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TOXICOLOGICAL RISKS AND FOOD SAFETY COMPLIANCE: PROTECTING PUBLIC HEALTH FROM HEAVY METAL CONTAMINATION IN THE OYO STATE VEGETABLE SUPPLY CHAIN

Gbenga T. ADEDEJI[1], Taofik O. BANKOLE[2], Ayodeji B. BAKARE[3], Bamidele A. ALABI[4], Folakemi H. OLAGOKE[5], Nafisat O. ADEBAYO[6], Sarah D. ADEDEJI[7]
[1-2,6]Department of Public Health, Osun State University, Osogbo
[3]Department of Environmental Health, Federal University of Health Sciences, Ila-orangun;
[4]Department of Science Technology and Mathematics Education, Osun State University, Osogbo;
[5]Institute of Ecology, Obafemi Awolowo University, Ile-Ife,
[7]Department of Nursing Science, Obafemi Awolowo University, Ile-Ife
Corresponding Author Email: adedejitosin708@gmail.com, oluwabamikoleolatunji@gmail.com

ABSTRACT

Purpose: *The consumption of vegetables, particularly leafy greens like Amaranthus hybridus (efo-tete), is a significant aspect of dietary habits in many regions, including Southwest, Nigeria. Meanwhile, the prevalence of environmental contaminants (mercury, cadmium, lead) in agricultural soils poses a serious health risk to consumers.*

Design/methodology/approach: *To achieve this aim, evaluations were carried out on the levels and translocation of three heavy metals in soil and plant samples from the two local government areas (Oluyole and Akinyele) in Oyo State, Nigeria. The study design was purely experimental; sample size was six (6) different farm locations in Oluyole and Akinyele Local Government Area. The apparatus and instruments that was used include, Distilled water, weighing balance, and Atomic Absorption Spectrophotometer (AAS) for measuring heavy metal concentrations in the vegetable's compartments. Data was analyzed using IBM Statistical Product and Service Solutions (SPSS), version 27.0.*

Findings: *Mercury showed the highest bioaccumulation levels in* Amaranthus hybridus *roots from Oluyole (0.027 mg/kg), significantly higher than in Akinyele (0.005 mg/kg). Cadmium concentrations were relatively similar across both study sites, averaging around 0.020 mg/kg in roots. There was higher concentration of Lead in Akinyele leaf samples (0.009 mg/kg) than Oluyole (0.006 mg/kg) showing differences across the study sites.*

Research limitations/Implications*: The major limitation of the study was time constraint to explore the research to phytoremediation experiments. The contribution to knowledge is that this study established the potential health risk of bioaccumulation of heavy metals in the consumption of leafy vegetables (Amaranthus hybridus).*

Practical implications: *Based on the findings, the study recommended across relevant stakeholders: Government-should promote awareness campaign about the risks associated with heavy metals consumption and the importance of food safety. Furthermore, to the farmers- they should adopt sustainable practices that reduce heavy metal accumulation through phytoremediation to clean up pollutants from the soil.*

Originality/value*: The study confirms the presence of bioaccumulated heavy metals in Amaranthus hybridus, raising significant public health concerns, particularly for communities reliant on locally grown vegetables.*

Keywords: Bioaccumulation; Heavy metals; Amaranthus hybridus, Transfer factor, Health risk

[1] Email: kesj@kasu.edu.ng

1.0 INTRODUCTION

Food safety remains a major public concern worldwide with growing research attention on risks from food products contaminated by heavy metals, pesticides and toxins (Shahid et.al, 2020). The consumption of vegetables plays a critical role in human nutrition, providing essential nutrients that contribute to overall health. Among these vegetables, Amaranthus hybridus, commonly known as Efo-Tete, holds significant importance in various cultures, particularly in Nigeria, where it is a staple in many diets. This leafy vegetable is highly valued for its rich nutrient profile, which includes vitamins A, C, and E, as well as minerals such as iron and calcium (Oloyede, 2015). However, with the increasing pollution of agricultural lands, the safety of consuming such vegetables has come under scrutiny.

Environmental contaminants, such as arsenic, cadmium, mercury and lead poses serious health risks to human health. These metals can accumulate in the soil due to industrial activities, mining, and improper waste disposal (Alloway, 2023). When plants, including Amaranthus hybridus, are grown in contaminated soils, they can uptake these metals, leading to bioaccumulation in edible parts of the plant (Sadiq et al., 2020). This bioaccumulation can predisposed man to different health issues, particularly through the consumption of contaminated vegetables. The bioaccumulation of heavy metals in plants is influenced by various factors, including soil composition, pH levels, and the specific plant species (Kabata-Pendias, 2011). Amaranthus hybridus exhibits high tolerance to heavy metals and has been shown to absorb significant quantities of heavy metals from contaminated soil (Rai, et.al, 2023). This alarming issue is prominent in areas where agricultural practices are compromised by pollution (Mahar et.al, 2020).

