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Assessment of Heavy Metal Distribution in *Amaranthus hybridus* L. and *Zea mays* L. Grown on an Undesignated Dumpsite Soil of Ibadan, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Heavy metal contamination from indiscriminate waste disposal poses significant environmental and health risks. This study assessed the levels, distribution, and effects of heavy metals on the growth and metal uptake of *Amaranthus hybridus* and *Zea mays* grown in an undesignated dumpsite soil in Ibadan, Nigeria. Soil and plant samples were analyzed for Fe, Zn, Cu, Pb, Ni, and Co

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concentrations using Atomic Absorption Spectrophotometry. Growth parameters, including plant height, stem diameter, leaf number, and leaf area, were recorded. The results showed that the heavy metal concentrations (mg kg^{-1}) were significantly higher ($p < 0.05$) in dumpsite soil, with Fe, Zn, Cu, Pb and Co exceeding at least one of FEPA, WHO and EU limits. While metal concentrations in plant tissues were mostly within normal ranges, Zn and Pb exceeded WHO permissible limits in *A. hybridus*. Growth analysis showed a significant increase ($p < 0.05$) in plant height, stem diameter, leaf number, and leaf area for *A. hybridus* in dumpsite soil, whereas *Z. mays* exhibited limited growth stimulation. Soil-plant metal analysis indicated that *Z. mays* is a poor accumulator of heavy metals (BF < 1), with limited translocation from roots to shoots (TF < 1). In contrast, *A. hybridus* demonstrated efficient Pb accumulation (BF = 3.84) and effective translocation of Zn, Pb, Ni, and Co from roots to leaves. Enrichment factor (EF) analysis further highlighted the phytoremediation potential of *A. hybridus* for Pb (EF = 8.22), compared to EF < 1 for all metals in *Z. mays*. This study concludes that the dumpsite soil is heavily contaminated with heavy metals, rendering crops grown on it unsafe for consumption. However, *A. hybridus* showed strong potential for consideration in the targeted remediation of Pb-contaminated soils. These findings highlight the urgent need for sustainable waste management and soil remediation strategies to mitigate pollution risks and ensure environmental and food safety.

Keywords: Amaranthus hybridus; bioaccumulation; dumpsite; metal contamination of soil; phytoremediation; Zea mays.

1. INTRODUCTION

Urbanization in developing countries, including Nigeria, has led to significant challenges in waste management, resulting in the accumulation of industrial and domestic wastes in urban areas (Adesuyi et al.,,2015). These wastes are often disposed of in poorly regulated or illegal dumpsites, exacerbating environmental pollution (Souri et al., 2016). Unlike municipal dumpsites, undesignated dumpsites are isolated plots of land, ranging from small plots to large acreages, where various household and municipal wastes, such as plastics, metals, glass, food scraps, animal droppings and yard waste, are discarded without proper environmental control (Hoornweg and Laura, 1999). Consequently, soils around these dumpsites often become repositories for persistent pollutants, such as heavy metals.

Heavy metals such as cadmium (Cd), lead (Pb), and nickel (Ni) are particularly concerning due to their persistence, bioaccumulation potential, and toxicity to living organisms (Chukwuka et al., 2023). These contaminants, once introduced into the soil, can be taken up by plants, accumulate in edible tissues, and subsequently enter the food chain, posing serious risks to human health and the environment (Raghavendra et al., 2013; Chibuike and Obiora, 2014). For instance, prolonged exposure to heavy metals from dietary consumption of contaminated food crops is associated with kidney damage, neurological disorders, and carcinogenic effects in humans (Flora et al., 2012; Jaishankar et al., 2014). In plants, excessive heavy metal uptake can impair growth, reduce crop yield, and inhibit essential physiological processes (Chibuike and Obiora, 2014). Although essential metals such as iron (Fe), copper (Cu), and zinc (Zn) play vital roles in plant metabolism, their excess levels become toxic. Conversely, non-essential metals like lead (Pb), cadmium (Cd) and chromium (Cr) lack biological functions and exhibit toxicity even at low concentrations (Souri et al., 2019; Chukwuka et al., 2023).

The bioaccumulation and translocation of heavy metals in plants vary depending on species-specific traits, soil characteristics, and the concentration of metals in the soil (Rafiq et al., 2014; Lu et al., 2017). While some plant species indicate suitability for phytoremediation by exhibiting metal hyperaccumulation without phytotoxic symptoms (Mellem et al., 2012), others may exhibit limited transport of these metals to edible tissues, reducing health risks along the food chain (Ndimele et al., 2017; Awa and Hadibarata, 2020). Understanding these dynamics is crucial for evaluating the safety of crops cultivated in contaminated soils and exploring their potential for soil remediation. *Amaranthus hybridus* (Green Amaranth) and *Zea mays* (maize) are widely cultivated in Nigeria for their nutritional and economic values. *A. hybridus* is a highly nutritious leafy vegetable rich in proteins, vitamins, and minerals, while *Z. mays* is a staple cereal crop valued for its versatility and high biomass yield (Ribeiro et al., 2018). However, both of these commonly consumed

crops are susceptible to heavy metal uptake when grown in contaminated soils (Ogoko, 2015; Ribeiro et al., 2018), raising concerns about food safety and health of consumers in this region.

Although numerous past studies have examined heavy metal bioaccumulation in plants from polluted environments (Khan et al., 2015; Ogoko, 2015; Pachura et al., 2016; Ndimele et al., 2017; Awa and Hadibarata, 2020), limited data exist on the extent of heavy metal contamination, uptake, and translocation in edible plants grown on soils from undesignated urban dumpsites. These dumpsites, often perceived as fertile due to waste decomposition, are increasingly used for farming in urban areas, despite the potential risks. Therefore, this study aims to investigate the levels, distribution and effects of selected heavy metals on the growth and development of *Amaranthus hybridus* and *Zea mays* cultivated on soils from an undesignated dumpsite in Ibadan, Nigeria. The specific objectives are to:

1. Assess the heavy metal concentrations (Zn, Cu, Ni, Fe, Co and Pb) in dumpsite soil compared to uncontaminated agricultural soil

2. Evaluate the effects of soil contamination on the germination, growth, and physiological traits of *A. hybridus* and *Z. mays*

3. Quantify the bioaccumulation and translocation of heavy metals in different parts of the plants (roots, stems, and leaves)

By addressing these objectives, this study contributes to bridging the knowledge gap on heavy metal dynamics in *A. hybridus* and *Z. mays*, providing insights into their suitability for consumption and potential for phytoremediation of soils impacted by indiscriminate waste management in urban regions.

2. MATERIALS AND METHODS

2.1 Study Location

The study was conducted between August 2021 and January 2022 at the Department of Botany, University of Ibadan, Ibadan, Nigeria (Fig. 1). Ibadan is located at 3°5′–4°36′ E longitude and 7°23′–7°55′ N latitude, featuring a transitional ecology between Nigeria's coastal and hinterland regions (Oyebamiji et al., 2019).

2.2 Soil Collection and Analysis

Soil samples were collected from an abandoned dumpsite in the Agbowo community, Ibadan North Local Government Area of Nigeria (Fig. 1). This area is characterized by high population density and mixed residential-commercial activities. Agricultural soil samples were also obtained from a cultivated field within the Department of Botany Research Farm at the University of Ibadan, Ibadan. Soil samples were collected from a depth range of 5 - 20 cm using a steel soil auger and bulked into composite samples. The samples were air-dried, sieved through a 2 mm mesh, and stored in kraft paper for further analyses. 1 gram of each soil sample was digested using a mixture of HNO_3 and HCl (5:1) and analyzed in triplicates for heavy metal concentrations (Fe, Zn, Cu, Pb, Ni, and Co) using an Atomic Absorption Spectrophotometer (Buck Scientific Model 210/211 VGP, East Norwalk, USA).

2.3 Experimental Design and Planting Procedure

The experiment was arranged in a randomized complete block design (RCBD) with two treatments (dumpsite soil and agricultural soil) and eight replicates per treatment for each plant species. To maintain uniformity and ensure independent randomization, the 16 replicates of *A. hybridus* plants were allocated across four blocks within a single plot, while the 16 replicates of *Z. mays* plants were randomly distributed across four blocks in a separate plot. Each of the prepared 32 plastic pots (5 L capacity) was filled with 4 kg of soil and irrigated to field capacity before planting. Seeds of *Amaranthus hybridus* (“Black Smooth” variety) and *Zea mays* (“DMR-LSR Yellow” variety) were obtained from the National Horticultural Research Institute, Ibadan. *Amaranthus hybridus* seeds (20 per pot) were broadcast, while *Zea mays* seeds (5 per pot) were planted at a depth of 2.5 cm. After germination, seedlings were thinned to one plant per pot. Distilled water was used for irrigation on alternate days to maintain uniform soil moisture. No chemical fertilizer or pesticide was applied to avoid exogenous input of metal contaminants.

