IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 12, Issue 6 Ver. II (June. 2018), PP 39-49
www.iosrjournals.org

Lead and Cadmium Bioaccumulation in *Amaranthus Cruentus* L. and its Health Implication

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***Abstract**: Lead and Cadmium are among the major toxic heavy metal contaminants found in anthropogenic soil. However, there has been a growing concern on human health risk from these metals bioaccumulation in vegetables grown on such contaminated soils. This study investigated lead and cadmium bioaccumulation in Amaranthus cruentus and the implications on human health. Pot culture experiments were carried out in which A. cruentus plants were grown in soil contaminated with varying concentrations of lead and cadmium salts (100 mgPb/kg+10 mgCd/kg, 200 mgPb/kg+20 mgCd/kg, and 400 mgPb/kg+40 mgCd/kg). Plants in the control soil were grown without the heavy metals salts. Plant growth was observed under greenhouse conditions and plants were harvested after five and ten weeks. The concentrations of lead and cadmium in the plant tissues were determined using Atomic Absorption Spectrophotometry. Throughout the experiment, no visible symptom of metal toxicity was observed on any plant. The concentrations of lead measured in plant shoot across the groups ranged from 11.5 to 135.7 and 30.5 to 200.5 mg/kg while that of cadmium ranged from 0.1 to 133.1 and 0.5 to 166.7 mg/kg at five and ten weeks, respectively. Lead and cadmium bioaccumulation in the plant increased significantly with increasing levels of soil contamination, and the values were far above FAO/WHO recommended safe limits of 0.3 and 0.2 mg/kg for lead and cadmium, respectively. The high capacity for lead and cadmium bioaccumulation in the edible parts of A. cruentus coupled with the absence of visible phytotoxic symptoms implies a potential danger for humans.*

***Keywords:** Lead, Cadmium, Amaranthus cruentus, Heavy metal bioaccumulation*

Date of Submission: 16-06-2018 Date of acceptance: 02-07-2018

I. Introduction

The growth and development of industries, melting of metals, use of chemical fertilizers and many other anthropogenic activities have turned heavy metal contamination of soils into a serious environmental problem particularly in areas with high anthropogenic pressure[1,2]. Heavy metals are primarily a concern because; they cannot be destroyed by degradation, they can be transferred from soil to plant and from plant to man, they have long biological half-lives and have the potential to accumulate in different organs of the human body where they exert toxic effects[3,4]. Lead (Pb) and Cadmium (Cd) are heavy metals which constitute a major threat to human health and are most frequently implicated in heavy metal toxicities[5]. These heavy metals have no known bio-importance in human biochemistry and physiology and consumption even at very low concentrations can be toxic[3,6]. Lead toxicity can affect every organ in the body, especially the brain, liver, bones and kidneys[7].A common effect of lead is its interference with the development of the grey matter of the brain in children, thereby resulting in poor intelligence quotient (IQ)[8]. Cadmium notably causes kidney and lung damage, it also affects the nervous system, liver and the skeletal system[6,9].

The common anthropogenic sources of lead and cadmium in soils include; atmospheric deposition arising from smelting and industrial operations, sewage sludge and industrial waste application to agricultural lands, uncontrolled dumping of municipal and hazardous waste, phosphate fertiliser application and automobile emissions[10,11]. The presence of these metals in soil raises a concern for crop growth and food quality[12]. Plants grown on soils contaminated with heavy metals usually present with symptoms of metal phytotoxicity leading to poor growth and poor plant yield[13]. On the other hand, some plant species are tolerant to heavy metal stress, showing little inhibition or damage and can accumulate high concentrations of the metals in their tissues[14]. Bioaccumulation is a term used to describe the process whereby a substance is taken up from the environment by a living organism and is stored in the tissues of that organism. It refers to the increase in the concentration of a chemical in a biological organism over time compared to the chemical's concentration in the environment. Compounds bioaccumulate in living things any time they are taken up and stored faster than they are broken down (metabolised) or excreted[15].

The tolerance of plants to elevated concentration of heavy metals in soil and the ability to bioaccumulate them poses a health risk to animals and humans. This is because the metals can be easily transferred to consumers through food supply and consequently causes health problems[16,17]. This is a special problem in vegetables (especially leafy) that accumulate metals in parts that are edible to human beings because they form important part of the human diet. As a result, human health risk from heavy metal bioaccumulation in vegetables has become a subject of growing concern in recent years[1,18]. The joint Food and Agricultural Organization/World Health Organization (FAO/WHO) codex alimentarius commission has thereby recommended safe limits of 0.3 and 0.2 mg/kg for lead and cadmium, respectively in green leafy vegetables[19].

