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Concentration and Health Risk Assessment of Selected Heavy Metals (HMs) in African spinach (*Amaranthus hybridus*) and Tomato (*Solanum lycopersicum*) Grown around Ashaka Community, Gombe State, Nigeria

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Abstract: Heavy metals are completely redundant in the human body and the ingestion of the metals poses a risk of adverse health effects. The study aimed to assess the heavy metal concentration and evaluation of health risks of selected heavy metals in African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) products collected from the Ashaka community in Gombe state, Nigeria. Heavy metal concentration was estimated using the Atomic Absorption Spectrophotometer (AAS, Perkin Elmer model 2130). The result showed that the concentrations of copper (Cu), zinc (Zn), lead (Pb), chromium (Cr) and nickel (Ni) were below the permissible level of FAO and WHO standards and the Chinese Department of Protective Medicines limit respectively except for Cadmium (0.210 mg/kg) in African spinach which exceeds the FAO/WHO limit (0.2 mg/kg). The daily plant metal intake for Cd (0.018 - 0.007 mg/kg) and Pb (0.024 - 0.014 mg/kg) were higher than the recommended daily intake of metals but within the tolerable limit. Health risk indices showed high values for Cd, Pb, and Ni, except for Cr, Cu and Zn. The IRS evaluated for all the studied HMs were greater than one (IRS > 1). This implies that exposed populations are susceptible to developing diseases associated with Cd, Pb, and Ni.

Keywords: African Spinach, Daily intake**,** Heavy metals, Health risk index, Tomatoes

1. Introduction

Heavy metals are hazardous contaminants of food and the environment which are non-biodegradable having long biological half-lives (Heidarieh *et al.*, 2013). In recent years, the global population's growing concern over food safety has intensified the scrutiny of the presence of heavy metals in commonly consumed vegetables (Ekundayo *et al.*, 2023). Vegetables such as African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) hold significant dietary importance, serving as staple ingredients in various cuisines worldwide. Therefore, the alarming rise in heavy metal

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contamination poses a severe threat to human health, urging a closer examination of the risks associated with their consumption (Shi *et al.,* 2020).

Heavy metals such as Cu, Zn, Pb, Cr, Cd and Ni are naturally occurring elements present in the Earth's crust (Alloway, 2013), while trace amounts of these metals are essential for biological functions an elevated concentration can lead to adverse health effects such as neurological, kidney and heart disorders to carcinogenicity (Famuyiwa *et al*., 2023). Plant species have various ways of removing and accumulating heavy metals, hence reports are indicating that some species may accumulate specific heavy metals, capable of causing serious risks to human health when plant-based foodstuffs are consumed. Consumption of high concentrations of heavy metals in vegetables can pose serious health hazards due to their potential carcinogenicity and human organ dysfunction (Gebreyohannes. & Gebrekidan, 2018). Although some heavy metals (Cu, Zn and Fe) are essential in plant nutrition, many of them do not play a significant role in plant physiology, for instance, Pb and Cd are among the most abundant HMs and are particularly toxic (Gebreyohannes. & Gebrekidan, 2018). The uptake of these HMs by plants especially leafy vegetables is the path of their entry into the human food chain which ends with harmful effects on health (Akan *et al.,* 2009).

Vegetables are edible plants which store up food reserves in their roots, stems, leaves and fruits. They play an important role in maintaining general good health due to the presence of mineral elements such as calcium, iron, sulphur, potassium and vitamins such as vitamins A, B complex and C. These substances help to build bone, and teeth and protect the body from diseases. They also regulate body processes on which vitality and good health depend. Leafy vegetables are widely used for culinary purposes. They are used to increase the quality of soup and for dietary purposes (Sobukola *et al.,* 2007). They contain cellulose and form roughage which helps the bowel to function regularly in the elimination of unwanted matter from the body. They also contain 70-75% water which is essential to the body system and also very important protective foods, useful for the maintenance of health, prevention and treatment of various diseases (D'Mello, 2003; Umoren *et al.,* 2022).

African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) being popularly cultivated vegetables across diverse agricultural landscapes, are susceptible to HMs uptake from contaminated soil and water sources (Kachenko and Singh, 2006; Aletan *et al.*, 2024). Therefore, this study aimed to determine the concentration and health risk of selected HMs in tomatoes and African spinach products from the Ashaka community, Gombe State, Nigeria.