2.4 Measurement of Growth Parameters

Growth parameters were assessed weekly, starting at 3 weeks after planting (WAP) except for seedling germination (a) that was recorded only in the first week of the experiment:

a) Seedling germination: Counted manually across 8 pots for each soil type
b) Plant height (cm): Measured from the base to the apex using a meter rule
c) Stem diameter (cm): Recorded at the base of the plants using a Vernier caliper
d) Number of leaves per plant: Counted visually
e) Leaf area (cm^2): Calculated using species-specific equations derived from leaf length (measured from the leaf tip to the point at which the lamina is attached to the petiole) and width (measured from edge to edge at the widest part of the leaf lamina). The equation used to derive the leaf area for *A. hybridus* (Carvalho and Christoffoleti, 2007) and *Z. mays* (Saxena and Singh, 1965) is as follows:

   0.75/0.7056 (length × width)

where; 0.75 and 0.7056 are correcting coefficients for *Z. mays* and *A. hybridus*, respectively.

f) Flowering time: Weeks to 50% flowering were recorded by observing the number of weeks it took half of the plants subjected to the same treatment to flower

2.5 Harvesting, Sample Preparation and Analysis

Plants were harvested after nine (9) weeks. The roots, stems, and leaves of each plant were separated, washed, and oven-dried at 60 ºC until constant weight. Dried samples were ground into powdered form using Cutting Boll Mill. Plant material digestion was carried out using the nitric-perchloric acid method described by Iriabije and Uwadiae (2020), in accordance with the recommendation of AOAC (AOAC, 2023). The sample (0.5 grams) was transferred into a 250 mL Pyrex beaker and 5 mL of an acid mixture containing HNO_3 and $HClO_4$ (2:1) was added. The mixture was heated at 120 – 200 ˚C for 45 minutes until a clear solution was obtained. The digested samples were measured in triplicates to determine heavy metal concentrations (Fe, Zn, Cu, Pb, Ni and Co) in the different plant parts using an atomic absorption spectrophotometer (AAS). Blanks were prepared as quality control samples by applying 5 mL of nitric acid (HNO_3) into empty digestion flasks and processed through the entire analytical method to ensure accuracy of data (AOAC, 2023).

2.6 Soil-Plant uptake analysis

The Bioaccumulation Factor (BF) was calculated to assess the movement of heavy metals from the soil to the roots of the plants. The Translocation Factor (TF) was determined to evaluate the efficiency of heavy metal translocation from the roots to the aerial (harvestable) parts of the plants. The Enrichment Factor (EF) evaluates the accumulation of heavy metals in aboveground tissues relative to the soil. These indices are important for determining phytoremediation potential and were estimated for *Amaranthus hybridus and Zea mays* using the following equations (Pachura et al., 2016):

$$BF = \frac{C_1}{C_2}$$

Where; BF - Bioaccumulation Factor, C_1 - heavy metal concentration in tissues of plant roots (mg kg^{-1}), C_2 - initial concentration of heavy metal in the soil (mg kg^{-1})

$$TF = \frac{C_3}{C_1}$$

Where; TF - Translocation Factor, C_3 - heavy metal concentration in above ground tissues of plant (mg kg^{-1})

$$EF = \frac{C_4}{C_2}$$

Where; EF - Enrichment Factor, C_4 - cumulative concentration of heavy metals in stem and leaf
Higher BF/TF/EF values ($\geq$1) indicate the plant's efficacy in absorbing and translocating heavy metals from the soil, making it suitable for phytoremediation. Conversely, lower BF/TF/EF values (<1) suggest a limited uptake and transfer of metals, rendering the plant safer for human consumption (Sharafi et al., 2024).

2.7 Statistical Analysis

Data on heavy metal concentrations, growth parameters, bioaccumulation (BF), translocation (TF), and enrichment (EF) factors were analyzed using one-way analysis of variance (ANOVA). Tukey's Honestly Significant Difference (HSD) test was applied for mean separation at a 5% significance level to determine statistical differences between treatments. Graphs and tables were created using Microsoft Excel and Word, respectively to visually illustrate treatment effects and variations in measured parameters.

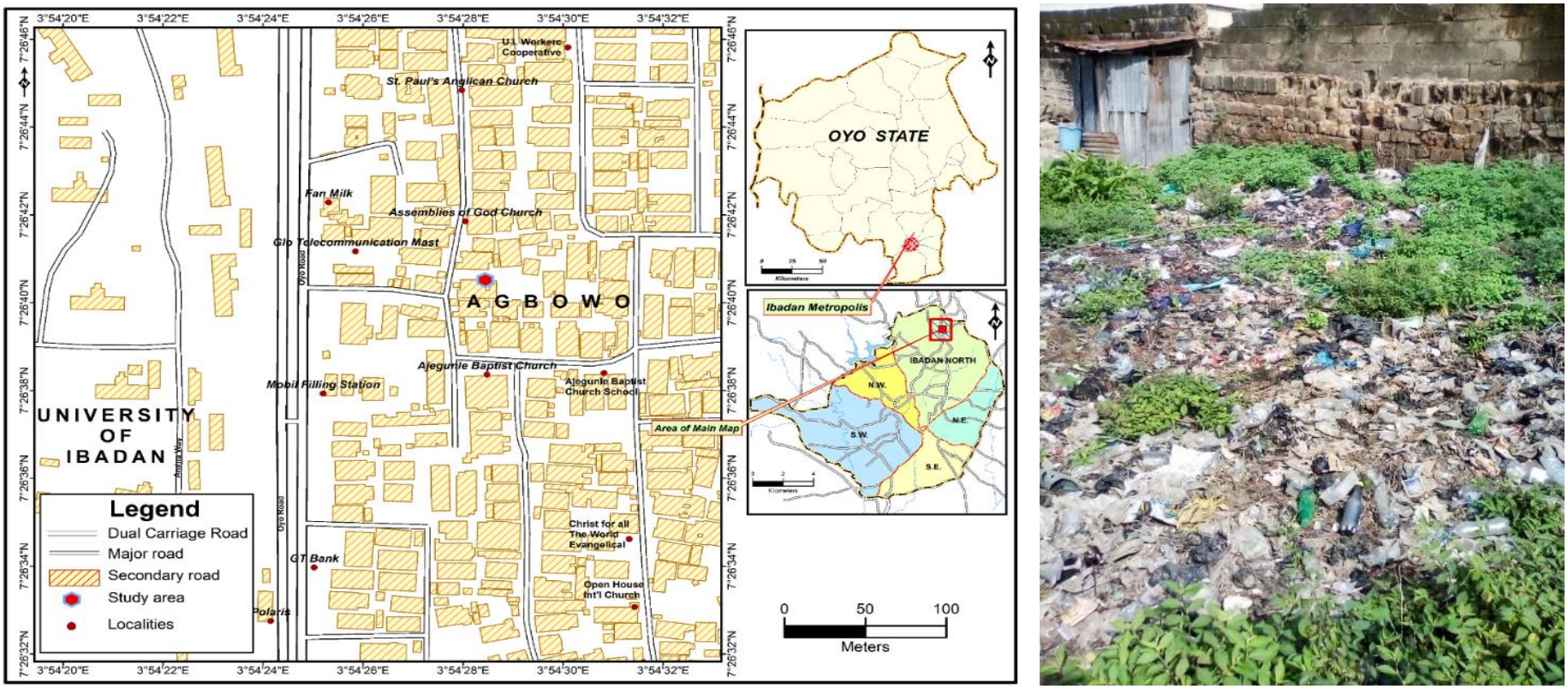


Fig. 1. Map of study area showing sampling site (undesignated dumpsite)

3.RESULTS

3.1 Heavy Metal Concentrations in Soil (Pre-sowing) and Plants' Parts (Post-Harvest)

The concentrations of heavy metals in the dumpsite and agricultural soils are presented in Table 1. Iron (Fe) and lead (Pb) respectively had the highest and least concentration of heavy metals in both dumpsite and agricultural soils. The concentrations of all heavy metals in the dumpsite soil were significantly higher ($p < 0.05$). Majority of the heavy metals exceeded at least one of the standard permissible limits as follows: WHO (Fe, Zn, Cu), FEPA (Fe, Zn, Cu, Pb), and EU (Zn, Co) (Table 1).

Iron (Fe) consistently recorded the highest concentrations among the analyzed metals in both plant species and soil types (Table 2). In *Z. mays* and *A. hybridus*, Fe concentrations ranked in the order root>leaf>stem, irrespective of the soil type. Fe concentrations in plant parts of both species was significantly higher ($p < 0.05$) in dumpsite soil compared to agricultural soil, except in the stem of *Z. mays*. In *Z. mays*, Zn was most concentrated in the stems for agricultural soil plants but shifted to the roots in dumpsite soil plants. Conversely, *A. hybridus* exhibited a higher Zn concentration in the leaves of agricultural soil plants but in the roots for dumpsite soil plants. With the exception of stem of *Z. mays*, concentrations of Zn in all parts of both plant species were significantly higher in dumpsite soils ($p < 0.05$). Also, the concentrations of Zn in all parts of *Z. mays* and *A. hybridus* exceeded the permissible limit (Table 2). Copper (Cu) accumulation followed a similar trend, with roots showing the highest concentrations in *Z. mays* grown on both soils, while in *A. hybridus*, Cu was predominantly found in the leaves for agricultural soil plants and in the roots for dumpsite soil plants. The stem of *Z. mays* consistently had the lowest Cu concentrations in both soils (Table 2). Significant differences ($p < 0.05$) in Cu concentrations between plant parts were observed for both species, with agricultural soil plants generally exhibiting higher Cu levels.