Amaranthus cruentus L. also called green amaranth is a popular vegetable that grows well in tropical fields and is the most commonly grown leafy vegetable in the lowland tropics in Africa and Asia[20]. It provides protein, minerals and vitamins in the diets of many developing countries and could be used to circumvent the problem of malnutrition[21].Studies have reported heavy metal contamination of *Amaranthus cruentus* grown along major highways and those sold in markets[22,23]. In Nigeria, *Amaranthus cruentus* is often found growing along road verges, major highways, dump sites and industrial areas where soils are most likely to be contaminated with heavy metals. This suggests that, the vegetable can accumulate and tolerate to some extent heavy metal contamination which could pose a health risk to consumers. Therefore, this study was designed to investigate the capacity of *Amaranthus cruentus* to bioaccumulate lead and cadmium in its tissues, and the consequent implications for human health.

II. Materials And Methods

Experimental Overview

Seeds of *Amaranthus cruentus* were purchased from the National Horticultural Research Institute (NIHORT), Eleyele, Ibadan, Oyo State, Nigeria. The seeds were sown and raised in nursery for two weeks till they fully germinated. The seedlings were transferred into soil pots contaminated with mixtures of lead and cadmium salts at varying concentrations and were allowed to grow in a green house. Their growth was monitored to assess the toxic effects of lead and cadmium on the plants. Lead and cadmium bioaccumulation in the plant were determined in two stages; after five weeks of plant growth (early maturity) and after ten weeks of growth (full maturity).

Soil Sampling and Analysis

Soil samples were collected from a field of the Teaching and Research Farm (TRF) of the University of Ibadan, Nigeria that has not been cultivated for at least ten years, so as to minimize the potential for contamination. Enough soil was obtained in a single batch for the study from a depth of 0-30 cm (top +sub soil) using a soil auger. The field was divided into four parts and samples were collected from each of the parts, these were thoroughly mixed to form composite samples. These samples were taken in triplicates to the soil laboratory of department of Agronomy, University of Ibadan, Nigeria for physico-chemical analysis. Measurements of total nitrogen in the soil[24], available phosphorus[25], available potassium[26], moisture content[24], pH[27], particle size distribution[28] and organic carbon[29] were carried out using standard procedures. Concentrations of lead and Cadmium in the soil were determined using wet digestion method and Atomic Absorption Spectrometry (AAS)[30]. The physicochemical properties of the soil are listed in Table no 1. Soil texture analysis showed that the soil is a sandy soil (87% of sand, 6% of silt and 7% of clay).

Greenhouse Test

The soil taken from Teaching and Research Farm was passed through 4-mm sieve after air drying and threshing. Five kilograms of soil each was weighed into test pots made of poly ethylene material. Lead and cadmium chloride were used to create heavy metal contamination of the soil. Varying concentrations of the heavy metal mixtures were added to the soil pots as listed in Table no 2. Each treatment had five pot replicates and the pots were randomly arranged using completely randomised design. *Amaranthus cruentus* seedlings of equal length (4cm) were transplanted into the soil pots. Pots were placed in a greenhouse under controlled light and temperature conditions. Plant watering and weeding of pots were carried out when necessary. Agronomic parameters such as plant height and number of leaves were measured on a weekly basis. Plants were also observed for visible symptoms of heavy metal toxicity such as chlorosis (yellowing of leaves), leaf roll, stunting and wilting.

Table no 1: Physical and Chemical Properties of Experimental Soil

Property	Quantity*
pH	6.05 ± 0.35
Moisture content (%)	0.28 ± 0.31
Organic Carbon (g/kg)	4.67 ± 3.72
Nitrogen (g/kg)	0.42 ± 0.30
Phosphorus (mg/kg)	9.26 ± 0.0
Potassium (g/kg)	0.23 ± 0.0
Clay (g/kg)	74.0 ± 0.0
Silt (g/kg)	57.0 ± 4.24
Sand (g/kg)	869.0 ± 4.24
Lead (mg/kg)	12.5 ± 2.29
Cadmium (mg/kg)	ND

*All values are expressed as mean ± standard deviation (n=3).
ND means Not Detected

Table no 2: Lead and Cadmium Contamination of Experimental Soil

Treatment	Cadmium (mg/kg)	Lead (mg/kg) *
T0-Contol	0	0
T1	10	100
T2	20	200
T3	40	400

All values calculated on a dry weight basis.
*The values do not include the background lead concentration of 12.5mg/kg detected in the soil.