2. Materials and Methods

2.1. Study Area

The study was carried out in two (2) locations of Ashaka community, Funakaye Local Government Areas (LGAs) in Gombe State (Latitude 10.8856° N and Longitude 11.5149° E), Nigeria with a population of 327,300 (Population census, 2006). The vegetation is within the Sudan/Guinea savanna which is characterized by shrubs and scattered trees with different species of grasses (Amos *et al*, 2015). The predominant tree species around and within the vegetation are the locust bean tree, Baobab tree, Moringa, Date-palm, and Neem trees. Wet season is oppressive and overcast while the dry season is partly cloudy, and it is hot year-round. Over the year, the temperature typically varies from 57°F to 100°F and is rarely below *52°F* or above *105°F.* in the North-East geopolitical region of the Federal Republic of Nigeria.

Sample Collection*:* Fresh samples of both African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) were collected from vegetable farms during the harmattan season in January 2022. Sampling was carried out at regular intervals and over the entire plot for each type of sample. Two different plants were sampled by separating the different plant tissues (roots, leaves, stems and fruits) of each plant using a ceramic knife to avoid contamination. To measure an average concentration, at the plot level, the samples were mixed by family and constituted an aliquot. Plant samples for analysis of heavy metal were placed in plastic bags. These samples were then stored at −20˚C in the Laboratory.

Sample Preparation: The vegetables were washed up with distilled water and dried thoroughly to remove dust particles, soil, unicellular algae, etc. (Umoren, 2021). Each African spinach (*Amaranthus hybridus*) and tomato (*Solanum lycopersicum*) sample, separately, taken in a clean porcelain crucible, was washed thoroughly with distilled water and dried at 85 °C for 48 h, in an oven to remove surface water. The vegetables were immediately kept in desiccators to avoid further evaporation of moisture from the materials. The dried vegetable samples were ground and homogenized into a fine powder using a grinding device (Moulinex France) and then stored in polyethene bags. 0.5g of each vegetable was weighed into an airtight polythene packet at room temperature before being taken to the laboratory for digestion and HM analysis.

Digestion and Metal Analysis: For digestion, 0.5 g of each vegetable sample was weighed into a digestion flask and treated with 9 ml of a mixture of concentrated nitric acid (HNO_3), hydrochloric acid (HCl) and sulphuric acid (H_2SO_4). A blank sample was prepared by applying 9ml of concentrated HNO_3, HCl and H_2SO_4 into an empty digestion flask. The samples were mixed and heated for 30 minutes on an electric hot plate at 80-900 °C at which they were brought to boil and a clean solution was obtained. The solution was filtered with Whatman filter paper after cooling and then 100ml volumetric flask was transferred quantitatively by adding 50ml of de-ionized water. The solution was then preserved in a universal bottle for further analysis. All reagents used were of analytical grade and the Atomic Absorption Spectrophotometer (AAS, Perkin Elmer model 2130) was used to determine the HMs (Cd, Ni, Cr, Zn, Cu and Pb). The final concentration of each metal in the vegetable was calculated using the following formula:

$$C_{final}\ (\text{mg/kg}) = \frac{C_{metal} \times \text{dilution} \times \text{nominal volume}}{\text{sample weight (g)}}$$

For the vegetables, the nominal volume is 20 ml and the sample weight is 0.5 g (Moumouni *et al*, 2011)

Health Risk Assessment

Daily Intake: The potential health risk linked to the ingestion of HMs through the consumption of vegetables is assessed based on the daily intake of the metal (DIM) and the health risk index (HRI). The daily intake of each HMs in this study is calculated using the formula below:

$$\text{DIM} = \frac{\text{C}_{\text{HMs}} \times \text{C}_{\text{factor}} \times \text{C}_{\text{veg.Con}}}{\text{B}_{\text{average weight}}}$$

Where C_{metal} is the concentration of HMs in vegetables (mg/kg), C_{factor} is the conversion factor, $C_{veg.\ con}$ is the daily intake of vegetables and $B_{average\ weight}$ is the average body weight for the consumer. The conversion factor of 0.085 is used to convert the weight of fresh vegetables to the weight of the dry substance, the daily amount of vegetables for an adult is assumed to be 65g, while the average adult consumer weight of the vegetable used is 65 kg in this study (Ramteke *et al.*, .2016; Hailu *et al*., 2020; Miranzadeh *et al.*, 2020).

Health Risk Index: The health risk index (HRI**)** was calculated using the formula below:

$$\mathrm{HRI} = \frac{\mathrm{DIM}}{\mathrm{ORI}}$$

Where DIM is the daily intake of the metal and ORI is the oral reference intake. ORI values for Pb, Cd, Cu, Zn, Cr and Ni are 0.0035, 0.001, 0.040, 0.300, 1.5 and 0.020 mg/kg/day respectively (Ramteke *et al.*, 2016; Adedokun AH, 2017). The HRI < 1 means that the exposed population is safe from the health risks of HMs while the HRI > 1 means the population is exposed to a high health risk from HMs (Khan *et al*., 2008).

