

# Assessing the Toxicity of *Colocassia Esculenta* (Cocoyam Plant) Grown on Mercury Contaminated Soil\*

<sup>1</sup>D. A. Asare, <sup>2</sup>E. Anderson, <sup>3</sup>M. E. Amosah, <sup>1</sup>R. Ntiri-Bekoh and <sup>1</sup>G. Ofori-Sarpong

<sup>1</sup>University of Mines and Technology, Tarkwa, Ghana

<sup>2</sup>Newmont Golden Ridge Limited, Akyem, Ghana

<sup>3</sup>Golden Star Resources, Wassa, Ghana

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## Abstract

The unsafe disposal of heavy metals is a serious environmental problem all over the world as it has devastating effects on plant biodiversity as well as animal and human health. Contamination can be caused by effluents from industries and exposure of rocks containing metalloid or heavy metals such as arsenic (As), lead (Pb), and mercury (Hg). Several techniques have been used to clean up soil and water bodies contaminated with these heavy metals or metalloid. Phytoremediation is one of the emerging methods which has proven to be ecofriendly and efficient. Plants such as *Colocassia esculenta* have been reported to be a hyperaccumulator. However, there are concerns regarding the excessive metal uptake by the plant when grown on mercury-contaminated sites, since high Hg levels can cause toxicity in human beings. This study was thus carried out to ascertain the toxicity of *C. esculenta* plants cultivated in 10 ppm Hg-induced soil sample for four weeks. The concentration of mercury in soil, water and cocoyam samples decreased after 28 days of planting. Accumulation of Hg in plant tissues was measured, and Translocation Factor (TF) was calculated. TF was in the order of Root-Stem (0.60) > Root-Leaves (0.56) > Soil-Root (0.23). The results indicated that Cocoyam plants have an excellent ability to remove Hg from contaminated soils and further accumulate it in their tissues. With the threshold level of Hg at 0.0016 mg/kg body weight (FAO/WHO), the results obtained suggest that cocoyam plants grown in such contaminated areas may pose health threats to humans.

**Keywords:** Environmental Pollution, Mercury, Phytoremediation, *Colocassia Esculenta*, Translocation

## 1 Introduction

### 1.1 Mercury and Its Usage

Land and water are sources of livelihood for many habitats, and access to good quality water has become a challenge faced by most Ghanaian rural sectors. Contamination of soil through mercury pollution is a universal problem in the present-day world as its concentration increases unceasingly due to improved industrialisation, curative, and domestic use of mercury (Rice *et al.*, 2014).

Heavy metals needed by living organisms in minute quantities for vital growth are iron, copper, zinc, and nickel. The non-essential ones include cadmium, lead, mercury, arsenic, and chromium (Wuana and Okieimen, 2011). Mercury is a naturally-occurring chemical element found in the Earth's crust. It is well known for being the only elemental metal that is liquid at room temperature and pressure. As any other metal, mercury exist in various forms: elemental mercury, inorganic mercury compounds, and methylmercury (Tangahu *et al.*, 2011).

A significant source of mercury emissions is Artisanal and Small-scale Gold Mining (ASGM) that occurs in many developing countries according to the United States Environmental Protection Agency (EPA). ASGM industry which plays an indispensable role in serving as a source of income for rural communities, use mercury to extract gold

in their mining activities (Wilson *et al.*, 2015). Mercury is mixed with gold to form an amalgam. The amalgam is then heated, which vapourises the mercury leaving behind a coating of gold. The process of burning mercury-gold amalgam is very dangerous and may lead to significant atmospheric exposure. When mercury is not appropriately handled, it is later released into the surrounding environment causing air, land and water pollution. Estimation has shown that ASGM is the predominant source of mercury pollution with about 38% mercury release globally. ASGM also introduces about 1,220 tonnes of mercury into land and water bodies, and hence, ASGM is the largest source of pollution to the air and water bodies (Anon, 2019b). Soils and water bodies contaminated with mercury transfer these pollutants through the food chain resulting in long-term health effect on the consumer. Because ASGM miners lack ore mining and processing skills, mercury loss on site occurs during amalgamation, due also to their inability to manage runoff and waste disposal (Esdaile and Chalker, 2018). When mercury is released into sediments and soil, their chemical state change from inorganic mercury to methylmercury, which is the most dangerous form of mercury compound for the ecosystem and human health (Anon, 2021).

