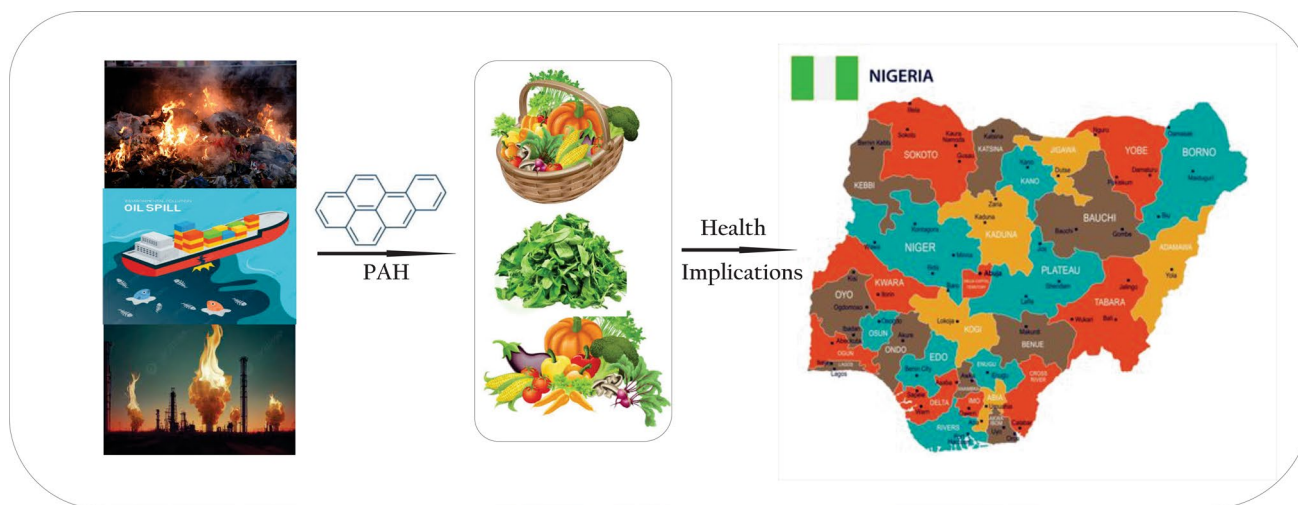
Abstract

Relevant research on polycyclic aromatic hydrocarbons (PAHs) concentrations and the health implications of the levels of PAHs in some vegetables in Nigeria were compiled using data obtained from a thorough review of contemporary literature between 2010 and 2023. Of the fifteen available studies on PAH in vegetables, around 67% of the studies sampled fluted pumpkin (*Telfairia occidentalis*). This could be a result of Fluted pumpkin being frequently used owing to its believed blood enrichment against anemia patients and having been shown to contain significant quantities of potassium and iron in its leafy vegetables and edible seeds. The vegetables with the highest PAHs concentrations followed the trend: Fluted pumpkin > African black pepper > Water leaf > Tomatoes > Others. Vegetables with high PAHs levels have been shown to contain less PAHs after being washed in distilled water and much less after being rinsed in a salt solution. This was mostly possible when the PAHs source(s) unto the vegetables were from dry depositions. The difference in PAHs concentration in the same type of vegetable from different locations revealed that there are different sources of PAHs to the vegetable in their respective locations. The potential for cancer risk and its impact on Nigerian health through continuous consumption of contaminated vegetables was evident. Therefore, vegetables are to be washed thoroughly before consumption at least to reduce the PAHs concentrations and in turn, its effects on man if such contaminated vegetables must be consumed.

✉ Hillary Onyeka Abugu, Hillary.abugu@unn.edu.ng; Edidiong Samuel Akwaowo, eddieakwaowo@gmail.com; Abib S. Lawal, abib.lawal@helsinki.fi | ¹Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka, Enugu, Nigeria. ²Department of Environmental Change and Global Sustainability, University of Helsinki, Helsinki, Finland.



Graphical Abstract



Keywords Environmental pollutants · Emerging contaminants · Edible vegetables · Health risks

1 Introduction

Vegetables are essential to human health since they are an excellent source of vitamins and minerals like iron and calcium. The majorities of vegetables are low in calories, and high in fiber, antioxidants, and water content (70%) [1]. For instance, Fluted pumpkin is known for its blood enrichment against anemia patients and has been shown to contain significant quantities of potassium and iron in its leafy vegetables and edible seeds, Vegetable meals with a lot of dietary fiber, such as pumpkin leaf, can aid in weight loss [2]. Vegetables are grouped differently, but according to the definition by Kalm-pourtzidou et al. [3], they are transient crops, unlike potatoes, legumes, and tubers, which are almost permanently grown. Vegetable intake in Nigeria has received a lot of attention as a result of a growing understanding of the health benefits of vegetables [4]. However, Nigeria was rated seventh in Africa (in 2022) for yearly vegetable consumption per capita, with an average of 75 kg of vegetables consumed, compared to the Food and Agricultural Organisation/World health organization (FAO/WHO's) recommendation of 146 kg per year per capita globally [5–7]. The safety of vegetables cannot be accounted for due to the population expansion/high demand for vegetables and the country's industrial development, as these factors increase the risk to consumers' health from toxin contamination [8]. The majority of vegetables can be poisoned by pre-infected soil or air deposition because they can grow on any soil [9]. Additionally, due to the effects PAHs has on the environment and people, out of all the poisons that have been recorded in the environment (such as pesticides, fertilizers, heavy metals, etc.), the presence of PAHs requires immediate attention [10, 11]. Human activities like burning of fossil fuels, petroleum cracking, oil spillage, the incineration of household and commercial waste, and many more, are typically to blame for soil contamination by PAHs [12].

