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Polycyclic Aromatic Hydrocarbons and Heavy Metal Contamination in Urban Street-Vended Plantain and Corn: A Case Study from Ibadan, Nigeria

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ABSTRACT

Street-vended roasted plantain and corn are widely consumed in urban Nigeria because they are affordable and readily available; however, contamination during processing may pose health risks. This study evaluated the levels of polycyclic aromatic hydrocarbons (PAHs) and heavy metals in fresh and roasted plantain and corn samples collected from Ibadan, Nigeria. PAHs were extracted using Soxhlet extraction, cleaned up and analyzed using Gas Chromatography-Mass Spectrometry (GC-MS), while heavy metals were determined using Atomic Absorption Spectrophotometry (AAS) after acid digestion. PAH concentrations ranged from 0.64–42.2 ng/g in fresh plantain, 3.8–45.2 ng/g in roasted plantain, 0.2–25.6 ng/g in fresh corn, and 2.8–38.6 ng/g in roasted corn. Heavy metal concentrations ranged from 0.04–32.5 ng/g in fresh plantain and 0.037–40.8 ng/g across the corn samples. Roasted samples generally contained higher contaminants level than fresh samples, indicating contamination during roasting and vending processes. Carcinogenic PAHs such as benzo (a) pyrene exceeded the European Union permissible limit in some roasted samples, while several detected PAHs were not specifically regulated. Although heavy metal concentrations were below international limits, prolonged consumption may pose health risks. The study emphasizes the need for regular food safety monitoring and cleaner roasting practices.

Keywords: Street foods, roasted plantain, roasted corn, polycyclic aromatic hydrocarbons, heavy metals, Nigeria.

INTRODUCTION

Street-vended foods constitute a critical component of daily nutrition in many urban centers, particularly in developing countries where rapid urbanization, economic constraints, and changing lifestyles have increased dependence on ready-to-eat meals [1,2]. In Nigeria, street foods such as roasted plantain (commonly known as *"bole"*) and roasted corn are widely consumed due to their affordability, convenience, and cultural acceptance. These foods are not only sources of energy but also provide essential nutrients; however, their safety has become a growing public health concern due to exposure to environmental contaminants during processing and vending [2,3].

Typically, street-vended foods are prepared in open environments, often in close proximity to busy roads, motor parks, and industrial activities. These locations are characterized by high levels of vehicular emissions, particulate matter, and combustion-derived pollutants, which can deposit directly onto food surfaces [4]. In addition, traditional roasting methods using firewood, charcoal, or kerosene further contribute to contamination through the generation of toxic compounds during incomplete combustion [5]. As a result, street foods serve as an important pathway for human exposure to hazardous environmental pollutants. Among these pollutants, polycyclic aromatic hydrocarbons are of significant concern. PAHs are a group of organic compounds composed of fused aromatic rings, primarily formed during the incomplete combustion of organic materials such as wood, coal, petroleum products, and biomass [6]. They can be generated during food processing techniques such as grilling, roasting, smoking, and frying, particularly when food is exposed directly to smoke or high temperatures [7].

PAHs are ubiquitous in the environment and can enter the human body through ingestion, inhalation, and dermal contact. Several PAHs have been identified as highly toxic, mutagenic, and carcinogenic. Notably, benzo(a)pyrene is widely used as a marker for carcinogenic PAHs and has been classified as a Group 1 carcinogen by the International Agency for Research on Cancer

(IARC) [8]. Long-term dietary exposure to PAHs has been linked to increased risks of cancers of the lung, skin, and gastrointestinal tract, as well as reproductive and developmental toxicity [9,10]. The persistence and lipophilic nature of PAHs also facilitate their bioaccumulation in biological systems, further amplifying health risks [11].

In addition to PAHs, heavy metals such as lead, cadmium, and nickel represent another major class of contaminants commonly found in street-vended foods. These metals originate from various anthropogenic sources, including vehicular emissions, industrial discharges, fuel combustion, and contaminated soils [12]. Unlike organic pollutants, heavy metals are non-biodegradable and can accumulate in food chains, posing long-term health risks even at low concentrations [13].

Lead exposure is associated with neurological impairment, particularly in children, as well as cardiovascular and hematological disorders in adults [14]. Cadmium is known for its nephrotoxic and carcinogenic effects, with prolonged exposure leading to kidney dysfunction and bone demineralization [15]. Nickel, although an essential trace element in small amounts, can cause allergic reactions, respiratory issues, and potential carcinogenic effects when present in elevated concentrations [16].

The contamination of street-vended foods by PAHs and heavy metals is influenced by multiple factors, including environmental conditions, type of fuel used, food composition, duration of cooking, and proximity to pollution sources [17]. For instance, foods with higher fat content tend to accumulate more PAHs due to lipid pyrolysis during heating [18]. Similarly, prolonged exposure to traffic emissions increases the likelihood of heavy metal deposition on food surfaces [19].

Previous studies conducted in various developing countries, including Nigeria, Ghana, and India, have reported elevated levels of PAHs and heavy metals in street-vended foods, often exceeding international safety limits [20-22]. In Nigeria, studies have highlighted significant contamination in roadside foods due to poor environmental sanitation and lack of regulatory enforcement [23]. However, inspite of the high consumption of roasted plantains and corns in urban motor parks popularly called garages, there is still a paucity of detailed data focusing specifically on contamination levels in these high-risk environments, particularly in Ibadan. Motor parks represent unique microenvironments with intense human and vehicular activities, making them hotspots for environmental pollution. Continuous emissions from buses, motorcycles, and diesel-powered vehicles contribute significantly to airborne contaminants, which may settle on exposed foods during processing and vending [24]. Furthermore, the use of low-quality fuels and inefficient roasting methods exacerbates the formation and deposition of toxic substances.

Previous studies have shown that street-vended and roasted foods are vulnerable to contamination by polycyclic aromatic hydrocarbons (PAHs) and heavy metals due to environmental pollution and roasting processes [18,20]. Roasting and smoking with charcoal or firewood generate PAHs, especially when foods are directly exposed to smoke and high temperatures. Common PAHs detected in roasted foods include benzo(a)pyrene, benzo(a)anthracene, chrysene, fluoranthene, pyrene, and anthracene (Figure 1). Research in Nigeria reported elevated levels of carcinogenic PAHs such as benzo(a)pyrene in roasted plantain, fish, meat, and corn sold near highways and motor parks [6,10].