Plant Harvesting and Analysis

Plants were harvested at two stages; first harvest, after 5 weeks of growth and second harvest, after ten weeks of full growth. Harvested plants were washed with deionised water, packed in paper envelopes, after which they were dried till constant weight was obtained and the plant biomass (dry weight) was recorded. The dried plants were separated into shoots (leaf + stem) and roots and were ground in a stainless steel mill. The ground plant samples were digested in a fume chamber with nitric acid (HNO_3) and hydrochloric acid (HCl) in the ratio 3:1. Lead and cadmium concentrations were then measured using an Atomic Asorption Spectrophotometer (Bulk Scientific, Model 210 VGP).

Bioaccumulation Factor (BAF: ratio of metal concentration in plant shoot to metal concentration in the soil) and Translocation Factor (TF: ratio of metal concentration in plant shoot to metal concentration in the root) was calculated to further assess heavy metal accumulation potential of *A.cruentus* in the edible portion of the vegetable and the consequent health implication.

$$\text{BAF} = (\text{Concentration of metal in plant shoot})/(\text{Concentration of metal in soil})$$ [31,32]

$$\text{TF} = (\text{Concentration of metal in plant shoot})/(\text{Concentration of metal in plant root})$$ [31,33]

Quality Assurance/Quality Control

Laboratory analyses were carried out following standard procedures at the Agronomy Research Laboratory, University of Ibadan. Analytical grade reagents were used to calibrate the instrumentation. The AAS was calibrated for both lead and cadmium by running different concentrations of certified reference standard solutions. Blanks and reference samples were used to control the quality of the analyses. Blanks and standards were run after five determinations to calibrate the instrument. Coefficients of variation of replicate analysis were determined for precision of analysis and variations below 10% were considered correct.

Statistical analysis

Data analysis was done using SPSS software version 16. Descriptive statistics (means and standard deviation), were used to summarise the data while ANOVA and Least Significant-Difference (LSD) tests were used to test for significant differences in means across the treatments. Correlation analysis and linear regression tests were used to determine the relationship between lead and cadmium concentrations in plant tissues and the soil, respectively.

III. Results

Plant Growth Parameters

Results as presented in Fig. 1 and Fig. 2 show the weekly trend in plant height and number of leaves, respectively for all treatments. The control plants outgrew those grown on the contaminated soils. The growth parameters were reduced in the lead and cadmium exposed plants and the difference grew wider with increasing weeks. At five weeks, the control plants (T0) had the highest growth values for Height (25.00 ± 5.13cm) and

Number of leaves (16.92 ± 5.18) while plants from T3 had the lowest values for Height (22.30 ± 6.07cm) and Number of leaves (15.52 ± 3.48). Similarly at ten weeks, the control plants (T0) had the highest growth values for Height (70.15 ± 9.70cm) and Number of leaves (30.40 ± 7.71) while plants from T3 had the lowest values for Height (52.20 ± 6.07cm) and Number of leaves (22.8±5.87). Analysis of variance showed that there were no significant differences in plant height ($F = 0.952$, $P = 0.419$) and number of leaves ($F = 0.540$, $P = 0.656$) amongst the treatments at five weeks of growth. However by ten weeks, a significant decrease in plant height ($F = 6.202$, $P = 0.002$) and number of leaves ($F = 4.625$, $P = 0.008$) was observed at all levels of lead and cadmium treatment compared to the control plants. No nutrient deficiency or toxicity symptoms were visible on any plant. The plants from all treatment groups looked healthy; they were green and fresh.

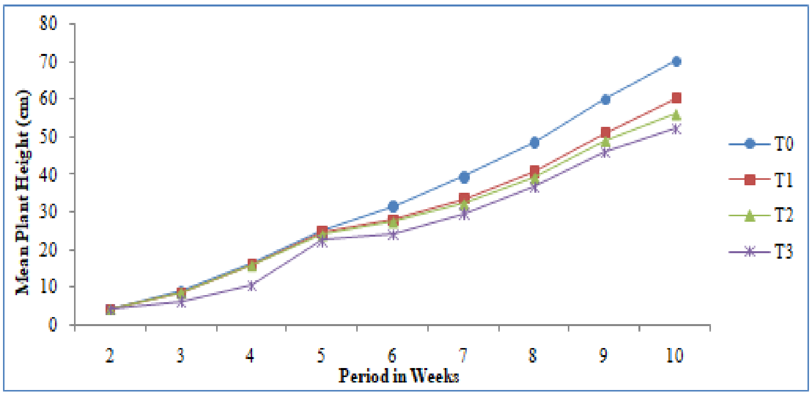

Fig.1: Weekly Plant height of Amaranthus cruentus plants grown in Lead and Cadmium contaminated soils
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