Polycyclic aromatic hydrocarbons (PAHs) can be described as aromatic compounds without any heteroatoms or substitutes, with more than two fused benzene rings. Also, PAHs are planar aromatic compounds with varying potencies of carcinogenicity defined by their individual structures [13–15]. They can be small (about 4 benzene rings) or large (greater than 4 benzene rings), with the larger one supposedly being more poisonous and very stable [12]. The benzene rings of PAHs consist exclusively of carbon and hydrogen atoms, which are linked together in various ring configurations ranging from simple to intricate. These rings possess a wide range of distinct physical, chemical, and toxicological characteristics [14]. PAHs exhibit a pronounced lipophilicity and affinity for lipids, resulting in their limited solubility in water but significant solubility in the majority of organic solvents [16]. It has been observed that the initial soil concentrations, the microbial community, and the type of plant all influence how much PAHs is absorbed by plants [4]. Forest fires, volcanic eruptions, bacterial and microbial synthesis, deterioration of rock layers

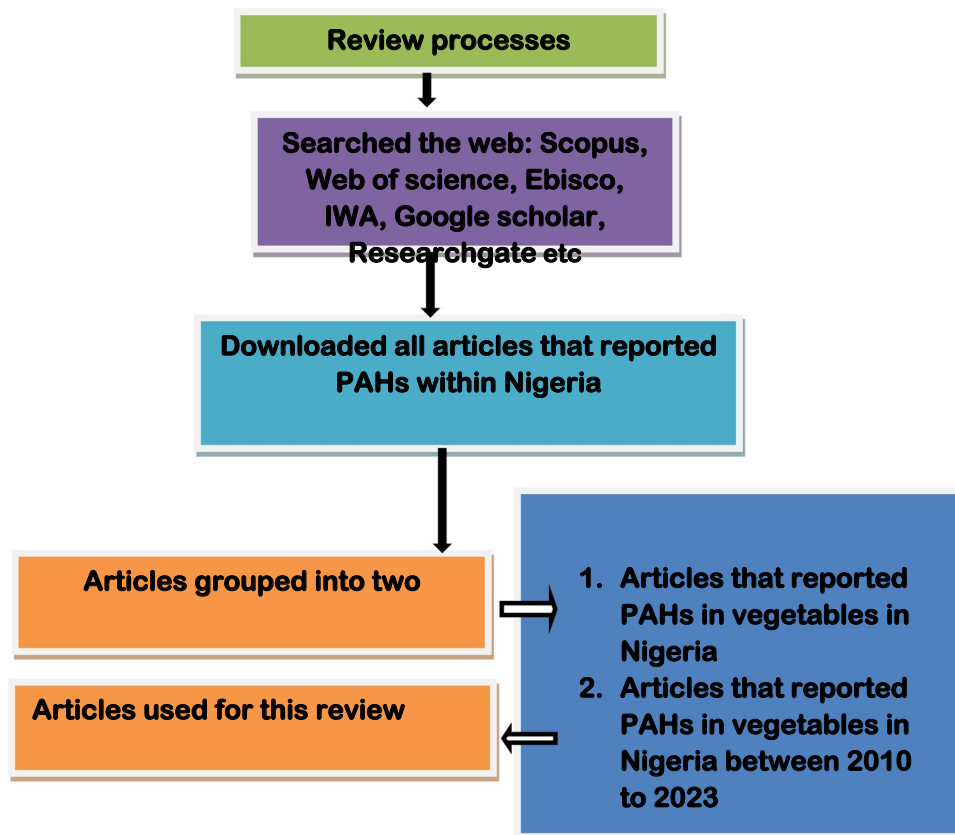
comprising hydrocarbons from oil, and decay of vegetative debris constitute natural conduits of PAHs production. Anthropogenic sources of PAHs include certain industrial operations involving incomplete combustion, automobile emissions, wood-burning stove smoke, airline emissions, smoking or tobacco fumes, crude oil accidental spills, as well as wastewater, among others [17–19].

PAHs could reach plants by the uptake of soil water by roots or by absorption through the stomata and they can accumulate in leafy vegetables than in root ones [20]. According to Rajendran et al. [21], they have been scientifically demonstrated to possess cancerous along with mutagenic properties. Environmental and public health organizations worldwide have been researching PAHs since 1970 [22]. Also, the health risks and concentrations of various polycyclic aromatic hydrocarbons have been reported in Nigeria in contaminated soil/farmlands [23, 24], water [8, 25], butter and edible oils [26], roasted food and meats [27, 51], fishes [28], pasta [29], rice [30, 31], higher plants [32], fruits [12, 15] and in edible vegetables [33, 34], etc. The objective of this study is to determine, compile, and summarize the levels of 16 priority polycyclic aromatic hydrocarbons (PAHs) in edible vegetable leaves in Nigeria from 2010 to 2023, and to assess the potential impacts on human health.

2 Methodology

A thorough review of the literature was done to assemble significant studies on PAHs contamination and its impact on human health in Nigerian vegetables. Standardized keywords and search engines were utilized to locate pertinent research publications, including Scopus, researchgate, Web of science, Ebisco, international water association (IWA), Google scholar. The papers were initially screened for titles and abstracts before retrieval, and then full-text screening was performed. Data on PAHs concentration, sample type, city (state), extraction method, analytical processes, PAHs, results, conclusion, and further study were mined from the qualified papers (Fig. 1).

Fig. 1 Flow diagram of the review process



3 Sample preparation, treatments and analysis

Before solvent extraction and organic solvent-based chromatography clean-up, the acquired vegetable samples are frequently oven-dried and homogenized using a blender/mortar and pestle. Before chemical analysis, other extraction techniques were carried out using an ultrasonic extractor, Soxhlet extractor or separating funnel (Table 1). Igbiri et al. [41] extracted PAHs from mushrooms and the surrounding environment using an ultrasonic bath (Elmsonic S40H). Before immersing the samples in an ultrasonic bath, the samples underwent extraction using a solution consisting of equal parts acetone and methylene chloride, which was augmented with 1 mL of the PAHs standard solution. Mass spectrometers, flame ionization and electron capture detectors have been coupled with the GC utilized by the different authors, while the HPLC instrument was coupled with a photodiode array detector. Lawal [14] noted that though these procedures ensure quality and sensitive data, sample preparation is labour intensive and it is expensive (Fig. 2).

4 PAHs in vegetables

Generally, vegetables and/or plants usually don't go in search of nutrients but nutrients get to them via deposition on leaves or absorbed by the root hairs (Fig. 3). Diffusion, root interception, and mass flow are the three mechanisms by which nutrients reach the hairs of the root surface [44]. Human exposure to environmental pollutants like PAHs can occur through vegetable consumption. According to Duan et al. [45], dietary consumption is one of the main ways that people are exposed to PAHs, and it is a very common form of exposure. Furthermore, studies have found that the levels of PAHs in vegetables are closely linked to the ambient levels of these contaminants as well as the biochemical and biological features of the vegetables [37, 46–48]. The recent discovery of PAHs in vegetables suggests a possible hazard to human well-being, as these vegetables may have been grown in soil, air, or water that was contaminated. Several different forms of uncooked food contain them at immeasurable quantities which is a reflection of their existence in the environment [14]. Based on the author's findings, plant-based lipids and oils include a greater amount of PAHs in their dietary category compared to meat. This is because PAHs levels are generally higher on the outermost layer of plants, such as foliage or peels, as opposed to the inner tissues of the plant.