Heavy metals including Pb, Cd, and Ni have also been detected in roadside foods, largely due to vehicular emissions and atmospheric deposition [12,16,20]. Similar findings have been reported in Ghana and India, where roasted and smoked foods exceeded international safety limits for contaminants. Studies further indicate that fuel type, roasting temperature, and cooking duration significantly influence contaminant formation [14,17,19]. Chronic exposure to PAHs and heavy metals has been associated with serious health risks, including cancer, kidney damage, and neurological disorders [4,6,8,12]. Despite these findings, limited studies have simultaneously assessed PAHs and heavy metals in roasted plantain and corn sold in Ibadan motor parks. Therefore, this study addresses this gap by evaluating dual contamination in commonly consumed street foods within a high-traffic urban environment. Therefore, this study aimed to determine polycyclic aromatic hydrocarbons (PAHs) and selected heavy metals in fresh and roasted plantain and corn sold at New Garage Motor Park, Orita Challenge, Ibadan, Nigeria. The study further seeks to compare the observed levels with established international standards, including those set by the European Union (EU) and the World Health Organization (WHO), in order to assess potential health risks associated with their consumption.

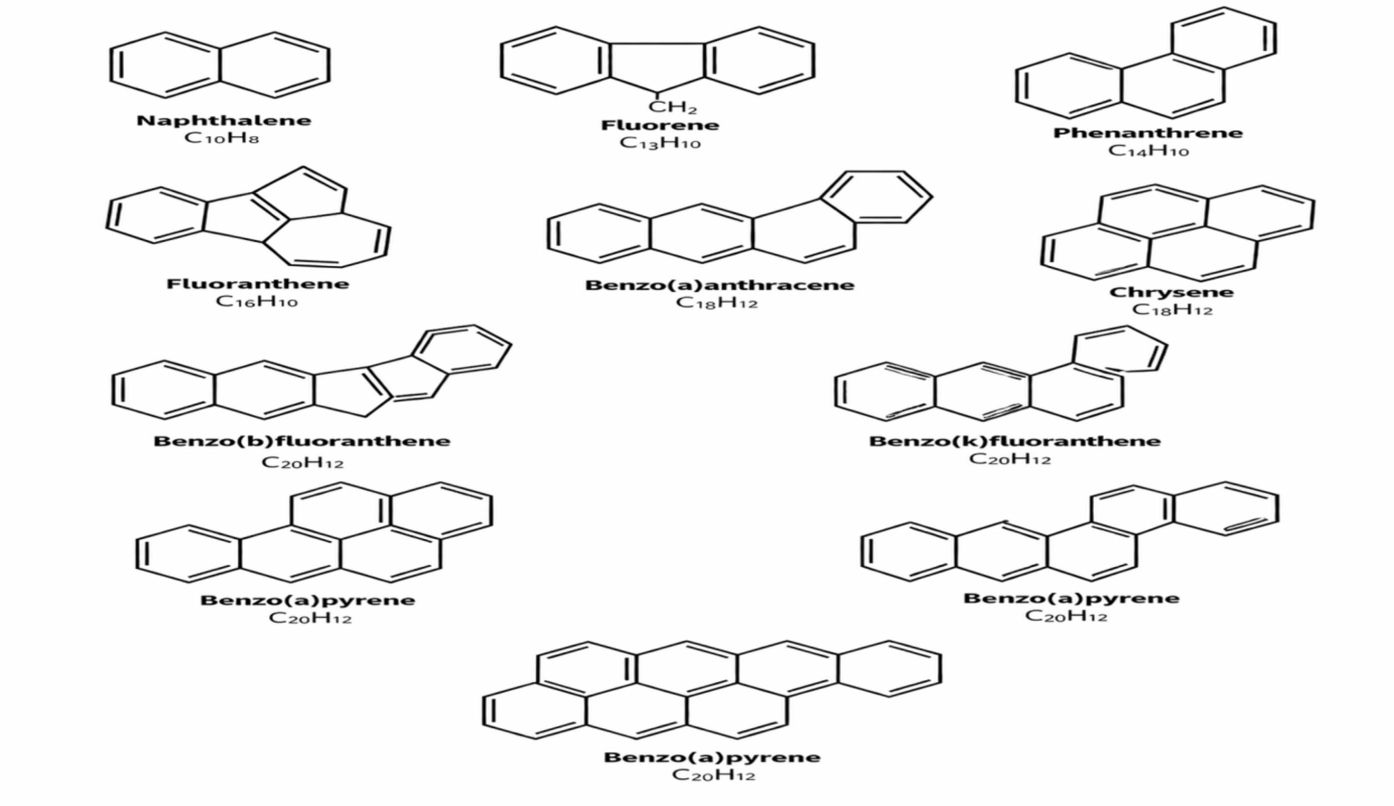

Figure 1: Structures of Investigated PAHs

MATERIALS AND METHODS

The selection of high-purity analytical grade reagents is critical to ensuring the reliability, accuracy, and reproducibility of analytical results in environmental contamination studies. In this study, certified standards of polycyclic aromatic hydrocarbons including acenaphthene, fluorene, phenanthrene, benz(a)anthracene, fluoranthene, and pyrene were employed due to their classification as priority pollutants. These compounds are widely recognized for their persistence in the environment, hydrophobic nature, tendency to bioaccumulate, and potential carcinogenic and mutagenic effects on humans [25]. Their inclusion provides a representative profile of low- and high-molecular-weight PAHs commonly associated with incomplete combustion processes.

The choice of organic solvents, specifically hexane and dichloromethane (DCM), was based on their complementary physicochemical properties. Hexane, being non-polar, facilitates the extraction of hydrophobic compounds, while DCM, with moderate polarity, enhances the recovery of semi-volatile PAHs from complex food matrices [26]. The combined use of these solvents in extraction ensures a broader spectrum recovery efficiency.

To improve extract purity and analytical performance, cleanup materials such as silica gel, glass wool, and anhydrous sodium sulfate were utilized. Silica gel serves as an adsorbent for removing polar interferences, glass wool aids in column packing and filtration, and sodium sulfate effectively removes residual moisture from extracts, thereby preventing interference during instrumental analysis [27].

For heavy metal analysis, strong oxidizing acids were such as concentrated nitric and hydrochloric used to achieve complete digestion of organic matter, releasing bound metal ions into solution. Hydrogen peroxide was incorporated as an auxiliary oxidizing agent to enhance the breakdown of resistant organic components [28]. The use of certified analytical standards for metals such as lead, zinc, copper, nickel, and chromium ensures accurate calibration of the analytical instrument and reliable quantification of metal concentrations [29].

