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Lead Uptake and Bioconcentration in Selected Vegetables: Implications for Phytoremediation of Heavy Metals

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ABSTRACT

The present study evaluated the uptake and accumulation of lead in vegetables grown on contaminated soils in Owerri, Nigeria. Lead (Pb), and three vegetables: Amaranthus (*Amaranthus viridis*), ginger (*Zingiber officinale*), and pepper (*Capsicum annum*) were used for the study. The experiment was mounted in a greenhouse at Alvan Ikoku University of Education Owerri. Lead (II) nitrate [Pb(NO3)2] was used as the source of lead. The study had five treatments and three replicate for each plant. A separate homogenous mixture of 2g, 4g, 6g and 8g of Pb salt were prepared. Each of the mixture was poured into 1000cm3 volumetric flask, water added, stirred and made up to the mark. The standard solutions were poured into soil (2.5kg) sample bags for each unit. The contaminated soils were left for four days to allow chemical – soil contact. Plants were allowed to grow for a period of ten weeks. Leaves and soil samples were collected and sent to the laboratory to determine lead concentration. Transfer factor were also computed. All Data were subjected to ANOVA. Mean separation was by Duncan, using SPSS version 20. Results showed that lead uptake were significantly different across treatments for all plants. Uptake increased with lead concentration in soil. uptake of 0.024-0.288mg/kg was recorded for Amaranthus; 0.415-1.451mg/kg for pepper; 0.052-0.212mg/kg for ginger; TF of 0.623, 3.938, 1.989 for Amaranthus, pepper and ginger respectively were recorded. The Study concluded that the order of the phytoextraction potentials for these plants were: Pepper >ginger>Amaranthus. There is need to modify these plants (genetically) in other to increase the remediation potential of these plants so as to offer a viable remediation solution for polluted soils.

Keywords: lead, transfer factor, excluder, hyperaccumulator, uptake

INTRODUCTION

Heavy metals generally have been of remarkable concern to researchers and scientist. Lead is one of the heavy metals with no biological value to plants, animals, and humans. Hence like other heavy metals in such class (Cadmium, Arsenic, and mercury) could be toxic even in little concentrations. Lead is described as the most important toxic heavy metal in the environment. Due to its important physico-chemical properties, its use can be retraced to historical times. Due to its non-biodegradable nature and continuous use, its concentration accumulates in the environment with increasing hazards (Nas and Ali, 2018; Babu et al 2021, Offor et al 2024). In plants, lead affects several processes, including photosynthesis. Same plants however can take up lead and serve as decontaminating organism for lead in soil. Several researches have established high concentrations of Lead and other heavy metals in plant tissues, both edible and non-edible parts (Offor et al, 2020a, Offor et al, 2020b) .

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Decontaminating soil from toxic metal pollution sometimes could be time-consuming and expensive process. Toxic metals pose a serious threat to human and animal health because of their long-term persistence in the environment (Tica, et al 2011; Babu et al 2021). The removal of significant amounts of heavy metal contamination using other processes could be costly and results in massive economic waste. Phytoremediation is a practical, dependable, eco-friendly, long-term practicable, and cost-effective method of decontaminating an area from toxic heavy metal pollution (Placek, et al 2016; Babu et al 2021).

Several researches on the applicability of plants for heavy metals phytoextraction has been gathered to date from both lab-scale studies performed under controlled model conditions and field experiment using real environmental conditions (Suman et al 2018).Plant species have been categorized by their capability of heavy metal uptake and sensitivity to high metal pollution: hyperaccumulator plants BAC>1, moderate accumulator plants 0.1<BAC<1.0, low accumulator plants 0.01<BAC<0.1 and non-accumulator plants BAC< 0.01. Plants that accumulate very high levels of metals in any shoot tissue in their natural habitat are called hyper-accumulators. Metal hyperaccumulators are plant species that bioaccumulate metals in their shoot tissues to levels far exceeding those present in the soil or in the non-accumulating species growing nearby. These plants are capable of taking up heavy metals from soils and accumulate them in their shoots, and they are widely used in phytoremediation (Moameri et al 2017). The present research investigated lead uptake and bioconcentration in Amaranthus, ginger, and pepper. These vegetables are cultivated widely in Nigeria and Africa as a continent.

MATERIALS AND METHODS

Study Area

The experiment was mounted in a greenhouse at Alvan Ikoku University of Education, Owerri Nigeria. Owerri is located at 5.48° North latitude, 7.03° East longitude and 159 meters elevation above the sea level. The area is a tropical rain forest region with annual rainfall of between 1,500mm to 2,200mm (60 to 80 inches). An average annual temperature above 20 °C (68.0 °F) creates an annual relative humidity of 75%, with humidity reaching 90% in the rainy season (Offor et al., 2020a).

