Innovations

Evaluating Soil-Plant Transfer and Partitioning of Toxic Metals in Cassava(*Manihot esculenta*): Implications for Food Safety around Mfamosing Cement Plant, Nigeria

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Abstract: *The study evaluated soil-plant transfer, partitioning, and bioaccumulation of toxic metals in cassava (Manihot esculenta) cultivated around the Mfamosing Cement Plant, Nigeria, to assess food safety risks. Soil and cassava samples (peeled tubers, peels, and leaves) were collected from farms at varying distances (0–1500 m) from the cement plant and analyzed using Atomic Absorption Spectrophotometry (Model AA-6800, Japan). Mean soil metal concentrations (mg/kg) ranged from 0.22±0.09 to 81.61±3.67, while concentrations (mg/kg) in peeled tubers, peels, and leaves ranged from 0.01±0.01 to 0.72±0.02, 0.01±0.00 to 2.48±0.04, and 0.01±0.00 to 1.03±0.06, respectively. Except for cadmium, mean soil metal concentrations were below regulatory thresholds. A significant decrease in lead, cadmium, and chromium concentrations in soil and cassava tissues with increasing distance from the cement plant suggests anthropogenic influence. Transfer factors for all metals were within acceptable ranges (0.01–0.1 Mg/kg), with chromium exhibiting efficient internal transport from roots to leaves (TF >1), whereas Pb, Cd, Hg, and As showed restricted mobility (TF <1). Results revealed that cassava peels and leaves preferentially accumulated Pb, As, and Cr, while peeled tubers stored mercury, suggesting varied metal partitioning patterns within the plant. Notably, Pb and Cd concentrations in peeled tubers and leaves exceeded WHO/FAO limits, highlighting concerns regarding food safety. The findings underscore the need for periodic monitoring, awareness campaigns on cassava tissue-specific metal bio-accumulation, and assessment of potential health risk pose by edible cassava tissues. Given cassava's role as a staple food, continuous exposure to these metals could have long-term health implications, necessitating stringent regulatory measures.*

Key Words: *Soil-plant transfer, Partitioning, Bioaccumulation, Heavy metals, Cassava plant, Food safety*

1.0: Introduction

The rapid expansion of industrialization and urbanization has driven an increased demand for cement production, fuelling infrastructure development worldwide. However, while cement manufacturing is vital for economic growth, it remains a major contributor to environmental pollution. Its impacts extend from landscape degradation to the emission of gaseous and particulate pollutants, with dust pollution being one of the most critical health and environmental concerns. Cement dust, enriched with toxic contaminants—including heavy metals—disperses over vast distances before settling on soil, vegetation, water bodies, and other exposed surfaces**(**El-Sherbiny *et al*., 2019; Chaurasia *et al*., 2013**)**.

Soil, acting as both a sink and a buffer, plays a crucial role in regulating the mobility and bioavailability of these contaminants across environmental compartments (Moreno, et al., 2010). However, the persistent accumulation of heavy metals in soil poses a significant threat, as these pollutants can leach into groundwater, be absorbed by plants, and ultimately enter the food chain through deposition on edible plant tissues (Olowoyo et al., 2012). Cement plants are known sources of hazardous elements such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr), all of which persist in the environment and have been linked to severe health risks upon bioaccumulation in food crops (Alloway, 2013; Kabata-Pendias, 2011).Heavy metal uptake by plants is influenced by several factors, including soil properties, plant physiology, and environmental conditions. The soil-plant transfer factor, translocation factor, and bioaccumulation factor provide insights into how metals move from soil into plant tissues and their potential impact on human consumption (Chibuike & Obiora, 2014). Metals with high soil-to-plant transfer and translocation factors are of particular concern, as they indicate efficient absorption and distribution within plant tissues. Plant's ability to exclude or accumulate specific metals in edible portions such as tubers and leaves is critical for evaluating food safety risks.

Given the reliance on cassava (*Manihot esculenta*) as a staple food in many communities near industrial zones in southern Nigeria, cassava's potential to accumulate heavy metals through different pathways (Figure 1), raises concerns regarding food safety and public health. Previous studies have investigated heavy metal contamination in various crops, but limited research has examined the chemo-dynamics of the metals (Usman et al., 2020; Olowoyo et al., 2015). Understanding the extent of soil-plant metal transfer, partitioning, and bioaccumulation is critical for assessing food safety risks. This study evaluates these processes in cassava grown around the Mfamosing Cement Plant, Nigeria. Additionally, understanding the preferential storage of heavy metals in different cassava tissues (peeled tubers, peels, and leaves) is crucial for assessing the potential health risks associated with cassava consumption.

Mfamosing Cement Plant, operates at an annual production capacity of 5 million tonnes. The production of one tonne of cement requires 2.6 to 2.8 tonnes of raw materials, of which 5-10% is released as dust into the surrounding environment (Makoju, 1992). Based on these figures, the estimated annual dust emission from the plant ranges from 659,000 to 1.4 million tonnes. This significant particulate release contributes to heavy metal contamination of nearby soils and crops, posing potential health risks to local communities. The Mfamosing cement plant which is the third largest cement producer in Nigeria is a modern production facility with state-of-the-art infrastructure. It is unlikely may have discharged the huge amount of dust estimated considering the downtimes for maintenance but even the most sophisticated cement plants have been severally implicated in environmental issues. Periodic evaluation of impacts on the environment may serve as early warning signal (Mishra, and Siddiqui, 2014; Rai, 2011; Makoju, 1992).