Extensive research has been conducted on Polycyclic Aromatic Hydrocarbons (PAHs) in vegetables throughout Nigeria. The specific vegetables that have been subject to the investigation include: Bitter leaf (*Vernonia amygdalina*), *Lasianthera africana* (local name: Editan), Fluted Pumpkin leaf (*Telfairia occidentalis*), Green leaf (*Desmodium intortum* cv), Mushroom, African black pepper (*Piper guineense*), Scent leaf (*Ocimum gratissimum*), Carrot (*Daucus Carota*), Tomatoes, Ewedu (*Corchorus olitorius*), Celosia argentea (Soko), Amunu tutu/White Spinach (*Basella alba*), Lettuce (*Lactuca Sativa*), Spring Onions/Alubasalewe (*Allium ascalonicum*), Water leaf (*Talinum triangulare*) and Utazi leaf (*Gnaphalium latifolium*) amongst others [4, 6, 15, 33–39, 49]. Notably, the majority research has been done just within the eastern and southern regions of the country (Fig. 4).

Also, when comparing the concentrations of different PAHs in vegetables studied, benzo(b)Flouranthene is observed to have the highest concentration (Table 1). Benzo(b)Flouranthene is formed during the partial oxidation of organic substances like coal, wood, oil, and gas and can be produced during certain industrial processes of which these activities are very peculiar to the cities reported in this research. Reports have it that exposure to this compound can lead to potential health effects such as cancer risk as they can accumulate in soil, sediments and water, posing a risk to humans, aquatic and other wildlife [16]. As shown in Table 1 above, levels of PAHs from different locations varied markedly as most vegetables were sampled in areas of high industrial activities [6], close to dumpsites or automobile repair workshop [35], places where wastewater are used for irrigation [40] and areas of high traffic especially in the markets [33, 37, 43].

According to studies conducted in the nation by Dan et al. [40] and Orhuamen et al. [50], water leaf and fluted pumpkin are the most popular and widely grown vegetables in Nigeria, respectively. Fluted pumpkin is also the vegetable that has been the subject of the most research. Among other vegetables, it was used in ten of the fifteen studies on vegetables that we uncovered throughout our review (Fig. 5). Adetunde et al. [4] reported that the fluted pumpkin exhibited steady growth across all soil types and their combinations indicating that the plant may possess some unique qualities that allow it to thrive even when planted in highly contaminated soils with high oil content

Table 1 PAH concentrations in different cities and methods of extraction in different vegetables

Vegetables	PAHs levels (mg/kg)	PAHs with high concentration	City/State	Method of extraction	Assay method	References
Bitter leaf	2.261	5 Rings: PAH (Benzo(a)Pyrene and Benzo(b)Flouranthene)	Asaba, Sapele, Ughelli & Warri	Soxhlet extraction	GC/MS	[6]
Green leaf	0.75					
Pumpkin leaf	1.324					
Water leaf	0.532					
Spring Onions	0.100–5.000	2–3 Rings PAHs	Lagos	Ultrasonic extraction	GC/MS	[4]
Lettuce						
Water leaf						
Pumpkin leaf						
White spinach		Anthracene and Phenanthrene,	Uyo	Separating funnel	GC/MS	[35]
Ewedu						
Shoko						
Tete						
L. Africanum	0.73	Benzo(b)fluoranthene	Owerri, Abia, Anambra, Ebonyi & Enugu	Separating funnel	GC/FID	[15]
V. amygdalina	0.81					
Bitter leaf	4.59					
Water leaf	23.36					
Fluted Pumpkin	36.29	Acenaphthylene	Aba south	Separating funnel	GC/MS	[34]
Water leaf	0.00–0.15					
Fluted Pumpkin	0.00–0.83					
Fluted Pumpkin						
Fluted Pumpkin	19.06 15.46 (UW) 9.49 6.43 (WTW) 2.35 3.47 (WSS)	Acenaphthylene	Abia (OkagweOhafia& Abia-Ohafia market)	Separating funnel	GC/MS	[33]
Fluted Pumpkin						
Fluted Pumpkin						
Fluted Pumpkin						
Fluted Pumpkin	0.3303–8.3716	Naphthalene	Rivers	Separating funnel	HPLC–PDA	[36]
Tomatoes	12.5 19.00 (UWS) 4.78 4.600 (WSD) 0.231 0.231 (WWW)					
Fluted Pumpkin						
Tomatoes						
Fluted Pumpkin		Fluorene Acenaphthene,	Ado-Ekiti (Ago-Aduloju& Sasha market)	Ultrasonic extraction	GC/FID	[37]
Scent leaf						
Bitter leaf						
Bitter leaf						
Utazi leaf	0.007	Benzo (a) anthracene	Rivers	Separating funnel	GC	[38]
Carrot	0.009					
Fluted Pumpkin	0.00273					
Scent leaf	0.00134					
Bitter leaf	0.00951	Pyrene	Alakahia & Eleme	Separating funnel	GC/FID	[20]
Water leaf	8.0×10^{-5} – 1.03×10^{-2}					
Fluted Pumpkin	3.0×10^{-5} – 1.02×10^{-2}					
Bitter leaf	6.0×10^{-6} – 1.28×10^{-2}					
Water leaf	6.53 7.33 5.12	Phenanthrene	Rumuosi&Choba	Separating funnel	GC/FID	[39]
Fluted Pumpkin	4.31 5.19 3.16					
Mushroom	0.02–3.37					
Bitter leaf	0.010–0.048					
Fluted Pumpkin	0.017–0.233	Acenaphthylene	Akwa Ibom	Separating funnel	GC/MS–MS	[40]
African Black Pepper (Uziza)	30.71 18.27 (UW) 22.18 15.59 (WTW) 8.31 1.20 (WSS)					
		Benzo(b)Flouranthene	Rivers	Ultrasonic extraction	GC/FID-ECD	[41]
		Benzo(b)Flouranthene	Port Harcourt	Soxhlet extraction	AAS	[42]
		Naphthalene Benzo[b]Flouranthene	Abia State (Oriegwabaisigate market)	Separating funnel	GC/MS	[43]

UW: Unwashed, WTW: Washed with tap water, WSS: Washed with an aqueous solution of sodium chloride, UWS: Unwashed, WSD: Washed with distilled water, WWW: Washed with warm distilled water

where other plants were unable to do so. The resilience of fluted pumpkin can also be linked to the following reasons [4, 58]; (I). Its ability to adapt to different light radiation conditions: whether very sunny, partially sunny or shady areas, it can thrive provided the soil is moist (II). It can also tolerate seasons of drought or limited soil water quantity.