Study Area

The study was conducted at New Garage Motor Park, located at Orita Challenge in Ibadan, a major urban center in southwestern Nigeria. This location is characterized by intense commercial activities, high vehicular traffic density, and widespread roadside food vending practices. Such environments are significant sources of environmental pollutants, including PAHs from fuel combustion and heavy metals from vehicular emissions, tire wear, and lubricating oils [30]. The open-air nature of food vending at this location exposes food items directly to atmospheric deposition of contaminants. Particulate matter containing PAHs and heavy metals can settle on food surfaces during preparation, roasting, and display.

Additionally, the use of biomass fuels such as charcoal and firewood for roasting contributes to the generation of PAHs through incomplete combustion [31]. Therefore, the study area (Figure2) provided a realistic representation of urban exposure scenarios in developing countries, where food safety regulations may be less strictly enforced, and street foods constitute a major component of daily dietary intake.

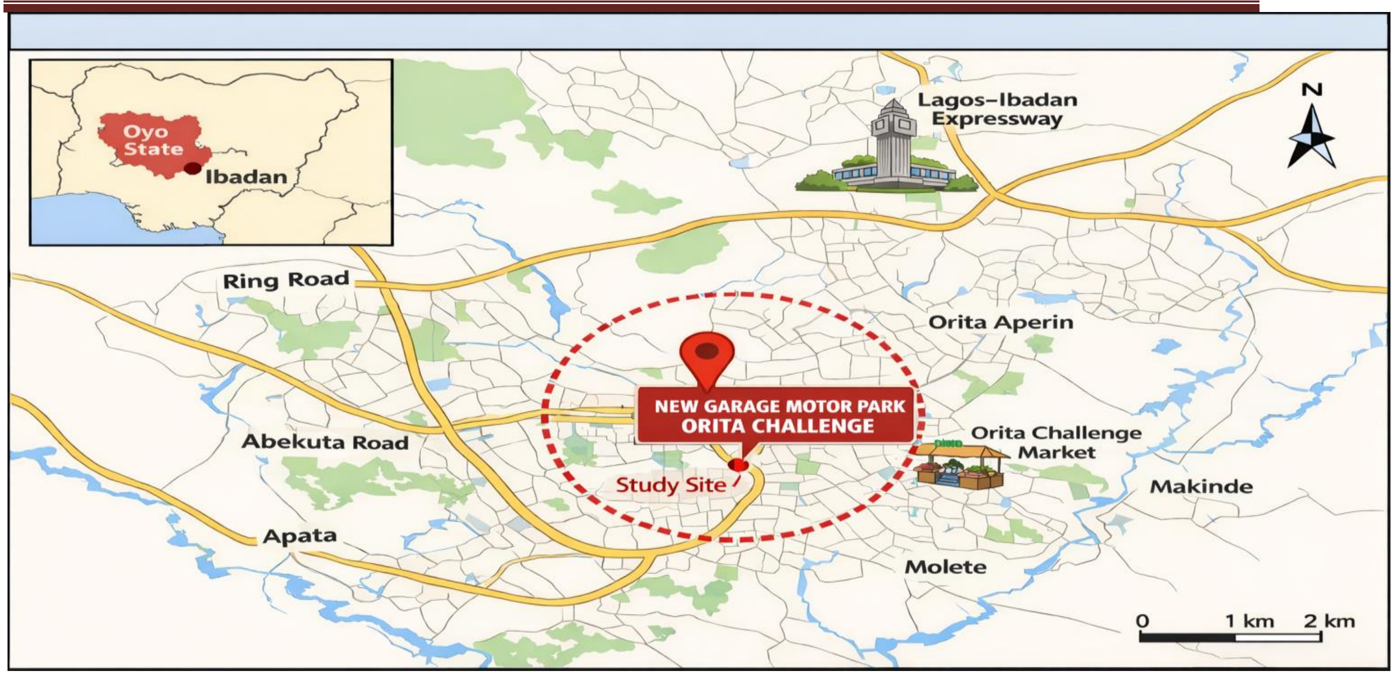

Figure2: Map of the Study Area

Sample Collection, Handling and Preservation

The sampling strategy was designed to capture both intrinsic and extrinsic sources of contamination. Fresh samples of plantain and corn were collected to represent baseline contamination levels, which may arise from agricultural practices, soil contamination, or post-harvest handling. In contrast, roasted samples were collected to evaluate additional contamination introduced during thermal processing and environmental exposure [3.8,12]. Sampling was conducted in triplicates for each food category to enhance statistical robustness and ensure reproducibility of results. Triplicate sampling reduces the influence of random variation and allows for more reliable estimation of mean concentrations [9,23,28]. Each replicate therefore represents an independent sample source, capturing vendor-to-vendor variability in contamination levels. In total, twelve (12) samples were collected.

The sampled food categories comprised plantain and corn, each evaluated under fresh (unprocessed) and roasted (thermally processed) conditions. The food samples for PAH analysis were wrapped in pre-cleaned aluminum foil, placed in amber glass containers with Teflon-lined caps to prevent photodegradation and volatilization, and transported in ice-packed coolers at approximately 4 °C [32]. In the laboratory, samples were homogenized, air-dried and stored at −20 °C prior to extraction to minimize degradation of target compounds [33]. The samples for heavy metal analysis were collected using acid-washed polyethylene containers and handled with non-metallic tools to avoid metal contamination. The dried samples were grounded and sieved to obtain uniform particle size, and stored in desiccators until acid digestion and instrumental analysis.

Sample Preparation for PAH Analysis

Dried samples were then homogenized using a clean, stainless-steel grinder to ensure uniform distribution of PAHs throughout the sample matrix [34-35]. Homogenization reduces variability between subsamples and enhances reproducibility of analytical results. Prepared samples were stored in amber glass containers at 4°C to minimize microbial activity and prevent chemical degradation of volatile and semi-volatile PAHs prior to extraction [36-37].

Sample Preparation for Heavy Metal Analysis.

Heavy metal determination in the food samples commenced with careful sample preparation to ensure representativeness and analytical accuracy. Homogenized sample (1 g) was weighed into a digestion flask and subjected to acid digestion. The digested solution was then filtered and diluted with deionized water to a known volume, making it ready for analysis by Atomic Absorption Spectrophotometry (AAS)[38].