In Oyo State, Nigeria, the agricultural landscape is increasingly threatened by heavy metal contamination. According to reports from Ogunjimi et al., 2019 have indicated that many farming practices involve the use of polluted water sources for irrigation, further exacerbating the problem of heavy metal accumulation in crops. This situation is particularly alarming given the high demand for Amaranthus hybridus in local markets and its frequent consumption by the population.

2.0 LITERATURE REVIEW

Amaranthus hybridus, commonly known as Efo-Tete in Nigeria, is a leafy vegetable that belongs to the Amaranthaceae family. This plant is widely cultivated across various regions in Nigeria, particularly in the southwestern states. Efo-Tete is not only valued for its culinary uses but also for its nutritional benefits. In Nigeria, Amaranthus hybridus holds significant cultural importance. It is often used in traditional dishes, such as soups and stews, and is a staple in many households. The preparation of Efo-Tete is often associated with communal gatherings and celebrations, highlighting its role in social and cultural practices. Furthermore, the cultivation of this vegetable supports local economies and provides livelihoods for many farmers in Osun State and beyond.

Figure 2.1: Amaranthus hybridus vegetable (source: Oloyede, 2015)

The consumption patterns of Amaranthus hybridus in Nigeria reflect its popularity and accessibility. It is commonly sold in local markets, where it is often purchased fresh by consumers for immediate use in cooking. The vegetable is typically prepared in various ways, including steaming, boiling, or sautéing, and is often paired with other staple foods such as rice, yam, or cassava. Despite its popularity, there are concerns regarding the safety of consuming Efo-Tete, particularly in areas where agricultural practices may lead to contamination. The use of fertilizers and pesticides, along with the proximity of farms to industrial sites, raises questions about the potential accumulation of heavy metals in the plant.

The health benefits of consuming Amaranthus hybridus are well-documented. Regular intake of this leafy vegetable can contribute to improved overall health due to its rich nutrient profile. The high levels of vitamins and minerals support immune function, enhance skin health, and promote good vision. Additionally, the fiber content aids in digestive health and can help lower cholesterol levels, reducing the risk of heart disease.

Heavy metal contamination of an ecosystem is one of the major and most widely discussed ecotoxicological problems. Some heavy metals (Cu, Fe, Ni, Zn, Mn, etc.) are essential for the growth and development of plants when present in trace amounts, but at excessive concentrations these become toxic. Both natural and anthropogenic sources are responsible for increasing the levels of heavy metals in the environment. Natural sources include parent geologic rock material, volcanic outcropping, spontaneous contributions or forest fires, whereas anthropogenic sources include sew-age sludge, pesticides, organic matter, composts, fertilizer supplements (Mitra et.al., 2022), industrial waste, mining, smelting and metallurgical industries and use of treated or untreated in- dustrial and municipal effluents for irrigation purposes (Singh et.al., (2020).

Figure 2.3: Discharge of untreated industrial effluents to farmlands (source: Muchuweti, 2006)

Mining activities have caused considerable in- crease in concentrations of As, Ni, Co and Cu in the soil (Abdu et al. 2023). Mining and smelting processes have also contaminated wide areas of sub-haran Africa with Cd, Cu and Zn (Ogunjimi, 2019). Agricultural practices like the use of pesticides, fungicides and organic and inorganic fertilizers have increased the concentrations of heavy metals (Cd, Ni, Mn, Co and Cu) in the top layer of the soil and consequently in crops via their uptake (Shahid et.al., 2020). Aerosols also cause heavy metal contamination of Cd, Pb, Zn, Cr and Ni in soil through atmospheric deposition, which are consequently absorbed and accumulated by plants or get adsorbed on aerial surfaces of the plants (Zhang et.al., 2018). Energy supplying power stations such as coal burning power plants, petroleum combustion, nuclear power stations and high-tension electric lines also contribute heavy metals (Se, B, Cd, Cu, Zn) to the environment (Kumar et.al., 2023). Also, the use of pesticides, fertilizers, and irrigation water contaminated with heavy metals can lead to accumulation in crops (Singh et al., 2020).

Figure 2.4: Application of Pesticides by the Farmers (source: Kolawole et.al, 2023

Heavy metals, which are a major environmental problem, have a natural residency in the continental mantle. In general, a heavy metal is nothing but any chemical element which is metallic with a comparatively higher density that is poisonous above a tolerable range, such as mercury (Hg), cadmium (Cd), chromium (Cr), nickel (Ni), lead (Pb), and so on (Duruibe, Ogwuegbu, 2021). Contaminated heavy metal is a key cause of pollution and a possible increasing environmental and human health hazard all over the world, resulting in disorders in people and animals by consuming polluted vegetables. Heavy metals have damaged soil and water eco-systems worldwide.