### 1.2 Toxicity of Mercury (Hg)

Mercury in the environment is continually cycled and recycled through a biogeochemical series. These

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result in the release of various forms of mercury into soil and water bodies, posing severe health risks to plants, humans, animals, and aquatic biota (Wuana and Okieimen, 2011). The effect of mercury after emission depends on the form, emission source, concentration, surrounding environment and the weather. Subject to these factors, mercury in the atmosphere can be transported over distances before deposited in soil or water (Anon, 2021). Mercury of all forms is dangerous and toxic. The United States Environmental Protection Agency (Anon, 2019a) estimates that more than 300,000 infants per year are at risk of increased learning incapacities due to exposure to methylmercury. According to the United States EPA, most people in the world have trace amounts of methylmercury in their bodies, reflecting its prevalence in the environment (Anon, 2020). Personal mercury contact occurs through inhalation of elemental mercury vapour via occupational and dental amalgam exposure or ingestion of mercury compound, primarily from seafood, and to a less significant extent, through the skin (Anon, 2009).

Toxicity in humans varies with the form of mercury, the dose, and the rate of exposure. Inhaled elemental mercury vapor is readily absorbed through mucous membranes and the lung, and quickly oxidised to other forms. The target organ for inhaled mercury vapor is primarily the brain. Mercury salts damage the gut lining and kidney, while the distribution of methyl mercury occurs throughout the body. Significant acute exposures to elemental mercury vapor induce severe pneumonitis, which can be fatal in extreme cases (Anon, 2009; Bernhoft, 2012; Hong *et al.*, 2012; Ali *et al.*, 2013). Hg toxicity to plant includes disturbances in the antioxidative system, photosynthetic system, inhibition of plant growth and yield production, and nutrient uptake and homeostasis (Kumar *et al.*, 2013).

### 1.3 Removal of Mercury and Phytoremediation

Due to concerns raised on ecological threats caused by mercury, an intensive discovery of new research works on how to eradicate the use of mercury and reduce the amount of mercury production have been suggested and implemented for continuous sustainability (Al-Hassan and Kuma, 2010; UN Environmental Programme, 2012; Minamata Convention, 2013). In order to maintain good quality of soil and water bodies, different approaches, such as mechanical separation and physiochemical means have been introduced to clean up contaminated areas (Wuana and Okieimen, 2011). Generally, the physiochemical methods suffer from limitations like high cost, technical complexity, intensive labour and environmental concerns if the pollutants are in high concentrations

(Ensley, 2000). However, advances in science and technology have increased the potential of biological diversity for the decontamination of heavy metal-polluted soils termed as Bioremediation (Donkor, 2016).

Phytoremediation is an aspect of bioremediation, that uses plants and related soil microbes to reduce the toxic effect of contaminants. This method is clean, simple, cost-effective, and, most importantly, an emerging field in environmental biotechnology (Yan *et al.*, 2020). As it functions to decontaminate soils and water, there are several categories of phytoremediation, including, phytoextraction, phytofiltration, phytostabilisation, phytovolatilisation and phytodegradation (Tangahu *et al.*, 2011).

Phytoremediation is useful because natural plants can bioaccumulate toxins in their above-ground parts. Records indicate various types of plant species to be hyper-accumulators, which gives them the aptitude to accumulate a remarkably high concentration of heavy metals (Barman *et al.* 2000). A study done by some researchers showed that plant species; *Mimosa pudica*, *Amaranthus retroflexus*, *Petris vital*, *Dicranopteris linearis*, *Jatropha curcas* and *Ocimum gratissimum* can be used as hyperaccumulators to remediate soils contaminated with zinc, cadmium, mercury, iron, lead, manganese, copper, nickel, cadmium, chromium, and cobalt (Chaiyarat *et al.*, 2011; Khoramnejadian and Saeb, 2015; Marrugo-Negrete *et al.*, 2015; Donkor, 2016). Some plants reduce the toxicity of inorganic contaminants in the environment through volatilisation. Recent work shows the use of *Arabidopsis thaliana* and a bacterial mercuric ion reductive enzyme for mercury removal (Sasi, 2011). Here, the plant absorbs the mercury and reduces it to a less toxic form by the enzyme's action and further volatilise it into the atmosphere. The above mentioned studies have indicated the use of good accumulators through phytoremediation technology is an alternative solution to remove heavy metals from contaminated areas. Effective phytoextraction of metal contaminated soils depends on the type and state of metal, condition of the land, properties of medium, root zone and the plant species (Yan *et al.*, 2020).

