Assessing the Toxicity of Lead in Edible Plants: A Case Study with *Colocasia esculenta* (Cocoyam Plant)

[1,2]E. Anderson, [2,3]M. E. Amosah, [2]D. A. Asare, [2]G. Ofori-Sarpong

[1]Newmont Golden Ridge Limited, Akyem, Ghana
[2]University of Mines and Technology, Tarkwa, Ghana
[3]Golden Star Resources, Wassa, Ghana

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Abstract

Industrialisation has led to the release of heavy metals such as lead into the environment. Lead can cause miscarriage, low sperm count, kidney, liver and brain damage. Human beings can be intoxicated with lead when they consume water and food such as cocoyam, contaminated with lead. Cocoyam has the potential to sorb Pb into its leaves, stem and root making it dangerous for the millions of lives that depend on cocoyam plant as a source of food. To contribute to the awareness of Pb toxicity, this paper assessed the sorption ability and translocation of lead into the stem, leaves and root of cocoyam plant. Cocoyam plants were grown in soils with solutions having Pb concentrations of 10 ppm and 0 ppm for 14 days. Pb was translocated to the leaves and stem through the root in the control and the 10-ppm Pb-induced soil. The control experiment with an initial soil Pb concentration of 0.757 ppm had 0.088 ppm, 0.07 ppm, 0.053 ppm and 0 ppm of Pb in its leaves, stem, roots and soil respectively in 28 days. The order of increasing lead retention in the plant parts was leaves > root > stem. Absorbance of lead in solution reduced to < 0.001 at day 14. The highest lead sorption occurred at 32.78% in the leaves of the setup containing 10 ppm Pb, while the bioconcentration factor and translocation factor of the plant were 5.87 and 2.11 respectively. The findings from this study indicate that cocoyam plant found in Pb-contaminated soil are prone to contamination, and thus poses health threats. The ability of the edible parts of the cocoyam plant to retain its Pb after boiling, and become bioavailable to human beings should therefore be ascertained.

Keywords: Lead, Cocoyam Plant, Sorption, Bioconcentration Factor, Translocation Factor

Introduction

1.1 Lead and Its Environmental Impact

Industrialisation has for centuries been the world's most revolutionary breakthrough and has provided many advantages in terms of knowledge, employment, economic growth, etc., and has made life a lot easier. Regardless, the release of various chemicals and metals into the environment through industrialisation has turned out to be one of the major concerns of various countries across the globe. Heavy metals such as mercury, iron, chromium, cadmium, lead, etc., are serious pollutants due to their persistence in the environment, bioaccumulation and toxicity to organisms with their major significant effects occurring with high concentrations in the environment (Chayapan *et al*.,2015). Industrial activities such as mining and smelting of non-ferrous metals and the historical use of Pb-containing products such as paint, leaded gasoline, and pesticides are the primary sources of lead contamination (Hettiarachchi *et al*., 2001). Lead can be discharged directly through spillage of chemical on the land, improper disposal of waste materials that contain lead and/or through improper disposal of industrial sewages containing lead. Lead also exists as a mineral in the soil. Pb is biogeochemically channelled through the atmosphere as dust, fumes, mists, and vapours, and

in the soil as a mineral (Sengar *et al*., 2008). Due to the presence of lead in soil, it is mostly available to plants and its availability is dependent on the soil conditions (Sharma and Dubey, 2005). Lead can easily be sorbed and accumulated into plant parts (Sharma and Dubey, 2005). The acceptable tolerance level of Pb by FAO/WHO is 5 mg/kg dry weight (Attanayake *et al*., 2014).

Lead is a toxic metal to the human body. The main exposure pathways to the human body are through inhalation and ingestion. Lead-exposed children can also suffer some effects such as brain damage, slowed growth and developmental as well as learning and behaviour problems (Anon, 2021). Lead in the body can be transported to target organs such as brain, kidney, liver, or bone before it harms the body cells. Low sperm count in men and miscarriage in women can occur with high levels of lead (Martin and Griswold, 2009).

