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Heavy Metal Concentrations and Associated Health Risks in Edible Vegetables Sold in Selected Market in Alimosho, Lagos State, Nigeria

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ABSTRACT
The concentrations of cadmium (Cd), lead (Pb), and zinc (Zn) in fluted pumpkin (*Telfairia occidentalis*), locally known as ugwu, and okra (*Abelmoschus esculentus*), from a selected local market in Alimosho Local Government Area, Lagos State, Nigeria was evaluated. The samples were analysed using Atomic Absorption Spectroscopy (AAS), and toxicological data were converted to a fresh weight baseline to accurately evaluate human health risks. Human health risk exposure was appraised for the local adult cohort using the Estimated Daily Intake (EDI), Hazard Quotient (HQ), Hazard Index (HI), and Lifetime Carcinogenic Risk (CR) indices based on standard regional ingestion rates (65 g/day for ugwu; 50 g/day for okra) and an average adult body weight of 60 kg. The analytical results revealed dry weight concentrations of 0.01 ± 0.01 mg/kg Cd, 0.05 ± 0.01 mg/kg Pb, and 54.11 ± 1.48 mg/kg Zn in ugwu, and 0.03 ± 0.02 mg/kg Cd, 0.15 ± 0.02 mg/kg Pb, and 11.07 ± 0.07 mg/kg Zn in okra. Based on regional moisture benchmarks, all heavy metal contents fell safely below the maximum permissible limits formalized by the FAO/WHO. Hazard Index was 0.0302 for ugwu and 0.0096 for okra; which are substantially below 1.0, the dietary intake of these crops poses no chronic non-carcinogenic health hazards to consumers. Furthermore, the lifetime incremental carcinogenic risk metrics for Pb in both vegetables ($<10^{-7}$) and Cd in ugwu 5.76 x 10^{-7} were classified as toxicologically negligible. While the CR for Cadmium via okra consumption marginally crossed the lower boundary threshold at 1.04 x $10^{-6,}$ it remained fully within the internationally accepted safe tracking corridor 10^{-6} to 10^{-4}. Overall, from these findings, the current consumption of ugwu and okra within Alimosho LGA is toxicologically safe, the long-term monitoring of heavy metal bioaccumulation in urban Lagos markets is recommended to sustain consumer safety.

Keywords: Heavy Metals, Bio Accumulation, Atomic Absorption Spectroscopy, Estimate Daily Ingestion, Hazard Index.

INTRODUCTION

Vegetables are essential components of human nutrition, providing vital vitamins, minerals, and fiber necessary for maintaining health (Sharma *et al*., 2018). However, in urban areas such as Alimosho, Lagos State, rapid industrialization, vehicular emissions, and poor waste management contribute to environmental pollution, leading to the accumulation of heavy metals in soils and water sources used for vegetable cultivation (Adeyeye, 2019; Olowu *et al*., 2020). In many developing countries, including Nigeria, vegetables constitute a significant portion of daily meals due to their affordability, availability, and nutritional value (Sharma *et al*., 2018). Commonly consumed vegetables in Lagos include fluted pumpkin (*Telfairia occidentalis*), popularly known as ugwu, and okra (*Abelmoschus esculentus*), which are widely cultivated and sold in local markets for use in traditional diets. Heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) are non-biodegradable and can bioaccumulate in edible plant tissues, posing significant health risks to consumers, including kidney damage, neurological disorders, and cancer (Tchounwou *et al*., 2012; WHO, 2017). Several studies have reported elevated levels of heavy metals in vegetables from various Nigerian markets. For instance, Akinola *et al*. (2021) found concerning concentrations of Pb and Cd in vegetables sold in Lagos markets, exceeding WHO permissible limits. Similarly, Ogundele and Adejumo (2020) highlighted the impact of traffic-related pollution on heavy metal contamination in leafy vegetables from urban farms. Recent Nigerian studies (2018-2024) have reported elevated Pb and Cd levels in vegetables sold in Lagos, Ibadan, Port Harcourt, and Kano markets (Akinola 2019; Adepoju-Bello 2020; Okereke 2023). The accumulation of heavy metals in vegetables is a significant public health concern because these elements can bioaccumulate in human tissues over time. Chronic exposure has been linked to kidney damage, neurological disorders, cardiovascular diseases, and certain forms of cancer (Orisakwe, 2019). The World Health Organization and Food and Agriculture Organization (FAO/WHO, 2011) have established permissible limits to protect consumers. However, monitoring systems in Nigerian urban markets remain limited in terms of determining the health risk inplications. Therefore, there is a need to assess the concentrations of heavy metals in these commonly consumed vegetables in Lagos state, to determine whether they fall within acceptable safety limits and to evaluate potential health risks associated with their consumption. The findings of this study will provide useful information for environmental monitoring, food safety regulation, and public health protection.