Nickel (Ni) was detected in varying concentrations across plant parts in both species. In agricultural soil plants of *Z. mays*, Ni concentrations were highest in the leaf, while in dumpsite soil plants, the roots had the highest levels. *A. hybridus* showed a reversed trend, with Ni primarily accumulating in the roots for agricultural soil plants but shifting to the leaves in dumpsite soil plants. Among all plant parts, the stem had the lowest Ni concentration across both species and soil types (Table 2). Differences between soil types were significant in all plant parts of *Z. mays* and *A. hybridus* ($p < 0.05$). Lead (Pb) and cobalt (Co) were not detected in *Z. mays* grown in either soil type. However, in *A. hybridus*, Pb was not detected in agricultural soil plants but was present in all parts of dumpsite soil plants, with the leaves and stems recording the highest and least concentrations, respectively. Co was accumulated in small amounts in *A. hybridus* grown in both soils, with no significant differences ($p > 0.05$) between plant parts (Table 2). However, concentrations in dumpsite soil for all parts was significantly higher ($p > 0.05$) compared to agricultural soil.

Table 1. Mean concentration of heavy metals (mg kg^{-1}) in dumpsite and agricultural soils, in comparison with standard permissible limits for heavy metals in soil

Heavy Metal	WHO Limit (mg kg^{-1})	FEPA Limit (mg kg^{-1})	EU Limit (mg kg^{-1})	Agricultural Soil (mg kg^{-1})	Dumpsite Soil (mg kg^{-1})
Fe	150	400	NA	263.08 ± 4.13	798.66 ± 9.09*
Zn	50	300 – 400	300	38.78 ± 0.47	616.37 ± 3.20*
Cu	36	70 – 80	140	10.14 ± 0.05	105.00 ± 1.26*
Pb	85	1.60	300	0.39 ± 0.01	5.25 ± 0.16*
Ni	35	NA	NA	9.27 ± 0.13	29.63 ± 0.21*
Co	NA	NA	5	2.14 ± 0.16	8.03 ± 0.17*

Values are mean ± S.E of three replicates; Means followed by (*) are significantly higher ($p < 0.05$) for both soil types EU European Union; FEPA Federal Environmental Protection Agency; WHO World Health Organisation (from Ogoko, 2015); NA = Not Available

Table 2. Heavy metal concentrations (mg kg^{-1}) in parts of *Z. mays* and *A. hybridus* plants grown in agricultural and dumpsite soils, in comparison with the permissible range in plants

		Zea mays		*Amaranthus hybridus*		
Heavy Metals	**Plant Part**	**Agricultural Soil (mg kg^{-1})**	**Dumpsite Soil (mg kg-1)**	**Agricultural Soil (mg kg^{-1})**	**Dumpsite Soil (mg kg^{-1})**	**Permissible range in plants (mg kg^{-1}) (WHO)**
Fe	Root	155.82±0.88^{ay}	296.80±1.13^{ax}	407.60±8.82^{ay}	736.66±14.31^{ax}	
	Stem	34.13±1.92^{cx}	20.63±0.73^{cy}	226.38±8.42^{by}	304.51±7.58^{cx}	640.00 – 2486.00
	Leaf	74.23±0.77^{by}	165.82±4.68^{bx}	392.30±9.55^{ax}	445.70±8.65^{by}	
Zn	Root	8.72±0.72^{ay}	13.60±0.35^{ax}	42.85±1.54^{bx}	91.71±1.94^{ay}	
	Stem	10.96±0.52^{ax}	6.22±0.22^{by}	30.94±0.88^{cx}	95.75±1.39^{ay}	0.60
	Leaf	2.53±0.07^{by}	3.68±0.11^{cx}	121.16±0.37^{ay}	153.50±11.49^{bx}	
Cu	Root	31.95±1.43^{ay}	27.23±1.20^{ax}	1.45±0.09^{ay}	3.73±0.44^{bx}	
	Stem	2.38±0.46^{bx}	2.28±0.33^{bx}	2.78±0.19^{bx}	2.25±0.16^{ay}	10.00
	Leaf	3.52±0.30^{bx}	4.60±0.29^{cx}	2.96±0.46^{bx}	2.29±0.37^{ay}	
Pb	Root	BDL	BDL	BDL	20.13±0.38^{b}	
	Stem	BDL	BDL	BDL	15.78±0.48^{a}	2.00
	Leaf	BDL	BDL	BDL	27.35±1.28^{c}	
Ni	Root	1.12±0.11^{by}	1.81±0.13^{ax}	3.35±0.24^{by}	8.59±0.65^{ax}	
	Stem	0.72±0.05^{cy}	1.06±0.05^{bx}	2.38±0.23^{ay}	7.98±0.42^{ax}	10.00
	Leaf	1.49±0.02^{ax}	1.12±0.02^{by}	2.58±0.25^{ay}	10.02±0.51^{bx}	
Co	Root	BDL	BDL	1.00±0.08^{ay}	2.84±0.15^{ax}	
	Stem	BDL	BDL	1.18±0.12^{ay}	2.69±0.22^{ax}	0.10 – 10.00
	Leaf	BDL	BDL	1.15±0.11^{ay}	3.21±0.19^{ax}	

Values are mean ± S.E. of three replicates; Means followed by different letters (x, y) in the same row for each soil type are significantly different (HSD at p < 0.05)
Means followed by different letters (a, b, c) in the same column for plant parts are significantly different (HSD at p < 0.05)
BDL represents Below Detectable Limit

3.2 Estimation of Growth Characteristics

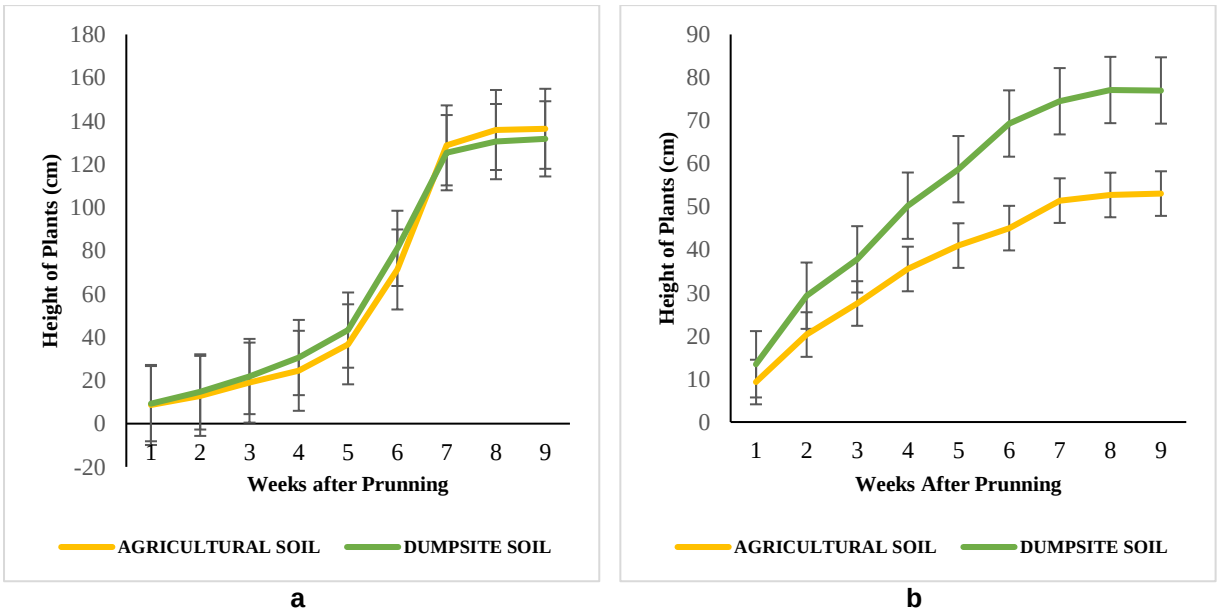
The germination rates of *A. hybridus* and *Z. mays* seeds grown in both soil types are summarized in Table 3. For both plants, the mean germination rate was slightly higher in the dumpsite soil compared to the agricultural soil, however, the differences between the two soil types were not statistically significant ($p > 0.05$). The average plant height of both *A. hybridus* and *Z. mays* increased with time across both soil types (Figs. 2a and 2b). For *Z. mays*, plants grown in the dumpsite soil showed greater mean heights during the first six weeks compared to those in the agricultural soil. However, the trend reversed during weeks 7 to 9, where plants in the agricultural soil surpassed those in the dumpsite soil (Fig. 2a). Significant differences in plant height for both soils were observed during weeks 2, 3, 4, and 5 ($p < 0.05$). In *A. hybridus*, plants cultivated in dumpsite soil consistently exhibited greater mean heights, peaking at 77.10 cm in week 8, compared to a maximum of 53.05 cm in week 9 for plants in agricultural soil (Fig. 2b). Throughout the planting duration, the mean height of *A. hybridus* plants was significantly higher ($p < 0.05$) in dumpsite soil compared to agricultural soil.