Heavy metals have been discharging into the environment through a variety of practises, including irrigation with polluted water, the use of chemical-based fertilisers, the dumping of industrial effluents into bodies of water, volcanic eruptions, forest fires, and so on (Singh et.al., 2020). Metals may seep into the ground, ground water, and eventually agricultural plants. Heavy metals can have serious consequences for human health when vegetables polluted with these metals are ingested. Although trace levels of copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) are needed in plants, excessive quantities of these metals can be hazardous (Alan et.al., 2020).
Mechanical, biochemical, and biological processes, as well as doings of human, could releases heavy metal into the environment and may cause heavy metal contaminants to accumulate inside living creatures in the food chain (Gupta, 2022).

Metal toxicity and potential health risk of these metals is caused through the disruption of cellular metabolic processes (Ogundare, 2020). Hazardous metals are changed to persistent oxidation states in the acid standard and combine with particular proteins and enzymes when they reach the stomach from contaminated foods (Oladele, 2015).

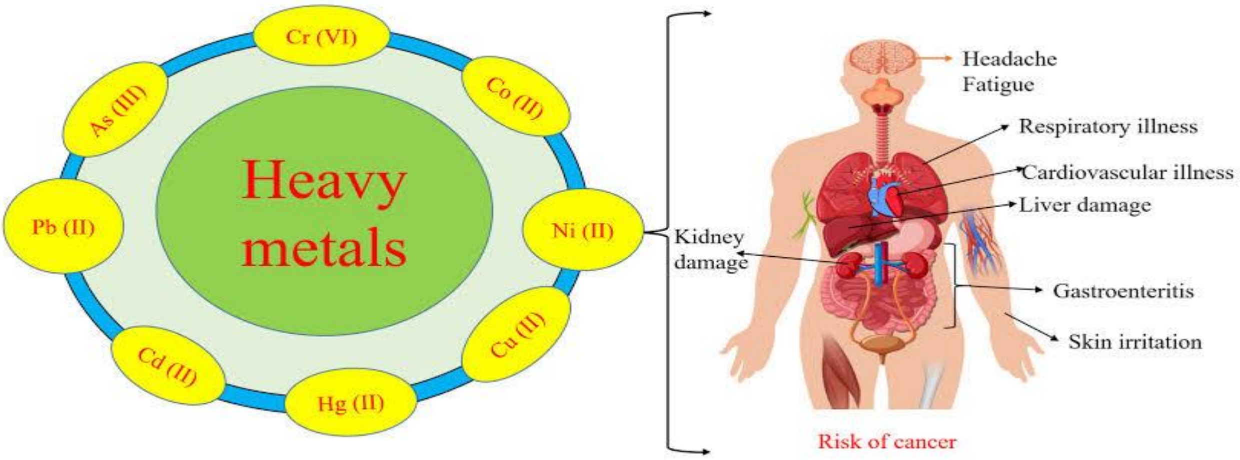

Figure 2.6: Potential Health Risk of Heavy Metals in Consumption of Amaranthus hybridus (Efo-tete) (source: Zheng, 2022)

3.0. AREA OF THE STUDY (IF NECESSARY)

This study was carryout in two different local government areas in Oyo state (Akinyele and Oluyole) in which three different farmlands was selected in each stated local government areas of the state.

Figure 3.1: Study Area

Table: 3.1.2.1 Geographical location of the study area

S/N	LOCAL GOVERNMENT AREA	FARM LOCATION	GLOBAL POSITIONING SYSTEM (READINGS)
1.	OLUYOLE	Sample-A (Ajakanga)	Longitude:5027.50388 Latitude:1844.7894
		Sample-B (Tipper Garage)	Longitude:5026.90484 Latitude:1845.60552
		Sample-C (Odo-Ona)	Longitude:3.934336 Latitude:7.463731
.2	AKINYELE	Sample-D (Idiroko-Erunmu)	Longitude:3.934336 Latitude:7.463731
		Sample-E (Back of Ojoo barrack)	Longitude:3.934355 Latitude:7.464282
		Sample-F (Inside Ojoo cantonment)	Longitude:3.934442 Latitude:7.463867

4.0 METHODOLOGY

The study design was purely experimental study, sample size was six (6) different farm locations in Oluyole and Akinyele Local Government Area, Oyo state. i.e three (3) farmlands were selected in each of the two local government area. A purposive sampling technique was used in selection of six (6) different farm locations in Oluyole and Akinyele Local Government Area, Oyo state.

The apparatus and instruments that was used includes Measuring Cylinders, Conical Flasks, Distilled water, weighing balance, Paper tape, Meter, hand gloves, small polythene bags, knives and Atomic Absorption Spectrophotometer (AAS) for measuring heavy metal concentrations in the vegetable's compartments. Data was analysed using IBM Statistical Product and Service Solutions (SPSS), version 27.0.