Extraction and Cleanup of PAH from Plantain and Corn Samples

Five grammes of the dried and homogenized sample was accurately weighed and mixed with anhydrous sodium sulfate to eliminate residual moisture. The mixture was then transferred into a cellulose extraction thimble and placed in the Soxhlet apparatus. A total volume of 150 mL of a binary solvent system consisting of n-hexane and dichloromethane (1:1, v/v) was added to the round-bottom flask. The extraction was carried out for 16 hours (approximately 8–10 cycles per hour), allowing continuous solvent reflux and ensuring exhaustive extraction of PAHs, particularly the hydrophobic fractions [37,38].

After extraction, the solvent extract was concentrated using a RE100-Pro Digital Rotary Evaporator-tube revolver rotator at 40 °C to about 2 mL. The concentrated extracts were further cleaned up using silica gel column chromatography (previously activated at 120 °C), where interfering compounds were removed, and PAHs were eluted using hexane/dichloromethane. The eluate was then concentrated to near dryness and reconstituted in 1 mL of n-hexane for instrumental analysis.

GC-MS Analysis

Gas Chromatography-Mass Spectrometry (GC–MS), Agilent 7890B Gas Chromatograph coupled with a 5977A Mass Selective Detector (Agilent Technologies, Santa Clara, CA, USA). The analysis was performed using a GC–MS system equipped with a capillary column (e.g., HP-5MS, 30 m length × 0.25 mm internal diameter × 0.25 µm film thickness). High-purity helium (99.999%) was used as the carrier gas at a constant flow rate of 1.0 mL/min. A 1 µL aliquot of the cleaned extract was injected in splitless mode, with the injector temperature maintained at 280 °C. The oven temperature program was set as follows: initial temperature of 60 °C (held for 2 minutes), ramped at 10 °C/min to 200 °C, then at 5 °C/min to 300 °C, and held for 10 minutes. The run time ensured adequate separation of both low- and high-molecular-weight PAHs.The mass spectrometer was operated in electron impact (EI) ionization mode at 70 eV. The ion source temperature was maintained at 230 °C, and the quadrupole temperature at 150 °C. Data acquisition was performed in selected ion monitoring (SIM) or full scan mode (m/z 50–500), depending on sensitivity requirements. Identification of PAHs was achieved by comparing retention times and mass spectra with those of certified reference standards and spectral libraries, while quantification was based on external calibration using multi-point standard curves prepared from PAH standard mixtures. The entire analytical procedure was conducted in accordance with EPA Method 8270D, ensuring high sensitivity, accuracy, and reproducibility of the results [39-40].

Heavy Metal Analysis Using AAS

The digested samples were analyzed for heavy metal concentrations using Atomic Absorption Spectrophotometry, a technique based on the absorption of element-specific wavelengths of light by free atoms in the gaseous state, ensuring high sensitivity and selectivity for trace metal determination [3,7,10,26]. Calibration standards were prepared from certified 1000 mg/L stock solutions of the target metals by serial dilution with 0.5% nitric acid, and reagent blanks were included to correct for background contributions. The instrument was calibrated using these standards, with appropriate hollow cathode lamps selected for each element. The digested samples were aspirated into the flame, atomized, and their absorbance measured at characteristic wavelengths.

Metal concentrations were subsequently determined from the calibration curves. All procedures were carried out in accordance with validated AOAC Official Methods of Analysis, thereby ensuring the accuracy, reliability, and reproducibility of the analytical results [6,8,10].

Data Analysis

Data analysis involved the calculation of mean concentrations of PAHs and heavy metals in the analyzed samples, providing a measure of central tendency. The coefficient of variation (CV) was also determined to assess the degree of variability and precision of the analytical measurements. Low CV values indicate high precision and reliability of the data. To evaluate the potential health risks associated with consumption of the contaminated food samples, the measured concentrations were compared with established regulatory limits. Standards set by the European Union for PAHs and the World Health Organization for heavy metals were used as benchmarks. This comparative approach provides a scientific basis for risk assessment, enabling determination of whether contaminant levels exceed permissible limits and pose potential health hazards to consumers. It also facilitates the formulation of recommendations for improving food safety and regulatory enforcement.

RESULTS AND DISCUSSION

The concentration of various PAHs presents in the locally processed food samples

The concentration of various PAHs presents in the locally processed food samples (fresh plantain, roasted plantain, fresh corn and roasted corn at New Garage motor park, Orita Challenge Ibadan is highlighted in Table1. The results obtained in this study clearly demonstrate that thermal processing, particularly roasting, plays a dominant role in elevating PAH concentrations in street-vended foods. Roasted plantain and roasted corn consistently showed higher PAH levels compared to their fresh counterparts, confirming that contamination is not solely environmental but significantly influenced by food processing methods. This observation aligns with previous studies by Adegun *et al.* [4], which attributed increased PAH levels in roasted foods to the pyrolysis of organic constituents such as lipids, carbohydrates, and proteins, as well as direct deposition of smoke-derived PAHs onto food surfaces. From a mechanistic perspective, PAHs are primarily formed during incomplete combustion of organic matter, particularly under conditions of limited oxygen supply. During roasting, especially with charcoal or firewood commonly used in roadside settings, fats and juices from the food may drip onto the heat source, leading to the generation of PAH-rich smoke.

This smoke subsequently deposits PAHs onto the food surface, thereby increasing contamination levels. Additionally, the proximity of the food to the heat source and duration of roasting further intensify PAH accumulation.

A detailed compositional analysis revealed that low molecular weight PAHs (LMW-PAHs), such as naphthalene and phenanthrene, were more predominant across all samples. These compounds are typically associated with petrogenic sources and atmospheric deposition, indicating that environmental pollution from vehicular emissions contributes significantly to baseline contamination levels. Given that the study area is a high-traffic motor park, the elevated presence of LMW-PAHs strongly reflects continuous exposure to fossil fuel combustion products.

However, of greater toxicological significance is the detection of high molecular weight PAHs (HMW-PAHs), including benzo(a)pyrene and chrysene. These compounds are primarily formed through high-temperature combustion processes and are well known for their carcinogenic and mutagenic properties [13]. Their presence in roasted samples indicates that roasting conditions reached temperatures sufficient to induce the formation of more stable and hazardous PAH compounds. Particularly concerning is the concentration of benzo(a)pyrene, which is widely used as a marker for PAH toxicity and carcinogenic risk.

The recorded concentrations in roasted plantain (4.6 ng/g) and roasted corn (3.9 ng/g) exceeded the maximum permissible limit of 2 ng/g established by the European Union for food safety. This exceedance highlights a significant public health concern, as chronic dietary exposure to benzo(a)pyrene has been linked to increased cancer risk. Comparable findings have been reported in similar studies conducted in Ghana and India [14,15], suggesting that traditional roasting practices in developing countries may consistently contribute to elevated PAH exposure.