This makes fluted pumpkin suitable for PAHs contamination site phytoremediation, claims the author. This implies that the level of soil pollution affects how much PAHs is absorbed by the produce. Additionally, the PAHs content in vegetables was highest in fluted pumpkin followed by African black pepper, water leaf, tomato and others.

In their research, Igwe et al. [33] investigated the occurrence of polycyclic aromatic hydrocarbons (PAHs) in fluted pumpkin samples obtained from two markets in Ohafia, Abia state. The researchers divided their sample into three parts: the original part was left not washed (UW), the subsequent portion was rinsed with tap water (WTW), and the last part was washed with an aqueous solution of sodium chloride (WSS) before undergoing the processes of being dried, grinding, and the extraction procedure. The authors elucidated that the concentration of PAHs in the samples exhibited a substantial reduction upon washing with water from the tap, and further diminished with washing with an aqueous solution of sodium chloride. Also, the same author gave similar conclusions when he carried out the same procedure but this time with African black pepper (*Piper guineense*) and in two different markets but in the same state.

In another piece of literature, three sections of tomato samples from two markets—one not washed (UWS), another rinsed with distilled water (WSD), and the third rinsed with lukewarm distilled water (WWW)—were evaluated for organic contaminants following established protocols. The measured concentrations (in milligrams per kilogram) for the Ago-Aduloju and Shasha samples showed that the ranges of polycyclic aromatic hydrocarbons (PAHs) were 0.447–12.5 and 0.231–19.000 [0.447 (WWW), 4.78 (WSD), and 12.5 (UWS) for Ago-Aduloju samples]. According to the findings, washing tomatoes in warm water is more effective than other methods in lowering pollutants [37]. This suggests that washing vegetables before eating them, particularly washing with purified water or a sodium chloride solution, is very crucial.

5 Health risks/effects of PAHs

Due to their harmful effects, PAHs have gained public attention in recent years, especially with the rate of industrialization growing faster and faster, causing pollution and environmental degradation. The rate of contamination is increasing year after year, and exposure to humans and the environment is inevitable [14]. PAHs, such as chrysene, indeno[1,2,3-cd]pyrene, benzo[b]fluoranthene, dibenz[ah]anthracene, benzo[k]fluoranthene, benzo[a]anthracene, and benzo[a]pyrene, are highly toxic and have been identified as potential human carcinogens by the International Agency for Research on Cancer (IARC). Exposure to these highly toxic PAHs poses a significant risk to human health [51]. However, other PAHs should not be disregarded as they also may pose a cancer risk. The most researched PAHs, which have unsubstituted multi-ring structures, do not interact with DNA and must be altered for them to cause cancer [52]. PAHs are taken in by humans through the act of inhalation, smoking, direct skin contact, and eating food that has been roasted or that has been cultivated on polluted land. The toxicity, mode of exposure, and exposed concentration all affect how it affects humans [53]. According to Abdel-Shafy and Mansour, [16], Polycyclic aromatic hydrocarbons (PAHs) can cause both immediate (e.g., eye or skin irritation, diarrhea, nausea, and vomiting) and long-term (e.g., glaucoma, kidneys and liver disease, respiratory issues, weakened antibodies, respiratory issues, and allergies) health impacts in people. In their study, Karimi et al. [54] elucidated that polycyclic aromatic hydrocarbons (PAHs) present in the atmosphere trigger allergies in children residing in industrialized countries. These PAHs are the primary cause of hospital admissions and school absenteeism among children.

The following was noted with the vegetables sampled in this study: Okereke et al. [20] examined amounts of Polycyclic Aromatic Hydrocarbons (PAHs) in three frequently eaten vegetables grown in farms located within two societies, Alakahia and Eleme, in Rivers state, Nigeria. Additionally, the possible impact of these PAHs levels on human health was investigated. The overall amounts of polycyclic aromatic hydrocarbons (PAHs) in vegetables vary between 1.34–9.51 µg/kg. The estimated concentrations of carcinogenic potency equivalents for vegetables taken from Alakahia and Eleme villages were also determined (0.31–1.51 and 0.37–0.97 µg/kg respectively). These values were higher than the screening threshold for vegetables (0.23), indicating that consuming these vegetables poses a danger to the population who is exposed.

In their investigation, Onuoha and Karibo [39] determined that the high levels of PAHs found in the veggies from Rumuosi and Choba offer a serious health risk to the population that regularly consume these plants. Communities in the research region should take a pro-active stance against people involved in unlawful practices like artisanal

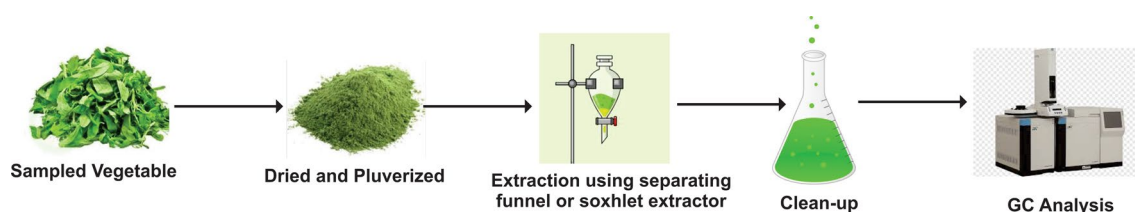
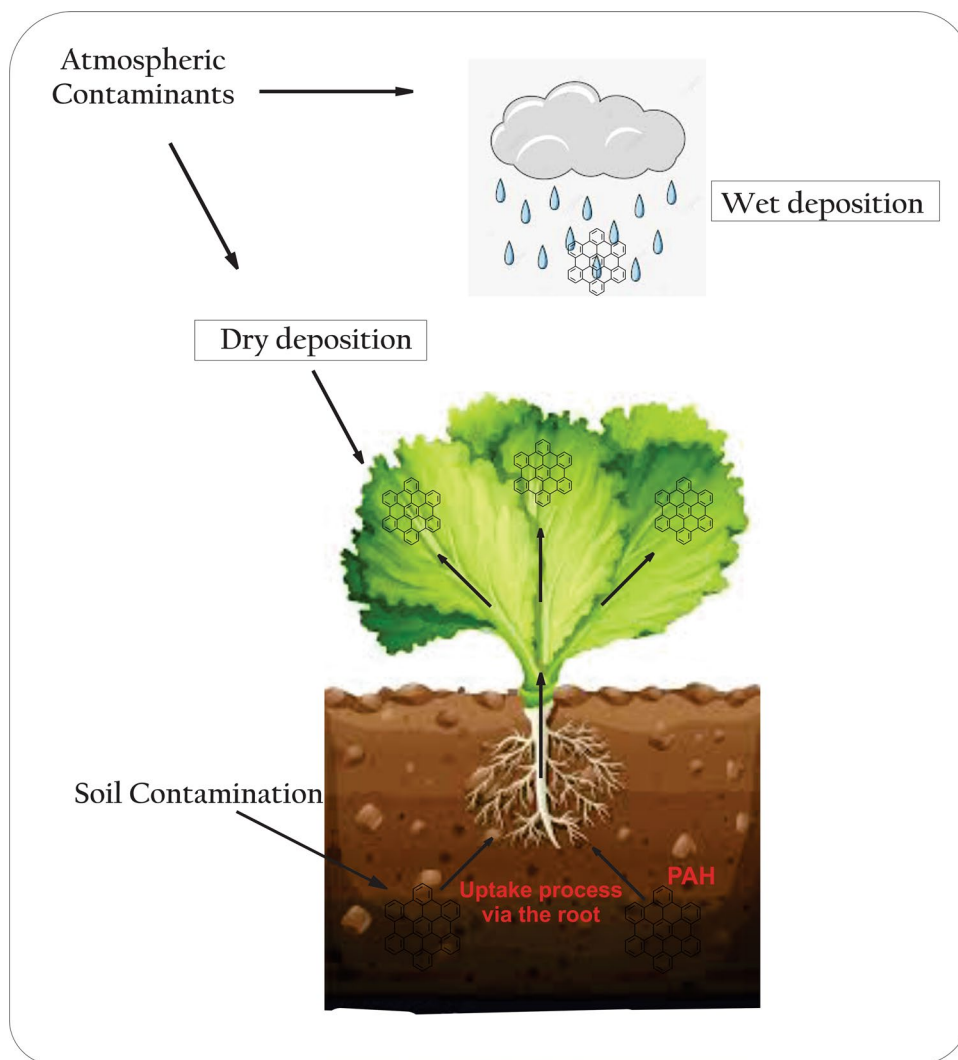