The stem diameter of *Z. mays* increased consistently from week 1 to week 7 across both soil types, with little to no change observed during weeks 8 and 9 (Fig. 3a). Plants grown in agricultural soil exhibited an average stem diameter ranging from 0.64 cm in week 1 to 2.15 cm in week 9, while those in dumpsite soil ranged from 0.70 cm to 2.10 cm within the same period. Significant differences in stem diameter between soil types were observed only in weeks 2 and 3 ($p < 0.05$). For *A. hybridus*, a steady increase in stem diameter was observed throughout the experiment (Fig. 3b). Plants grown in dumpsite soil exhibited significantly higher stem diameters ($p < 0.05$) across all weeks compared to those in agricultural soil. The stem diameter ranged from 0.88 cm in week 1 to 1.53 cm in week 9 for dumpsite soil plants, and from 0.44 cm to 1.13 cm for plants grown in agricultural soil.

Table 3. Seed germination rates of *A. hybridus* and *Z. mays* grown in dumpsite and agricultural soils

Plant species	Dumpsite Soil	Agricultural Soil
A. hybridus	6.50±0.33	6.38±0.38
Z. mays	2.75±0.16	2.50±0.19

Values are presented as mean ± S.E



a **b**

Fig. 2. Height of *Zea mays* (a) and *Amaranthus hybridus* (b) grown in agricultural and dumpsite soils from weeks 1 – 9

The number of leaves in *Z. mays* plants grown in both soil types increased from weeks 1 to 3, followed by fluctuations with slight declines in weeks 4 and 5, increases in weeks 6 and 7, and decreases in weeks 8 and 9 (Fig. 4a). The average leaf count ranged from 4.88 in week 1 to 8.88 in week 9 for agricultural soil plants and from 4.88 to 9.00 for dumpsite soil plants. While plants in dumpsite soil had slightly higher leaf numbers in most weeks, the differences were not statistically significant ($p > 0.05$). In *A. hybridus,* a consistent increase in the number of leaves was recorded across both soil types (Fig. 4b). The average leaf count ranged from 9.00 in week 1 to 45.38 in week 9 for agricultural soil plants and from 11.25 to 60.00 for dumpsite soil plants. Plants grown in dumpsite soil consistently exhibited significantly higher leaf counts ($p < 0.05$) compared to agricultural soil plants, except in week 7.

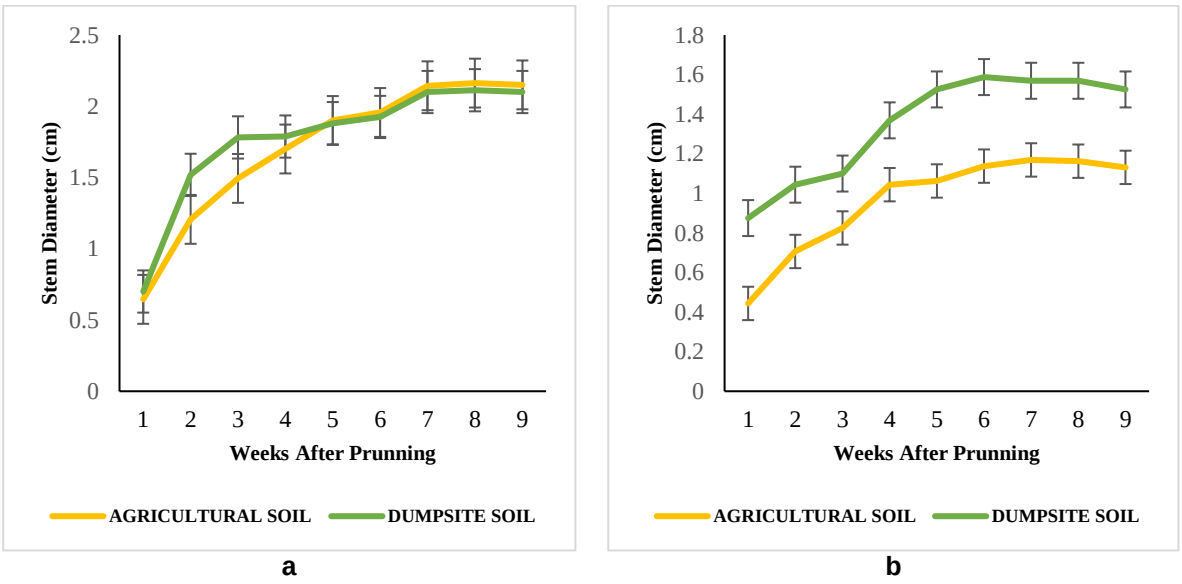


Fig. 3. Stem diameter of *Zea mays* (a) and *Amaranthus hybridus* (b) grown in agricultural and dumpsite soils from weeks 1 – 9

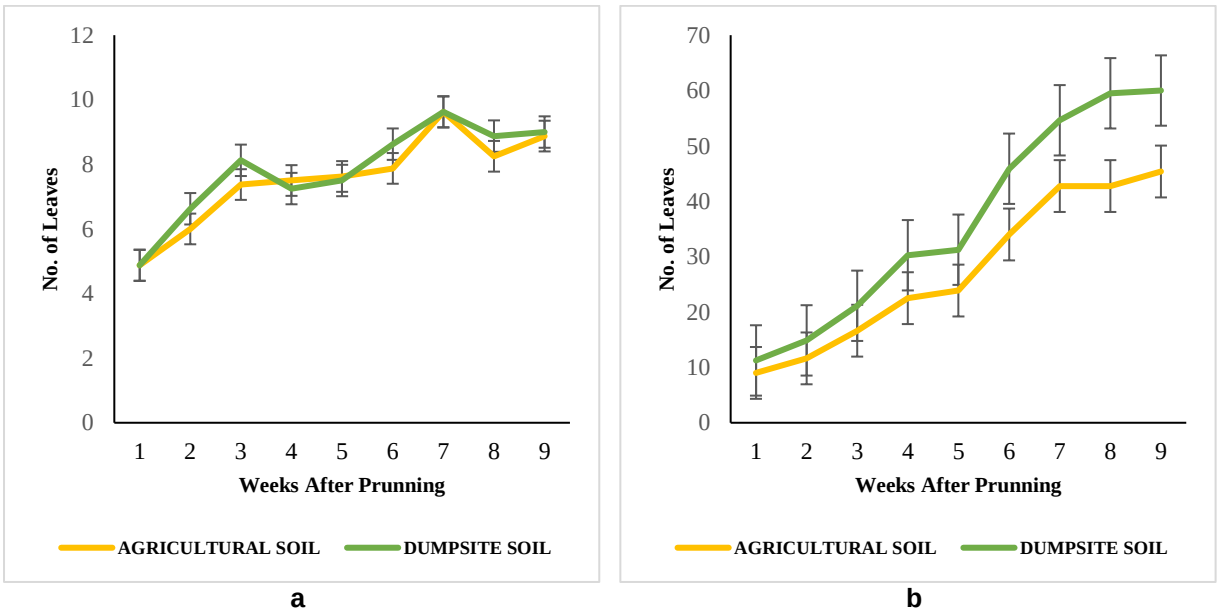


Fig. 4. Number of leaves of *Zea mays* (a) and *Amaranthus hybridus* (b) grown in agricultural and dumpsite soils from weeks 1 – 9

The average leaf area of *Z. mays* plants grown in dumpsite soil increased during the first seven weeks but declined slightly in the eighth week, before peaking at 321.87 cm² in week 9 (Fig. 5a). The average leaf area of agricultural soil plants (24.72 cm² in week 1 to 327.94 cm² in week 9) displayed a similar trend of fluctuation, characterized by slight declination in weeks 6 and 8. Plants in dumpsite soil exhibited higher leaf areas during weeks 1 to 4, while agricultural soil plants had larger areas from weeks 5 to 9. Significant differences in leaf area between soil types were observed in weeks 2, 4, and 5 ($p < 0.05$). For *A. hybridus*, the average leaf area of agricultural soil plants increased steadily from 11.36 cm² in week 1 to 56.54 cm² in week 9 (Fig. 5b). In contrast, dumpsite soil plants showed a more irregular pattern, with increases from week 1 to week 4, a slight drop in week 5, subsequent increases in weeks 7 and 8, and a final decrease in week 9. The leaf area of dumpsite soil plants ranged from 24.05 cm² to 55.51 cm². *Zea mays* and *Amaranthus hybridus* plants grown in dumpsite soil attained 50% flowering in week 8, compared to week 9 for those grown in agricultural soil (Figs. 6a and b).

3.3 Quantification of Bioaccumulation, Translocation, and Enrichment Factors

The dynamics of heavy metal uptake, translocation, and enrichment in *Zea mays* and *Amaranthus hybridus* grown in agricultural and dumpsite soils are summarized in Tables 4 and 5. In *Z. mays*, Cu (3.15) and Fe (0.37) exhibited the highest accumulation for agricultural and dumpsite soils, respectively. The BF values of Pb and Co were found to be negligible (Table 4), as their concentrations were below detection limits in the roots of *Z. mays* grown on both soils (Table 2).

For all the metals, BF values were significantly higher ($p < 0.05$) in agricultural soil compared to dumpsite soil. In *A. hybridus* from agricultural soil, BF values ranked in the following order: Fe>Zn >Co>Ni>Cu>Pb. However, in dumpsite soil, Pb (3.84) displayed the highest BF, while Cu (0.04) had the lowest BF value (Table 5). In comparison with dumpsite soil, *A. hybridus* grown on agricultural soil had significantly higher BF values ($p < 0.05$) for all metals except Co and Pb.