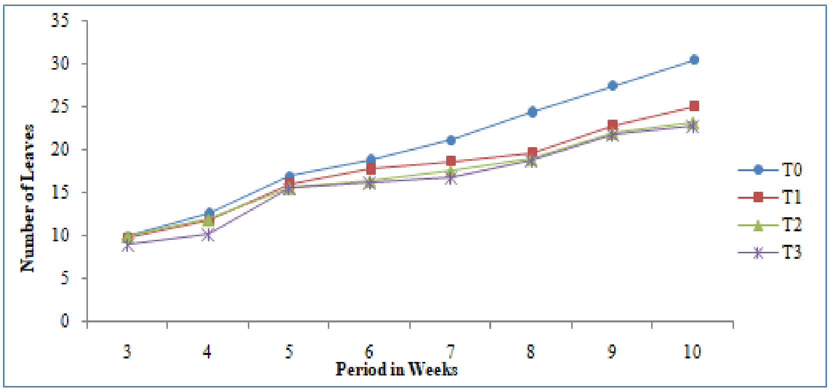

Fig. 2: Weekly Number of Leaves of *A.cruentus* plants grown in Lead and Cadmium contaminated soils
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

Plant Biomass

The plant biomass (dry weights) was observed to decrease with increasing levels of soil lead and cadmium contamination both at the first and second harvest. In comparison to the control, plant biomass decreased by 9%, 25%, and 48% in treatments T1-T3, respectively at first harvest. Plant biomass also decreased by 42%, 48% and 55% in treatments T1-T3, respectively at second harvest. Analysis of variance however, showed that at first harvest, the decrease in plant biomass was only significant in group T3 ($F = 4.92$, $P = 0.004$). At second harvest, plant biomass was significantly reduced at all levels of lead and cadmium treatments compared to the control ($F = 9.843$, $P = 0.000$). This is shown in Fig. 3 and Fig. 4.

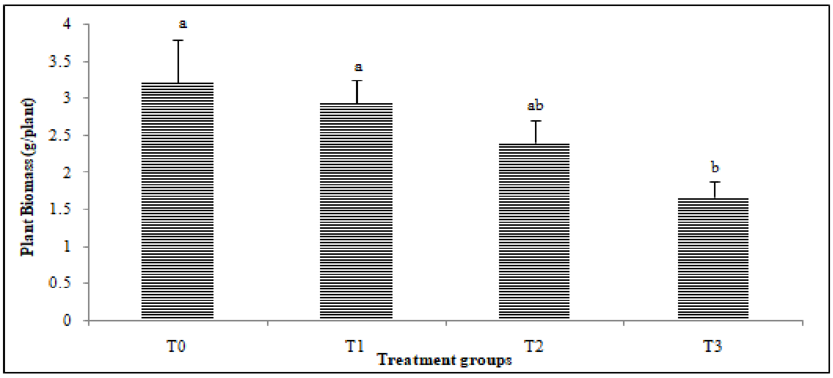

Fig. 3: Plant biomass (dry weight) of *Amaranthus cruentus* plants at first harvest
Error bars indicate Standard Deviation. Means with different letters (a, b) are significantly different from one another ($P<0.05$) according to LSD.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

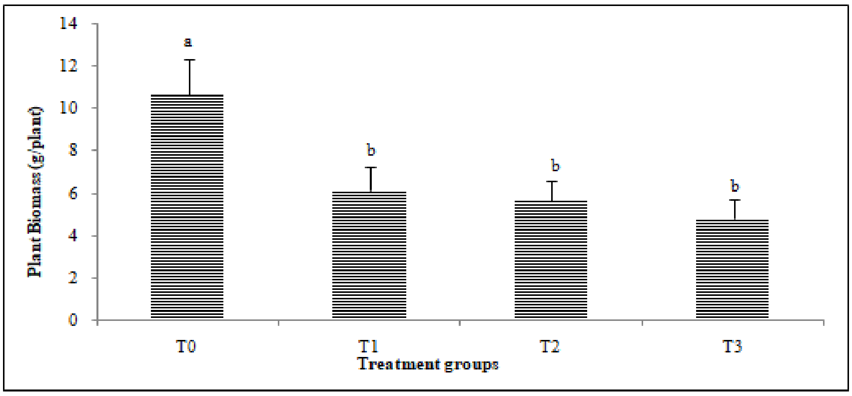

Fig. 4: Plant biomass (dry weight) of *Amaranthus cruentus* plants at second harvest
Error bars indicate Standard Deviation. Means with different letters (a, b) are significantly different from one another ($P<0.05$) according to LSD.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2 = 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