Fig. 2 Sample preparation, treatment and analysis

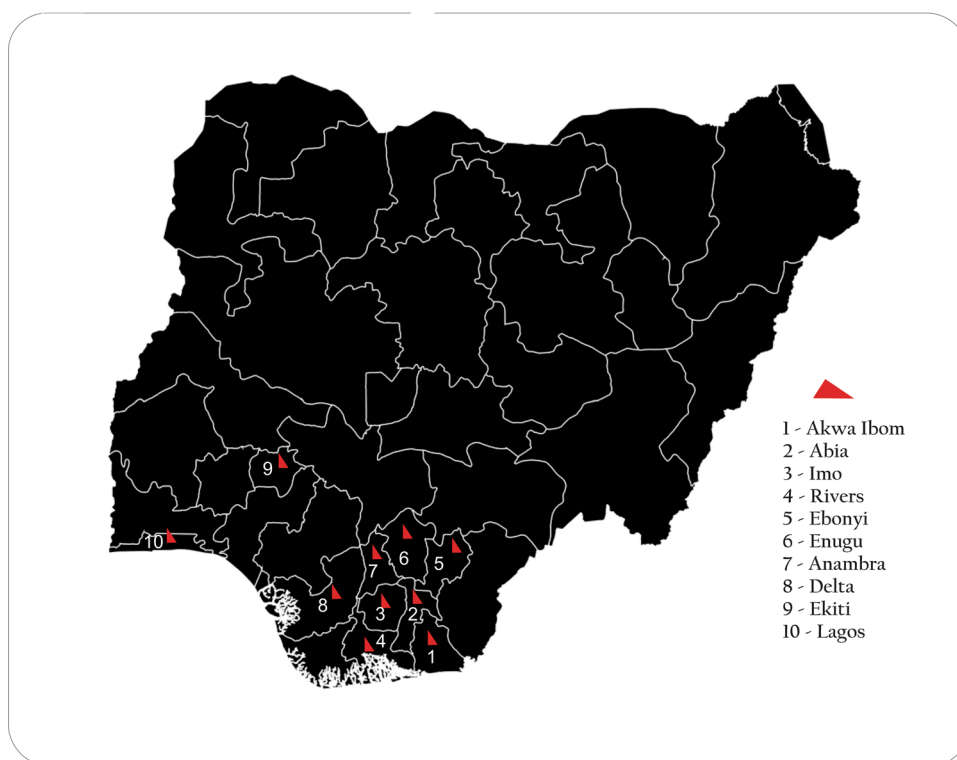
Fig. 3 PAHs Pathway from soil and atmosphere to vegetables



refining and burning of petroleum products. These activities have a significant negative influence on public health and way of life by leaving a large environmental footprint.

The presence of PAHs in vegetables grown near hair salon places is becoming increasingly worrying, as highlighted by Ijere et al. [34]. This is particularly worrisome because a significant portion of the population, including urban residents in Aba South and Umuahia South, as well as rural areas in Isuikwuato and Ohafia, rely on these vegetables as a source of essential nutrients in their daily diet. The study utilized a gas chromatograph (GC) to analyze 19 distinct polycyclic aromatic hydrocarbons (PAHs) present in waterleaf and fluted pumpkin leaves. The results were compared to the Control samples obtained from the research locations, and also to the standards set by FEPA [55] and FAO/WHO [56]. The concentration of polycyclic aromatic hydrocarbons was beyond the acceptable threshold, indicating their potential danger to human consumption.