The movement of metals from roots to aerial plant parts (TF) varied across both species and soils. In *Z. mays*, Zn (1.27) and Cu (1.61) respectively demonstrated the highest translocation efficiencies in stems and leaves from agricultural soil, while Fe (0.22) and Zn (0.29) exhibited the least TFs for the respective plant parts (Table 4). Dumpsite soil plants showed a similar pattern, with Cu and Ni displaying higher TF values than other metals for both stems and leaves, but overall translocation was reduced compared to agricultural soil (Table 4). In both soils, TFs (leaf) were higher than TFs (stem) for all metals except Zn, where the trend was reversed. Significant differences

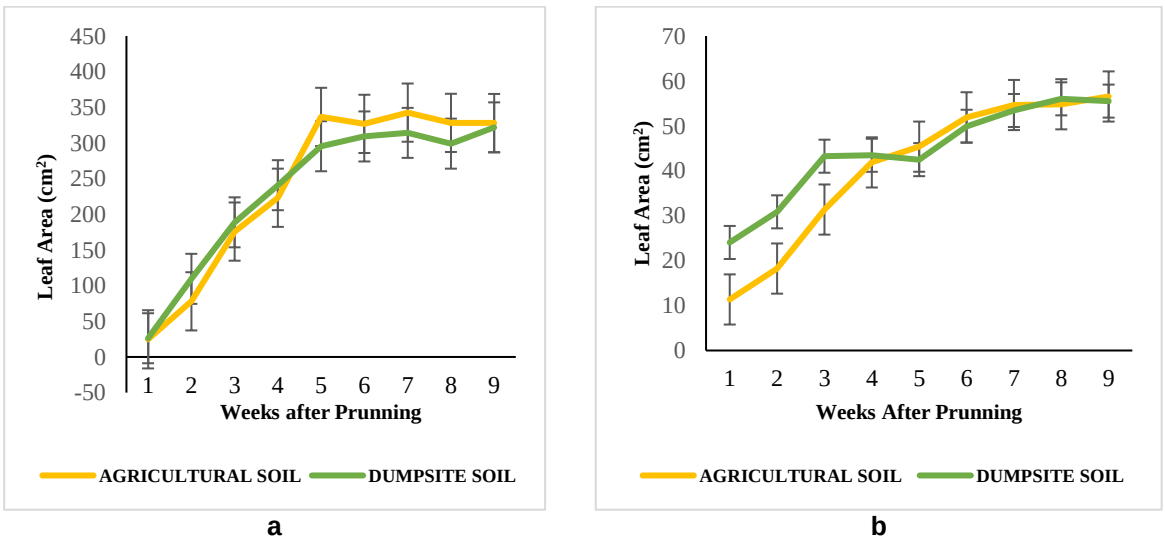


Fig. 5. Leaf area of *Zea mays* (a) and *Amaranthus hybridus* (b) grown in agricultural and dumpsite soils from weeks 1 – 9

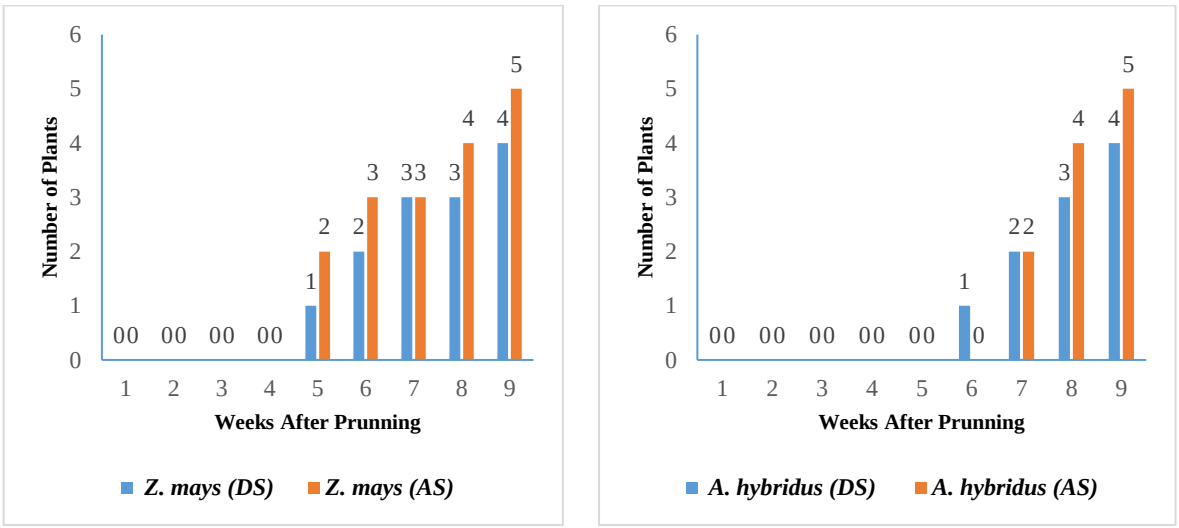


Fig. 6. Weeks to 50% flowering of *Zea mays* (a) and *Amaranthus hybridus* (b) grown in agricultural and dumpsite soils from weeks 1 – 9

($p < 0.05$) were observed between leaf and stem TF values for most metals in both soils. In *A. hybridus* grown in agricultural soil, Zn exhibited the highest translocation efficiency to leaf (2.85) while Cu exhibited the highest to stem (1.92), with Pb found to be negligible. In both soils, the TF (leaf) was higher than TF (stem) for all metals except Co in agricultural soil plants (Table 5). Dumpsite soil plants exhibited irregular patterns of translocation, with TF values ranging from 0.41 (Fe) to 0.95 (Co) in stems and 0.61 (Fe) to 1.67 (Zn) in leaves (Table 5).

Phytoremediation potential, as assessed by EF, was metal- and soil-dependent. In agricultural soil, Cu (0.58) and Zn (3.92) showed the highest EF in *Z. mays* and *A. hybridus*, respectively (Tables 4 and 5). In both soils, *Z. mays* demonstrated EF values < 1 across all metals (Table 4). EF values for all metals in *Z. mays* were significantly higher ($p < 0.05$) in agricultural soil compared to dumpsite soil. Dumpsite soil plants of *A. hybridus* recorded significantly higher EF values ($p < 0.05$) for Pb (8.22) compared to other metals (Table 5).

Table 4. Bioaccumulation (BF), Translocation (TF), and Enrichment (EF) Factors of *Zea mays* cultivated in dumpsite and agricultural soils

	Agricultural Soil			Dumpsite Soil		
Heavy Metals	**BF**	**TF**	**EF**	**BF**	**TF**	**EF**
Fe	0.60*	Stem - 0.22^{bx} Leaf - 0.47^{ax}	0.41*	0.37	Stem - 0.07^{by} Leaf - 0.56^{ax}	0.23
Zn	0.22*	Stem - 1.27^{ax} Leaf – 0.29^{bx}	0.35*	0.02	Stem - 0.46^{ay} Leaf - 0.27^{bx}	0.02
Cu	3.15*	Stem – 1.07^{bx} Leaf – 1.61^{ax}	0.58*	0.26	Stem - 0.83^{bx} Leaf - 1.69^{ax}	0.07
Pb	0.00	Stem - 0.00 Leaf – 0.00	0.00	0.00	Stem - 0.00 Leaf - 0.00	0.00
Ni	0.12*	Stem - 0.65^{bx} Leaf - 1.36^{ax}	0.24*	0.06	Stem - 0.59^{ax} Leaf - 0.62^{ay}	0.07
Co	0.00	Stem - 0.00 Leaf – 0.00	0.00	0.00	Stem - 0.00 Leaf – 0.00	0.00

Table 5. Bioaccumulation (BF), Translocation (TF), and Enrichment (EF) Factors of *Amaranthus hybridus* cultivated in dumpsite and agricultural soils.

	Agricultural Soil			Dumpsite Soil		
Heavy Metals	**BF**	**TF**	**EF**	**BF**	**TF**	**EF**
Fe	1.55*	Stem - 0.56^{bx} Leaf – 0.96^{ax}	2.35*	0.92	Stem - 0.41^{ay} Leaf - 0.61^{by}	0.94
Zn	1.11*	Stem – 0.72^{by} Leaf – 2.85^{ax}	3.92*	0.15	Stem – 1.04^{ax} Leaf – 1.67^{by}	0.40
Cu	0.14*	Stem - 1.92^{ax} Leaf - 2.03^{ax}	0.57*	0.04	Stem - 0.61^{ay} Leaf - 0.62^{ay}	0.04
Pb	0.00	Stem - 0.00^{ax} Leaf - 0.00^{ax}	0.00	3.84*	Stem - 0.78^{ay} Leaf - 1.36^{by}	8.22*
Ni	0.36*	Stem - 0.71^{ax} Leaf - 0.77^{ay}	0.54	0.29	Stem - 0.94^{ax} Leaf - 1.18^{bx}	0.61
Co	0.55	Stem - 1.18^{ax} Leaf - 1.15^{ax}	1.28	0.35	Stem - 0.95^{ax} Leaf - 1.13^{bx}	0.73