### 1.4 *Colocasia Esculenta*

*Colocasia esculenta* (taro) is an ancient vegetative root crop grown in tropical areas. It is widely cultivated and belongs to Araceae plant family, having its origin from South-east Asia and spreading across Africa, West Indies, and South America (Rashmi *et al.*, 2018). *Colocasia esculenta* has numerous adaptations that support its growth, and because of its fast-growing invasiveness, it is considered a weed (Anon, 2019b). Taro tubers are

grown all through Ghana for its palatable corms and nutritious leaves as it grows even under harsh natural environmental conditions. Taro is locally referred to in the Ghanaian Akan tongue as “mankeni”, and it nurtures with an irregular shaped corm, lying below the surface of the soil. It has heart-shaped green leaves upward, together with long petioles, downward growth of fibrous roots, while the daughter corms and runners grow laterally as depicted in Fig. 1.



**Fig. 1** *Colocasia Esculenta* (Cocoyam Plant)

The taro leaves as locally known in Ghana as “nkantomire” is rich in minerals like calcium, phosphorus, iron, fibers, starch, vitamin A, B, C and protein content of about 23%. Roots and tubers of this plant serve as food for humans and provide energy in the form of carbohydrates (Pawar *et al.*, 2018). Reports by Food and Agriculture Organisation (FAO) prove that carbohydrate and protein content in cocoyam are higher than other root crops like yam, cassava, or sweet potato (Adeyanju *et al.*, 2019). The benefits of cocoyam include; cancer prevention, reduction in symptoms of arthritis, regulation of cholesterol levels and blood pressure, and boosting of the immune system. Cocoyam also maintains digestive health, reduces muscle cramps, boosts vision (sight), prevents diabetes and hydrates the skin (Adeyanju *et al.*, 2019). This makes it one of the most sought-after plants in Ghana. Aside from *C. esculenta* providing food and energy for man, Table 1 shows some healing and pharmaceutical purposes of cocoyam plant extract.

**Table 1** Summary of Medicinal Uses of *C. Esculenta*

Plant Part	Purpose
Leaves	Applied over scorpion sting or snake bite and also used in food poisoning. Used for anti-depressant, anxiolytic, sedative, and smooth muscle relaxant activity
Corm	Used as an antifungal and treatment of body ache, Applied over stings of wasps and other insects.
Stalks	An absorbent in cases of inflamed glands and prevention of excessive secretion of phlegm in asthmatic individuals.

### 1.5 Motivation for this Research

Several studies have shown positive results on the use of *C. esculenta* plant for the phytoremediation of soil and aquaculture wastewaters containing cadmium, zinc, mercury, lead, and arsenic (Chayapan *et al.*, 2015; Ponnanna *et al.*, 2016; Ang *et al.*, 2017). However, as presented in the preceding Section, *C. esculenta* grows widely in Ghana, and it is mainly cultivated for its nutritious leaves and starchy corms (which are boiled, fried, or roasted); while its leaves are used to prepare stew or soup. They provide essential nutrients and health benefits for humans; thus, they are present in most Ghanaian dishes. There are therefore ethical questions with respect to its use as a phytosorbent since it is a good source of food and medicine. This present study thus sets out to investigate the toxicity of *Colocasia esculenta* as a phytosorbent when grown in mercury-contaminated soils.

## 2 Resources and Methods Used

### 2.1 Materials and Equipment Used

Dried soil samples, weighing 8 kg by mass were collected at the Kamponase area, Tarkwa, Ghana. Two *Colocasia esculenta* (cocoyam) plants of similar sizes were uprooted from a deserted refuse damp site. Plastic buckets (with volume of about 6 L) for planting and sampling bottles were also acquired at the Tarkwa Nsuaem Municipal Market, Ghana. Concentrated mercury solution (1000 ppm), deionised water, nitric acid, hydrochloric acid, electric hot plate, 4-mm test sieve and electronic mass balance were obtained from the Minerals Engineering laboratory of the University of Mines and Technology, Tarkwa, Ghana.

### 2.2 Methods Employed

The experimental work was carried out in the Minerals laboratory, University of Mines and

Technology, (UMaT), Tarkwa, Ghana. The work was characterised into sample preparation, growth of *C. esculenta*, and acid digestion of solid residue. Parameters used in the experimental work were time and Hg concentrations in the soil and various parts of *C. esculenta*.