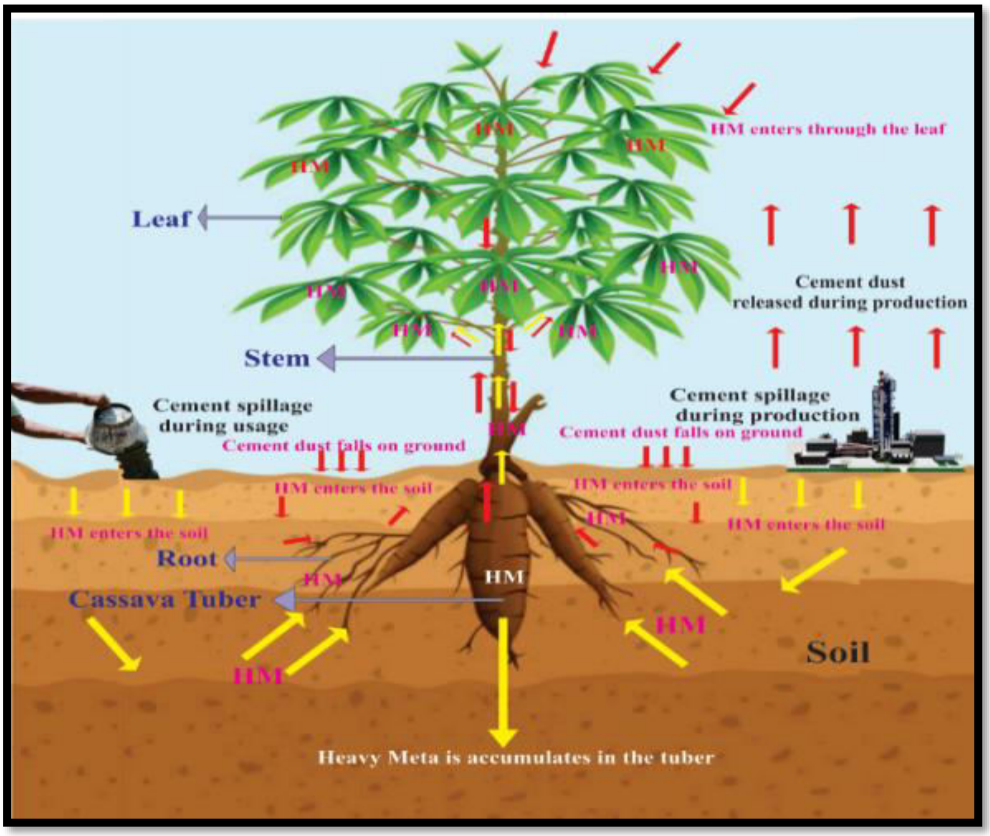

Figure 1: Pathways for metals uptake by cassava plant

2.0: Materials and Methods

2.1: Study Area

Lafarge African Plc, Mfamosing Cement plant, Nigeria, is located within the Cross River limestone belt at Mfamosing, Akamkpa Local Government Area, Cross River State, Nigeria, between latitude $4^0 53'$ N and $5^0 05'$ N, and longitude 8^0 15' E and 8^0 27' E) (Figure 1). It is cited within Lafarge cement concession area (a mining lease area available to Lafarge Holcim) at AbiMfam (Lafarge, 2022; Edet et al., 2019; UniCem, 2014). The climate is tropical and the vegetation is prominently tropical rainforest. The area experiences an average annual rainfall of about 1600 mm, and temperature ranging between 26 ^{0}Cand 36 ^{0}C with distinct wet (April-October) and dry (November-March) seasons (Olowoyo et al., 2015). Farming is the main occupation in the area. Cassava is the most cultivated crop on small farm holdings and the main staple food. Cassava cultivation is essentially by traditional methods, farmers depend on the natural fertility of the soil with no application of fertilizers or other agrochemicals.

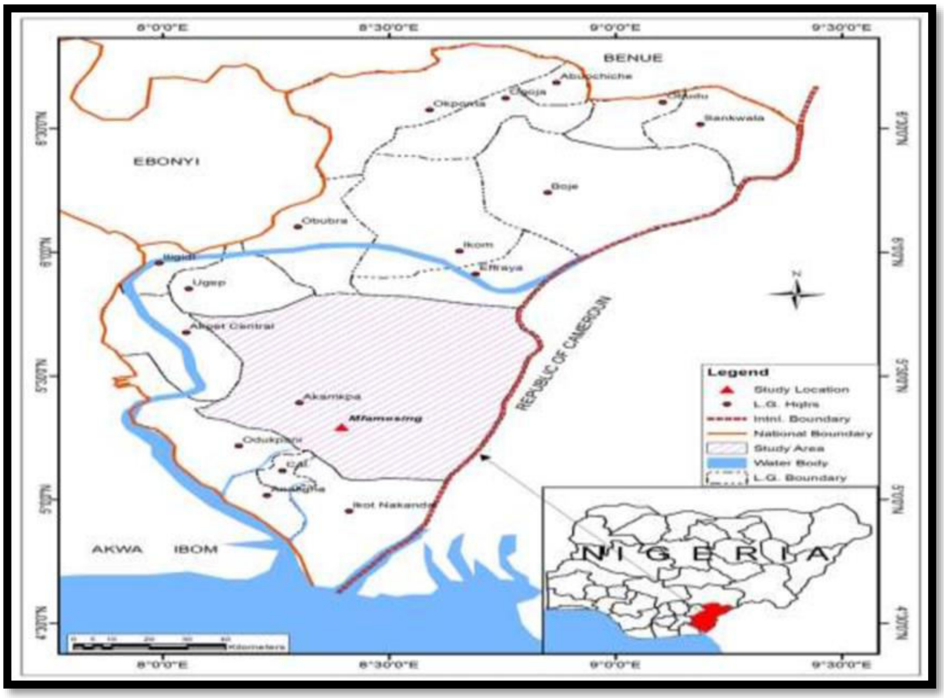

FIG. 1; Map of study area showing Lafarge African Plc, Mfamosing Cement plant, Akamkpa Local Government Area, Nigeria