Fig. 4 Locations in Nigeria where PAH in vegetables had been studied



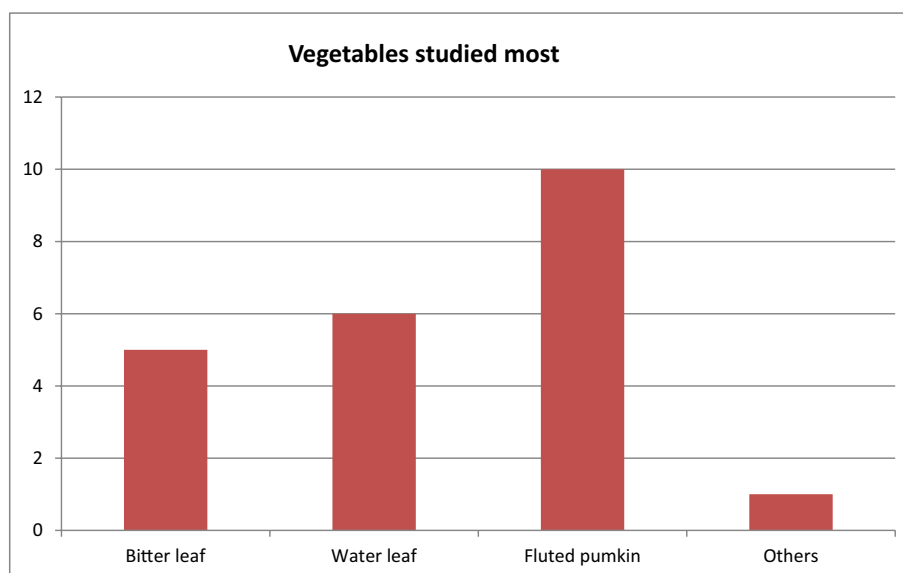
In a particular study, the estimated daily intake values for children's exposure varied as follows 459–4876 (benzo[a]pyrene), 1809 to 8378 (PAH₂), 2733–13,036 (PAH₄), and 4143–12,568 (PAH₈) ng kg⁻¹ bw day⁻¹, respectively. For adult exposure, the estimated daily intake values ranged from 115–1219 (benzo[a]pyrene), 452–2095 (PAH₂), 683–3259 (PAH₄), and 1036–3142 (PAH₈) ng kg⁻¹ bw day⁻¹, respectively. The estimated MOE (Margin of Exposure) value was less than 10,000, indicating that the veggies were unsuitable for human consumption. While the cancer risk levels ($> 1 \times 10^{-6}$) suggested that consuming these veggies could increase the risk of cancer due to PAHs, the Hazard Index levels were less than one (1), indicating that they had no other non-carcinogenic problems associated with them [6]. In addition to the aforementioned studies, others found a lower carcinogenic risk of PAHs from vegetables; although they argued that future PAHs health risks should be monitored carefully and prevented by taking precautions.

Animals (especially mice) used in laboratory studies developed stomach cancer while the pregnant ones gave birth to offspring with defects and decreased body weight after ingesting PAHs in food over time, as reported by the US EPA (Environmental Protection Agency), even though studies weren't specifically done using vegetables and weren't done in Nigeria [16, 57–60]. Despite this, it remains undetermined if it also becomes applicable to individuals.

6 Limitations of this study

This review was based on a search and data obtained from the following: Scopus, Web of science, Ebsco, IWA, and Google scholar alone. As a result, we might have missed certain works. We believe that the publications we found accurately reflect the current level of knowledge regarding the potential health effects of PAHs in Nigerian vegetables. Furthermore, because there is little information available on the PAHs levels in vegetables in Nigeria that were collected from ten (10) different states in the nation, the concentrations presented may not be an accurate reflection of the PAHs levels in Nigerian vegetables. Additionally, there may be variations in extraction, analytical procedures, and strategies responsible for the pronounced variations in PAHs values reported in the research we analyzed. Furthermore, no biological investigation was carried out or health center reports were consulted to determine the direct effects of PAHs on a specific living thing or a person who ate a contaminated vegetable. Despite these drawbacks, this study emphasizes the need for greater research on PAHs and its effects on health in Nigeria as there is evidence for a wide range of exposures from a variety of sources.

Fig. 5 Vegetables studied most based on articles used in this review



7 Conclusion and future research prospect

To assess the health implications of PAHs exposure in Nigeria, we evaluated their concentrations in vegetables and examined the associated impacts. This analysis was based on publications spanning from 2010 to the present. The majority of the research from the 15 publications consulted for this study was conducted in 10 states, mostly in the Eastern (Abia, Anambra, Ebonyi, Enugu, and Imo) and Southern (Akwa Ibom, Delta, and Rivers) regions of the nation. No studies from the North, just one from the West (Lagos) and middle-belt (Edo) were found. In the articles utilized in this study, fluted pumpkin, water leaf, and bitter leaf were the veggies that were most frequently sampled. It was claimed that fluted pumpkin was a crop with potential for phyto-remediation of PAHs in contaminated locations, though more research is required to confirm this. To make PAHs-contaminated locations safe, it is very important to explore various bio-remediation techniques in Nigeria. In part of the literature, the vegetables exhibited elevated concentrations of PAHs, and subsequent investigation revealed that the application of water (preferably lukewarm water that had been distilled) and a salt solution resulted in a notable reduction in these levels. However, further research is required to validate these findings. Only a small number of articles have addressed the potential for cancer, but it is crucial for Nigeria to diligently evaluate the physiological impacts of the overall intake of polycyclic aromatic hydrocarbons (PAHs) into the body via the consumption of food, particularly vegetables. The sources of PAH and its effects on health should be widely known and understood by the general people. Policies must be put in place to safeguard citizens from untreated industrial effluents dumped into the environment.

Author contributions All authors contributed equally.

Funding The authors did not receive any funding.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate Not applicable.