Means followed by (*) are significantly higher ($p < 0.05$) for each of BF and EF (rows), Letters 'xy' show the significant differences (HSD at $p < 0.05$) between the mean TF for both soil types per metal (rows), Letters 'ab' show the significant differences (HSD at $p < 0.05$) between the mean TF for both plant parts per metal (columns)

4. DISCUSSION

4.1 Heavy Metal Concentrations in Soils and Plants

Soil contamination with heavy metals poses a major environmental challenge, especially in densely populated urban regions with inadequate waste management practices. This study examined heavy metal concentrations in soil from an undesignated dumpsite in Ibadan, Nigeria and investigated the effects on metal uptake and growth of *Amaranthus hybridus* and *Zea mays* cultivated on such soils. The analysis of agricultural and undesignated dumpsite soils confirmed the presence of Fe, Zn, Cu, Pb, Ni, and Co. The significantly higher concentrations of these heavy metals in the dumpsite soil can be attributed to its accumulative exposure to municipal and residential wastes, whose heavy metal contents leach into the soil as confirmed by the studies of Hoornweg and Laura (1999) and Abduls-Salam (2009). This also corroborates previous findings indicating that landfill leachates contribute to elevated heavy metal concentrations in soil and groundwater (Alao et al.,, 2024). Comparable trends of elevated metal concentrations in dumpsite soils have also been reported in other urban areas of Nigeria including Owerri (Chizoruo et al., 2017), Ilorin (Abduls-Salam, 2009) and Port Harcourt (Ogbonna et al., 2009). Globally, similar patterns have been documented, including higher metal concentrations in soil samples from municipal dumpsites in Allahabad, India (Tripathi and Misra, 2012), organic fraction of municipal solid waste (OFMSW) in Varanasi, India (Srivastava et al.,, 2020), deactivated dumpsite in the municipality of Paraná, Brazil (de Souza et al., 2023), Ariyamangalam dumpsite in Tiruchirappalli, India (Kanmani et al., 2013) and Iringa municipal dumpsites in Tanzania (Sanga and Pius, 2024). These results affirm that dumpsites act as significant point sources of heavy metal contamination in soils.

The findings from this study revealed that *A. hybridus* and *Z. mays* plants grown in contaminated dumpsite soil generally absorbed significantly higher concentrations of heavy metals in their roots, stems, and leaves compared to plants cultivated in agricultural soil. This is consistent with the substantially higher initial concentrations of heavy metals in the dumpsite soil. Similar trends have been documented by other researchers. For example, Eid et al., (2017a) reported that heavy metal accumulation in cucumber tissues increased proportionally with the application of sewage sludge, while Opaluwa et al., (2012) observed elevated levels of metals, including Fe, Co, Cu, and As, in various crop tissues harvested from refuse dumpsites compared to uncontaminated farmland. In *Z. mays* plants grown in dumpsite soil, the roots accumulated significantly higher concentrations of heavy metals compared to the stems and leaves. In contrast, *A. hybridus* exhibited a more varied distribution of heavy metals across plant parts, with Fe and Cu predominantly concentrated in the roots. The

higher concentrations of metals in the roots of both species are consistent with observations by Singh and Agrawal (2007) and Eid et al., (2017b), who found that metal accumulation is generally greater in roots than in shoots of plants grown on contaminated soils. This pattern can be attributed to the direct contact between roots and metal-laden soil and the ability of roots to sequester metals through complexation and immobilization processes (Soriano-Disla et al., 2014). Another plausible explanation is the fact that the cations of these heavy metals are less mobile in plant than many nutrients, and after uptake are majorly accumulated in root tissues. This is particularly true for trace metals of Fe, Mn, Zn and Cu (Souri et al., 2019). Alao (2024) also reported that organic matter and cation exchange capacity are some of the factors affecting the retention and release of heavy metals in soil. The retention of metals in roots suggests the existence of a defense mechanism, as documented by Basta et al., (2005), limiting their transfer to the shoot. When compared to WHO standards, the concentrations of Zn in both species and Pb in *A. hybridus* exceeded normal thresholds (Table 2), indicating the risks associated with cultivating these plants in contaminated dumpsite soils.

4.2 Growth Variations of Plants in Response to Metal Contamination

In this study, germination rates of seeds sown in dumpsite and agricultural soils were comparable ($p > 0.05$), indicating that the presence of heavy metals in contaminated soil did not affect the germination of *Z. mays* and *A. hybridus*. These findings align with Mahmood et al., (2005) and Chetan and Ami (2015), who reported that contamination with Cu, Zn, and Cd did not influence germination in *Z. mays* and *Amaranthus* spp., respectively. However, they contrast with the findings of Hussain et al., (2013), who observed germination inhibition in *Z. mays* under Pb stress. Similarly, Srivastava et al., (2020) reported adverse effects of heavy metals and organic waste on the germination and physiology of *Z. mays* in municipal dumpsite soil, further underscoring the variability in plant responses to metal contamination. Plant growth responses to heavy metal contamination varied significantly between the two species. *A. hybridus* demonstrated remarkable growth stimulation in contaminated soil, with significant increases in plant height, stem diameter, leaf number, and leaf area. Additionally, plants of both species grown in dumpsite soil reached 50% flowering earlier than those grown in agricultural soil. These results are consistent with Hussain et al., (2019), who observed enhanced growth in carrot, spinach, and radish cultivated in heavy metal-contaminated soils, and Eid et al., (2017a), who reported substantial improvements in cucumber morphometric parameters when grown in sewage sludge-amended soils. The observed growth stimulation may be attributed to the micronutrient roles of metals such as Zn and Cu in plant metabolism and species-specific tolerance to heavy metal stress (Hussain et al., 2019).

In contrast, *Z. mays* exhibited mixed growth responses to heavy metal contamination. While plants grown in dumpsite soil were taller for most of the experiment (Fig. 2a), trends in stem diameter and leaf area showed that plants grown in agricultural soil outperformed their dumpsite counterparts later in the growth cycle. Similar patterns were reported by Okonokhua et al., (2010), who observed reductions in root length and plant height of *Z. mays* under heavy metal stress in later growth stages. This phenomenon may be linked to the early absorption and translocation of metals into the shoots, as noted by Ameh et al., (2020), who found that plants translocate higher quantities of metals to aerial parts during their initial growth stages. Leaf number remained unaffected by heavy metal contamination, with comparable values ($p > 0.05$) across both soil types.

The response of plants to heavy metal contamination is influenced by species-specific tolerances and soil contamination levels. As reported by Khan et al., (2015), plants grown in less contaminated soils generally exhibit superior growth compared to those exposed to higher levels of heavy metals, however, in this study, the ability of *A. hybridus* to consistently thrive under heavy metal stress underscores its potential for phytoremediation in contaminated soils. However, further investigation is necessary to evaluate the long-term impacts of heavy metal accumulation in edible tissues and to ensure the safe cultivation of these crops in urban environments.

4.3 Heavy Metal Dynamics in *Z. mays* and *A. hybridus*

The Bioaccumulation Factor (BF) was used in this study to quantify the transfer of heavy metals from soil to plant roots. BF values < 1 recorded for the heavy metals in *Z. mays* indicate that it is

a poor accumulator of Fe, Zn, Cu, Ni, Pb and Co. In contrast, *A. hybridus* exhibited efficient accumulation of Pb in dumpsite soil, with a mean BF value > 3, classifying it as an effective accumulator of this metal. The process of heavy metal accumulation in plants is influenced not only by the physicochemical properties and composition of the soil, climatic conditions, and heavy metal concentrations but also by the physical and physiological characteristics of individual plant species (Basta et al., 2005; Sharafi et al., 2024). This study confirms that heavy metal absorption is not uniform across metals and is not solely dependent on soil concentration. Plants can continuously absorb and translocate heavy metals, leading to elevated metal concentrations in their tissues, even when soil levels are low (Sharafi et al., 2024). This explains why Pb, despite its relatively low concentration in dumpsite soil, exhibited the highest BF in *A. hybridus*. Certain plant species, known as hyper-accumulators, specialize in absorbing and accumulating high levels of specific heavy metals. However, *A. hybridus* is among those vegetable crops in which even low levels of heavy metal can pose significant health risks due to its widespread fresh consumption (Souri et al., 2019). The significantly higher accumulation ($p < 0.05$) of most heavy metals by plants in agricultural soil may be attributed to differences in soil pH, moisture and organic matter content, which influence the availability and subsequent uptake of metals from soils. For instance, numerous researchers have attributed the reduced availability and mobility of heavy metals in dumpsite soils to their slight alkalinity (Abdus-Salam, 2009; Agbeshie et al., 2020), potentially resulting from an abundance of alkaline-earth metals, liming materials and microbial decomposition.

The movement of heavy metals from roots to shoots depends on factors such as their chemical form, plant physiology, species characteristics, and water transport mechanisms (Kalis et al., 2008). This translocation largely determines the fraction of metals that may enter the food chain, making the Translocation Factor (TF) a critical parameter for assessing metal exposure risks to consumers. In this study, TF values for all metals from the root to stem in *Z. mays* grown in contaminated soil were < 1, indicating limited movement. Similarly, most TF values from root to leaf in *Z. mays* were also below 1, except for Cu. For *A. hybridus* grown in dumpsite soil, TF values from the root to stem were < 1 for all studied metals except Zn. However, TF values from the root to leaf exceeded 1 for all metals except Fe and Cu, indicating efficient translocation of these metals to the leaves. These findings are consistent with Mellem et al., (2012), who reported limited shoot translocation (TF < 1) for some metals like Pb and Ni in *A. dubius*, but high translocation (TF > 1) for others like Zn and Cr. Similarly, Emurotu and Onianwa (2017) observed variable TF values for metals in food crops grown on farmland soils in Kogi, Nigeria.