MATERIALS AND METHODS

Study Area and Sample Collection

Four fresh samples each of okra (*Abelmoschus esculentus*) and fluted pumpkin (*Telfairia occidentalis*), locally known as ugwu, were collected from vendors at a selected local market in Alimosho Local Government Area, Lagos State, Nigeria. Representative photographs of ugwu and okra at the market are presented in Figures 1 and 2 respectively.The samples were placed in clean polyethylene bags, labelled according to vegetable type, and transported to the Chemistry Laboratory of the University of Lagos, Nigeria, for preparation and analysis.



Figure 1: Ugwu (*Telfairia Occidentalis*) Displayed



Figure 2: Okra (*Abelmoschus esculentus*) displayed

Sample Preparation

Sample preparation was carried out following the procedure described by Oladele *et al.* (2019), with appropriate modifications where applicable. The vegetable samples were thoroughly washed with distilled water to remove adhering dirt and other surface contaminants. The samples were cut into smaller pieces and oven-dried at 100°C until the required degree of drying was achieved. The dried samples were ground into fine powder using a commercial blender and stored in clean polyethylene bags until digestion. The resulting powdered samples were used for the determination of cadmium (Cd), lead (Pb) and zinc (Zn). The concentrations obtained were expressed in milligrams per kilogram (mg/kg) of dry weight (DW).

2.3. Acid Digestion and Determination of Heavy Metals

The digestion procedure was adapted from Oladele *et al.* (2019) and Allen *et al*., (1986). 1g of each dried, powdered vegetable sample was weighed into a digestion vessel. A 15 mL tri-acid mixture of concentrated nitric acid (HNO_3, 70%), perchloric acid ($HClO_4$, 65%) and sulphuric acid (H_2SO_4, 70%), mixed in a volume ratio of 5:1:1, was added to the sample. The mixture was heated at 80°C until a clear digest was obtained. After cooling, the digest was filtered through Whatman No. 42 filter paper, and the filtrate was diluted to a final volume of 50 mL with deionised water.

The concentrations of Cd, Pb and Zn in the digested samples were determined using an atomic absorption spectrophotometer (AAS). The measured concentrations were calculated and reported as mg/kg dry and fresh weight respectively. Instrumental operating conditions, calibration ranges, detection limits and the specific wavelengths used for each metal should be reported where these records are available.

2.4. Quality Assurance, Control and Health risk assessment

Quality assurance and quality control procedures were employed to improve the reliability of the analytical results. These procedures included the use of analytical-grade reagents, calibration of the atomic absorption spectrophotometer with appropriate standard solutions, analysis of reagent blanks and replicate analysis of selected samples, following the quality-control approach described by Yahaya *et al.* (2025).

To convert dry weight (DW) heavy metal concentrations to fresh weight (FW) values for the risk assessment, we used the standard food chemistry conversion formula and according to Gav *et al.*, (2024):

Fresh weight concentration = Dry weight concentration x (1-moisture content/100)

According to Gav *et al.*, (2024) and based on regional agricultural and proximate analysis benchmarks for Southwest Nigeria, the standard average moisture contents used are:

i. Ugwu (Fluted Pumpkin leaves): 86.29% moisture (13.71% dry matter factor).
ii. Okra (Pods): 89.00% moisture (11.00% dry matter factor).

To evaluate the potential health risks associated with the chronic dietary consumption of fluted pumpkin leaves (*Telfairia occidentalis*) Ugwu) and okra (*Abelmoschus esculentus*) contaminated with trace heavy metals (Cd, Pb, and Zn) for consumers in Alimosho,Lagos, following methods described by Antoine *et al*., (2017) and Afsaneh *et al*., (2022); the four core metrics; the Estimated Daily Intake (EDI), Hazard Quotient (HQ), Hazard Index (HI), and Carcinogenic Risk (CR) were calculated for the adult cohort. The formal toxicological modeling parameters including oral reference doses (RfD) and oral cancer slope factors(SF) were parameterized in accordance with the US EPA Integrated Risk Information System database standards.