2.2: Sample Collection and Preservation

Sample collection and preservation followedAbida, *et al*., (2009). Sampling was carried out between June and December 2021. Four cassava farms (100 m x 50 m each) were systematically selected for the study. Farm 1 was just outside the factory gate (zero meters), farm 2 was 500 meters from the gate, farm 3 was 1000 meter from the factory gate and farm 1500 meters from the factory gate. Each of the farms was divided into ten strata and numbered 1-10. Samples were randomly collected from 3 of the strata for each farm. Soil, mature cassava roots (tubers) and leaves were harvested from the three sampling points in each farm with consent of the respective farm owners. Samples from each farm were pooled together to form composite sample for effective representation of the farm and stored in labelled black polyethylene bags. Cassava samples were similarly collected from three cassava farms at Atimbo village, Calabar Municipal local government area and used as control. Collected samples were transported to Zoology and Environmental Biology laboratory, university of Calabar sample preparation.

2.3: Sample Preparation

Cassava tissues (leaves and tubers) were thoroughly washed so as to remove all adhered soil. The tubers were peeled and cut into pieces. Leaves were also cut into pieces. Samples (soil, peeled tubers, peels and leaves) were air dried for 5 days in the laboratory before oven drying for 4 hours at 103°C. The driedsamples were pulverized (ground into powder), passed through 1 mm sieve and digested. For the digestion, 1g of the sieved sample was treated with 20 ml of concentrated nitric acid according to Awofolu, (2005). Procedure for soil digestion was adopted from Baker and Amacher, (1982) with slight modification. Dried soil samples were crushed and sieved with 2 mm mesh before wet digestion. I g of a well-mixed sample from each farm was taken into a 250 ml glass beaker and digested with 20 ml of concentrated nitric acid, perchloric acid and hydrofluoric acid in the ratio 3:1:1 on a hot plate. After evaporating to near dryness, 20 ml of 2 % nitric acid was added, filtered into 50 ml volumetric flask, then made up to the mark with distilled deionized water.

2.4: Sample analysis

Digested samples were analyzed for Pb, Cd, Hg, As, and Cr using Atomic Absorption Spectrophotometry (Model AA-6800, Japan) following standard quality control procedures (Malik et al., 2010).

***2.5:* Quality Control Measures**

Strict protocols were followed to prevent cross-contamination, and reference materials were used to validate analytical accuracy. Glassware was cleaned thoroughly, and only high-purity reagents were used- - HNO_3 (Riedel-deHaen, Germany), HF (Sigma Aldrich, Germany) and $HClO_4$ (British Drug House Chemicals Limited, England) were of analytical grade. The result of the analysis was validated by digesting and analyzing Standard Reference Materials (Lichens coded IAEA-336) following the same procedure. The analyzed values and the certified reference values of the elements determined were compared to ascertain the reliability of the analytical method employed.

***2.6:* Data Analysis**

Statistical analysis was performed using SPSS 23.0. Analysis of Variance ANOVA and independent t-tests were used to determine variations in metal concentrations across sampling points and seasons. Correlation analysis assessed relationships between metal levels in soil and cassava tissues at $\alpha = 0.05$ (Islam et al., 2020). Probabilities less than 0.05 ($p < 0.05$) were considered statistically significant.

2.7: Soil-Plant Transferand Translocation (Transport Factor)

The level of a given heavy metals in plant is a function of the transport factor (Transfer factor from soil to plant root and translocation factor from plant root to leaves and vice versa) and is based on the interactions between the plant and the soil.

2.7.1: Transfer Factor (Plant Contamination Factor)

The transfer factor of lead, cadmium, mercury, arsenic and chromium from soil to cassava tuber (peeled tubers and peels) was calculated according to Malik*et al.,* (2010)as:

$$Transfer\ Factor = \frac{HMT}{HMS} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where HM_T is mg heavy metal per kg cassava tuber and HM_S is total content heavy metal per kg soil.

2.7.2: Translocation Factor (TF)

Translocation Factor (TF) was described as the ratio of metals in cassava leaves to that in the cassava tuber as given in equation 2Malik*et al.,* (2010)

$$TF = [Metal_{leaves}] / [Metal_{tubers}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2.7.3: Bioaccumulation Factor (BAF)

The ability of Plant (cassava) to accumulate metals with respect to its concentration in soil is called index of bioaccumulation for metals. BAF was calculated according to Addo *et al.,*(2013) as given in equation (3)

$$BAF = [M_{leaves}] / [M_{soil}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, $[M_{leaves}]$ represent metal concentration of metals in edible cassava leaves and $[M_{soil}]$ concentration of lead in soil.

3.0: Results and Discussion

3.1 Analytical quality assurance

Standard reference material, Lichen (IAEA – 336) was analyzed in the same manneras the samples, to assess the accuracy and precision of the analytical process used. The analyzed values were within the acceptable limits of the certified reference values of the elements determined indicating the method's reliability (Table 1).

Table 1: Results of analyzed reference material (Lichen IAEA - 336) compared to the certified reference values (Mg/kg).