Lead Concentration in the Plant Tissues

The concentrations of lead absorbed and distributed into the plant parts (root and shoot) at first and second harvest are shown in Table no 3. The concentrations in the shoot which is the edible part of the plant were much higher than in the root for all treatments. With the background level of lead (the control; 12.5 mg/kg), the concentration of lead in the shoot was 5.27 mg/kg. With the highest soil lead treatment (400 mg/kg), shoot lead concentration rose to 135.72 mg/kg at second harvest. The lead concentration in the plant roots and shoots increased significantly across the treatments. This showed that as the concentration of lead in the soil increased, the uptake of lead into the plant root and shoot also increased significantly. Statistical analysis involving computation of correlation coefficients indicated that the lead concentration in edible parts (shoot) of the amaranth vegetable was positively and significantly correlated with the lead concentration in soil ($r= 0.901$, $P<0.01$). Linear regression analysis also showed a significant linear relationship between lead concentration in the soil and lead concentration in plant shoot ($R^2 = 81.2\%$). Results shown in Fig. 5 is a fitted line plot showing the linear relationship between lead concentration in the soil and in the plant shoot.

Table no 3: Mean Lead levels in *Amaranthus cruentus*grown in Lead and Cadmium contaminated soils.

Treatment	Lead Concentration in Plant Parts (mg/kg)			
	Fist Harvest		Second Harvest	
	Root	Shoot	Root	Shoot
T0	2.27 ± 1.15 ^{a}	5.27 ± 1.25 ^{a}	6.58 ± 1.44 ^{a}	11.54 ± 0.63 ^{a}
T1	25.00 ± 0.50 ^{b*}	33.17 ± 0.76 ^{a}	25.17 ± 3.33 ^{b*}	35.86 ± 0.12 ^{b*}
T2	68.37 ± 0.55 ^{c*}	88.63 ± 1.46 c *	102.70 ± 16.58 ^{c*}	134.80 ± 17.77 ^{c*}
T3	81.00 ± 0.00 ^{d*}	126.67 ±16.51 ^{d*}	106.80 ± 7.29 ^{cd*}	135.72 ± 0.75 ^{c*}
F-anova	1590.235	237.637	109.228	128.252

Means with * are significantly different from control group (T0) while means with non-identical superscripts (a, b, c) within the same variable are significantly different from one another (P<0.05) according to LSD.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

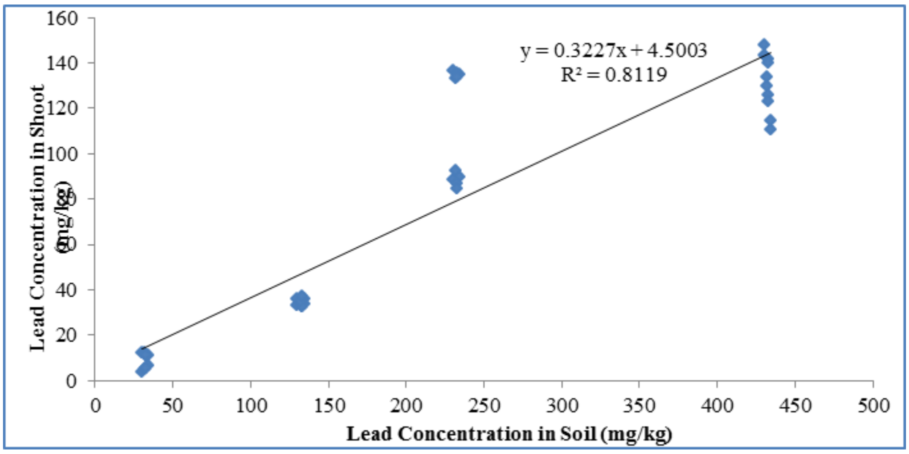

Fig. 5: Relationship between Lead concentration in soil and in plant shoot

Cadmium Concentration in the Plant Tissues

The concentrations of cadmium absorbed and distributed into the plant parts (root and shoot) at first and second harvest are shown in Table no 4. The cadmium concentration in the shoot was also observed to be much higher than its concentration in the root for all treatments. Cadmium was not detected in the control plants. In the treatment groups however, cadmium concentration in the shoot ranged from 19.17 mg/kg to 133.1 mg/kg. Cadmium concentration in the roots and shoots increased significantly across the treatments, revealing that the uptake of cadmium into the plant parts increased significantly as the soil cadmium level increased. Statistical analysis involving the computation of correlation coefficients indicated that the cadmium concentration in edible parts (shoot) of the amaranth vegetable was positively and significantly correlated with the cadmium concentrations in soil (r= 0.986, P<0.01). Linear regression analysis also showed a significant linear relationship between cadmium concentration in the soil and cadmium concentration in plant shoot (R^2 = 97.2%). Results presented in Fig. 6 is a fitted line plot showing linear relationship between cadmium concentration in the soil and in plant shoot.

Table no 4: Mean Cadmium levels in Amaranthus cruentus grown in Lead and Cadmium contaminated soils.