Competing interests The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in

the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. Britannica T. Editors of Encyclopaedia. Vegetable. Encyclopaedia Britannica. 2023. <https://www.britannica.com/topic/vegetable>.
2. Ibironke SI, Owotomo I. Haematology and comparative study of fluted pumpkin leave vegetable and seed nutrients (*Telfairia occidentalis*). Arch Nutr Public Health. 2019;1(2):1–6.
3. Kalmpourtzidou A, Eilander A, Talsma EF. Global vegetable intake and supply compared to recommendations: a systematic review. Nutrients. 2020;12(6):1558. <https://doi.org/10.3390/nu120661558>.
4. Adetunde OT, Mills GA, Oluseyi TO, Oyeyiola AO, Olayinka KO, Alo BI. Polycyclic aromatic hydrocarbon in vegetables grown on contaminated soils in a sub-saharan tropical environment – Lagos, Nigeria. Polycycl Aromat Compd. 2020;40(4):979–89. <https://doi.org/10.1080/10406638.2018.1517807>.
5. WHO Guidelines for Drinking-Water Quality, 3rd edn. Chemical Fact Sheets, World Health Organization, Geneva, Switzerland, 2004; p. 25.
6. Tesi GO, Okirorolnighe P, Lari B, Obi-Iyeke G, Ossai JC. Polycyclic aromatic hydrocarbons (PAHs) in leafy vegetables consumed in southern nigeria: concentration, risk assessment and source apportionment. Environ Monit Assess. 2021;193(7):443. <https://doi.org/10.1007/s10661-021-09217-5>.
7. Landgeist. Vegetable consumption in Africa. 2022. <http://www.landgeist.com/2022/06/20/vegetable-consumption-in-africa/>
8. Ejioogu CC, Udensi JU, Okere AI, Iwuji KM, Uyo CN, Akueshi CU, Okore C. Study of the concentration of polycyclic aromatic hydrocarbons and sundry parameters of refinery oil on Eleme River, Port-Harcourt, Nigeria. Int J Sci Eng Appl Sci. 2021;7(2).
9. Bolor VK, Boadi NO, Borquaye LS, Aful S. Human risk assessment of organochlorine pesticide residues in vegetables from Kumasi, Ghana. J Chem. 2018. <https://doi.org/10.1155/2018/3269065>.
10. Agarwal T. Concentration level pattern and toxic potential of PAHs in traffic soil of Delhi, India. J Hazard Mater. 2009;171:894–900.
11. Ashraf MW, Taqvi SIH, Solangi AR, Qureshi AU. Distribution and risk assessment of polycyclic aromatic hydrocarbons in vegetables grown in Pakistan. J Chem. 2013;2013:5.
12. Abugu HO, Ezugwu AL, Ihedioha JN. Assessment of polycyclic aromatic hydrocarbon contamination of fruits, leaves, and soil within automobile repair workshops in Nsukka Metropolis. Polycycl Aromat Compd. 2022;43:1–23.
13. Nkpaa KW, Wegwu MO, Essien EB. Assessment of polycyclic aromatic hydrocarbons (PAHs) levels in two commercially important fish species from crude oil polluted waters of Ogoniland and their carcinogenic health risks. J Environ Earth Sci. 2013;3:128–37.
14. Lawal AT. Polycyclic aromatic hydrocarbons. A review. Cogent Environ Sci. 2017;3(1):1339841. <https://doi.org/10.1080/23311843.2017.1339841>.
15. Onyedikachi UB, Belonwu CD, Wegwu MO. The determination of polycyclic aromatic hydrocarbons in some foods from industrialized areas in South Eastern Nigeria: human health risk impact. Ovidius Univ Ann Chem. 2019;30(1):37–43.
16. Abdel-Shafy HI, Mansour MSM. A review on polycyclic aromatic hydrocarbons: source, environmental impact, effect on human health and remediation. Egypt J Pet. 2016;25(1):107–23.
17. Ling W, Ren L, Gao Y, Zhu X, Sun B. Impact of low-molecular weight organic acids on the availability of phenanthrene and pyrene in soil. Soil Biol Biochem. 2009;41:2187–95.
18. Bruns EA, Krapf M, Orasche J, Huang Y, Zimmermann R, Drinovec L, Prévôt ASH. Characterization of primary and secondary wood combustion products generated under different burner loads. Atmos Chem Phys. 2015;15:2825–41.
19. Fernando S, Shaw L, Shaw D, Gallea M, Vandenenden L, House R, McCarry BE. Evaluation of firefighter exposure to wood smoke during training exercises at burn houses. Environ Sci Technol. 2016;50:1536–43.
20. Okereke CJ, Essien EB, Wegwu MO. Distribution and risk assessment of polycyclic aromatic hydrocarbons in vegetables and agricultural soils from two communities in Rivers State, Nigeria. J Res Env Sc Toxicol. 2016;5:18–25.
21. Rajendran P, Jayakumar T, Nishigaki I, Ekambaram G, Nishigaki Y, Vetrivel J. Immunomodulatory effect of mangiferin in experimental animals with Benzo(a)pyrene-induced lung carcinogenesis. Int J Biomed Sci. 2013;9:68–74.
22. Svetlana STM, Sarieh T, Elena A, Elizaveta KC, Tamara D, Andrey BR. PAHs accumulation in soil-plant system of *Phragmites australis* cav soil under long-term chemical contamination. Eurasian J Soil Sci. 2020;9(3):242–53.
23. Oketola A, Oyeleke P. Heavy metals and polycyclic aromatic hydrocarbons in soil from E-waste dumpsites in Lagos and Ibadan, Nigeria. J Health Pollut. 2017;7:71–84. <https://doi.org/10.5696/2156-9614-7.15.71>.
24. Ogbemudia FO, Ita RE, Udo ED. Pedological and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in farmlands of a tropical oil producing region in Akwa Ibom State, Nigeria. Int J Biol Environ Eng. 2018;1(1):17–23.
25. Ololade IA, Oladoja NA, Ololade OO, Saliu TD, Alabi AB, Obadawo SB, Anifowose MM. Bioaccumulation and toxic potencies of polycyclic aromatic hydrocarbons in freshwater biota from the Ogbese River, Nigeria. Environ Monit Assess. 2021;193:1–15.
26. Iwegbue CM, Ogbuta AA, Otutu JO, Obi G, Egbueze FE, Martincigh BS. Evaluation of human exposure to polycyclic aromatic hydrocarbons from some edible oils and shea butter in Nigeria. Polycyclic Aromat Compd. 2019;13(8):44–54.
27. Olabemiwo OM, Tella AC, Omodara NB, Esan AO, Oladapo A. Polycyclic aromatic hydrocarbons in three local snacks in ogbomoso. Am J Food Nutr. 2013;3(2):90–7.
28. Ogbonna N, Ndukwu DO, Abam KS, Ngah TAS. Ecological risk assessments of heavy metal contamination in water, sediment and biota of Otamiri and Imo rivers, Nigeria. 2021.
29. Ihedioha JN, Okali EE, Ekere NR, Ezeofor CC. Risk assessment of polycyclic aromatic hydrocarbons in pasta products consumed in Nigeria. Iran J Toxicol. 2019;13(1):19–26.