When evaluated in a global context, the PAH concentrations observed in this study present a distinct contamination profile. The levels are notably higher than those reported in processed foods from European countries [16], where stricter environmental regulations and controlled food processing conditions limit PAH formation. Conversely, the concentrations are comparable to those reported in roadside foods from densely populated Asian urban centers [17], where similar environmental and processing conditions exist. However, the values remain slightly lower than those observed in heavily smoked meat products [18], which are typically subjected to prolonged exposure to smoke and higher temperatures.

This comparative trend suggests that while roasted plantain and corn are not subjected to the same intensity of smoking as meat products, the combination of open-air exposure, traffic emissions, and traditional roasting techniques significantly elevates contamination levels beyond those observed in regulated food systems.

Furthermore, the coefficient of variation (CV) values obtained for PAHs indicate a high degree of variability in contamination levels across samples. This variability reflects the lack of standardized roasting conditions among vendors, including differences in fuel type (charcoal vs. firewood), roasting temperature, duration, and distance between the food and heat source. Environmental factors such as wind direction and traffic density may also influence the extent of pollutant deposition. These findings are consistent with the work of Kuppusamy [19], who identified processing conditions as critical determinants of PAH formation in thermally processed foods. The observed variability underscores the importance of controlling roasting parameters to minimize PAH formation and reduce consumer exposure. The general trend of the distribution of these PAHs is: roasted plantain > roasted corn > fresh plantain > fresh corn (Figure 3).

Table 1: Mean concentration of various PAHs presents in the locally processed food samples

Heavy Metal	Fresh Plantain (ng/g)	Roasted Plantain (ng/g)	Fresh Corn (ng/g)	Roasted Corn (ng/g)	Maximum Residue Limit (MRL) in Foods (ng/g)	CV (%)
Naphthalene	42.2 ± 2.1	45.2 ± 3.1	25.6 ± 2.4	38.6 ± 2.7	Not specifically regulated	95.4
Fluorene	2.03 ± 1.2	15.3 ± 1.8	2.9 ± 1.3	12.9 ± 1.4	Not specifically regulated	14.79
Phenanthrene	33.0 ± 3.0	35.4 ± 3.5	17.7 ± 2.2	29.7 ± 2.3	Not specifically regulated	64.7
Fluoranthene	25.3 ± 2.6	28.4 ± 3.0	19.2 ± 2.5	21.5 ± 2.0	Not specifically regulated	51.32
Benzo(a)anthracene	10.5 ± 1.5	8.9 ± 1.1	5.4 ± 1.0	7.3 ± 0.9	Included in PAH4 limit = 12 ng/g	74
Chrysene	8.59 ± 1.2	10.2 ± 0.9	7.5 ± 1.3	6.4 ± 1.0	Included in PAH4 limit = 12 ng/g	48

Benzo(b)fluoranthene	3.4 ± 0.7	6.8 ± 0.9	1.4 ± 0.6	5.2 ± 1.3	Included in PAH4 limit = 12 ng/g	14
Benzo(k)fluoranthene	0.64 ± 0.3	3.8 ± 0.5	0.2 ± 0.3	3.1 ± 0.3	Not specifically regulated	37.76
Benzo(a)pyrene	2.5 ± 0.2	4.6 ± 0.5	0.98 ± 0.08	2.8 ± 0.4	2 ng/g	12

The concentrations of PAHs obtained in this study show both agreement and variation when compared with values reported by previous authors. For instance, the concentration of naphthalene in the present study ranged from 25.6 to 45.2 ng/g. Farhadian *et al*.,[40] reported naphthalene levels of 18.0-39.5 ng/g in grilled meat samples, which are slightly lower but comparable, indicating general agreement in the dominance of low molecular weight PAHs in thermally processed foods with this current study Similarly, Welting *et al;* [41], reported naphthalene concentrations up to 50 ng/g in smoked foods, closely aligning with the upper range observed in this study. Chen -Chen *et al*. [42], reported fluorene concentrations ranging from 3.1 to 12.4 ng/g in roasted plant products, which falls within the same range, suggesting strong agreement with this current study. However, the slightly higher values observed in roasted plantain (15.3 ng/g) in this study may be attributed to more intense roasting conditions.

Fluorene (2.03-15.3 ng/g) and phenanthrene (17.7-35.4 ng/g) concentrations in this study were compared with 419 ng/g in certain cereals and staples reported by Ogwu *et al* [43] on Nigerian staple foods. This comparison suggests that lighter PAHs such as fluorene and phenanthrene can attain comparable magnitudes in some food matrices, particularly when exposed to smoke or environmental contamination. While absolute concentrations differ depending on food type and processing conditions, the observed trends are generally consistent in terms of the presence and relative abundance of these PAHs. The 19.2 to 28.4 ng/g level of fluoranthene reported in this current study was slightly higher than the 10-25 ng/g reported by Kazerouni *et al.*

[44]. This difference suggests a relatively higher level of contamination in the current study, possibly due to direct exposure to smoke during local roasting practices. High molecular weight PAHs such as benzo(a)pyrene (BaP) are of particular toxicological concern. In this study, BaP levels ranged from 0.98 to 4.6 ng/g. Rose *et al* [45] reported BaP concentrations of 0.5-3.0 ng/g in cereal based and grilled foods, which are slightly lower than the maximum value observed in roasted plantain.

This indicates that while the present results are generally comparable, some samples exceed typical reported ranges, suggesting higher exposure risk. Similarly, benzo(b)fluoranthene and benzo(k)fluoranthene concentrations in this study (up to 6.8 ng/g and 3.8 ng/g, respectively) are consistent with previously reported ranges of 1.0-7.0 ng/g in thermally processed foods, [41,44] indicating agreement in the formation patterns of high molecular weight PAHs during roasting. Roasted plantain and roasted corn generally contained higher concentrations of PAHs than the fresh samples, indicating that roasting enhanced PAH formation through incomplete combustion during heating. Naphthalene showed the highest concentrations in all samples, although it is not specifically regulated by EU, WHO, or FAO standards. Benzo(a) pyrene, a carcinogenic PAH used as a regulatory marker, exceeded the EU maximum permissible limit of 2 ng/g in fresh plantain, roasted plantain, and roasted corn, while fresh corn remained below the limit. Benzo(a)anthracene, chrysene, and benzo(b)fluoranthene were below the EU PAH4 limit of 12 ng/g in all samples. These findings suggest that roasting contributes significantly to PAH contamination and may increase long-term carcinogenic risks.