Element (Mg/kg)	Pb	Cd	Hg	As	Cr
A value	5.25	0.140	4.00	1.20	29.18
R value	4.2-5.5	0.1-2.34	3.1- 4.1	1.00-1.50	27.00-

					30.00

A value = Analyzed value *R value = Reference value*

3.2: Mean Concentrations of Heavy Metals in Soil, Peeled Cassava Tubers, Cassava Peels and Cassava Leaves

Results obtained from the determination of heavy metals concentration in soil and cassava tissues across farms presented in Table 2 indicates that, the mean concentrations (mg/kg) of heavy metals in soil, peeled tubers, peels and leaves were of the ranges9.12±0.01-81.61±3.67, 0.11±0.01-0.72±0.02, 0.13±0.02-2.48±0.04 and 0.08±0.01-1.03±0.06 respectively for lead, 0.22±0.09-9.03±0.65**,** 0.09±0.02-0.50±0.02, 0.10±0.01-0.67±0.02 and 0.06±0.01-0.56±0.04 respectively for cadmium, 0.68±0.04-0.77±0.01, 0.01±0.01-0.04±0.01, 0.01±0.01-0.02±0.01 and 0.02±0.01-0.04±0.01 respectively for mercury, 5.00±0.10-5.63±0.02, 0.01±0.01-0.02±0.01, 0.01±0.01-0.03±0.01 and 0.01±0.01-0.03±0.01 respectively for arsenic and 8.32±0.09-35.65±1.14, 0.01±0.01-0.11±0.11, 0.02±0.01-0.08±0.01 and 0.02±0.00-0.68±0.04 respectively for chromium.Soil quality is known to play significant role in food production (Laniyan & Adewumi, 2020). The mean soil lead, cadmium, mercury, arsenic and chromium concentrations were below their respectivesoil guideline values (mg/kg) of 200, 10, 11, 32 and 300and the Dutch soil remediation intervention values (mg/kg) of 530, 12, 10, 55 and 380 (Jeffries, 2017; Claire, 2010; DEFRA & Environment Agency, 2004; Dutch Target and Intervention Values, 2000). The metals were therefore not implicated in soil except cadmium which in addition to being mobile in soil and relatively more bioavailable was as found to be above United State Environmental Protection Agency (US-EPA) and European Union maximum permissible limit for cadmium in soil of 3 mg/kg (Environment Agency, (2014). Uptake of the metals by plant is a function of several factors. Such factors that influence the availability of heavy metals in soil and uptake by plants are; chemical form of the metal, soil organic matter content, soil-pH and cation exchange capacity, which eventually can determine the solubility, adsorption, retention and movement of the heavy metals. Soil moisture content play useful role in enhancing each of the factors (Chibuike & Obiora, 2014).

A comparison of metal concentrations in peeled cassava tubers with WHO permissible limits for metals in root and tuber crops showed that Pb and Cd levels exceeded the maximum allowable limits (Pb: 0.1 mg/kg; Cd: 0.2 mg/kg) (WHO/FAO, 2011). Mercury concentrations in peeled tubers, though relatively

Table 1:Total Heavy Metals Concentrations in Soil and Cassava Tissues across Farms

Farms	Metals	Soil		Peeled Tubers		peels		leaves	
		Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
1	Pb	59.41±3.94[a]	81.61±3.67[b]	0.65±0.01 [a]	0.72±0.02[a]	1.68±0.44 [a]	2.48±0.04[a]	0.83±0.08 [a]	1.03±0.06[a]
	Cd	7.50±0.24[a]	9.03±0.65[b]	0.44±0.02 [a]	0.50±0.02[a]	0.60±0.05 [a]	0.67±0.02 [a]	0.56±0.04 [a]	0.56±0.02 [a]
	Hg	0.73±0.01 [a]	0.74±0.02 [a]	0.03±0.01 [a]	0.04±0.01[a]	0.02±0.01	0.01±0.01 [a]	0.03±0.01 [a]	0.04±0.01 [a]
	As	5.50±0.05 [a]	5.63±0.02 [a]	0.01±0.01[a]	0.01±0.01 [a]	0.03±0.01[a]	0.03±0.01 [a]	0.02±0.01 [a]	0.03±0.01 [a]
	Cr	32.53±1.24 [a]	35.65±1.14 [a]	0.05±0.01 [a]	0.06±0.01 [a]	0.08±0.01 [a]	0.08±0.01 [a]	0.64±0.02 [a]	0.68±0.04 [a]
2	Pb	47.01±4.07[a]	76.45±3.14 [b]	0.47±0.04 [a]	0.47±0.04[a]	1.01±0.09[a]	1.10±0.05 [a]	0.71±0.05 [a]	0.83±0.04 [a]
	Cd	6.96±0.07 [a]	7.53±0.36 [a]	0.31±1.11 [a]	0.34±0.01 [a]	0.54±0.03 [a]	0.55±0.02 [a]	0.43±0.01 [a]	0.46±0.04 [a]
	Hg	0.73±0.01[a]	0.73±0.01[a]	0.03±0.01 [a]	0.04±0.01 [a]	0.01±0.01 [a]	0.01±0.00 [a]	0.03±0.01 [a]	0.03±0.01 [a]
	As	5.29±0.05 [a]	5.60±0.29 [a]	0.01±0.01 [a]	0.02±0.01 [a]	0.03±0.01 [a]	0.03±0.01 [a]	0.02±0.00 [a]	0.02±0.01 [a]
	Cr	25.41±0.53 [a]	26.94±0.06[a]	0.04±0.01 [a]	0.04±0.01 [a]	0.06±0.01 [a]	0.07±0.01 [a]	0.49±0.02 [a]	0.42±0.03 [a]
3	Pb	40.04±3.15 [a]	63.67±6.61 [b]	0.37±0.02 [a]	0.35±0.03 [a]	0.69±0.05 [a]	0.81±0.05 [a]	0.46±0.02 [a]	0.49±0.01 [a]