The high accumulation of these metals in the environment has attracted a lot of public attention and as such, a lot of research have been undertaken in an attempt to curb and/or reduce the concentrations of Pb in some affected areas. Physical and chemical remediation methods have been employed but are cost-intensive, difficult to operate, disturbs the natural structure of the soil and poses a threat of secondary pollution (Rahman *et al*., 2016; Mazurkiewicz *et al*., 2020). Phytoremediation debunks these limitations in the physical and chemical methods and, as such, has gained a lot of attention recently. Categories of phytoremediation include phytoextraction (the use of plants to remove contaminants from soils), phytovolatilisation (the use of plants to transform and volatilise elemental metal species), rhizofiltration (the use of plant roots to remove contaminants from flowing water) and phytostabilisation (the use of plants to transform soil metals to less toxic forms, but not remove the metal from the soil). Phytostabilisation or phytoimmobilisation is the use of certain plants for the stabilisation of contaminants in contaminated soils thereby decreasing their availability to plants (Pamar and Singh, 2015), and it is known to be suitable for lead (Chaney *et al*., 1997). This technique is used to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into the food chain (Ali *et al*., 2013).

Various plants (edible and non-edible) have been assessed on their ability to remove heavy metals from the environment. Different plants behave differently to heavy metal uptake from soil. Causes of variations in plant uptake of Pb can be due to soil pH, particle size, cation exchange capacity of the soil, as well as root exudation, plant age, plant species, soil organic matter content, soil texture, climate, topography, pollution, and geological history of the soil (Nas and Ali 2018). Consequently, some plants have very high uptake capacities and accumulate particular metals or metalloids in their living tissues in high levels for a long period. These plants are termed as hyper accumulators. For instance, Hui *et al*., (2017) established that, *Colocasia esculenta* has high potential to absorb heavy metal and thus, is a hyperaccumulator.

Even though Pb is not readily available to plants, it forms compounds with other elements which are readily absorbed by the plant roots, making it dangerous for human because of the threats it poses through the food chain (Islam *et al*., 2016). The mode of lead uptake by plants includes plant roots and the atmosphere through the foliage of the plant.

1.2 *Colocasia esculenta* and Phytoremediation Ability.

Colocasia esculenta (cocoyam plant) is a heart-shaped herbaceous monocotyledonous plant (Figure 1) with a height of 1 m or more (Rashmi *et al*., 2018). It can also be easily cultivated, has a high resistance to environmental stresses and competitive ability among other plants (Kashem *et al*., 2008). The leaves and corms are also consumed by Ghanaians mostly as a staple food for its health benefits.

Cocoyam is a good source of iron, phosphrus, vitamin C, thiamine, riboflavin niacin calcium, fibre and protein (Otekunrin *et al.,* 2021). The leaves of cocoyam can enhance memory, prevent cancer, boost the immune system, reduce cholesterol level, help in weight loss, prevent anaemia and even increase sperm production (Appiyah, 2021)

The easily digestible starch of cocoyam also makes it suitable for invalids with peptic ulcer , gall bladder disease, inflammatory bowel disease and chronic liver problems (Rashmi *et al*., 2018). It is

estimated that about 400 million people around the globe depend on it as a source of food, especially people in West Africa (Boakye *et al*., 2018). The leaves are boiled alongside other vegetables and are used to prepare "kontomire" (a local dish) stew and can be complemented with its boiled corms, yam or plantain. This makes *Colocasia esculenta* one of the most sought-after plants in Ghana.

Figure 1 A Fully Matured *Colocasia Esculenta* Plant

Research works have classified cocoyam plant as a hyperaccumulator with an ability to remediate Pb from the environment through its roots to the aerial parts of the plant (Parma *et al*., 2012; Maderra-Parra *et al*., 2015; Islam *et al*., 2016). *Colocasia esculenta* has the potential to sorb lead through its roots to the leaves and can phytostabilise lead. The danger occurs where the plant cannot degrade lead but only stabilises it.