Treatment	Cadmium Concentration in Plant Parts (mg/kg)			
	Fist Harvest		Second Harvest	
	Root	Shoot	Root	Shoot
T0	ND[a]	ND[a]	ND[a]	ND [a]
T1	13.13 ± 0.42 [b*]	19.97 ± 4.25 [b*]	18.74 ± 2.10 [b*]	30.56 ± 1.01 [b*]
T2	34.78 ± 0.63 [c*]	41.53 ±1.27 [c*]	45.80 ± 0.78 [c*]	61.80 ± 0.44 [c*]
T3	46.27 ± 0.25 [e*]	128.32 ± 0.59 [d*]	51.40 ± 2.14 [d*]	133.10 ± 0.94 [d*]
F-anova	8158.351	3479.40	1239.881	2935.280

Means with * are significantly different from control group (T0) while means with non-identical superscripts (a, b, c) within the same variable are significantly different from one another (P<0.05) according to LSD.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2 = 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

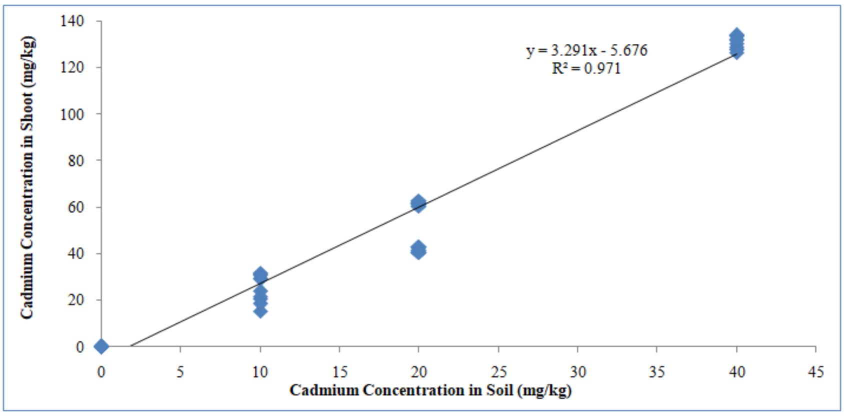

Fig. 6: Relationship between Cadmium concentration in soil and in plant shoot

Translocation and Bioaccumulation Factors of Lead and Cadmium in A.cruentus

The Translocation Factors and Bioaccumulation Factors of lead and cadmium in *A.cruentus* for the different treatment groups are shown in Fig. 7 and Fig. 8 respectively. The TF of lead ranged from 1.32-2.32 with the highest value observed in the control and the lowest observed in group T2. The TF of cadmium ranged from 1.27-2.68 with the highest value observed in group T3 and the lowest observed in group T2. The BAF of lead ranged from 0.31-0.69 with the highest value observed in the control and the lowest values observed in groups T1 and T3. The BAF of cadmium ranged from 2.53-3.27 with the highest value observed in group T3 while the lowest was observed in group TI. The TF and BAF of cadmium could not be calculated for the control group because cadmium was not detected in the control soil.

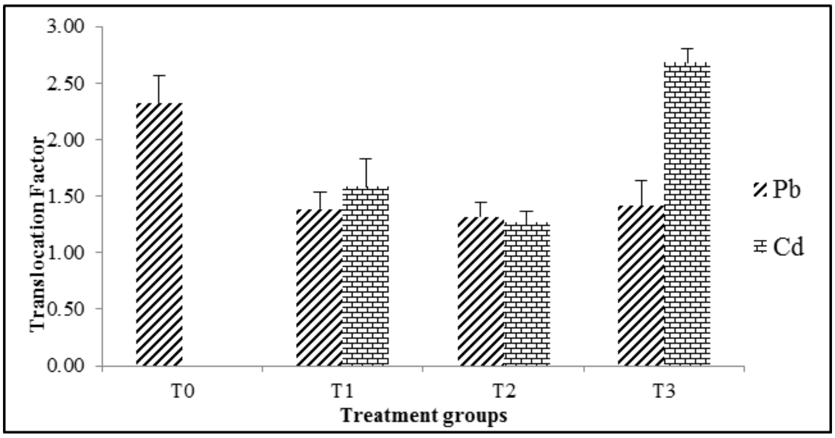

Fig. 7: Translocation Factors of Lead and Cadmium in *Amaranthus cruentus*
Error bars indicate Standard Deviation.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