	Cd	4.98±0.28ᵃ	5.66±0.11 ᵇ	0.21±0.02 a	0.25±0.01 a	0.33±0.02 a	0.36±0.02 a	0.32±0.02 a	0.35±0.02 a
	Hg	0.68±0.04 a	0.77±0.01a	0.02±0.01 a	0.04±0.01 a	0.01±0.01 a	0.01±0.01 a	0.03±0.01 a	0.04±0.01 a
	As	5.07±0.04 a	5.53±0.15 a	0.01±0.01 a	0.02±0.01 a	0.03±0.01 a	0.03±0.01 a	0.02±0.01 a	0.03±0.01 a
	Cr	16.03±0.37a	16.80±0.06 a	0.11±0.11 a	0.03±0.03 a	0.05±0.01 a	0.05±0.01 a	0.30±0.02 a	0.31±0.02 a
4	Pb	22.67±2.78 a	29.56±3.39 a	0.20±0.01 a	0.22±0.01 a	0.48±0.01 a	0.47±0.03 a	0.36±0.02 a	0.39±0.02 a
	Cd	2.89±0.54 a	2.88±0.08 a	0.13±0.01 a	0.15±0.01 a	0.26±0.05 a	0.28±0.03 a	0.24±0.02 a	0.27±0.01 a
	Hg	0.71±0.02a	0.71±0.01 a	0.02±0.01 a	0.03±0.01 a	0.01±0.01 a	0.01±0.00 a	0.03±0.01 a	0.03±0.01 a
	As	5.02±0.32 a	5.34±0.22 a	0.01±0.01 a	0.02±0.01 a	0.02±0.00 a	0.02±0.01 a	0.02±0.00 a	0.02±0.01 a
	Cr	10.38±0.10 a	11.08±0.16a	0.02±0.01 a	0.02±0.00 a	0.04±0.01 a	0.04±0.01 a	0.20±0.02 a	0.28±0.03 b
Control	Pb	9.12±0.01a	9.13±0.01 a	0.11±0.01a	0.12±0.01 a	0.13±0.02a	0.15±0.01 a	0.08±0.01a	0.08±0.01 a
	Cd	0.22±0.09a	0.23±0.01 a	0.09±0.02a	0.11±0.01 a	0.10±0.01 a	0.11±0.00 a	0.06±0.01 a	0.06±0.01 a
	Hg	0.69±0.01 a	0.70±0.02a	0.02±0.01 a	0.01±0.01 a	0.01±0.00 a	0.01±0.00 a	**0.02±0.01** a	0.02±0.01 a
	As	5.00±0.10 a	5.34±0.23 a	0.01±0.01 a	0.01±0.01 a	0.01±0.00 a	0.01±0.01a	0.01±0.00 a	0.01±0.01 a

	Cr	8.32±0.09 [a]	8.35±0.08 [a]	0.01±0.01 [a]	0.01±0.01 [a]	0.02±0.01 [a]	0.03±0.01 [a]	0.02±0.00 [a]	0.02±0.00 [a]

Means with different superscripts for dry and wet seasons indicate significant ($p < 0.05$, ANOVA) difference in metals concentration low, require continuous monitoring to prevent long-term health risks. Arsenic and chromium levels were within acceptable limits, suggesting minimal risks associated with their presence in tubers. Similarly, cassava leaves were compared with WHO standards for leafy vegetables (WHO/FAO, 2011). Pb and Cd concentrations in cassava leaves were above the recommended limits (Pb: 0.3 mg/kg; Cd: 0.2 mg/kg), posing potential dietary risks for consumers. Chromium levels were also slightly elevated, while arsenic and mercury concentrations remained within safe limits. The high accumulation of Pb and Cd in cassava leaves underscores the need for caution in consuming unprocessed cassava foliage, which is often used as livestock feed and in traditional medicine.

3.3: Seasonal and Spatial Comparison of the Concentrations of Heavy Metals in soil and Cassava Tissues

The concentration of lead and cadmium in soil showed significant difference ($p < 0.05$) between dry and wet seasons for farm 1, 2 and 3, the concentrations during wet season being significantly higher than dry season. This observation is likely due to increased metal mobility from rainfall-induced leaching and runoff.Soil moisture content has been reported to play useful role in enhancing factorsthat influence the availability of heavy metals and subsequent uptake (Chibuike & Obiora, 2014).

The difference in soil lead, cadmium and chromium concentrations between the farms (farm 1, 2, 3 and 4) and, between the farms and control station were found to be significant (ANOVA, $p < 0.05$), displaying a pattern which showed significant decrease in concentration with increasing distance from the cement plant (farm 1 > farm 2 > farm 3 > farm 4 > farm 5 > control). A similar pattern was displayed by lead, cadmium chromium contents of peeled tubers, peels and leaves suggesting two possibilities. Firstly, decrease in the concentration of these metals in soil brings about decrease in their uptake by cassava plant and secondly that anthropogenic activities may be responsible for the presence of the metal at the concentration determined. This may indict cement production which is the major human activity in the area outside traditional farming. This finding agrees with Semhi *et al*., (2010) who reported that dust emitted from cement factory in Oman show high concentration of heavy metals within a radius of 0.5 km and 2 km around the cement factory. Mercury and arsenic content of soil, peeled tubers, peels and leaves did not display significant difference between the farms, and between the farms and the control suggesting that the human activities may not have significant influence on the concentration of the two metals (mercury and arsenic). Geogenic sources may therefore be responsible for their presence at the concentrations determined in the environment under study.

2.4: Soil-Plant Transfer and Translocation Factor (Transport Factor)

The level of a given heavy metal in plant is a function of the transport factor (Transfer factor from soil to plant root and translocation factor from plant root to leaves and vice versa) and is based on the interactions between the plant and the soil.Plants require some elements (essential/trace elements) within a certain threshold for their growth and physiological development. Above the threshold even the most essential element could be toxic to plants (Chibuike & Obiora, 2014). The ability of plant to uptake essential elements also enables them to acquire non-essential/toxic heavy metals such as lead, cadmium, mercury and arsenic considered in this study. In all cases, transfer factor less or equal to 0.1 indicates that plant excludes the metal from its tissues, 0.1-0.9 indicates poor response of plant towards the metal absorption from the soil and higher values above unity indicates a higher absorption of the metal from soil by the plant (bioaccumulation) and suitability of the plant for phyto-extraction and phytoremediation (Catherine & Oniovosa, 2019). Generally, if transfer factor of a metal is greater than 0.5, the metal has greater chances of contamination by anthropogenic activities (Catherine & Oniovosa, 2019).