Having surveyed the dependence of this plant as a source of food to numerous people, the plenitude of Pb in the soils and wastewaters, and the tendency of the *Colocasia esculenta* to take up these dangerous metals and transfer it to man through the food chain, this study sought to ascertain the lead-sorption ability of *Colocasia esculenta (*cocoyam plant) when growing in lead-contaminated soil, the extent of accumulation in the edible part, and the potential level of toxicity of lead transferred through the food chain into the human body.

2 Materials and Methods Used

2.1 Materials and Equipment Used

Two (2) buckets with a water capacity of 6000 ml were purchased from the Tarkwa market. Two *Colocasia esculenta* (Cocoyam plants) of similar biomass were uprooted and 6 kg of fertile loamy soil was fetched from Tarkwa near the UMaT entrance. A 4-mm aperture size screen, filter papers, measuring cylinder, 1000-ppm lead stock solution, concentrated nitric acid, concentrated hydrochloric acid, pH meter, electric burner and beaker were all available at the Minerals Engineering Laboratory of the University of Mines and Technology (UMaT). Shimadzu UV-3600 Plus (UV-VIS-NIR) Ultraviolet Spectrophotometer (UV) was available in the Environmental Monitoring Laboratory of UMaT.

2.2 Method Employed

2.2.1 Sample Preparation and Planting of *Colocasia esculenta*

The fertile soil was air-dried to remove moisture. The dried fertile soil was screened through 4-mm screen, and 3 kg of the -4 mm product was weighed into each of the two buckets. The uprooted plants were washed to get rid of soil particles attached to the corms of the plant. The buckets were labelled A and B. Into the content of bucket A was added 10 ppm lead solution prepared by adding 30 ml of 1000-ppm lead stock solution to 2970 ml of water (Setup A). The volume of water added to the content of bucket B was 3000 ml which served as a control experiment (Setup B). The content in all Setup A and Setup B was stirred to obtain a homogeneous pulp (50% w/v). The two *Colocasia esculenta* plants were planted in Setup A and Setup B respectively. Samples weighing 50 g of soil, leaves, stem and root of the plant were collected for acid digestion prior to planting of the plants.

2.2.2 Sampling from the Planting Set-ups

A sample of the mixture of lead solution and water was taken to ascertain its concentration. Samples were taken from all two buckets and filtered immediately after planting. Other samples were taken at 24 hours, week 1, 2, 3 and, 4 respectively. All the samples were filtered and the filtrates, analysed using Shimadzu UV-3600 Ultraviolet Spectrophotometer (UV) to determine the amount of lead concentration remaining in the Setup A and Setup B at the various sampling times.

2.2.3 Acid Digestion of Solid Residue

The leaves, stem and roots from the uprooted plant were cut into pieces. Samples of the soil, stem, leaves and root of the plant (weighing 50 g each) were digested using aqua regia (3:1 of HCl and HNO_3) to ascertain the amount of Pb already existing in them before planting in pulp. Similar samples taken after the period of the experiments were also subjected to the same process. Digested solutions were allowed to cool, and then filtered. The filtrates were diluted, and samples of 100 ml each were taken for AAS analysis.

2.3 Analysis

All post-treated filtrates were analysed using UV and the results were used to calculate for lead uptake. The percentage of lead uptake was calculated using Equation 3.1;

$$\%\text{Lead Uptake} = \frac{Pb\ Conc._{initial} - Pb\ Conc._{t}}{Pb\ Conc._{initial}} \quad (1)$$

Where: Pb $Conc_{plant\ part/soil}$ = Pb concentration in the plant parts / soil; Pb $Conc_{total}$ = total Pb concentration in the plant parts and soil

The Bioconcentration Factor was calculated using Equation 2;

$$BCF = \frac{Conc._{plant\ tissue}}{Conc._{soil}} \quad (2)$$

Where: $Conc_{plant\ tissue}$ = concentration of metal in whole plant tissue in mg/kg; $Conc_{soil}$ = concentration of metal in soil in mg/kg