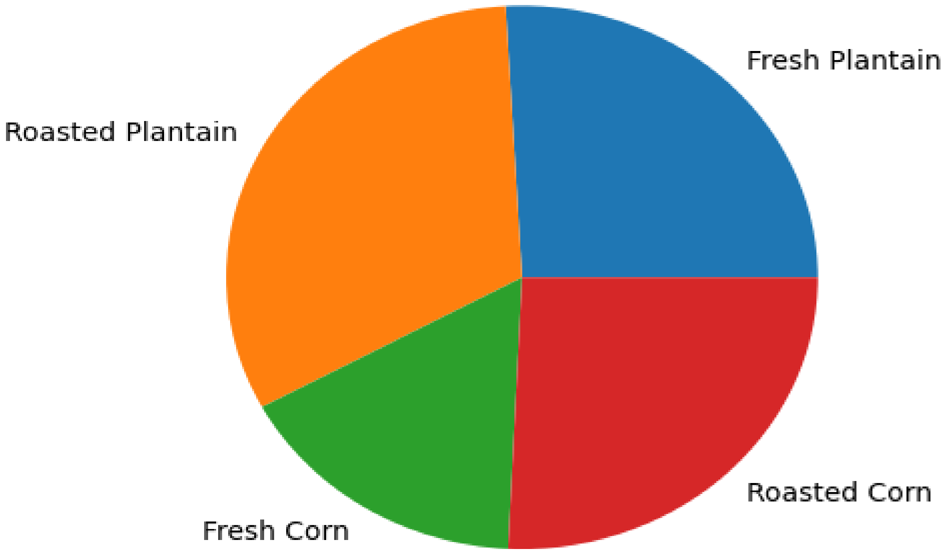

Figure 3: Distribution of total PAHs in plantains and corns

Heavy Metal Concentrations in Roasted Plantains and Corns

The analysis of heavy metals in fresh and roasted plantains and corns (Table 2) reveals significant differences in concentration patterns across metals and sample types, reflecting the combined effects of environmental exposure and food processing. Among the metals analyzed, lead concentrations were relatively low but consistent, with roasted plantain (0.62 ± 0.02 ng/g) and roasted corn (0.55 ± 0.02 ng/g) showing slight increases compared to fresh samples. Although these concentrations are below the WHO permissible limit for lead in foods [25-26], their presence indicates continuous environmental deposition from vehicular emissions and road dust, particularly in high-traffic locations like the New Garage Motor Park. The coefficient of variation of 24% for Pb further indicated variability in contamination levels, likely arising from inconsistent roasting practices, fuel types, and proximity to emission sources, as previously noted in urban food contamination studies [27]. Cadmium concentrations displayed a more pronounced increase after roasting. Fresh plantain contained 0.04 ± 0.03 ng/g Cd, whereas roasted plantain had 0.15 ± 0.2 ng/g. Similarly, Cd levels in fresh and roasted corn increased from 0.037 ± 0.1 ng/g to 0.12 ± 0.03

ng/g. This pattern is consistent with findings in street-vended foods in other African and Asian cities, where roasting and open-air exposure amplify Cd deposition from environmental and fuel sources [28,29]. The observed lower CV of 5% suggests relatively consistent Cd levels across samples, likely reflecting uniform environmental exposure rather than process-induced variability [30]. Zinc was the most abundant metal across all samples, reflecting its status as an essential micronutrient commonly present in plant foods. Fresh plantain had 32.5 ± 2.0 ng/g Zn, increasing slightly to 33.07 ± 1.3 ng/g after roasting. Fresh corn contained 40.5 ± 2.4 ng/g, rising marginally to 40.8 ± 2.08 ng/g upon roasting. This minor increase suggests that Zn contamination from roasting is minimal, and observed concentrations primarily reflect natural uptake from soil during cultivation [31]. The CV of 9% indicates moderate variability, likely influenced by differences in environmental deposition and minor processing effects. These values are comparable to those reported in urban street foods in Nigeria and Ghana, where Zn is typically the most abundant trace metal [32,33].

Copper showed a slightly different pattern. Fresh plantain had 14.2 ± 1.1 ng/g, decreasing to 13.2 ± 1.2 ng/g after roasting, while fresh corn had 9.5 ± 1.4 ng/g, increasing to 11.6 ± 1.3 ng/g in roasted samples. The decrease observed in plantain could be attributed to thermal degradation or leaching during roasting, whereas the increase in corn may reflect deposition from metallic cooking equipment or smoke particulates [34]. The CV of 10% suggests moderate variability, consistent with heterogeneous roasting conditions and differences in food handling among vendors [35]. Nickel concentrations remained relatively stable across all sample types. Fresh plantain and roasted plantain both contained 2.4 ng/g, while fresh corn had 1.9 ± 0.2 ng/g and roasted corn 2.1 ± 1.3 ng/g. These values indicate minimal influence of roasting on Ni accumulation. Sources of Ni are primarily environmental, including vehicular emissions and dust deposition at the vending site [36]. The CV of 8% reflects minor variability, suggesting uniform exposure across different samples.

Comparatively, the metal levels observed in this study are generally lower than those reported in industrially polluted urban areas but are consistent with concentrations reported in street foods from other urban centers in Africa and Asia [37,38]. For instance, Pb and Cd levels are lower than those found in heavily trafficked street foods in Accra, Ghana [28], whereas Zn and

Cu levels are similar to concentrations in Nigerian urban foods reported by Orisakwe *et al*., [38]. The stability of Ni and minor increases in Zn and Cu indicate that roasting contributes minimally to the accumulation of essential metals, whereas toxic metals like Pb and Cd are more sensitive to environmental and processing influence [40-43]. The general trend of the distribution of these heavy metals is: roasted plantain > roasted corn > fresh plantain > fresh corn (Figure 4) For heavy metals, all detected concentrations of lead, cadmium, zinc, copper, and nickel were below the permissible limits established by WHO/FAO and EU regulations. Although slight increases in some metals were observed after roasting, none exceeded international safety thresholds.

Therefore, the heavy metal contents of both fresh and roasted plantain and corn do not pose immediate health risks, whereas the elevated benzo(a)pyrene levels in roasted samples indicate possible toxicological concerns [44-45]. associated with frequent consumption of roasted foods.