3. Results and Discussion

Various sources of environmental contamination have been implicated as routes for HMs in Wastewater irrigation, air deposition, and spillage are the major pathways to HM bioaccumulation in vegetables and plants (Singh *et al*., 2010; Oluwole *et al*., 2013; Adesuyi *et al*., 2015). A vegetable is a major part of the Nigerian diet and is very susceptible to environmental pollution due to the activities and processes going on or practiced in the area where it is cultivated or obtained. The recommended maximum limit of cadmium, nickel, chromium, lead and copper for vegetables by FAO/WHO (2001) is 0.2, 5.0, 2.3, 0.3 and 40 mg/kg respectively (Maleki and Zarasvand, 2008) while the Chinese Department of Protective Medicines (CDM, 1994) has the safe limit for zinc in vegetables is 20 mg/kg (Asdeo and Loonker, 2011). The results obtained from the vegetable samples collected from the Ashaka community is shown in Tables 1-3.

Table 1. Heavy Metals Concentration in African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) in comparison with standard limits.

Vegetable	Heavy Metal (mg/kg)					
	Cu	Ni	Zn	Cd	Cr	Pb
African Spinach	0.206	0.619	0.231	0.210	0.073	0.290
Tomato	0.100	0.133	0.229	0.088	0.099	0.167
FAO/WHO (2001)	40	5.0	-	0.2	2.3	0.3
CPDM (Asdeo & Loonker, 2011)	-	-	20	-	-	-

Copper (Cu) is essential to human life as metalloproteins and functions as enzymes, however, critical doses lead to health risks such as anaemia, diabetes, inflammation, kidney and liver dysfunction and vitamin C deficiency (Lokeshappa *et al*., 2012. Although the toxicity of copper is rare, its metabolism is enhanced by molybdenum and zinc constituents in the body (Oladele and Fadare, 2015). The concentration of Cu in the vegetables ranged between 0.206 mg/kg in African spinach and 0.100 mg/kg in Tomato. The Cu levels for the vegetables were lower than the WHO/FAO safe limits (40 mg/kg).

Nickel is essential for growth and reproduction in livestock and man, but could be carcinogenic in high amounts in the body. In this study, the concentrations of Ni in the vegetables ranged between 0.619 mg/kg in African spinach and 0.133 mg/kg in Tomato. The concentration of Ni in vegetables was found to be lower than the guideline set by WHO/FAO (5.0 mg/kg). These variations of Ni concentration between the vegetables might be due to the HM pollutants in soil, air, water, factory wastages, sewerages etc. Nickel has been reported to be a common cause of allergies such as dermatitis (Adedokun *et al*., 2017).

Zinc (Zn) is essential for normal growth, mental ability, immune system, reproduction and healthy function of the heart (Adedokun *et al*., 2017). The concentration of Zn in the vegetables ranged between 0.231 and 0.229 mg/kg with the highest recorded in African spinach. Zinc is a natural constituent of soils in terrestrial ecosystems and it is taken up actively by roots (Adesuyi *et al*., 2015), It is quite abundant in the vegetables. Although not exceeding the CDPM safe limit (20 mg/kg) (Asdeo and Loonker, 2011). High concentrations of zinc in vegetables may lead to vomiting, renal damage, cramps etc. (Ladipo and Doherty, 2011).

The concentrations of Cd in the vegetables ranged between 0.210 mg/kg in African spinach and 0.088 mg/kg in tomato. In this study, the concentration of Cd was below the permissible levels by FAO/WHO (0.2 mg/kg) except African spinach 0.210 mg/kg) which is slightly higher. The most common sources of Cd in vegetables are sewage sludge application, deposition from fossil fuel combustion, phosphate fertilizers etc. (Adesuyi *et al*., 2015). Cadmium accumulates especially in the kidneys leading to dysfunction with increased secretion such as proteinuria and other effects (Waalkes, 2000).

Chromium (Cr) concentration in the vegetable ranged between 0.073 mg/kg in African spinach and 0.099 mg/kg in Tomato. Chromium concentration were found to be lower than the guideline set by

WHO/FAO (2.3 mg/kg). Chromium depending on the valence can be beneficial or harmful; the hexavalent state of chromium is harmful (Umoren *et al.*, 2024). Chromium is known to help maintain normal blood glucose levels by enhancing the effects of insulin (Chove *et al*., 2006). The most widespread human effect is chromium allergy caused by exposure to chromium (especially Cr (VI) compounds), and they are assumed to cause cancer (Taiwo *et al.*, 2019).