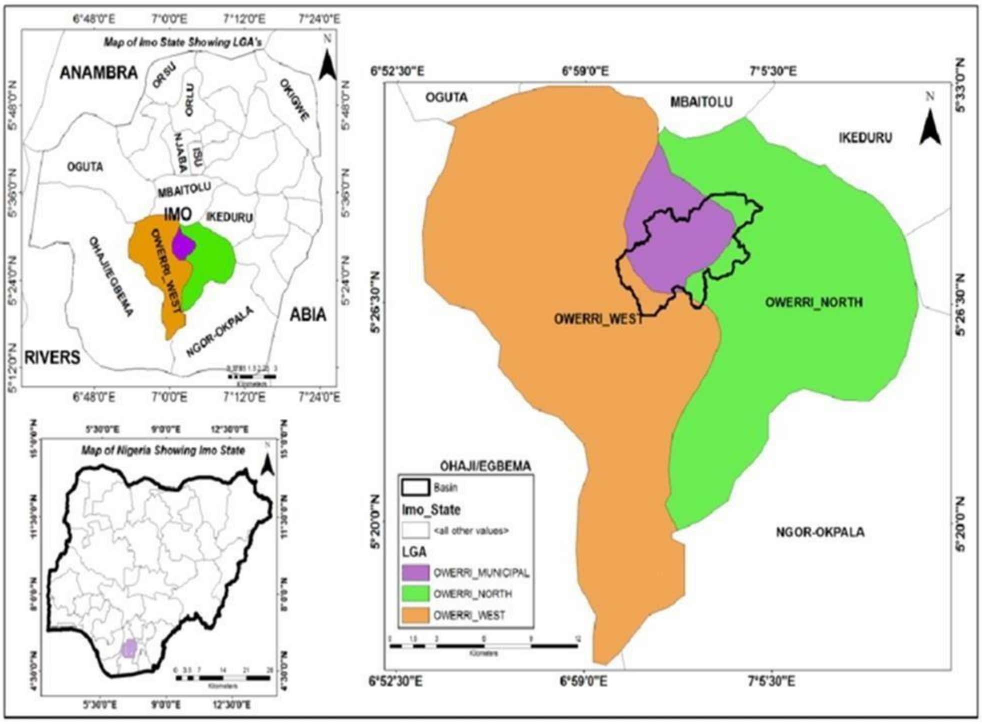

Fig 1: Map of the research area

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Research design and Procurement of Materials

The research was a pure experimental design. The salt used for the experiment – Lead (II) nitrate was procured from Chemi Sciences Ltd, Owerri Imo State. Vegetables planting materials and experimental bags were procured from reliable source in Owerri, soil used for the research was collected from a location within the Institution where the study was conducted.

Soil Preparation

The soil used was analyzed for heavy metals and other parameters. Soil was passed through 2mm sieve and air dried for 48 hours. 2.5kg of the soil was poured into the experimental bags. The salt used to contaminate the soil was Lead (II) nitrate $Pb(NO_3)_2$,. A separate homogenous mixture of 2g, 4g, 6g and 8g of Pb salt was prepared. Each of the mixture was poured into 1000cm^3 volumetric flask, deionized water added, stirred and made up to the mark.

The standard solutions containing mixtures of 2g, 4g, 6g, and 8g, salt was poured into soil sample bags labeled A to E respectively. The standard solutions of heavy metals and the soil samples were mixed thoroughly using a hand trowel. The contaminated soils were left for fourdays to allow chemical – soil contact.

Experimental Set Up

The experimentcomprised of five treatments for each metal designated A, B, C, D, and Erespectively. Each treatment was replicated three times. Vegetables were grown on the contaminated soils at the various concentrations. Treatments A had no Pb salt contamination (0g). B-E had 2g, 4g,6g, and 8g respectively for each vegetable. The research had a total of fifteen (15) treatments and forty-five (45) experimental units. ginger was planted directly while pepper and Amaranthus were raised in the nursery. Organic tea (poultry dropping soaked in water in a tank and allow for 4-5 days) was added to all treatments at same quantity twice a week to provide plant nutrients.

Sample Collection and Analysis

For each leaves samples were collected for analysis during the experimental period. Soil samples were collected for analyses before spiking with heavy metals and same was done after the experiment. Samples were analyzed at the Environmental and laboratory Services, International Energy Services Limited Porthacourt, Rivers State Nigeria. The digested soil and vegetable samples were analysed following the instruction of Instrument operational manual provided by manufacturer. Analysis of Pb was carried out using Atomic Absorption Spectrophotometer. All concentrations were reported in mg/kg.