Table 2: Heavy metals concentrations in roasted plantain and corn (ng/g, dry weight basis)

Heavy Metal	Fresh Plantain (ng/g)	Roasted Plantain (ng/g)	Fresh Corn (ng/g)	Roasted Corn (ng/g)	Maximum Residue Limit (MRL) in Foods (ng/g)	CV (%)
Lead (Pb)	0.62 ± 0.04	0.62 ± 0.02	0.52 ± 0.03	0.55 ± 0.02	100–300	24
Cadmium (Cd)	0.04 ± 0.03	0.15 ± 0.02	0.037 ± 0.01	0.12 ± 0.03	50–100	5
Zinc (Zn)	32.5 ± 2.0	33.07 ± 1.3	40.5 ± 2.4	40.8 ± 2.08	50,000	9
Copper (Cu)	14.2 ± 1.1	13.2 ± 1.2	9.5 ± 1.4	11.6 ± 1.3	10,000	10
Nickel (Ni)	2.4 ± 2.0	2.4 ± 0.15	1.9 ± 0.2	2.1 ± 1.3	200–500	8

Lead concentrations in this study for roasted plantain (0.62 ± 0.02 ng/g) and roasted corn (0.55 ± 0.02 ng/g) are substantially lower than the values reported by Yusuff Oluwadamilare *et al*.

[46], who found 5700 ng/g in roasted plantain and 4800 ng/g in roasted maize. This indicates that the Pb levels in the current samples are not in agreement with those of previous studies. The difference may arise from variations in geographical location, roasting methods, environmental contamination, and analytical procedures. While prior studies reflect higher contamination likely due to street roasting and environmental exposure, the very low levels observed in this study suggest minimal lead contamination in the sampled foods, possibly due to controlled handling and cleaner processing conditions.

The cadmium level in both plantain (0.15 ± 0.02 ng/g) and corn (0.12 ± 0.03 ng/g) from this study aligns with trends reported in other studies showing that processing can sometimes concentrate Cd due to moisture loss and exposure to environmental particulates during roasting. However, their levels in this current study remain generally lower than those reported for roasted plantain in Port Harcourt, where Cd in roasted plantain was observed at 0.062 ± 0.1289 mg/kg (approximately 62 ng/g) in a study by Dumka and Clement [47], though wide variability was reported across locations. This suggests that your study's Cd values are lower than some roadside roasted samples, possibly reflecting differences in environmental exposure. Zinc levels in your study (33-40 ng/g) were consistent with concentrations seen in roasted plantain from Nigeria that remained within safe limits. Dumka & Clement [47] also reported Zn in roasted plantain at around 21–30 mg/kg (21 000-30 000 ng/g) but noted considerable variation depending on sampling sites and vehicular exposure intensity. Compared to that, this current study level was much lower, suggesting slower environmental inputs of Zn or differences in roasting conditions. The current roasted plantain and corn levels (13.2-14.2 ng/g) were similar in magnitude to those seen in street-roasted foods in Nigeria, where Cu was one of the detectable metals though at variable levels depending on food type and roasting method [48]. This suggests some consistency in Cu behavior across studies, likely due to its ubiquitous presence and moderate mobility in the environment. [49-50]. Figures 5 and 6 gives the representative chromatographic peaks of roasted plantain and corn respectively