2.4.1: Transfer Factor from Soil to Peeled Cassava Tubers

Transfer factor is a good indicator of how much of the metal is bioavailable. It is a function of both soil and plant properties, and one of the major components of human exposure to metals through the food chain.The average values of transfer factor of the metals from soil to peeled tubers for both dry and wet seasons were 0.01 and 0.01 for lead, 0.05 and 0.05 for cadmium, 0.04 and 0.05 for mercury and 0.002 and 0.004 for arsenic and 0.002 and 0.002 for chromium (Table 3). The average transfer factors of the metals followed the trend Cd> Hg > Pb > As > Cr.The uptake of heavy metals from soil is through ionic exchange, redox reaction, desolation-precipitation and several other processes which depend on several factors. The distribution in plant is controlled by genetic, environmental and toxic factors. Thus, different species of plant grown in same soil may contain different levels of same element (Mirecki et al., 2015). The acceptable range of transfer factor suggested by Kloke *et al.*, (1994) for a normal plant (0.01- 0.1)was used as generalized range for comparison. The transfer factor of lead, cadmium, mercury, arsenic and chromium from soil to peeled tubers for both dry and wet season (Table 3) were lower than the values suggested by Kloke, therefore within the acceptable range for a

Table 3:Heavy Metals Transfer Factor from Soil to Peeled Cassava Tubers

Sampling Station	Dry Season					Wet Season				
	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr
Farm 1	0.01	0.06	0.04	0.00 2	0.002	0.01	0.05	0.0 5	0.00 2	0.002
Farm 2	0.01	0.04	0.04	0.00 2	0.002	0.01	0.05	0.0 5	0.00 4	0.001
Farm 3	0.01	0.04	0.03	0.00	0.001	0.01	0.04	0.0	0.00	0.002

				2				5	4	
Farm 4	0.01	0.04	0.03	0.002	0.002	0.01	0.05	0.04	0.004	0.002
Average	0.01	0.05	0.04	0.002	0.002	0.01	0.05	0.05	0.004	0.002
Control	0.01	0.41	0.03	0.002	0.001	0.01	0.47	0.01	0.002	0.001

normal plant. The values revealed that cassava plant excludes the metals from uptake. This observation may be attributed to the interplay of several factors such as cassava species, chemical form of the metals, soil chemistry, cation exchange capacity, pH and multiple other factors, and not just concentration of the metals in soil. The implication here is that only small proportion of the metals are probably taken up by the plant.

3.4.2: Heavy Metals Transfer Factor from soil to Cassava Peels

The average values of transfer factor of the metals from soil to cassava peels for both dry and wet seasons were 0.02 and 0.02 for lead, 0.08 and 0.08 for cadmium, 0.01 and 0.01 for mercury and 0.005 and 0.005 for arsenic and 0.003 and 0.003 for chromium. The average transfer factors of the metals also followed the trend Cd> Pb > Hg > As > Cr (Table 4). The transfer factor of the metals from soil to peels for both dry and wet season were lower than the values suggested by Kloke, therefore within the acceptable range for a normal plant. The values revealed that cassava plant also excludes the metals from soil to cassava peels. This study thus revealed that, cassava plantdisplays poor response towards absorption of the metals under study from soilto roots (peeled tubers and peels) and exclude them (Table 3 and 4), suggesting that only negligible portion of the metals in soil is up-taken by the roots.This implies that,the source of metals in cassava plant may not only be a result of uptake from the soil. Olowoyo*et al*., (2015) noted that concentrations of heavy metals in vegetables might be due not only to soil composition but also to absorption capacities of the vegetables and atmospheric deposition which may be influenced by numerous environmental factors. Absorption from atmospheric deposition may have contributed to the metals contents of cassava tissues.

Table 4: Heavy Metals Transfer Factor from soil to Cassava Peels

Sampling Station	Dry Season					Wet Season				
	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr
Farm 1	0.03	0.08	0.01	0.005	0.002	0.03	0.07	0.01	0.005	0.002
Farm 2	0.02	0.08	0.01	0.006	0.002	0.01	0.07	0.01	0.005	0.003

Farm 3	0.02	0.07	0.01	0.006	0.003	0.01	0.06	0.01	0.005	0.003
Farm 4	0.02	0.09	0.01	0.004	0.004	0.02	0.10	0.01	0.004	0.004
Average	0.02	0.08	0.01	0.005	0.003	0.02	0.08	0.01	0.005	0.003
Control	0.01	0.45	0.01	0.002	0.002	0.02	0.48	0.01	0.002	0.004

3.4.3: Translocation Factor (TF) and Bioaccumulation Factor of Heavy Metal in Cassava Leaves

The translocation factor of chemical substances in plant is a pointer of the extent to which such substances can be transported from the root to accumulate in the above ground part of the plant. It explains the mobility of substances from the root to other parts of the plant. A major characteristic of hyperaccumulators of heavy metal is the efficient transport from root to the above ground parts distinguished by translocation factor greater than unity (Islam et al., 2020). The average translocation factor of lead, cadmium, mercury, arsenic and chromium from cassava roots to leaves for both dry and wet seasons were 0.45 and 0.46, 0.56 and 0.55, 0.75 and 0.70, 0.56 and 0.53, and 4.46 and 4.31 respectively. Average translocation factor in the study followed the trend Cr > Hg > Cd > As >Pb (Table 5). Chromium showed the highest affinity to translocate from cassava root to leaves with TF > 1. Lead, cadmium, mercury and arsenic showed TF < 1, suggesting that limited portions of these metals were translocated from roots to leaves. Translocation factor is mainly controlled by the pressure of roots, leaves transpiration and solubility of the metal (Catherine & Oniovosa, 2019). The high translocation factor shown by chromium indicates relatively low restriction hence the efficiency of the internal transport of chromium from the roots towards the leaves while the mobility of Pb, Cd, Hg and As are restricted. Mirecki et al., (2015), opined that, plants absorb metals from the soil through the roots and from the atmosphere through the vegetative parts such as the leaves. The exceedance of the maximum permissible limit for consumed vegetables by lead and cadmium contents of cassava leaves in this study also suggest that absorption from the roots may not be the only source of the metals in the plant. Absorption from the atmosphere through the leaves may have contributed significantly to the presence of the metals at the concentrations determined.