RESULTS

Table 1: Physicochemical Properties of Experimental Soil

Parameters	Unit	Test Method	Values
PH	–	EPA9045D	5.05
Electrical conductivity	us/cm	EPA9050A	12
Sand	%	ASTMD422	95.33
Silt	%	ASTMD422	1.76
Clay	%	ASTMD422	2.91
Nitrogen	Mg/Kg	EPS352.1	0.623
Phosphorus	Mg/Kg	EPS352.1	0.109

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Organic matter	%	EPA 9060A	2.36
Calcium	Mg/Kg		22.468
Potassium	Mg/Kg		1.769
Magnesium	Mg/Kg		5.931
Lead	Mg/Kg		0.063

Table 1 showed the physicochemical properties of the soil used for the experiment. PH of the soil indicated it is slightly acidic soil. soil particle size percentage shows the soil is sandy. Minerals concentrations were also reported. The lead concentration in the soil is not of high value.

Table 2: Heavy Metals concentrations in Experimental units [soils] [Mg/Kg]

Heavy metal	Treatments	Amaranthus	Pepper	Ginger
Lead (Pb)	Pb 0g	0.087	0.096	0.053
	Pb 2g	6.34	0.333	0.096
	Pb 4g	0.039	0.28	0.107
	Pb 6g	6.42	0.227	0.061
	Pb 8g	0.117	0.428	0.114

Table 2 reported the lead concentrations in the treatments/ experimental unit soils. Samples for this result were collected when the vegetables samples were also collected. This was needed to compute the transfer factor for lead in the vegetables.

Table 3: Lead uptake/accumulation by vegetables [Mg/Kg]

Heavy metal	Trts	Amaranthus	SD	Pepper	SD	Ginger	SD
Pb	Pb 0g	0.024**	0.009	0.415**	0.1	0.052**	0.001
	Pb 2g	0.087**	0.002	1.236**	0.1	0.087**	0.002
	Pb 4g	0.098**	0.001	1.010**	0.001	0.119**	0.001
	Pb 6g	0.288**	0.01	1.058**	0.01	0.133**	0.002
	Pb 8g	0.031**	0.001	1.451**	0.1	0.212**	0.002
Mean		0.106	1.034	0.121			
P. Value		0		0		0	

**Means with same superscript are not significantly (P>0.05) different

Table 3 showed the lead uptake at each treatment for the three vegetables. The result indicatedlead uptake across treatments were significantly different for the three vegetables evaluated. Pepper had higher uptake of lead, followed by ginger. Amaranthus had least lead uptake.

Table 4: Bioconcentration Factor [BCF] /Transfer Factor [TF] of Lead in Vegetables

Treatments Amaranthus	Pepper	Ginger	P.Value(Sig)
Pb 0g	0.276	4.323	0.981
Pb 2g	0.014	3.712	0.906
Pb 4g	2.513	3.607	1.112
Pb 6g	0.045	4.661	2.18
Pb 8g	0.265	3.39	1.859

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Mean	0.623**	3.938**	1.989**
SD	1.064	0.532	0.575

**Means with same superscript are not significantly (P>0.05) different

$$TF/BCF = \frac{C_{plant}}{C_{soil}} \quad \text{.......... Equation 1}$$

Where, plant C_{plant} : metal concentration in vegetable tissue, mg kg^{-1} and soil C_{soil} : metal concentration in soil, mg kg^{-1}.

Table 4 reported BCF/TF of lead for the three vegetables studied. The result showed that mean TF across vegetables differ significantly. Pepper had higher BCF for lead, followed by ginger. Amaranthus had least lead coefficient.