The variability in TF values among metals reflects differences in their mobility and transport mechanisms within plants. The high translocation of Pb, Zn, Ni, and Co in *A. hybridus* may be attributed to efficient metal transport systems in the plant (Zhao et al., 2002). Furthermore, Zn's essential role in enzymatic and photosynthetic processes likely contributes to its higher translocation (Stancheva et al., 2014). Conversely, the limited accumulation and translocation of metals from root to shoot in *Z. mays* suggests the operation of an exclusion strategy. This mechanism comprises avoidance of metal uptake and restricted transport to shoots, enabling plants to tolerate heavy metal contamination and survive in polluted soils (Nawab et al., 2016). This strategy also implies that *Z. mays* effectively minimizes heavy metal entry into the food chain, reducing potential health risks to humans and wildlife. Based on these findings, *Z. mays* plants grown in dumpsite soil did not accumulate and translocate heavy metals at levels that pose significant risks (BF/TF < 1), suggesting they are generally safe for consumption. However, the exceedance of WHO permissible thresholds for certain metals (Table 2), such as Zn (all plant parts) and Cu (roots), warrants caution. In contrast, the substantial accumulation of Pb in *A. hybridus*, particularly its translocation to the leaves, renders plants cultivated on this soil unsuitable for human consumption.

Enrichment factor (EF) is an essential metric for assessing the phytoremediation potential of plant species, as it reflects a plant's ability to absorb, translocate, and store heavy metals in its aerial parts (Zhao et al., 2002). In this study, *Zea mays* exhibited EF values < 1 for all studied heavy metals, indicating limited metal availability and poor mobility from soil to plant tissues, consistent with the findings of Stancheva et al., (2014). In contrast, *A. hybridus* demonstrated its highest EF for Pb, with a value of 8.22, and was notably the only metal with an EF value > 1 in dumpsite soil.

This high enrichment capacity suggests that *A. hybridus* can accumulate Pb in aboveground tissues at levels substantially higher than its concentration in the soil, a trait valuable for remediating contaminated soils. The physiological mechanisms enabling *A. hybridus* to accumulate Pb likely involve enhanced root absorption and efficient transport systems that selectively bind and sequester Pb ions (Sharafi et al.,, 2024). The phytoremediation potential of *Amaranthus* species has been similarly documented in previous studies. Chinmayee et al., (2012) reported *A. spinosus* as an effective agent for heavy metal accumulation and translocation, with an EF value of 2.09 in contaminated soils. Huang et al., (2019) further observed that *A. spinosus* effectively stabilizes Pb and Cd within tolerable limits, supporting the genus's potential for phytoremediation. The absence of metal-induced phytotoxicity in *A. hybridus*, as evidenced by the positive growth responses observed on contaminated dumpsite soil (Figs. 2b–6b), further underscores its potential as a hyperaccumulator and an efficient candidate for the phytoremediation of Pb.

5. CONCLUSION

This study provided valuable insights into the levels of heavy metal contamination in an undesignated dumpsite soil and their effects on the growth and performance of *Amaranthus hybridus* and *Zea mays*. The dumpsite soil was found to contain significantly higher concentrations of heavy metals (Fe, Cu, Zn, Ni, Co, and Pb) than agricultural soil, with levels exceeding permissible limits set by WHO, FEPA, and the EU. While heavy metal concentrations in plant tissues were generally within normal ranges, Zn and Pb exceeded permissible levels in the roots, stems, and leaves of plants grown in dumpsite soil. Growth responses varied, with *A. hybridus* exhibiting significant increases in all measured growth parameters, while *Z. mays* showed limited growth stimulation. Soil-plant uptake analysis indicated that *Z. mays* is a poor accumulator of the studied heavy metals (BF < 1), with limited translocation of metals from roots to shoots (TF < 1), and demonstrated minimal enrichment capability (EF < 1), making it unsuitable for phytoremediation applications. In contrast, *A. hybridus* exhibited a strong ability to accumulate Pb (BF = 3.84) and efficiently translocated most metals (TF > 1), particularly to its leaves. The high EF value for Pb (8.22) underscores the potential of *A. hybridus* for targeted remediation of Pb-contaminated soils. Despite its phytoremediation potential, cultivating *A. hybridus* on dumpsite soils poses significant health risks due to its high affinity for heavy metal accumulation and efficient translocation to edible tissues. Although *Z. mays* showed limited metal uptake and translocation in contaminated soil, caution is advised regarding its safety for consumption when cultivated continuously on such soils. This study highlights the need for protective and rehabilitative measures before using dumpsite soils for agriculture. Furthermore, it is recommended that crops grown on contaminated soils, particularly *A. hybridus*, should not be consumed directly or indirectly in processed forms to mitigate potential health risks.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abdus-Salam, N. (2009). Assessment of heavy metals pollution in dumpsites in Ilorin metropolis. *Ethiopian Journal of Environmental Studies and Management, 2*(2), 71-73.

Adesuyi, A. A., Njoku, K. L., & Akinola, M. O. (2015). Assessment of heavy metals pollution in soils and vegetation around selected industries in Lagos State, Nigeria. *Journal of Geoscience and Environment Protection, 3*, 11-19. https://doi.org/10.4236/gep.2015.37002

Agbeshie, A., Adjei, R., Anokye, J., & Banunle, A. (2020). Municipal waste dumpsite: Impact on soil properties and heavy metal concentrations, Sunyani, Ghana. *Scientific African, 8*, e00390. https://doi.org/10.1016/j.sciaf.2020.e00390

Alao, J. O. (2024). The factors influencing the landfill leachate plume contaminants in soils, surface and groundwater and associated health risks: A geophysical and geochemical view. *Public Health and Environment, 1*(1).

Alao, J. O., Otorkpa, O. J., Abubakar, F., Eshimiakhe, D., Aliyu, A., Abdulsalami, M., & Abdulmalik, D. O. (2024). Geoelectrical resistivity and geochemistry monitoring of landfill leachates due to the seasonal variations and the implications on groundwater systems and public health. *Scientific Reports, 14*(1), 26542.

Ameh, G. I., Nwamba, H. O., Nwani, C. D., & Ofordile, E. C. (2020). Effects of heavy metals on agronomic attributes of some selected cereal crops (Zea mays and Sorghum bicolor). *Journal of Applied Life Sciences International, 23*, 24-30.

Association of Official Analytical Chemists (AOAC). (2023). *AOAC official methods of analysis* (22nd ed.). Association of Official Analytical Chemists. [Accessed: December 7, 2024]. Available from: https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.2023.pdf

Awa, S. H., & Hadibarata, T. (2020). Removal of heavy metals in contaminated soil by phytoremediation mechanism: A review. *Water, Air, and Soil Pollution, 231*(2), 47.

Basta, N. T., Ryan, J. A., & Chaney, R. L. (2005). Trace element chemistry in residual-treated soil: Key concepts and metal bioavailability. *Journal of Environmental Quality, 34*(1), 49-63.

Carvalho, S. J. P., & Christoffoleti, P. J. (2007). Leaf area estimation of five Amaranthus species using leaf blade linear dimensions. *Planta Daninha, 25*, 317-324.

Chetan, A., & Ami, P. (2015). Effects of heavy metals (Cu and Cd) on growth of leafy vegetables–Spinacia oleracea and Amaranthus caudatus. *International Research Journal of Environment Sciences, 4*(6), 63.

Chibuike, G. U., & Obiora, S. C. (2014). Heavy metal polluted soils: Effect on plants and bioremediation methods. *Applied and Environmental Soil Science, 2014*, 243-254.

Chinmayee, M. D., Mahesh, B., Pradesh, S., Mini, I., & Swapna, T. S. (2012). The assessment of phytoremediation potential of invasive weed Amaranthus spinosus L. *Applied Biochemistry and Biotechnology, 167*, 1550-1559.

Chizoruo, I. F., Osiuku, B. O., & Ebere, E. C. (2017). Trace metals analysis of soil and edible plant leaves from abandoned municipal waste dumpsite in Owerri, Imo State, Nigeria. *World News of Natural Sciences, 13*, 27-42.

Chukwuka, K. S., Adesida, S. O., & Alimba, C. G. (2023). Carcinogenic and non-carcinogenic risk assessment of consuming metal-laden wild mushrooms in Nigeria: Analyses from field-based and systematic review studies. *Environmental Analysis Health and Toxicology, 38*(2), e2023013. https://doi.org/10.5620/eaht.2023013

de Souza, V. B., Hollas, C. E., Bortoli, M., Manosso, F. C., & de Souza, D. Z. (2023). Heavy metal contamination in soils of a decommissioned landfill in southern Brazil: Ecological and health risk assessment. *Chemosphere, 339*, 139689. https://doi.org/10.1016/j.chemosphere.2023.139689

Eid, E. M., Alrumman, S. A., El-Bebany, A. F., Hesham, A. E. L., Taher, M. A., & Fawy, K. F. (2017a). The effects of different sewage sludge amendment rates on the heavy metal bioaccumulation, growth and biomass of cucumbers (Cucumis sativus L.). *Environmental Science and Pollution Research, 24*, 16371-16382.