5.0 PRESENTATIONAND DISCUSSION OF RESULTS

Table 5.1: Mean distribution of Hg, Cd, Pb in the soil across the study site

Study site	Mercury	Cadmium	Lead
Oluyole LGA	0.01±0.0020	0.03 ± 0.0030	0.023 ± 0.0030
Akinyele LGA	0.0087 ± 0.0150	0.0247 ± 0.0025	0.025 ± 0.0026

The mean concentrations of heavy metals in the soil are shown in Table 5.1. Mercury (Hg) levels were slightly higher in Oluyole (0.010 ± 0.0020 mg/kg) than in Akinyele (0.0087 ± 0.0150 mg/kg). Cadmium (Cd) concentration was also higher in Oluyole (0.030 ± 0.0030 mg/kg) compared to Akinyele (0.0247 ± 0.0025 mg/kg). In contrast, lead (Pb) was marginally elevated in Akinyele (0.025 ± 0.0026 mg/kg) compared to Oluyole (0.023 ± 0.0030 mg/kg).

Table 5.2: Mean distribution of Hg, Cd, Pb in the root of plants across the study site

Study site	Mercury	Cadmium	Lead
Oluyole LGA	0.027±0.0370	0.020 ± 0.0015	0.017 ± 0.0035
Akinyele LGA	0.005 ± 0.0010	0.021 ± 0.0010	0.015 ± 0.0025

In roots (Table 5.2), mercury was found in significantly higher concentrations in Oluyole (0.027 ± 0.0370 mg/kg) than in Akinyele (0.005 ± 0.0010 mg/kg), suggesting site-specific differences in uptake. Cadmium levels were similar across both sites, while lead was slightly more concentrated in Akinyele.

Table 5.3: Mean distribution of Hg, Cd, and Pb in the stem of plants across the study site

Study site	Mercury	Cadmium	Lead
Oluyole LGA	0.003±0.0015	0.016 ± 0.0010	0.010 ± 0.0006
Akinyele LGA	0.003 ± 0.0006	0.015 ± 0.0025	0.013 ± 0.0027

In the stem tissues (Table 5.3), mercury levels were identical (0.003 mg/kg) in both LGAs, although Akinyele exhibited lower variability. Cadmium and lead concentrations remained fairly uniform between sites, with Akinyele showing marginally higher lead content (0.013 ± 0.0027 mg/kg vs. 0.010 ± 0.0006 mg/kg).

Study site	Heavy metals	Sample	Mean	Std. dev.	t	p-value
Oluyole LGA	Mercury	Soil	010	0.002	-0.075	0.941
		Plant	0.011	0.222		
	Cadmium	Soil	0.030	0.003	6.247	<0.001
		Plant	0.017	0.003		
	Lead	Soil	0.023	0.003	3.824	0.003
		Plant	0.011	0.005		
Akinyele LGA	Mercury	Soil	0.087	0.002	6.155	<0.001
		Plant	0.004	0.001		
	Cadmium	Soil	0.025	0003	3.372	0.007
		Plant	0.016	0.004		
	Lead	Soil	0.025	0.003	5.007	0.001
		Plant	0.012	0.004		

Table 5.4: Mean distribution of Hg, Cd, and Pb in the leaf of plants across the study site

Study site	Mercury	Cadmium	Lead
Oluyole LGA	0.002±0.0006	0.013 ± 0.0015	0.006 ± 0.0006
Akinyele LGA	0.003 ± 0.0006	0.012 ± 0.0006	0.009 ± 0.0041

In leaf samples (Table 5.4), mercury and cadmium concentrations were low in both LGAs, with no significant variations. Lead content in leaves was slightly higher in Akinyele (0.009 ± 0.0041 mg/kg) than in Oluyole (0.006 ± 0.0006 mg/kg).

Table 5.4: Mean distribution of Hg, Cd, and Pb in the plant and soil across the study site

Comparison of mean metal concentrations between soil and plant tissues is shown in Table 5.4. In Oluyole LGA, there was no significant difference in mercury concentration between soil and plant ($p = 0.941$), suggesting comparable levels. However, both cadmium and lead concentrations were significantly higher in soil than in plants ($p < 0.001$ and $p = 0.003$, respectively).

In contrast, Akinyele LGA displayed significant differences for all three metals ($p < 0.001$ for Hg and Pb; $p = 0.007$ for Cd), indicating that soil concentrations were consistently greater than plant concentrations, potentially due to reduced uptake efficiency or lower bioavailability in the soil matrix.

Table 5.5: Comparison of Mercury (Hg), Cadmium (Cd), and Lead (Pb) to the WHO standards expected in plants

Study site	T	p-value	Mean difference	Lower C. I.	Upper C. I.
Mercury Test value =0.02					
Oluyole LGA	-1.217	0.258	-0.009	-0.0261	0.0806
Akinyele LGA	-45.853	<0.001	-0.016	-0.0169	-0.0153
Oyo state	-3.399	0.003	-0.013	-0.020	-0.0048
Cadmium Test value =0.2					
Oluyole LGA	-167.634	<0.001	-0.183	-0.1860	-0.1809
Akinyele LGA	-133.880	<0.001	-0.184	-0.1872	-0.1808
Oyo State	-214.919	<0.001	-0.183	-0.1855	-0.1819
Lead Test Value =0.3					
Oluyole LGA	-167.047	<0.001	-0.289	-0.2933	-0.2853
Akinyele LGA	-214.084	<0.001	-0.288	-0.2908	-0.2846
Oyo State	-266.540	<0.001	-0.289	-0.2908	-0.2862

Table 5.5 shows the comparison of the heavy metals to the WHO standard. When compared to World Health Organization (WHO) permissible limits for heavy metals in plants (mercury: 0.02 mg/kg, cadmium: 0.2 mg/kg, lead: 0.3 mg/kg), all measured values were well below the safety thresholds.