The translocation factor (TF) was calculated using Equation 3 (Soda *et al*., 2012);

$$TF = \frac{Conc._{pas}}{Conc._{pbs}} \quad (3)$$

Where: $Conc_{pas}$ = concentration of metal in plant parts above soil in mg/kg, $Conc._{pbs}$ = concentration of metal in plant parts below soil in mg/kg

3 Results and Discussion

This paper assessed the toxicity of lead in *Colocasia esculenta* (Cocoyam plant). *Colocasia esculenta* was planted in a 0-ppm and 10-ppm lead-contaminated soil for 4 weeks with solution samples taken at different time intervals and digested soil and plant parts filtrate analysed using Shimadzu UV-3600 Plus (UV-VIS-NIR) Ultraviolet Spectrophotometer (UV) The results obtained are discussed in the sections below.

3.1 Effect of Pb on Biomass

The plants were carefully studied during the period of the experiment to notice the effect of Pb toxicity on the growth of the plant. Plant growth was significantly affected by the Pb toxicity in Setup A, and showed a visible reduction in weight though the plant survived while Setup B showed a normal growth rate. The ability of the plant to tolerate Pb was established when about 1 to 2 leaves sprouted in a week after planting as seen in Figure 2. The plant growth rate then increased with increasing time. It was observed that the plant survived under different conditions.

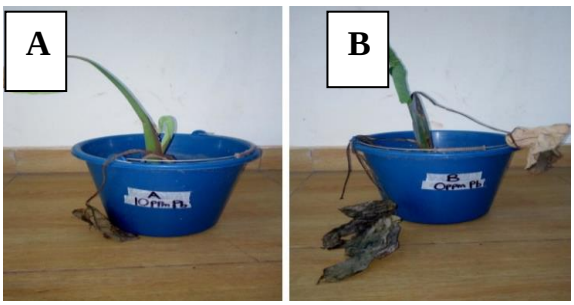

Figure 2 Sprouting of Leaves After 1-Week Growth

3.2 Lead in Water

The absorbance spectroscopy of the 10-ppm Pb solution samples over the days of experiment (Figure 3) indicated that there was a general reduction of absorbance in solution and absorbance reduced to < 0.001 proving a reduction of lead in solution. Hence, the concentration decreased from about 10 ppm to about 0 ppm after 14 days of inception of the experiment. There was no lead in the solution from day 15 till the end of the experiment even though some of the soil lead might have solubilised. This is evident that lead in solution has immobilised to either the soil or the plant.

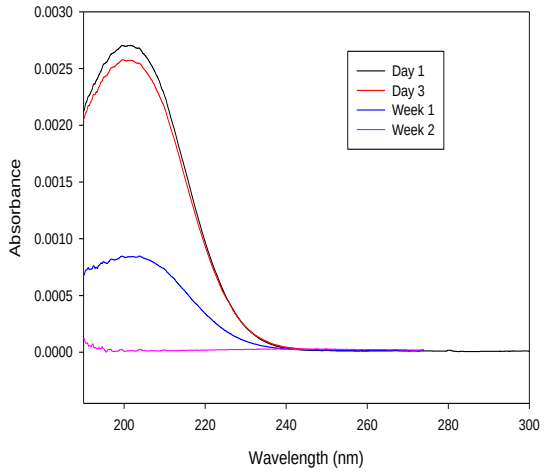

Figure 3 UV Spectra of Residual Pb in Solution Based on the Absorbance

3.3 Lead in Soil

Before setting up the experiment, 50 g of the soil was acid digested to determine the amount of lead already existing in the soil, and the results showed about 0.757 ppm Pb. Setup B showed about 0.2105 ppm of lead in the plant parts. However, there was no lead left in the soil indicating that all the lead in the soil was solubilised throughout the experiment to make it available for the plant root to absorb and translocate. This phenomenon can be due to the plant having developed certain mechanisms for solubilising heavy metals in soil with mobilising substances such as *Phytosiderophores* in the rhizosphere being secreted by the plant roots to solubilise the metal making it more bioavailable to the plant as explained by Lone *et al*. (2008). The Setup, to which about 10 ppm of lead in solution was added (Setup A) making available 10.757 ppm for sorption, had about 0.0475 ppm remaining in the soil at the end of the experiment.