Eid, E. M., El-Bebany, A. F., Alrumman, S. A., Hesham, A. E. L., Taher, M. A., & Fawy, K. F. (2017b). Effects of different sewage sludge applications on heavy metal accumulation, growth and yield of spinach (Spinacia oleracea L.). *International Journal of Phytoremediation, 19*(4), 340-347.

Emurotu, J. E., & Onianwa, P. C. (2017). Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, North Central Nigeria. *Environmental Systems Research, 6*(1), 1-9.

Flora, G., Gupta, D., & Tiwari, A. (2012). Toxicity of lead: A review with recent updates. *Interdisciplinary Toxicology, 5*(2), 47-58.

Hoornweg, D., & Laura, T. (1999). *What a waste: Solid waste management in Asia* (Working Paper Series, Urban Development Sector Unit, East Asia and Pacific Region, 5).

Huang, Y., Xi, Y., Gan, L., Johnson, D., Wu, Y., Ren, D., & Liu, H. (2019). Effects of lead and cadmium on photosynthesis in Amaranthus spinosus and assessment of phytoremediation potential. *International Journal of Phytoremediation, 21*(10), 1041-1049.

Hussain, A., Abass, N., & Arshad, F. (2013). Effects of diverse doses of lead (Pb) on different growth attributes of Zea mays L. *Agricultural Sciences, 4*(5), 262-265.

Hussain, A., Priyadarshi, M., & Dubey, S. (2019). Experimental study on accumulation of heavy metals in vegetables irrigated with treated wastewater. *Applied Water Science, 9*, 1-11.

Iriabije, T. O., & Uwadiae, S. (2020). Analysis of some heavy metal contents in selected vegetables and fruits from states in Nigeria. *American Journal of Bioscience, 8*(2), 37-40.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology, 7*(2), 60–72.

Kalis, E. J., Temminghoff, E. J., Town, R. M., Unsworth, E. R., & van Riemsdijk, W. H. (2008). Relationship between metal speciation in soil solution and metal adsorption at the root surface of ryegrass. *Journal of Environmental Quality, 37*(6), 2221-2231.

Kanmani, S., & Gandhimathi, R. (2013). Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. *Applied Water Science, 3*, 193–205. https://doi.org/10.1007/s13201-012-0072-z

Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plant nutrients, and associated health risk: A review. *Environmental Science and Pollution Research, 22*, 13772-13799.

Lu, K., Yang, X., Shen, J., Robinson, B., Huang, H., Liu, D., Bolan, N., Pei, J., & Wang, H. (2017). Effect of bamboo and rice straw biochars on the bioavailability of Cd, Cu, Pb and Zn to *Sedum plumbizincicola*. *Agriculture, Ecosystems and Environment, 191*, 124-132.

Mahmood, S., Hussain, A., Saeed, Z., & Athar, M. (2005). Germination and seedling growth of corn (*Zea mays* L.) under varying levels of copper and zinc. *International Journal of Environmental Science and Technology, 2*(3), 269-274.

Mellem, J. J., Baijnath, H., & Odhav, B. (2012). Bioaccumulation of Cr, Hg, As, Pb, Cu, and Ni with the ability for hyperaccumulation by *Amaranthus dubius*. *African Journal of Agricultural Research, 7*(4), 591-596.

Nawab, J., Li, G., Khan, S., Sher, H., Aamir, M., Shamshad, I., & Khan, M. A. (2016). Health risk assessment from contaminated foodstuffs: A field study in chromite mining-affected areas northern Pakistan. *Environmental Science and Pollution Research, 23*(12), 12227-12236.

Ndimele, C. C., Ndimele, P. E., & Chukwuka, K. S. (2017). Accumulation of heavy metals by wild mushrooms in Ibadan, Nigeria. *Journal of Health and Pollution, 7*(16), 26–30.

Ogbonna, D. N., Kii, B. L., & Youdeowei, P. O. (2009). Some physico-chemical and heavy metal levels in soils of waste dumpsites in Port Harcourt municipality and environs. *Journal of Applied Sciences and Environmental Management, 13*(4), 65-70.

Ogoko, E. C. (2015). Accumulation of heavy metal in soil and their transfer to leafy vegetables with phytoremediation potential. *American Journal of Chemistry, 5*(5), 125-131.

Okonokhua, B. O., Ikhajiagbe, B., & Anoliefo, G. O. (2010). The effects of spent engine oil on soil properties and growth of maize (*Zea mays* L.). *Journal of Applied Sciences and Environmental Management, 11*(3), 147-152.

Opaluwa, O. D., Aremu, M. O., Ogbo, L. O., Abiola, K. A., Odiba, I. E., Abubakar, M. M., & Nweze, N. O. (2012). Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. *Advances in Applied Science Research, 3*(2), 780-784.

Oyebamiji, D. A., Ifeoluwa, O., & Hassan, A. A. (2019). Risk of exposure to soil-transmitted helminths in the zoological garden in southwestern Nigeria. *Asian Journal of Epidemiology, 12*(1), 17-24.

Pachura, P., Ociepa-Kubicka, A., & Skowron-Grabowska, B. (2016). Assessment of the availability of heavy metals to plants based on the translocation index and the bioaccumulation factor. *Desalination and Water Treatment, 57*(3), 1469-1477.

Rafiq, M. T., Aziz, R., Yang, X., Xiao, W., Rafiq, M. K., Ali, B., & Li, T. (2014). Cadmium phytoavailability to rice (*Oryza sativa* L.) grown in representative Chinese soils. A model to improve soil environmental quality guidelines for food safety. *Ecotoxicology and Environmental Safety, 103*, 101-107.

Raghavendra, M., Reddy, A. M., Yadav, P. R., Raju, A. S., & Kumar, L. S. (2013). Comparative studies on the in vitro antioxidant properties of methanolic leafy

extracts from six edible leafy vegetables of India. *Asian Journal of Pharmaceutical and Clinical Research, 6*(3), 96-99.

Ribeiro, J., Pieterse, P., & Famba, S. (2018). Vegetative growth of *Amaranthus hybridus* and *Amaranthus tricolor* under different watering regimes in different seasons in southern Mozambique. *South African Journal of Plant and Soil, 34*, 1-10.

Sanga, V. F., & Pius, C. F. (2024). Heavy metal contamination in soil and food crops and associated human health risks in the vicinity of Iringa Municipal dumpsite, Tanzania. *Discover Environment, 2*, 104. https://doi.org/10.1007/s44274-024-00137-y

Saxena, M. C., & Singh, Y. (1965). A note on leaf area estimation of intact maize leaves. *Indian Journal of Agronomy, 10*(3), 437-439.

Sharafi, K., Omer, A., Mansouri, B., Massahi, T., Soleimani, H., Moradi, M., Parnoon, K., & Ebrahimzadeh, G. (2024). Transfer of heavy metals from soil to vegetables: A comparative assessment of different irrigation water sources. *Heliyon, 10*, e32575. https://doi.org/10.1016/j.heliyon.2024.e32575

Singh, R. P., & Agrawal, M. (2007). Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. *Chemosphere, 67*(11), 2229-2240.

Soriano-Disla, J. M., Gómez, I., Navarro-Pedreño, J., & Jordán, M. M. (2014). The transfer of heavy metals to barley plants from soils amended with sewage sludge with different heavy metal burdens. *Journal of Soils and Sediments, 14*(4), 687-696.

Souri, M. K., Alipanahi, N., & Tohidloo, G. (2016). Heavy metal content of some leafy vegetable crops grown with waste water in southern suburb of Tehran-Iran. *Vegetable Science, 43*(2), 156–162.

Souri, M. K., Hatamian, M., & Tesfamariam, T. (2019). Plant growth stage influences heavy metal accumulation in leafy vegetables of garden cress and sweet basil. *Chemical and Biological Technologies in Agriculture, 6*, 25. https://doi.org/10.1186/s40538-019-0170-3

Srivastava, V., Barkha, V., Rajeev, P. S., & Pooja, S. (2020). An insight to municipal solid waste management of Varanasi city, India, and appraisal of vermicomposting as its efficient management approach. *Environmental Monitoring and Assessment, 192*, 1-23.

Stancheva, I., Geneva, M., Markovska, Y., Tzvetkova, N., Mitova, I., Todorova, M., & Petrov, P. (2014). A comparative study on plant morphology, gas exchange parameters, and antioxidant response of *Ocimum basilicum* L. and *Origanum vulgare* L. grown on industrially polluted soil. *Turkish Journal of Biology, 38*(1), 89-102.

Tripathi, A., & Misra, D. R. (2012). A study of physico-chemical properties and heavy metals in contaminated soils of municipal waste dumpsites at Allahabad, India. *International Journal of Environmental Sciences, 2*(4), 2024.

Zhao, F. J., Hamon, R. E., Lombi, E., McLaughlin, M. J., & McGrath, S. P. (2002). Characteristics of cadmium uptake in two contrasting ecotypes of the hyperaccumulator *Thlaspi caerulescens*. *Journal of Experimental Botany, 53*(368), 535-543.

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