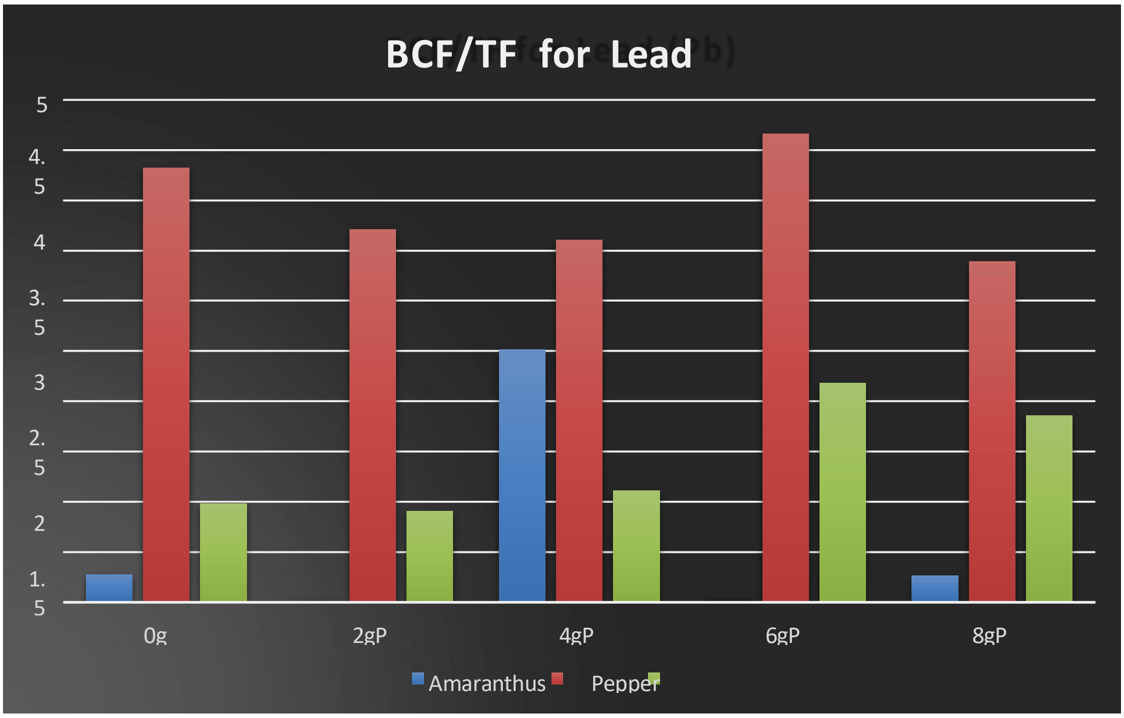

Fig 1: BCF/TF of Lead in the three vegetables

DISCUSSION

The data for heavy metal uptake and accumulation by plants were presented in table 3. Lead,showed increase in uptake with increase in metal concentration. Lead had between 0.024-0.288mg/kg for Amaranthus; 0.052-0.212mg/kg for ginger; and 0.415-1.451mg/kg for pepper. These values for lead uptake are slightly lower than uptake recorded by Mansah et al (2008) for carrot, lettuce and cabbage. Like the present research, uptake was also influence by treatment concentrations. Sharma and Dubey (2005) had opined that lead uptake in ariel part are usually dependent on atmospheric conditions, and argued that soil lead can accumulate in roots of plants. The results of this study however disagree with that assertion as lead uptake reported was from lead concentration in the soil. pepper however showed higher uptake of lead than Amaranthus and ginger. The uptake of lead by pepper was slightly higher than the values reported by Milam et al (2018) for okra but was within the range reported for Amaranthus. Adekunle et al (2018) reported very high uptake of lead (11.5-135.7mg/kg) in Amaranthus far above the range of the present study. The three plants studied showed lead extraction potential, since the treatments had higher accumulation of lead than the control for all the plants.

Bioconcentration factor/transfer factor of lead was 0.014-2.513 for Amaranthus; 3.390-4.661 for pepper; 0.906-2.180 for ginger. Adekunle et al (2018)reported TF of 0.3-0.6 in Amaranthus. 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 (Adekunle et al 2018). These studies have shown that plants with high metal accumulation potential usually have TFs and BAFs greater than one. Zhao et. al. (2006) 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. From the results, pepper has higher potential to accumulate lead than ginger and Amaranthus. Metal-contaminated soils are notoriously hard to remediate. Current technologies resort to soil excavation and either land filling or soil washing followed by physical or chemical separation of the contaminants.Phytoremediation is an effective and affordable technology used to remove inactive metals and metal pollutants from contaminated soil and water. TF clearly explains such potential of any plant. This is one of the needs for pot experiment under controlled environment.

CONCLUSION AND RECOMMENDATIONS

The research result showed that the three vegetables are good bioindicators of Lead. This is because lead concentration in vegetables for control treatment were lower than the other treatments. The result has proved that Lead can also be taken up from soil and not only from the atmosphere. BCF/TF was greater than one for pepper and ginger, but less than one for Amaranthus. Hence pepper and ginger are better accumulators of Lead than Amaranthus. Lead phytoremediation potential of the vegetables was in the order: Pepper>Ginger>Amaranthus.

The following recommendations are hereby made:

- There is a need to modify these plants (genetically) in other to increase the remediation potential of these plants so as to offer a viable remediation solution for polluted soils or farmlands.
- Investigation can be carried out on how to recover these metals extracted to avoid reintroducing the metal contaminants into the environment.
- Further research is necessary in order to find the potential transformation mechanisms for heavy metal phytoextraction in vegetables.
- Other local plants with the same morphology as the studied plants could be investigated for better phytoremediation of these metals and other metals not studied in this research.
- There is need for constant soil testing by farmers before cultivation of plants for consumption.
- Plants produce should be tested for possible heavy metal bioaccumulation to levels that pose high health risk.

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