The concentration of Lead (Pb) ranged from 0.167mg/kg in tomatoes and 0.290mg/kg in African spinach. The concentration is below the FAO/WHO safe limit (0.3 mg/kg). The concentrations of Pb in the vegetables in this study were lower than the concentrations recorded in vegetables studied in Pakshi, Bangladesh (Tasrina *et al*., 2015; Edogbo *et al.*, 2020). Lead contamination is commensurate with population/vehicular density (Adedokun *et al*., 2016). Generally, lead contaminations occur in vegetables grown on contaminated soils, through air deposition or sewage sludge/wastewater application (Oluwole *et al*., 2013). In overall, cadmium concentrations above the WHO/FAO was recorded in African spinach which could have consequences on the human health of the consuming population in the Ashaka community.

Health Risk Assessment: The assessment of health risks due to the presence of HMs in the vegetables consumed was done by calculating the daily intake of heavy metals and the health risk index.

Daily Intake: The results of the daily dose of HMs with the recommended daily intake and the tolerable limits of the daily intake established by the Institute of Medicine in the United States of America for aged populations between 19 and 70 years old (Adedokun *et al*., 2017) are presented in Table 2. The degree of HM toxicity in humans depends on the daily intake. The daily plant metal intake for Cd (0.018 - 0.007 mg/kg) and Pb (0.024 - 0.014 mg/kg) is higher than the recommended daily intake of HMs but does not exceed the tolerable limit while the daily intake of Cu, Ni and Zn is lower. Furthermore, the calculated daily intake for Cr (0.006 - 0.008 mg/kg) was lower than the recommended reference dose of 1.5 mg/kg (USEPA, 2010).

Table 2. Daily intake of heavy metals

Vegetable	Cu	Ni	Zn	Cd	Cr	Pb
African spinach	0.018	0.053	0.019	0.018	0.006	0.024
Tomato	0.009	0.011	0.019	0.007	0.008	0.014
Recommended daily intake	0.9	0.5	8	0	-	0

Upper tolerance daily intake	10	1	40	0.064	-	0.24

Health Risk Index (HRI): Generally, the HRI < 1 means that the exposed population is safe from the health risks of metals while the HRI > 1 means the population is exposed to a high health risk from heavy metals (Khan *et al*., 2008). Except for Cu, Cr, Zn and Ni in tomato, the HRI assessed for all studied HMss was greater than one implying that Cd, Pb, and Ni in African spinach could pose severe health risks to humans on consumption. The health risk indices for HMs in the vegetables are as follows: Cu (0.45 to 0.225), Ni (2.65 to 0.55), Zn (0.063 to 0.063), Cd (18.00 to 7.00), Cr (0.004 to 0.005) and Pb (6.857to 4.00). The result of the health risk index shows high values for Cd, Pb, and Ni while low values were observed for Cu, Cr and Zn (Table 3).

Table 3. Health risk index

Vegetable	Cu	Ni	Zn	Cd	Cr	Pb
African spinach	0.45	2.65	0.063	18.00	0.004	6.857
Tomato	0.225	0.55	0.063	7.00	0.005	4.00

4. Conclusions

The study to investigated the concentration and health risk of selected HMs in vegetables, that is African spinach (*Amaranthus hybridus*) and Tomatoes (*Solanum lycopersicum*) from the Ashaka community. This study indicated that concentrations of Cd, Cr, Cu, Zn, Pb and Ni in African spinach and tomato were below the safe limits by WHO/FAO except for Cd in tomatoes respectively. The daily HM intake for Cd (0.018 - 0.007 mg/kg) and Pb (0.024 - 0.014 mg/kg) is higher than the recommended daily intake of HMs but does not exceed the tolerable limit. The HRI result showed high values for Cd, Pb, and Ni indicating that Cd, Pb, and Ni could pose severe health risks to consumers of African spinach and tomatoes from the Ashaka community.

Authors Contribution

Conceptualization, MIF and MI.; Methodology, MIF and MAI.; Formal Analysis, BJN.; Investigation, EOM and MBS.; Resources, EOM, MBS and UOD and BKN.; Data Curation, MIF and MI.; Writing – Original Draft Preparation, MIF, MI and MAI.; Writing – Review & Editing, UOD.

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