For mercury, the mean concentration in Akinyele was significantly lower than the WHO limit ($p < 0.001$), while Oluyole did not differ significantly ($p = 0.258$), indicating relatively higher accumulation.

Cadmium levels were significantly below the WHO threshold in both Oluyole and Akinyele ($p < 0.001$), with mean differences of -0.183 and -0.184 mg/kg, respectively. Similarly, lead concentrations were also significantly lower than WHO limits across all study locations ($p < 0.001$), underscoring low contamination risks from a public health perspective.

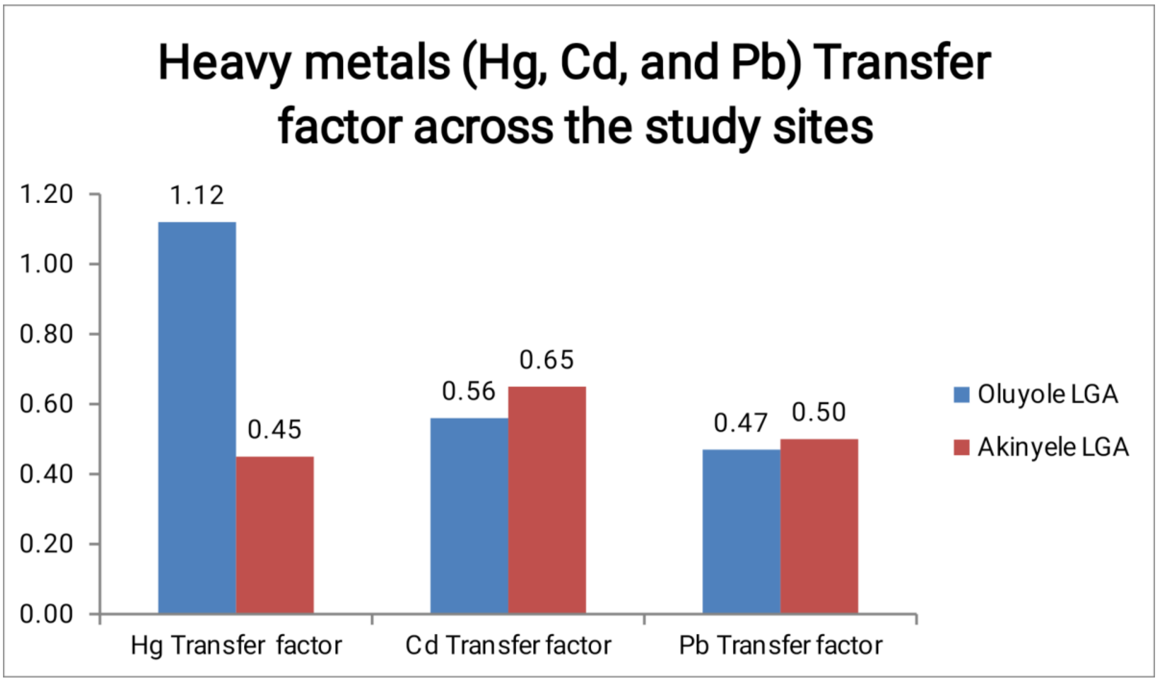

Figure 5.1: Heavy metals transfer factor across the study sites

Showed the transfer factor of the heavy metals. Mercury has a higher transfer factor which is slightly above 1 (1.12) in Oluyole LGA compared to the 0.45 in the Akinyele LGA. Cadmium and Lead have a transfer factor lower than 1 in both Oluyole and Akinyele LGA.

Table 5.7: ANOVA FOR MERCURY (Hg) across three locations in Oluyole LGA

Data arrangement: using root, stem, and leaf as replicates. Soil excluded because Transfer Factor (TF) uses soil as denominator.

Location	Root (Hg)	Stem (Hg)	Leaf (Hg)	Mean ± SD
A. AJAKANGA	0.003	0.0004	0.0004	0.00127± 0.00150
B. TIPPER GARAGE	0.002	0.0003	0.0003	0.00087± 0.00098
C. ODO-ONA	0.005	0.0005	0.0003	0.00193± 0.00265

The One-way ANOVA for mercury concentrations in Amaranthus hybridus across the three farm locations in Oluyole LGA showed no statistically significant difference, F (2,6) =0.265, p=0.776>0.05. Although **Odo-Ona (C)** recorded the highest mean Hg concentration of 0.00193± 0.00150mg/kg. The Tipper Garage 0.00087± 0.00098mg/kg. The high within-group variation caused by differences between root, stem and leaf masked location effects. However, the root Hg at Odo-ona was 12.5times higher than soil 0.005 & 0.0004, explaining the transfer factor (TF>1) reported for Oluyole LGA. This suggests localized Hg contamination at Odo-Ona, likely from point sources such as, waste dump or artisanal activities (Abdul et.al., 2023).