3.4 Lead Uptake by Plant and Soil

The leaves, stem and roots of the plants were cut into their various sections and digested before and after the experiment and the results indicated that about 0.432 ppm, 0.663 ppm and 0.329 ppm respectively already existed before the experiment started. Figures 4 to 6 depict the percentages of soluble lead that was sorbed into each part of the plant and soil in both Setup A and Setup Brespectively as well as the percentage of lead available in each part before the experiment. It was observed both Setup A and Setup Bestablished the ability of the plant parts to sorb Pb. Setup A and Setup B had about 10.757 ppm and 0.757 ppm of available lead for sorption respectively. Of the total concentration of lead available that already existed in the plant and soil before the start of the experiment, the soil, leaves, stem and root recorded 35%, 20%, 30% and 15 % respectively as illustrated in Figure 4. This indicates that the environment that the plants were originally growing had some amount of lead already existent.

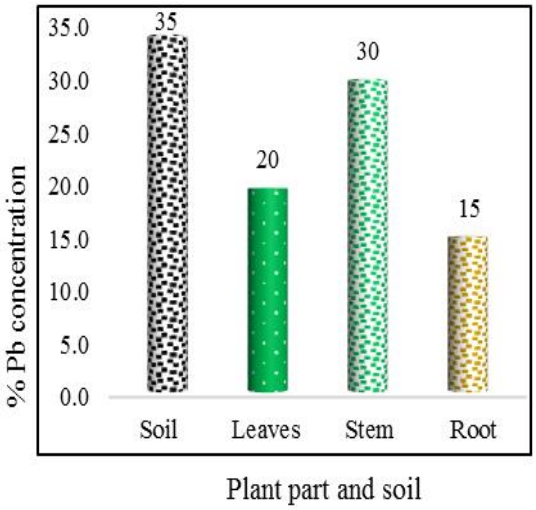

Figure 4 Percentage Pb Concentration in Plant Parts and Soil at 0 hr

Comparing the plant parts in Setup A after the experiment, the leaves had the highest percentage of lead, recording 32.78% of the total lead in the plant. The root, stem and soil followed with 27.48%, 25.18%, and 14.55% respectively as exhibited in Figure 5. However, the cumulative concentration of lead at the end of the experiment was lower than the concentration of lead at the beginning of the experiment. This can be due to phytovolatilisation; the tendency of the plant to biologically convert the elemental form of metal or pollutants into gaseous form within the plant, and transfer it into the atmosphere through transpiration (Padmavathiamma and Li, 2003).

Setup B had very low lead available for sorption with the leaves, stem and root having 41.75%, 33.21% and 25.05% respectively for the low initial concentration as shown in Figure 6.