Standard Equations and Model Assumptions:
To maintain local accuracy for adult consumers in Southwest Nigeria, the calculations utilize the following standard United States Environmental Protection Agency (US EPA, 2005) parameters as well as Subramaniam *et al*., (2006) and Bukar and Onoja (2020). Body Weight (BW): 60 kg (Standard regional adult average). Ingestion Rate (IR): 65 g/day (0.065 kg/day) for Ugwu (leafy vegetables) and 50 g/day (0.050 kg/day) for Okra. Exposure Frequency & Duration: Assumed 365 days/year (EF)) across a lifetime (ED), meaning exposure variables cancel out directly into the standard daily format:
EDI = C (fresh) x IR
BW
Oral Reference Dose (RfD), mg/kg/day: Cd: 0.001, Pb: 0.004, Zn: 0.3
Cancer Slope Factor (CSF,mg/kg/day) Cd: 0.38; Pb: 0.0085 Zn: N/A (Non-carcinogenic)
Cancer risk is then calculated as chronic daily intake multiplied by the cancer slope factor; CR = CDI × CSF
Toxicological Thresholds (US EPA IRIS)

Data Analysis
The heavy-metal concentrations were expressed as mean ± standard deviation (SD), in mg/kg dry weight. Statistical analyses were performed using Microsoft Excel and Origin version 5.0. Differences in the mean concentrations of Cd, Pb and Zn between ugwu and okra were evaluated separately for each metal using one-way analysis of variance (ANOVA), where the experimental design and independence of observations justified this test. Statistical significance was assessed at ($p<0.05$). The results were in triplicates and compared with permissible limits recommended by the WHO and the FAO. The software was also used to calculate the EDI, CR, HI and HQ of the heavy metals.

RESULTS AND DISCUSSION

Table 1: Heavy Metals Concentration Values (Mg/Kg) Within The Vegetables

Metal	Ugwu Dry Weight (Given)	Ugwu Fresh Weight (Converted)	Okra Dry Weight (Given)	Okra Fresh Weight (Converted)	WHO/FAO Codex Limit (mg/kg, vegetables)
Cd (Cadmium)	0.01 ± 0.01	0.0014 ± 0.0014	0.03 ± 0.02	0.0033 ± 0.0022	0.1 mg/kg
Pb (Lead)	0.05 ± 0.01	0.0069 ± 0.0014	0.15 ± 0.02	0.0165 ± 0.0022	0.3 mg/kg
Zn (Zinc)	54.11 ± 1.48	7.4185 ± 0.2029	11.07 ± 0.07	1.2177 ± 0.0077	50-100mg/kg

The results of heavy metal analysis from the selected vegetables (ugwu and okra), as seen in table 1 revealed notable variations in the concentrations of cadmium (Cd), lead (Pb), and zinc (Zn), reflecting differences in their accumulation patterns and possible environmental exposure sources. Cadmium concentrations were observed to be relatively low in both vegetables, with ugwu recording a mean dry weighhts value of 0.01 ± 0.01 mg/kg and okra showing a value of 0.03 ± 0.02 mg/kg. Although these values fall below generally acceptable limits for edible vegetables.
Lead concentrations followed a similar trend, dry weights value for okra (0.15 ± 0.02 mg/kg) exhibiting significantly higher levels than ugwu (0.05 ± 0.01 mg/kg), but certainly not above permissible limit. This is of particular concern given the toxic nature of lead, even at low concentrations. In contrast, zinc concentrations in dry weights, were markedly higher in ugwu (54.11 ± 1.48 mg/kg) compared to okra (11.07 ± 0.07 mg/kg). Zinc is an essential micronutrient required for various biological functions; however, excessively high levels may indicate environmental contamination. The high zinc content in ugwu may be linked to its strong bioaccumulation capacity or higher zinc availability in the soil where it was cultivated. These differences highlight the role of plant species, environmental conditions, and agricultural practices in heavy metal uptake. The presence of these metals, even at low concentrations, underscores the need for regular monitoring of vegetables sold in local markets to ensure food safety and protect public health. The concentrations of cadmium (Cd), lead (Pb), and zinc (Zn) observed in ugwu and okra in this study were compared with international standards and recent empirical studies to provide a robust and current scientific interpretation.

Table 2: Health Risk Metrics Calculated Results for Both Vegetables

Vegetable	Metal	EDI (mg/kg BW/day)	HQ (Non-Carcinogenic)	CR (Carcinogenic Risk)
Ugwu (Leafy)	Cd Pb Zn	1.52×10^{-6} 7.48×10^{-6} 8.04×10^{-3}	0.0015 0.0019 0.0268	5.76×10^{-7} 6.35×10^{-8} N/A
	HI	-	0.0302	-
Okra (Fruiting)	Cd Pb Zn	2.75×10^{-6} 1.38×10^{-5} 1.01×10^{-3}	0.0027 0.0034 0.0034	1.04×10^{-6} 1.17×10^{-7} N/A
	HI	-	0.0096	-