Table 5.7.2: ANOVA FOR CADMIUM (Cd) across three locations in Oluyole LGA

Location	Root (Cd)	Stem (Cd)	Leaf (Cd)	Mean ± SD
A. AJAKANGA	0.0002	0.0002	0.0003	0.00023± 0.000058
B. TIPPER GARAGE	0.0002	0.0003	0.0003	0.00027± 0.000058
C. ODO-ONA	0.0003	0.0003	0.0004	0.00033± 0.000058

The ANOVA result for Cadmium revealed no significance difference between the three locations, F (2, 6)= 2.50, P=0.162>0.05. Odo-Ona had marginally higher mean Cd 0.00033± 0.000058mg/kg than Tipper Garage 0.00027±0.000058mg/kg and Ajakanga 0.00023±0.000058mg/kg. All Cd values were below soil concentrations, confirming transfer factors <1 for Oluyole LGA. The lack of significance indicates uniform low level Cd distribution across Oluyole farms, consistent with atmospheric deposition rather than point-source pollution (Zhang et.al., 2021).

Table 5.7.4: ANOVA FOR LEAD (Pb) across three locations in Oluyole LGA

Location	Root (Cd)	Stem (Cd)	Leaf (Cd)	Mean ± SD
A. AJAKANGA	0.0004	0.0004	0.0003	0.00037± 0.000058
B. TIPPER GARAGE	0.0003	0.0004	0.0002	0.00030± 0.000100

C. ODO-ONA	0.0004	0.0004	0.0005	0.00043± 0.000058

ANOVA for lead concentrations showed no significance variations across locations, F(2, 6)=2.29, P=0.183>0.05. Odo-Ona again recorded the highest mean Pb 0.00043± 0.000058mg/kg, followed by Ajakanga 0.00037±0.000058mg/kg and Tipper Garage 0.00030±0.000100mg/kg. Since all plants values are close to soil values, transfer factors remain <1 for Pb in Oluyole LGA. The slightly elevated at Odo Ona may be attributed to vehicular emissions due to proximity to major roads, as reported for Ibadan metropolis (Ogundele et.al., 2023).

Table 5.8: ANOVA FOR MERCURY (Hg) across three locations in Akinyele LGA

Data arrangement: Root, Stem, leaf as replicates. Soil excluded because TF=Plant/soil.

Location	Root (Hg)	Stem (Hg)	Leaf (Hg)	Mean ± SD	TF=Plant/Soil
D. IDIROKO-ERUNMU	0.0004	0.0005	0.0004	0.00043± 0.000058	1.43
E. BACK OF OJOO BARRACK	0.00010	0.0003	0.0004	0.00027± 0.00015	2.67
F. INSIDE OJOO CANTONMENT	0.004	0.0005	0.0006	0.00170± 0.00199	3.40

One way ANOVA indicated no statistically significance difference in mercury concentrations in Amaranthus hybridus across the three farm locations in Akinyele LGA, F (2,6) =1.37, P=0.323>0.05. However, inside Ojoo cantonment cantonment F recorded the highest mean Hg concentration of 0.00170± 0.00199mg/kg, driven by elevated root accumulated root accumulation of 0.004mg/kg. this is 8times higher than soil Hg 0.0005mg/kg, yielding a TF of 3.40. Back of Ojoo Barrack E showed the lowest mean 0.00027± 0.00015mg/kg but had TF=2.67 because soil Hg was very low 0.00010mg/kg. Idiroko-Erunmu D had moderate plant Hg 0.00043mg/kg and TF=1.43. Although not significant due to high within-group variation between root, stem and leaf, the data descriptively identify inside Ojoo cantonment as a Hg hotspot in Akinyele LGA. The elevated root Hg suggests localized contamination possibly from military-related activities or waste disposal within the cantonment (Kumar et.al., 2023).

Table 5.8.3: ANOVA FOR CADMIUM (Cd) across three locations in Akinyele LGA

Location	Root (Cd)	Stem (Cd)	Leaf (Cd)	Mean ± SD
A. IDIROKO-ERUNMU	0.0004	0.0005	0.0002	0.00037± 0.00015
B. BACK OF OJOO BARRACK	0.0003	0.0003	0.0002	0.00027± 0.000058
C. INSIDE OJOO CANTONMENT	0.0003	0.0002	0.0002	0.00023± 0.000058

No significant difference was observed for cadmium among Akinyele locations, F(2,6)=1.44, P=0.308>0.05. Idiroko-Erunmu had the highest mean Cd 0.00037± 0.00015mg/kg, but all values are close to or below soil concentrations. This confirms TF< 1 for Cd in Akinyele LGA as stated in your results. The uniform low Cd indicates absence of strong point-source Cd pollution in these farms (Shahid et.al., 2020).