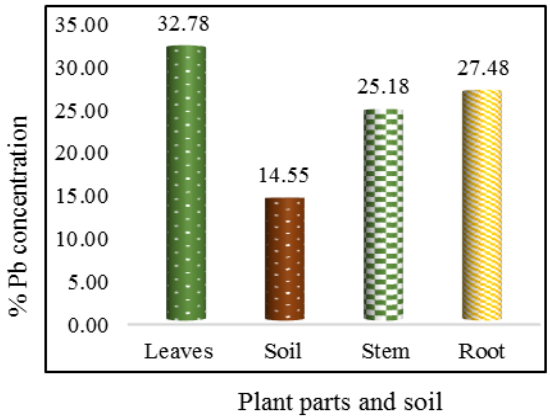

Figure 5 Percentage Pb Concentration in Plant Parts and Soil in Setup A

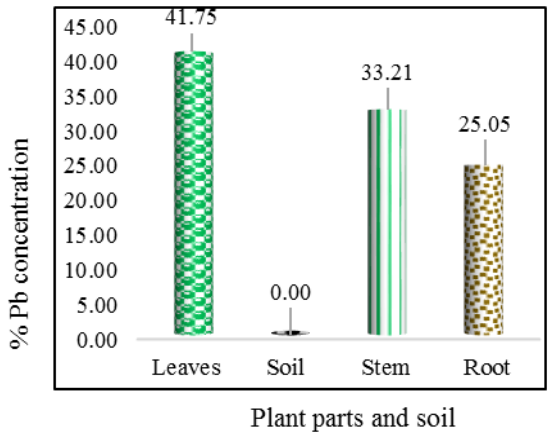

Figure 6 Percentage Pb Concentration in Plant Parts and Soil in Setup B

These trends of lead accumulation in the plant parts deviated from that of Parmar *et al*. (2012), Madera-Parra *et al*. (2015) and Islam *et al*. (2016) , in that the highest percentage of Pb2+ was recorded in the roots (Roots>> Shoot), in contrast to their findings (Shoot>> Root). This may be due to the difference in climatic changes and environmental conditions such as a change in temperature and pH that existed during the period of the experiment.

The calculated Bioconcentration Factor and Translocation Factor for Setup A were 5.87 and 2.11 respectively. The high Bioconcentration factor >> 1 indicates that the plant phytoaccumulates (Madera-Parra *et al*., 2015) and Translocation factor >> 1 indicates that the plant has high translocation capacity (Van der Ent *et al*., 2013). This confirmed the ability of the cocoyam plant to sorb Pb.

4 Conclusions

This study focused on the toxicity of lead in *Colocasia esculenta* as an edible plant. The result of these studies indicated that cocoyam plant can sorb Pb into the stem, leaves and roots from a Pb-contaminated soil. Again, it was established that cocoyam plant is prone to phytotoxicity in a Pb-contaminated environment irrespective of the concentration present in the soil.

Although the concentration of Pb in the leaves, stem and roots did not exceed the maximum permissible limit of Pb in food (3 ppm) it is not recommended to ingest Pb-containing cocoyam plants since continual intake would result in bioaccumulation as the Pb enters the body. This ascertains the fact that cocoyam plant in a Pb-contaminated area is not viable for consumption since it can be detrimental to our health.

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Authors

E. Anderson is a Graduate Trainee at Newmont Golden Ridge Limited, Akyem Mine. She holds BSc. Minerals Engineering graduate from the University of Mines and Technology, Tarkwa, Ghana. She is a Member of the Australasian Institute of Mining and Metallurgy (AuSIMM) and the Organiser (Industry) for the Ladies in Mining and Allied Professions in Ghana. Her areas of research interest include precious minerals beneficiation, phytoremediation and industrial waste management.

M. E Amosah is a Plant Metallurgical Intern at Golden Star Resources, Wassa. She holds BSc Minerals Engineering from the University of Mines and Technology, Tarkwa, Ghana. She is a fellow of the Australasian Institute of Mining and Metallurgy (AuSIMM) and Ladies in Mining and Allied Professions in Ghana. Her areas of research interest include mineral beneficiation, water quality management, bio and phyto remediation, flotation studies and environmental management.

D. A Asare is the Director for Royals Waakye, in Adenta. She holds BSc in Minerals Engineering from the University of Mines and Technology, Tarkwa, Ghana. She is a fellow of the South African Institute of Mining and Metallurgy (SAIMM). Her areas of research interest include small-scale mining, waste management, mineral beneficiation, phytoremediation and environmental management.

Grace Ofori-Sarpong is a Professor of Minerals Engineering at the University of Mines and Technology, Tarkwa. She holds PhD in Energy and Mineral Engineering from Pennsylvania State University, MSc in Environmental Resources Management and BSc in Metallurgical Engineering, both from the Kwame Nkrumah University of Science and Technology, KNUST, Kumasi, Ghana. She is a Fellow of Ghana Academy of Arts and Sciences and West African

Institute of Mining, Metallurgy and Petroleum (WAIMM). She is also a member of the Society for Mining, Metallurgy and Exploration Engineers (SME), Society of Petroleum Engineers (SPE) and the Founder and President of Ladies in Mining and Allied Professions in Ghana. Her areas of research interest include microbial-mineral interaction, artisanal and small-scale gold processing, acid mine drainage issues and precious minerals beneficiation.