Estimated Daily Intake (EDI) and Chronic Non-Carcinogenic Risks (HQ/HI)
The calculated EDI and chronic non-carcinogenic risk metrics (HQ) and (HI)) for adult consumers are comprehensively summarized in Table 2. The EDI values across all evaluated metals were low, mirroring the fully compliant fresh weight contaminant baseline found in the crops following fresh -to dry conversion matrices. For Ugwu, the average adult EDI values followed the decreasing sequence of:
Zn 8.04×10^{-3} mg/kg/BW/day > Pb 7.48×10^{-6} mg/kg/BW/day > Cd 1.52×10^{-6} mg/kg/BW/day. A matching compositional pattern was observed in okra, with Zn exhibiting the highest daily metabolic ingestion; 1.1×10^{-3} mg/kg/BW/day, followed by Pb 1.38×10^{-5} mg/kg/BW/day and Cd 2.75×10^{-6} mg/kg/BW/day. These baseline intakes fall completely below the maximum provisional tolerable daily intakes (PTDI) set by the Joint FAO/WHO Expert Committee on Food Additives.To appraise the potential chronic non-carcinogenic systemic hazards, individual Hazard Quotients (HQ) were computed by dividing the EDI values against their specific metal oral reference doses ($RfD_{Cd} = 0.001$, $RfD_{Pb} = 0.004$ $RfD_{Zn} = 0.3$ mg/kg/day. In all instances, the HQ values for individual metals fell profoundly below the regulatory threshold value of 1.0, signifying a lack of individual metal risks. For Ugwu, individual HQ values were 0.0268, 0.0019, and 0.0015 for Zn,

Pb, and Cd, respectively. For okra, the HQ metrics were tightly clustered at 0.0034 (for both Pb and Zn) and 0.0027 (for Cd).

Because municipal consumers are concurrently exposed to complex toxicological mixtures of chemical contaminants in their diet, cumulative chronic systemic risk was characterized using the Hazard Index(HI) framework. The additive HI was determined to be 0.0302 for Ugwu and 0.0096 for okra. Because both calculated indices are substantially below unity HI < 1.0, it can be concluded with high confidence that the routine consumption of these vegetables at current regional consumption rates poses zero cumulative, non-carcinogenic health hazards to the adult population of Lagos.

Carcinogenic Risk (CR) Assessment

The lifetime incremental carcinogenic risk (CR) was tracked for Cd and Pb using their established oral cancer slope factors $SF_{Cd} = 0.38$, $SF_{Pb} = 0.0085 mg/kg/day^{-1}$, as Zinc is classified as an essential nutrient and holds no human carcinogenic slope factor data. According to the regulatory risk boundaries formalized by the US EPA, \(CR\) values falling below 10^{-6} are considered negligible, values spanning 10^{-6} to 10^{-4} denote an acceptable or legally tolerable risk baseline, and values exceeding 10^{-4} signify an unacceptable oncological risk requiring rapid public health intervention.

The CR values for Pb in both vegetables 6.35×10^{-8} for Ugwu and 1.17×10^{-7} for okra along with Cd in Ugwu 5.76×10^{-7} fell safely below the 10^{-6} absolute target, designating their capability to induce target tissue carcinomas as entirely negligible. Conversely, the lifetime CR for Cadmium via okra consumption was evaluated at 1.04×10^{-6} While this specific parameter sits exactly at the lower operational boundary of the 10^{-6} to 10^{-4} risk spectrum, it remains entirely within the internationally recognized safe and tolerable baseline. This marginal elevation indicates that while current okra consumption remains safe, the continuous bioaccumulation of Cd inside regional urban agricultural soils around the Lagos metropolis justifies long-term toxicological surveillance programmes.

Non-Carcinogenic Risk (HQ & HI < 1): For both crops, every individual Hazard Quotient (HQ) is well below 1.0. Furthermore, the Hazard Index (HI) which sums the cumulative systemic risk of all target metals was 0.0302 for Ugwu and 0.0096 for Okra. Because these integrated values are vastly lower than 1.0, adult consumers face no non-carcinogenic health anomalies from consuming these vegetables in Lagos.

Carcinogenic Risk (CR within $\times 10^{-6}$ to $\times 10^{-6}$): The Lifetime Carcinogenic Risk values for Lead (Pb) and Cadmium (Cd) hover around the $\times 10^{-7}$ to 10^{-6} range. According to US EPA risk characterization guidelines, values below 10^{-6} indicate negligible risk, while values between 10^{-6} and 10^{-4} represent an acceptable/safe risk baseline. Cadmium in Okra sits right at 1.04×10^{-6}, indicating an entirely acceptable status.