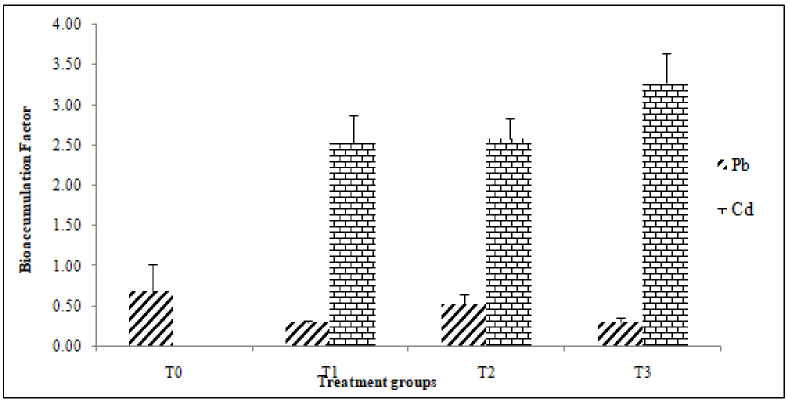

Fig. 8: Bioaccumulation Factors of Lead and Cadmium in *Amaranthus cruentus*
Error bars indicate Standard Deviation.
T0 = control (absence of the heavy metals mixture)
T1 = 100 mgPb/kg + 10mgCd/kg
T2= 200 mgPb/kg + 20 mgCd/kg
T3= 400 mgPb/kg + 40 mgCd/kg

IV. Discussion

Studies have shown that the presence of heavy metals in soil can exert phytotoxic effects including inhibition of plant growth, reduction of crop yield and visible symptoms such as chlorosis, stunting and wilting of leaves and death of plant[13]. Some plants however have been found to have the ability to survive and thrive in a heavy metal contaminated soil that is rather toxic to other plants[34,35].

In this study, at first harvest, no significant reduction in plant growth was observed at all the levels of lead and cadmium treatment compared to control plants. Likewise, there was no significant reduction in crop yield up to the 200mgPb/kg and 20mgCd/kg lead and cadmium treatment. In addition, there was no observation of any visible symptoms of heavy metal toxicity or nutrient deficiency on the plants throughout the experiment. These facts suggest that to some extent, *Amaranthus cruentus* is a heavy metal tolerant vegetable. Similar studies such as Darshana *et al.*also reported absence of visible signs of toxicity and no significant reduction in the dry matter yield of spinach plantsthat spinach plants exposed to cadmium up to 50µg/g in soil[36]. Atayese *et al*. also reported no visible toxicity symptoms in *A.cruentus* plants grown on soils contaminated by traffic pollutants[22].

Though the exact mechanisms of heavy metal tolerance in plants are still being debated, it has however been suggested that tolerance in metal accumulating plants may be due to highly efficient intracellular compartmentalization and chelation of the metals. Heavy metals entering the plant cells may have been transported into the vacuole, thereby removing the metals from the cytosol or other cellular compartments where sensitive metabolic activities take place[37]. Advances in science have also shown the role of some metabolite, trace elements, transcription factors, plant hormones and stress inducible proteins in the tolerance of plants to heavy metal environment[35].

At second harvest, significant reduction in plant height, number of leaves and plant biomass was observed at all levels of lead and cadmium treatment compared to the control. Though no visible symptom of toxicity was observed on the plants, the decrease in plant growth and yield parameters demonstrated that the increased accumulation of lead and cadmium in the plant tissues may have exceeded the plant tolerance limit and exertedsome toxic effects on the plant. This substantiates literature reports of the effects of lead and cadmium on plant growth[13,38]. Syed observed a reduction in growth parameters of plants *Dalbergiasissoo* and *Eucalyptus camaldulensis* irrigated with cadmium and chromium contaminated wastewater[38] while Sharma and Dietz explained that excess accumulation of heavy metals in plant cells results in alterations of different plant physiological processes, including inactivation of enzymes, denaturation of proteins, displacement or substitution of essential nutrients and disruption of membrane integrity which finally leads to altered plant metabolism and can hamper plant growth[13].

The results of this study have also revealed the ability of *Amaranthus cruentus* to uptake and accumulate large amounts of lead and cadmium in its tissues. Lead and cadmium accumulation in the plants increased as the metal concentrations in the soil increased. More of the metals accumulated by the plant were distributed to the shoot, which showed that the plant may possess effective mechanisms for translocating the metals absorbed by root into the shoot. This conforms to the reports of heavy metal accumulation in edible vegetables by Atayese *et al*.[22], Khan *et al.*[12], Nwoko and Egunobi[39]. At first harvest, the lead and cadmium concentrations in the shoot reached 126.67 and 128.32 mg/kg, respectively at the highest soil contamination level, while at second harvest, the lead and cadmium concentrations in the shoot reached 135.72 and 133.10 mg/kg, respectively. These values were several times higher than the FAO/WHO stipulated safe limits of 0.3 and 0.2 mg/kg for lead and cadmium, respectively in green leafy vegetables[19].