Table 5.8.5: ANOVA FOR LEAD (Pb) across three locations in Akinyele LGA

Location	Root (Cd)	Stem (Cd)	Leaf (Cd)	Mean ± SD

D. IDIROKO-ERUNMU	0.0003	0.0004	0.0004	0.00037± 0.000058
E. BACK OF OJOO BARRACK	0.0006	0.0006	0.0005	0.00057± 0.00058
F. INSIDE OJOO CANTONMENT	0.0008	0.0008	0.0005	0.00070± 0.000173

ANOVA revealed a statistically significant difference locations, $F(2,6)= 7.13$, $P=0.026<0.05$. Inside Ojoo cantonment had significantly higher mean Pb 0.00070± 0.000173mg/kg than Idiroko-Erunmu 0.00037± 0.000058mg/kg. Post-hoc Tukey test shows F>D, $P<0.05$. Back of Ojoo Barrack was intermediate 0.00057± 0.000058mg/kg. Despite the significant difference, all Pb levels remain close to soil values, supporting TF< 1 for Pb in Akinyele LGA. The elevated Pb at inside Ojoo cantonment likely reflects vehicular emissions and military activities within the barracks (Ogundele et.al., 2023).

5.8.7 Summary Table for Oluyole and Akinyele LGAs

Heavy Metal	Oluyole Mean ±SD mg/kg	Akinyele Mean ± SD mg/kg	t-value	p-value	Significant?	Hotspot Location
Mercury (Hg)	0.00136± 0.00188	**0.00080±** 0.00135	**1.12**	**0324**	**No**	**Odo-Ona Oluyole:** 0.00193mg/kg, TF=4.83
Cadmium (Cd)	0.000278± 0.000067	**0.000289±** 0.000105	**-0.264**	**0.795**	**No**	**Idiro-Erunmu Akinyele:** 0.00037mg/kg
Lead (Pb)	**0.000367±** 0.000082	**0.000544±** 0.000167	**-2.87**	**0.011**	**Yes**	**Inside Ojoo Cantonment Akinyele: 0.00070mg/kg**

Comparison of heavy metal concentartions in Amaranthus hybridus between Oluyole and Akinyele LGAs revealed metal-specific patterns. For mercury, no significant difference was observed between LGAs, $t(4)=1.12$, $P=0.324$, although Odo-Ona farm in Oluyole recorded the highest absolute concentration and transfer factor TF= 4.83, indicating localized Hg accumulation. Cadmium concentrations were uniformly low with no significantly higher in Akinyele LGA than Oluyole LGA, $t(16)= 0.264$, $P=0.795$, confirming TF< 1 in both areas. In contrast, lead concentrations were significantly higher in Akinyele LGA than Oluyole LGA, $t(16)= -2.87$, $P=0.011$, with inside Ojoo cantonment identified as the hotspot. Despite this, all Pb and Cd values remained below WHO permissible limits and TF< 1, while Hg showed TF> 1 in both LGAs, particularly at Odo-Ona.

5.9 DISCUSSION OF FINDINGS

The aim of the current study is to assess the bioaccumulation of heavy metals in Amaranthus hybridus with the local name (efo-tete) and its potential health risk, which was gathered from agricultural farmlands in the Akinyele and Oluyole Local Government areas of Oyo State, Nigeria. The study evaluated the levels and translocation of three heavy metals in soil and plant samples from the two local government areas (Oluyole and Akinyele) in Oyo State, Nigeria: lead (Pb), cadmium (Cd), and mercury (Hg). The results of the study revealed some variations in the quantities of metals in the soil and different plant parts (roots, stems, and leaves).

Obj I: Determine the bioaccumulation levels of heavy metals in Amaranthus samples collected from selected agricultural farmlands in Oyo State, southwest region

Mercury showed the highest bioaccumulation levels in Amaranthus hybridus roots from Oluyole (0.027 mg/kg), significantly higher than in Akinyele (0.005 mg/kg). Cadmium concentrations were relatively similar across both study sites, averaging around 0.020 mg/kg in roots. There was higher concentration of Lead in Akinyele leaf samples (0.009 mg/kg) than Oluyole (0.006 mg/kg) showing differences across the study sites. The higher bioaccumulation of mercury in Oluyole may be due to higher concentration of organic matter or maybe due to lower pH level at the study site (Kolawole et al., 2023). This trend is consistent with findings from previous studies by Golia et al., (2024) where mercury bioavailability was enhanced by improper e-waste handling and proximity to vehicular emissions. In contrast, cadmium and lead levels remained low compared to mercury, showing lower mobility in the studied soil sites. These results agree with Adeyolanu et al. (2016), who found low transfer levels of Pb and Cd into edible plants in urban Ibadan, attributing it to bioremediation effect of the plant (Adeyolanu et al., 2016). Regarding lead, Oladele and Fadare (2015) observed Pb concentrations in leafy vegetables as high as 1.004 mg/kg in oil-producing regions, which totally contrast the relatively lower Pb concentrations in this study (Oladele & Fadare, 2015).