Overall, the findings demonstrate that okra only have the tendency to accumulate toxic heavy metals such as cadmium and lead, while ugwu shows a greater affinity for zinc accumulation. These differences highlight the role of plant species, environmental conditions, and agricultural practices in heavy metal uptake. The presence of these metals, even at low concentrations, underscores the need for regular monitoring of vegetables sold in local markets to ensure food safety and protect public health. The concentrations of cadmium (Cd), lead (Pb), and zinc (Zn) observed in ugwu and okra in this study were compared with international standards and recent empirical studies to provide a robust and current scientific interpretation.

Discussion

Cadmium concentrations were below the permissible limits recommended by FAO/WHO (0.05-0.2 mg/kg). This finding aligns with a study that examined heavy metal concentrations in crops and consistently documents low baseline levels of cadmium in vegetables cultivated in uncontaminated or background-level environments (Kubier *et al*., 2019). While broad environmental reviews and monitoring studies highlight that background soil concentrations and corresponding plant uptake remain well within safe regulatory tolerances when industrial inputs or contaminated water sources are absent (Pan & Han, 2023). However, contrasting results have been reported in more contaminated regions. For instance, vegetables grown in industrial zones in Kano State showed cadmium concentrations as high as 0.44 mg/kg, far exceeding FAO/WHO limits (Suleiman & Ibrahim, 2025). Similarly, Bawa (2023) reported cadmium levels exceeding WHO limits in several food crops irrigated with contaminated water. These comparisons suggest that the relatively low cadmium levels observed in this study may reflect lower environmental contamination, although the higher concentration in okra supports the notion of species-dependent metal uptake (Gupta *et al.*, 2022). Lead concentrations in ugwu and in okra were within FAO/WHO permissible limits (0.1-0.3 mg/kg), but the value for okra approaches the lower safety threshold. This trend is consistent with recent findings indicating that lead contamination remains a significant concern in Nigerian vegetables. A 2025 study reported that heavy metal levels in some vegetables exceeded regulatory limits and posed health risks, particularly in areas affected by certain activities (Danladi *et al*., 2025). Although the values in this study are within permissible limits, the elevated level in okra suggests potential long-term health concerns with continuous consumption.

Zinc concentrations were significantly higher in ugwu compared to okra (but both values fall within the permissible limit (~99 mg/kg). This observation is consistent with recent studies showing that zinc is often present at higher concentrations in vegetables but generally remains within safe limits. Additionally, Otukam *et al*., (2024) recently confirms that leafy vegetables such as ugwu tend to accumulate higher levels of metals due to their physiological characteristics, including higher transpiration rates and larger surface areas. While zinc is an essential micronutrient, excessive accumulation may still indicate environmental inputs such as fertilizer application or soil enrichment.

Overall, the findings of this study are consistent with recent literature indicating that heavy metal concentrations in vegetables vary widely depending on environmental conditions such as proximity to industrial activities, exhaust fumes, waste disposal sites, and irrigation practices. Although the concentrations of Cd, Pb, and Zn in this study are within international safety limits, recent evidence suggests that localized contamination can lead to excrescences, particularly for cadmium and lead (Bawa, 2023). Importantly, even when concentrations fall within permissible limits, continuous dietary exposure may result in bioaccumulation and chronic health risks, as highlighted by Bawa (2023).

CONCLUSION

Cadmium concentrations in both ugwu and okra were relatively low and fell below the maximum permissible limits established by the Food and Agriculture Organization and the World Health Organization (FAO, 2011; WHO, 2017). However, okra recorded slightly higher cadmium levels than ugwu, suggesting a comparatively greater capacity for cadmium uptake, although still within safe regulatory limits.

Lead (Pb) concentrations in both vegetables were within acceptable limits but were higher in okra than in ugwu. Although these values did not exceed international guideline thresholds, the presence of lead at any detectable level remains a public health concern due to its potential for long-term toxicity by bioaccumulation, even at low exposure levels. Zinc concentrations were also significantly higher in *Telfairia occidentalis* (ugwu) compared to *Abelmoschus esculentus* (okra). Overall, the study demonstrates that while the levels of Cd, Pb, and Zn in the analyzed vegetables are within internationally accepted safety limits, continuous consumption may pose potential health risks due to bioaccumulation over time.

RECOMMENDATION

The study therefore recommends that there should be continuous monitoring of heavy metal concentrations in vegetables sold in local markets by government agencies, to ensure compliance with food safety standards set by FAO and WHO. Farmers and consumers should be educated on the risks associated with heavy metal contamination and the importance of safe agricultural practices.

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