The concentration of lead in the control plants (5.27 mg/kg) also exceeded safe limit despite the fact that the concentration of lead in the control soil (12.5 mg/kg) was below soil quality guideline limits of 70-100mg/kg lead in agricultural soil[40,41]. This suggests that *Amaranthus cruentus* is capable of concentrating lead in its shoot even when present at low levels in soil. This corroborates the report of Atayese *et al*. who after studying heavy metal concentrations in amaranthus cultivated on soils characterized by heavy traffic, found out that while the levels of metals in soil were within the critical limits, the range absorbed in the plant leaves were above the safe limit for human consumption[22].

Strong positive correlations between the concentrations of lead and cadmium in soil and plant shoot were observed in this study. Similar observations of linear relationships between heavy metal in plant tissue versus heavy metal in soil have been reported by other researchers. Ni *et al.* reported that cadmium concentration in edible parts of Chinese cabbage, winter greens and celery were positively correlative to the extractable cadmium content in the soil in which the vegetables were grown[42]. Likewise, Xiong and Wang in their study on copper bioaccumulation in Chinese cabbage also observed positive correlations between copper concentrations in soil and shoot[43].

The bioaccumulation factor provides a useful indication of relative metal availability from soils to plants and it also estimates a plant's ability to bioaccumulate metals from soil. Likewise, the translocation factor shows how effectively the absorbed metal is translocated from the roots to the aerial plant parts[31,32,33]. These studies have shown that plants with high metal accumulation potential usually have TFs and BAFs greater than one. Zhao *et. al.*explained that a key trait of metal hyper-accumulators is the efficient metal transport from roots to shoots which is characterized by the TF being greater than one[44]. The result of this study showed a TF>1 for both lead and cadmium in all the treatment groups, suggesting that the metals are effectively translocated from the roots to the shoot which is the edible portion of the vegetable. The BAF for lead was less than one in all treatments while a BAF>1 was observed for cadmium in all the groups. This shows higher efficient accumulation of cadmium from soil to the vegetable. Cadmium has been reported to be retained less strongly by the soil and is more mobile than other metals[45]

The results of this study point towards the human health implications of lead and cadmium bioaccumulation in *A. cruentus*. The high level of tolerance of *A.cruentus* to lead and cadmium in soil, its ability to accumulate large amounts of the metals in its edible parts, and the high TFs and BAFs implies a health risk to consumers of the vegetable. The bioaccumulation potential of the plant would not suffice for determining the associated health risk, as this would also depend on the dietary pattern of the consumers and the average amount of *A. cruentus* consumed per day by a person, of which there is limited information on this. However, the Codex

Committee of Food additives and contaminants of the Joint FAO/WHO Food Standards programme have recommended maximum intake limits of 0.3 and 0.2 mg/kg for lead and cadmium, respectively in green leafy vegetables. The concentrations of lead and cadmium accumulated by *A. cruentus* in this study are far above the recommended safe limits. It can therefore be implied that the bioaccumulation of lead and cadmium in *A. cruentus* grown on contaminated soils has the potential to contribute substantial amounts of lead and cadmium to the human diet which points to a potential danger for humans.

V. Conclusion

This research was set out to assess the bioaccumulation of lead and cadmium in *Amaranthus cruentus* (edible amaranth) grown on lead and cadmium polluted soils and the health implications for consumers. The results obtained from this research have demonstrated that green amaranth has a high capacity for lead and cadmium accumulation in its tissues and exhibits some level of tolerance to the soil lead and cadmium treatments as there were no visible symptoms of toxicity. Unfortunately, from the point of view of the food chain, the high capacity for lead and cadmium accumulation in the edible parts of *Amaranthus cruentus* together with the absence of visible toxic symptoms poses a risk to human health. There is the possibility that people will eat healthy looking green amaranth that actually has a high content of heavy metals that are deleterious to human health. Regular consumption of such contaminated vegetable may result in long-term low level accumulation of the heavy metals in the body and the detrimental impact may become apparent after several years of exposure.

Public awareness should therefore be generated on the dangers of consuming *Amaranthus cruentus* grown on heavy metal contaminated soils and that people should desist from growing green amaranth at road verges, in industrial areas, dumpsites and other areas where soils are most likely contaminated with heavy metals. Periodic monitoring and assessment of heavy metal concentrations in *Amaranthus cruentus* from market and production sites should also be conducted so as to limit the risk of health hazards to humans.

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Samuel T. Adekunle " Lead and Cadmium Bioaccumulation in *Amaranthus Cruentus* L. and its Health Implication." IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) 12.6(2018): 39-49.