The tendency for cassava plant to uptake and retain lead, cadmium, mercury, arsenic and chromium it its leaves was considered in this study as bioaccumulation of the metal. Bioaccumulation factor in this study mirrors the efficiency of cassava plant to accumulate each of the metal. Total bioaccumulation depends on rate of uptake of each of the metals from all available sources versus the rate at which the plant is capable of eliminating or breaking them down

Table 5: Translocation Factor (TF) and Bioaccumulation Factor of Heavy Metal in Cassava Leaves

Sampling Station	Translocation Factor										Bioaccumulation Factor									
	Dry Season					Wet Season					Dry Season					Wet Season				
	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr	Pb	Cd	Hg	As	Cr
Farm 1	0.36	0.53	0.75	0.50	5.33	0.33	0.48	0.66	0.60	4.86	0.01	0.07	0.04	0.004	0.02	0.01	0.06	0.05	0.005	0.02
Farm 2	0.48	0.51	0.75	0.50	4.9	0.53	0.52	0.60	0.40	3.82	0.01	0.06	0.04	0.004	0.02	0.01	0.06	0.04	0.004	0.02
Farm 3	0.43	0.59	0.75	0.50	4.29	0.42	0.57	0.80	0.60	3.88	0.01	0.06	0.04	0.004	0.02	0.01	0.06	0.05	0.005	0.02
Farm 4	0.53	0.62	0.75	0.75	3.33	0.57	0.64	0.75	0.50	4.67	0.02	0.08	0.04	0.004	0.02	0.01	0.09	0.04	0.004	0.03
Average	0.45	0.56	0.75	0.56	4.46	0.46	0.55	0.70	0.53	4.31	0.01	0.07	0.04	0.004	0.02	0.01	0.07	0.05	0.005	0.03
Control	0.33	0.32	0.75	0.5	0.5	0.30	0.27	1	0.33	0.5	0.01	0.27	0.03	0.002	0.002	0.01	0.26	0.04	0.002	0.002

through metabolic processes. Bioaccumulation factor (BAC) values > 1 indicates that accumulation in the plant tissue is greater than the accumulation in the soil. The average values of bioaccumulation factor of the metals in cassava leaves for both dry and wet seasons were 0.01 and 0.01 for lead, 0.07 and 0.07 for cadmium, 0.04 and 0.05 for mercury and 0.004 and 0.005 for arsenic and 0.02 and 0.02 for chromium (Table 5). The average bioaccumulation factors of the metals also followed the trend Cd> Cr > Hg > Cd > As. The BAC in this study indicates that, accumulation of the metals in cassava leaves is within the acceptable range. The acceptable range of bioaccumulation factor is between 0.01 and 0.1 (Kloke *et al.*, 1994). Cassava plant is therefore not a hyper accumulator of the metal.

3.5: Comparison of Heavy Metals in concentrations in soil, cassava peels, peeled cassava tubers and cassava leaves

The comparison of lead, cadmium, mercury, arsenic and chromium concentrations in soil, peeled tubers, peels and leaves presented in Table 6 indicates that, average metals concentrations were 52.551±2.38, 0.418±0.17, 1.091±0.66 and 0.639±0.24 respectively for lead. 5.928±2.13, 0.403±0.56, 0.450±0.15 and 0.396±0.12 respectively for cadmium, 0.726±0.03, 0.030±0.01, 0.013±0.01 and 0.033±0.01 respectively for mercury, 5.372±0.29, 0.015±0.01, 0.028±0.01 and 0.023±0.01 respectively for arsenic and 21.853±9.04, 0.035±0.01, 0.057±0.02 and 0.417±0.16 respectively for chromium. The concentration of each of the metals in soil was found to be significantly higher than the concentration in cassava tissues indicating that the rate at which the plant uptake and retain the metal from all applicable sources is low as reflected by low transfer, translocation and bioaccumulation factors. Cadmium, lead and chromium have previously been reported to exhibit high affinity to organic matter, hence not readily available for uptake by plant (Usman et al., 2020).Lead, arsenic and chromium concentrations were significantly higher in peels than leaves and in leaves than peeled tubers, suggesting that peels and leaves may be the preferred storage organs for the metals in cassava plant. This observation is in agreement with IGCP/SIDA, (2012) and Udiba *et al.*, (2019). Cassava is rich in cyanogenic glucosides which are readily converted hydrocyanic acid (HCN). The higher the concentrations of HCN in cassava tissues the higher the ability to accumulate heavy metals (Gideon-Ogero, 2008). Cassava leaves and peels have been reported as the tissues with higher concentrations of HCN in the plant (Gideon-Ogero, 2008). This may account for the high concentration of the two metals in them. Mercury levels in peels was significantly lower than peeled tubers which was in turn lower than leaves. Cassava leaves have

Table 6:Comparison of lead, cadmium, mercury, arsenic and chromium concentrations in soil, peeled tubers, peels and cassava leaves