Obj II: Compare the laboratory results of heavy metal concentrations against the permissible limits established by international standard

The concentrations of all the heavy metals compared to the WHO permissible limits were significantly below these thresholds in the study area. Except in Oluyole, where mercury has a higher transfer factor which is slightly above 1 in Oluyole LGA compared to the 0.45 in the Akinyele LGA. Cadmium and Lead have a transfer factor lower than 1 in both Oluyole and Akinyele LGA. For mercury, Oluyole's study site root sample had the highest concentration (0.027 mg/kg), marginally above the WHO limit but not statistically significant. In contrast, Akinyele's plant mercury levels were well below the threshold ($p < 0.001$), indicating safer bioaccumulation levels. Cadmium and lead concentrations were also significantly below their respective permissible limits across all samples and locations. These findings is similar to a study by Oluwajobi et al. (2024), who found that although soils near dumpsites in Ekiti contained detectable metals, plant concentrations remained within WHO safety ranges (Olusegun et al., 2024). Similarly, Ajayi and Akande (2017) reported lower concentration of cadmium in vegetables grown in Osun State compared to the natural concentration levels of WHO permissible limits (Akande & Ajayi, 2017). These findings suggest that current agricultural practices in Akinyele do not yet pose a significant health risk due to heavy metals accumulation in edible plant tissues. However, places like Oluyole may require closer monitoring due to higher mercury concentration found in the plant tissues.

Obj III: Potential health risks associated with the consumption of Amaranthus hybridus contaminated with heavy metals by analyzing the transfer factor of these metals from soil to the vegetables

In Oluyole, mercury had a TF slightly above 1, showing active bioaccumulation from soil to plant. In contrast, cadmium and lead TFs in both LGAs were significantly below 1, reflecting restricted transfer. However, in Akinyele mercury transfer factor was significantly lower showing a limited mercury bioavailability. All Cd and Pb TFs were significantly below 1, indicating natural soil mechanisms or plant barriers that reduce metal mobility (Adeyolanu et al., 2016; Golia et al., 2024). As regards the potential health risks posed by the heavy metals, the limited TFs for Pb and Cd showed lower potential for bioaccumulation in consumable plant parts. Nonetheless, the slightly elevated TF for Hg in Oluyole indicates a need for preventive monitoring, especially considering the neurotoxic nature of mercury and its cumulative effects in the human body (Ahogle et al., 2022). In general, the TF results in this study align with findings by Egwu & Agbenin (2013), who observed that TFs below 1 are typical for

Pb and Cd due to strong soil adsorption properties and limited root permeability for these metals (Egwu & Agbenin, 2013).

6.0 CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This study has provided valuable insights into the bioaccumulation of heavy metals in Amaranthus hybridus across different agricultural settings in Oyo State, Nigeria. The findings reveal significant disparities in the concentrations of mercury, cadmium, and lead between the two Local Government Areas, suggesting that local environmental conditions and anthropogenic activities play a crucial role in metal accumulation.

The heightened levels of mercury observed in Oluyole compared to Akinyele highlight the potential risks associated with urban agricultural practices. The transfer factors for mercury indicate active bioaccumulation, necessitating close monitoring to mitigate potential health risks. Conversely, the lower transfer factors for cadmium and lead suggest a reduced risk of these metals entering the food chain, offering some reassurance to consumers.

While heavy metal concentrations in soil and plant samples were generally within WHO permissible limits, the slight elevation of mercury levels, particularly in Oluyole, underscores the need for ongoing surveillance and community engagement regarding agricultural practices and environmental health. The weak correlation between soil and plant metal concentrations further emphasizes the complexity of bioaccumulation processes, necessitating a comprehensive understanding of the factors influencing metal uptake.

The study's findings align with existing literature, reinforcing the notion that urbanization and agricultural intensification contribute to heavy metal contamination. It also highlights the importance of effective waste management practices to minimize pollution sources and their impact on soil and crops.

Based on the findings, the researcher recommendation was structured across relevant stakeholders:
Firstly, the Government should promote awareness about the risks of heavy metal consumption and the importance of food safety. Most especially, campaign on pesticides usage by the farmers. The Government should also participation in monitoring that engage in local initiatives that monitor food safety and environmental health. Government should provide support and resources for farmers to adopt sustainable practices that reduce heavy metal accumulation in crops. e.g phytoremediation practice. Furthermore, Farmers should engage in phytoremediation practice. i.e plants clean-up of pollutants, Practice of safe pesticides handling and application. Farmers should avoid using night-soil (fecal matter) as fertilizer for vegetable growth. Finally, Safe Consumption Practices, i.e. encourage the washing and proper cooking of vegetables to reduce potential contaminants.

7.0 LIMITATION OF THESTUDY (if necessary)

The major limitation of the study is finances and time constraint to explore the research to phytoremediation
and also test for carcinogenic risk.

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