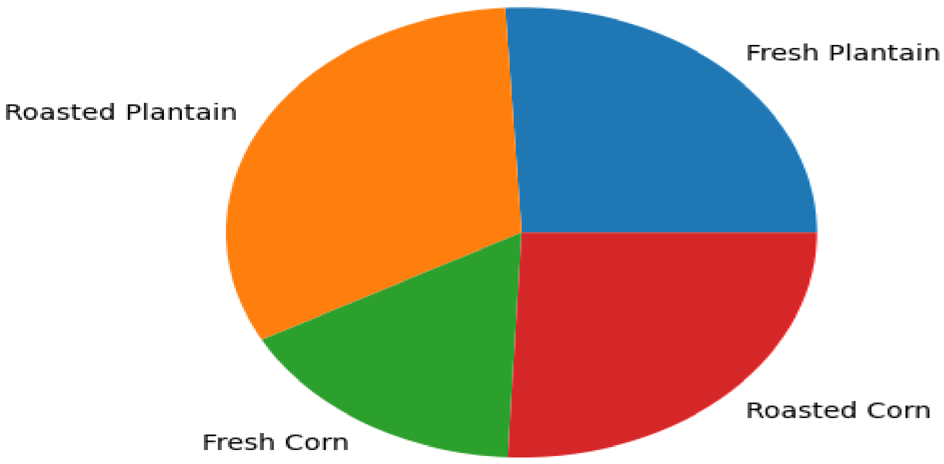

Figure 4: Distribution of total heavy metals in plantains

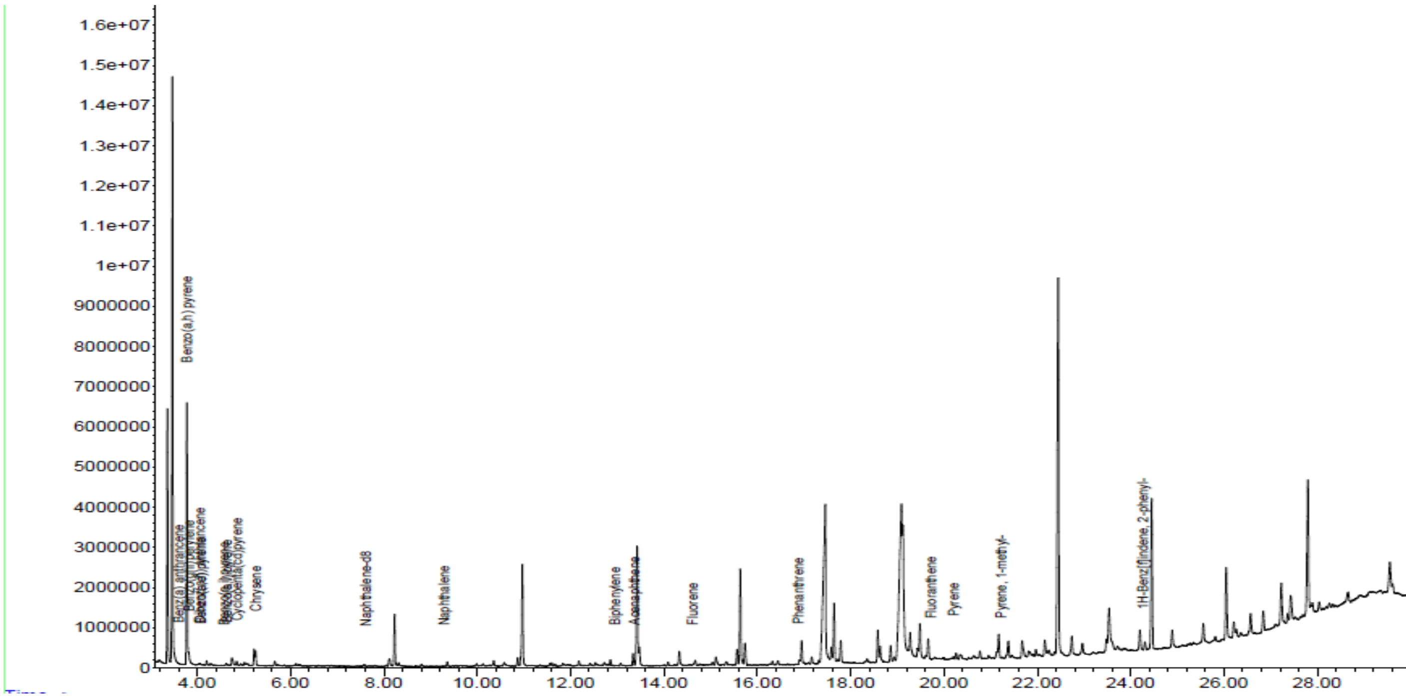

Figure 5: Representative Chromatogram Roasted plantains

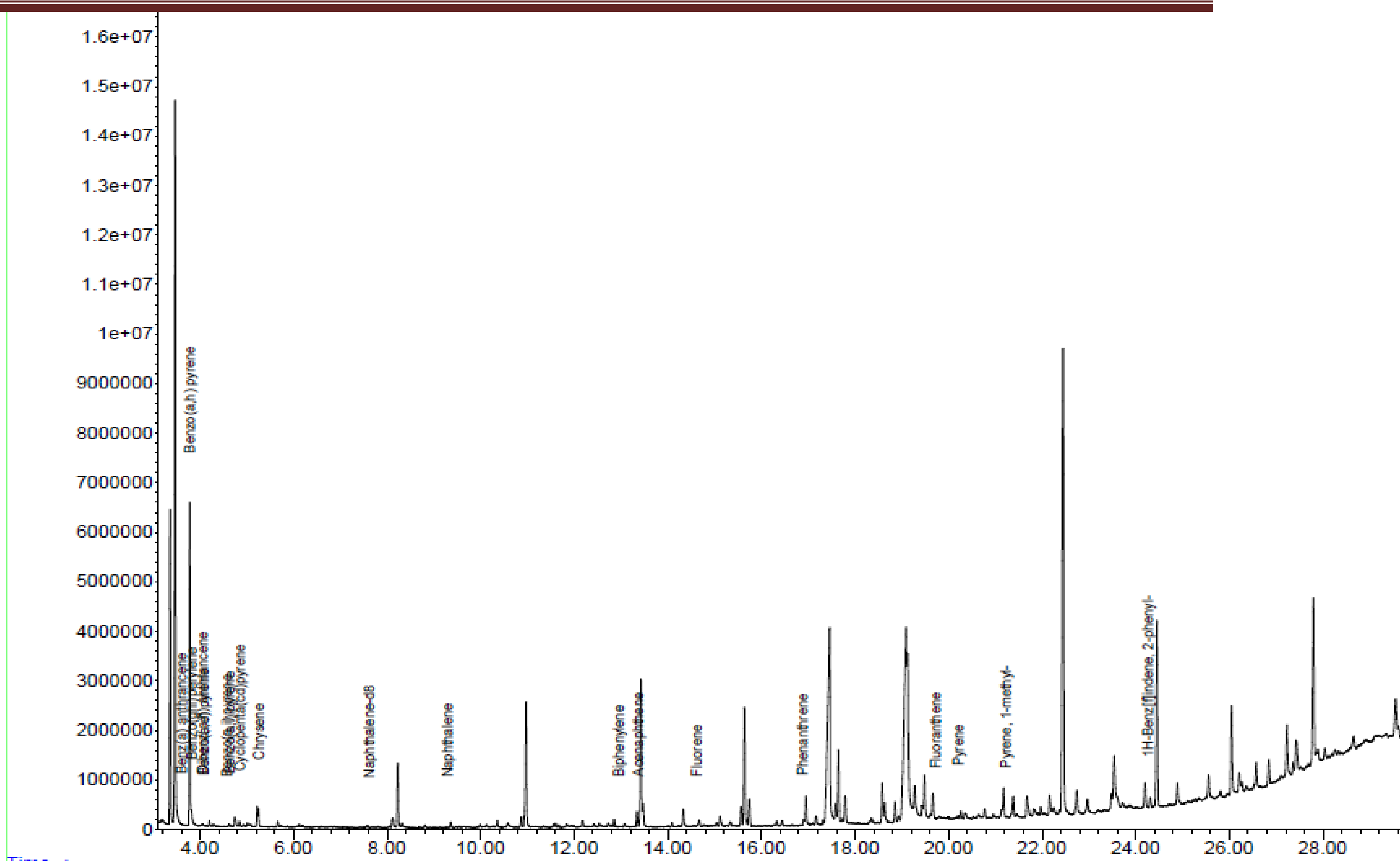

Figure 6: Representative Chromatogram Roasted corn

CONCLUSION

This study showed that roasting significantly increased the concentrations of PAHs and some heavy metals in street-vended plantain and corn sold in Ibadan, Nigeria. Carcinogenic PAHs such as benzo(a)pyrene were detected at levels exceeding recommended European Union limits in some roasted samples, indicating potential health risks associated with roasting processes and environmental pollution. Although the heavy metals detected were below international maximum residue limits, their presence suggests possible long-term accumulation risks from regular consumption. The findings highlight the need for continuous food safety monitoring, improved roasting methods, and vendor education to reduce contamination in commonly consumed street foods.

Recommendations

To mitigate the identified risks, regulatory agencies such as NAFDAC, SON, and NESREA should implement routine monitoring of PAHs and heavy metals in street-vended foods. Establishing localized maximum permissible limits consistent with EU, Codex Alimentarius, and WHO/FAO standards would provide a benchmark for safer food practices. The adoption of alternative fuels such as gas or electricity, instead of firewood or kerosene, can reduce contaminant formation during roasting.

Consumer awareness campaigns are necessary to educate the public on the potential health risks of frequent consumption of contaminated roasted foods, while food safety training should be integrated into vendor and community health programs. Finally, relocating roasting activities away from high-traffic areas and major motor parks would help minimize contamination from vehicular emissions, further improving the safety of these widely consumed foods.

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