	Soil	Peeled tubers	peels	leaves
Lead	52.551±2.38[a]	0.418±0.17[b]	1.091±0.66[c]	0.639±0.24[d]
Cadmium	5.928±2.13[a]	0.403±0.56[b]	0.450±0.15[b]	0.396±0.12[b]
Mercury	0.726±0.03[a]	0.030±0.01[b]	0.013±0.01[c]	0.033±0.01[b]
Arsenic	5.372±0.29[a]	0.015±0.01[b]	0.028±0.01[b]	0.023±0.01[c]
Chromium	21.853±9.04[a]	0.035±0.01[b]	0.057±0.02[b]	0.417±0.16[c]

Means with different superscripts across the row indicate significant ($p < 0.05$, ANOVA) difference in metals concentration

previously reported to contain more mercury than peels and flesh which is in agreement with the findings of this study.Cassava storage root (tuber) is made up of three distinct tissues- periderm (back), Cortex (peel) and parenchyma (Adjorlolo-Gasokpoh et al., 2012). The parenchyma which is the edible portion of the fresh root (referred to as peeled tuber in this study) comprises about 85 % of the total weight consisting of xylem vessels distributed in a matrix of starch containing cells (Daminabo & Okparanta, 2020). This suggest that mercury absorbed from the soil is preferentially stored in the peeled tubers (parenchyma) and translocated to the leaves. The higher mercury content of cassava leaves compared to the roots indicates low restriction of the metal hence the efficiency of the internal transport of the toxic metal from the roots towards the aerial parts. Cadmium concentration in the underground part (peeled tubers and peels) and the above ground part (leaves) are more or less the same as the differences were not statistically significant at 95% confidence level. This finding is in agreement with IGCP/SIDA, (2012).

3.6: Relationship between lead, cadmium, mercury, arsenic and chromium concentrations in soil, cassava peels, peeled cassava tubers and cassava leaves

The Pearson product moment correlation coefficients used to assess the degree of association (relationship) between metals levels in soils and cassava tissues is presented in Table 7. The significant ($P < 0.01$) strong positive correlation observed in lead and chromium concentrations between soil and peeled tubers, soil and peels, soil and leaves, indicates that an increase in the concentrations of lead and chromium in soil is accompanied by increase in the concentrations of the metals in peeled tubers, peels and leaves suggesting that soil available lead and chromium have significant effects in the levels present in cassava grown in the soil and that same source may be responsible for the presence of these metals at the concentrations determined. The significant ($P < 0.01$) strong positive correlation observed in lead and chromium concentrations between peeled tubers and peels, peeled tubers and leaves, peels and leaves, indicates that increase in the concentrations of lead and chromium in peeled tubers is accompanied by increase in the concentrations of the metals in peels and leaves. This also suggests that same source may be responsible for the presence of these metals at the concentrations determined. Cadmium only displayed significant ($P < 0.01$), strong positive correlation between soil and peels, soil and leaves, and between peels and leaves indicating that increase in cadmium concentration in the soil is accompanied by significant increase only in cassava peels and leaves suggesting that same source may be responsible for their presence at the concentrations determined in these tissues. The correlations displayed by mercury and arsenic concentrations between soil and cassava tissues were not significant except the correlations between mercury concentration in soil and peeled tubers and, between mercury in soil and cassava leaves which though significant were weak.

Conclusion:

Soil acts not just a sink for the contaminants but also a natural buffer controlling the transport of contaminants between spheres- atmosphere, hydrosphere and the biosphere. The present study revealed that, except for cadmium, the mean soil concentrations of the metals were below soil guideline values and the Dutch soil remediation intervention values. Lead and cadmium concentrations in edible cassava tissue (peeled tubers and leaves) exceeded WHO/FAO limits. Lead, cadmium and chromium in soil and cassava tissues decreased significantly with increase in distance from the cement plant suggesting anthropogenic activities may be responsible for the presence of the metal at the concentration determined. The research confirmed that cassava is not a hyper-accumulator of lead, cadmium, mercury, arsenic and selenium, but it exhibits selective translocation tendencies, particularly for chromium, which was efficiently transported from roots to leaves. The preferential accumulation of Pb, As, and Cr in peels and leaves, and the retention of mercury in peeled tubers, suggest that different cassava tissues play varying roles in metal storage and mobility. The exceedance of food safety limits by lead and cadmium contents of edible cassava tissues, highlights concerns regarding potential risks to food safety. Given these findings, the study recommends periodic environmental monitoring of soil and crop contamination levels in areas surrounding cement plants, awareness campaigns on cassava tissue-specific metal bio-accumulation, and assessment of potential health risk pose by edible cassava tissues

Table 7:Relationship between Metals concentrations in soil, cassava peels, peeled cassava tubers and cassava leaves

Pearson Moment Product Correlation Coefficients							**Interpretation of Pearson Moment Product Correlation Coefficient**	
Metals	Soil against Peeled tubers (r)	Soil against Peels (r)	Soil against Leaves (r)	Peeled tubers against peels(r)	Peeled tubers against leaves (r)	Peels against leaves (r)	Correlation Value	Strength and Direction of Correlation
Pb	+0.693**	+0.752**	+0.839**	+0.904**	+0.866**	+0.908**	(-0.2) – (-0.5)	Weak negative relationship
Cd	+0.310NS	+0.936**	+0.914**	+0.381 NS	+0.270 NS	+0.935**	(+0.2) – (-0.2)	No relationship
Hg	+0.413*	+0.277 NS	+0.454*	-0.221 NS	+0.250 NS	-0.154 NS	(+0.2) – (+0.5)	Weak positive relationship
As	+0.088 NS	+0.363 NS	+0.330 NS	+0.300 NS	+0.153 NS	+0.254 NSC	(+0.5) – (+0.8)	Moderate positive relationship
Cr	+0.889**	+0.938**	+0.958**	+0.768**	+0.855**	+0.892**	(+0.8) – (+1.0)	Strong positive relationship

** *Correlation is significant at the 0.01 level (2-tail),* * *Correlation is significant at the 0.05 level (2-tail),* NS *Correlation is not significa*

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