30. Akan J, Dawa J, Bukar L, Muhammed Z. Polycyclic aromatic hydrocarbons in different varieties of rice (*Oryza sativa*) from Yobe state, Nigeria. *Environ Pollut*. 2018;7(2):21–31.
31. Odika IM, Okoye CB, Nwanisobi GC, Odionyenma OM, Okpala UV. Risk assessment of polycyclic aromatic hydrocarbons in foreign and local rice consumed in South East Nigeria. *Asian J Food Res Nutr*. 2022; 58–66.
32. Sojini OS, Sonibare OO, Ekundayo O, Zeng ED. Biomonitoring potentials of polycyclic aromatic hydrocarbons (PAHs) by higher plants from an oil exploration site, Nigeria. *J Hazard Mater*. 2010;184:759–64.
33. Igwe OU, Ogbu UO, Egwu AC. Polycyclic aromatic hydrocarbons (PAHs) in *Telfairia occidentalis* from two markets in Ohafia Area, Abia State, Nigeria. *ChemSearch J*. 2022;13(1):106–10.
34. Dike IN, Okechukwu R. Bioaccumulation of PAHs and heavy metals by waterleaf and fluted pumpkin harvested in four communities around hairdressing salon facilities in Abia State, Nigeria. *J Environ Sci Public Health*. 2022;6(4):281–98.
35. Inam E, Ibanga F, Essien J. Bioaccumulation and cancer risk of polycyclic aromatic hydrocarbons in leafy vegetables grown in soils within automobile repair complex and environ in Uyo, Nigeria. *Environ Monit Assess*. 2016;188:681–90.
36. Alani RA, Olayinka KO, Alo BI. HPLC analysis of soils and vegetables from the Niger Delta for polycyclic aromatic hydrocarbons (PAHs) using the photodiode array detector. *J Sci Res Dev*. 2011;13:159–70.
37. Araromi A, Ayodele O, Azeez M, Olanipekun E. Assessment of trace organics in tomatoes from selected markets in Ado-Ekiti, Nigeria. *J Mater Environ Sci*. 2020;11:2084–94.
38. Ideriah Tubonimi JK. Evaluation of proximate, heavy metals and polycyclic aromatic hydrocarbons concentrations in selected food stuffs in open markets in port harcourt, Nigeria. *IOSR J Environ Sci Toxicol Food Technol*. 2019.
39. Onuoha SC, Karibo O. Assessment of polycyclic aromatic hydrocarbon concentration in some vegetables in rivers state, Nigeria. *Int J Curr Res*. 2018;10(9):73739–42.
40. Dan EU, Ebong GA, Etuk HS, Daniel IE. Carcinogenic potentials of toxic metals and polycyclic aromatic hydrocarbons in *Telfairia occidentalis* and *Talinum triangulare* impacted by wastewater, Southern Nigeria. *Environ Protect Res*. 2023; 110–129.
41. Igberi S, Udowelle NA, Ekhatior OC, Asomugha RN, Igweze ZN, Orisakwe OE. Polycyclic aromatic hydrocarbons in edible mushrooms from Niger Delta, Nigeria: carcinogenic and non-carcinogenic health risk assessment. *Asian Pac J Cancer Prev APJCP*. 2017;18(2):437.
42. Okaba FA, Daka ER, Tulonimi JK. Evaluation of polycyclic aromatic hydrocarbons and toxic elements in some vegetables cultivated along roadsides in Port Harcourt and Environs. *J Environ Sci Toxicol Food Technol*. 2020;14:14–31.
43. Igwe OU, Nwosu EN, Egwu AC. Polycyclic aromatic hydrocarbons (Pahs) In the leaves of piper guineense from two markets within Umuahia Metropolis. *J Chem Soc Nigeria*. 2022; 47(3).
44. George R. Movement of nutrients from soil to plants. *Ag Water Exchange*. 2016. <https://agwaterexchange.com/2016/09/20/movement-of-nutrients-from-soil-to-plants/>.
45. Duan X, Shen G, Yang H, Tian J, Wei F, Gong J, Zhang J. Dietary intake polycyclic aromatic hydrocarbons (PAHs) and associated cancer risk in a cohort of Chinese urban adults: Inter- and intra-individual variability. *Chemosphere*. 2016;144:2469–75.
46. Li H, Zhu D, Lu X, Du H, Guan S, Chen Z. Determination and risk assessment of sixteen polycyclic aromatic hydrocarbons in vegetables. *J Environ Sci Health Part A*. 2017. <https://doi.org/10.1080/10934529.2017.1377573>.
47. Isabel M, Gemma P, Roser M, Victoria C, Juan ML, Jose LD. Polycyclic aromatic hydrocarbons (PAH) in Foods and estimated PAH intake by the population of Catalonia, Spain: temporal trend. *Environ Int*. 2010;36(5):424–32.
48. Paris A, Ledauphin J, Poinot P, Gaillard JL. Polycyclic aromatic hydrocarbons in fruits and vegetables: origin, analysis, and occurrence. *Environ Pollut*. 2018;234:96–106.
49. Gushit JS, Ekanem EO, Adamu HM, Chindo IY. Analysis of herbicide residues and organic priority pollutants in selected root and leafy vegetable crops in plateau state, Nigeria. *World J Anal Chem*. 2013;1(2):23–8.
50. Oluwatoyin OE, Kehinde SO, Christiana OA. Proximate analysis of fresh and dry leaves of *Telfairia occidentalis* (Hook. f.) and *Talinum triangulare* (Jacq.) willd. *Hrvatski časopis za prehranbenutehnologiju biotehnologiju i nutricionizam*. 2012;7(3–4):188–191.
51. IARC, “Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposures,” IARC Monographs on the Evaluation of Carcinogenic Risks to Humans 2010; 92:1–853. <http://monographs.iarc.fr/ENG/Monographs/vol92/mono92-6.pdf>.
52. Brody S, Wang L, Cai Y, Jia L, Shapiro R, Patel DJ, Geacintov NE. Covalent polycyclic aromatic hydrocarbon-DNA adducts: carcinogenicity, structure, and function. *Curr Cancer Res*. 2011;6:181–207.
53. ACGIH (American Conference of Governmental Industrial Hygienists). Polycyclic aromatic hydrocarbons (PAHs) biologic exposure indices (BEI) Cincinnati. OH: American Conference of Governmental Industrial Hygienists; 2005.
54. Karimi P, Peters KO, Bidad K, Strickland PT. Polycyclic aromatic hydrocarbons and childhood asthma. *Eur J Epidemiol*. 2015;30:91–101.
55. FEPA. PAHs in Europe: A comparison of present, pre-ban and background levels (Technical report). Luxembourg: Office for Official Publications of the European Communities, 1995.
56. FAO WHO. Joint FAO/WHO Food Standards Programmes. Codex Committee on Contaminants in Foods 2011; 10: 21 – 25
57. US EPA (Environmental Protection Agency). Polycyclic aromatic hydrocarbons (PAHs) — EPA fact sheet. Washington (DC): National Center for Environmental Assessment, Office of Research and Development; 2008
58. Igbeneghu OA, Abdu AB. Multiple antibiotic-resistant bacteria on fluted pumpkin leaves, a herb of therapeutic value. *J Health Popul Nutr*. 2014;32(2):176–82.
59. Okafor VN, Omokpariola DO, Igbokwe EC, Theodore CM, Chukwu NG. Determination and human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in surface and ground waters from Ifite Ogwari, Anambra State, Nigeria. *Int J Environ Anal Chem*. 2022;104(6):1381–403. <https://doi.org/10.1080/03067319.2022.2038587>.
60. Okafor VN, Omokpariola DO, Agu MO, Odidika CC, Okabekwa CV, Ogbuo LC, Obiatuegwu MCC. Assessment of polycyclic aromatic hydrocarbons (Pahs) in alcoholic beverages consumed in Awka, Southeast Nigeria. *Bull Chem Soc Ethiop*. 2023;37(4):805–15. <https://doi.org/10.4314/bcse.v37i4.1>.