### 2.2.1 Sample Preparation

Plant samples were washed with deionised water to remove surface soil. A total sample of 7 kg soil was sun-dried, riffled, and divided. An electronic mass balance was used to weigh the sample into two different 3-kg samples, and placed in a bucket. Plastic buckets were considered for planting to avoid any leakage. A pulp density of 50% solids was prepared for both setups. Table 2 shows the initial mercury content in the cocoyam plant and soil samples that were analysed before the addition of mercury solution for the setup. A 10 ppm mercury solution in 3-L deionised water was added to one bucket and labelled as 10-M. For the control setup, no mercury was added, only 3 L of deionised water was used and labelled as 0-M.

**Table 2 Initial Hg Concentration in the Soil and Cocoyam Plants Before the Study**

Samples	Before (mg/l)
Soil	0.2251
Leaves	0.0652
Stem	0.0523
Root	0.0421

### 2.2.2 Growth of *Colocasia esculenta* (Cocoyam)

Cocoyam plants were cultivated in both setups for a month. Liquid samples of each setup were taken daily, followed by weekly sampling. Irrigation was done every week. In each setup, sampling was done by filtering the solution around the plant in the bucket, and the filtrate was sent for Hg analysis. The sampling points selected for the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis are presented in Table 3.

**Table 3 Summary of Solution Samples Collected at Time Interval for Hg analysis**

Time	Sample Type
Day 1	Solution
Day 2	Solution
Day 3	Solution
Day 4	Solution
Day 5	Solution
Day 6	Solution
Week 1	Solution
Week 3	Solution
Week 4	Solution

### 2.2.3 Preparation of Soil and Plant Extract for Hg Analysis

The concentration of mercury left in the soil samples and plant tissues (root, leaves, and stem), were also analysed using ICP-MS. The final harvested tissues of the cocoyam plant and residual soils were dried and digested in conical flasks. Respective amounts of 75 ml and 25 ml of nitric acid, and hydrochloric acid were added. Each mixture was heated for 10 minutes using an electric hot plate and allowed to cool. After cooling, the filtrate was taken for mercury analysis using NexION 2000 ICP-MS at Crystal Scientifics Laboratory, Tarkwa, Ghana. Table 4 shows summary of samples selected after the cultivation of the cocoyam plant for Acid-Digestion.

**Table 4 Summary of Acid Digested Samples**

At the End of the Experiment (4 <sup>th</sup> week of planting)	
10-M	0-M
Soil	Soil
Leaves	Leaves
Stem	Stem
Root	Root

### 2.3 Calculation of Translocation Factor and Average Hg Recovery

The analysis of Hg content was done before, during and after the experiment. The results obtained from the ICP-MS were analysed using Equation 1, where Translocation Factor was calculated. The average amount of mercury in the 10 ppm setup was also calculated using Equation 2. The resulting value was compared to the World Health Organisation (WHO) permissible level of Hg in foods and drinking water.

Translocation Factor (TF) =

$$\frac{\text{Concentration of Hg in plant tissue (parts)}}{\text{Concentration of Hg in corresponding soil or root}} \quad (1)$$

Average Mercury in 10 ppm setup =

$$\frac{\text{Hg concentration in various plant tissues}}{\text{Total Number of plant parts (3)}} \quad (2)$$

## 3 Results and Discussion

This research sought to determine mercury toxicity in *Colocassia Esculenta* (Cocoyam plant), which is edible plant consumed widely in Ghana. The plant's level of mercury (Hg) absorption was examined for 4 weeks, and mercury concentrations were measured by ICP-MS. The results obtained are discussed in the Sections following.

### 3.1 Visible Analysis of the Plants

As seen from Fig. 2, the cocoyam plants looked very fresh and green just as they were uprooted. However, after 5 days of planting (Fig. 3), both plants showed dry leaves, and were now adapting to the new environment; hence fresh leaf was observed shooting out. After the second week of the experiment (Fig. 4), it was observed that both plants showed full emergence of fresh leaves as they had completely adapted to the new environment, and the old leaves died. By the end of the month of planting (Fig. 5), plants in both setups grew perfectly without showing any negative signs in germination and flowering during the study period.



Fig. 2 Day 1 of the Experiment



Fig. 3 Day 5 of Planting



Fig. 4 2nd Week of Planting



Fig. 5 One Month of Planting

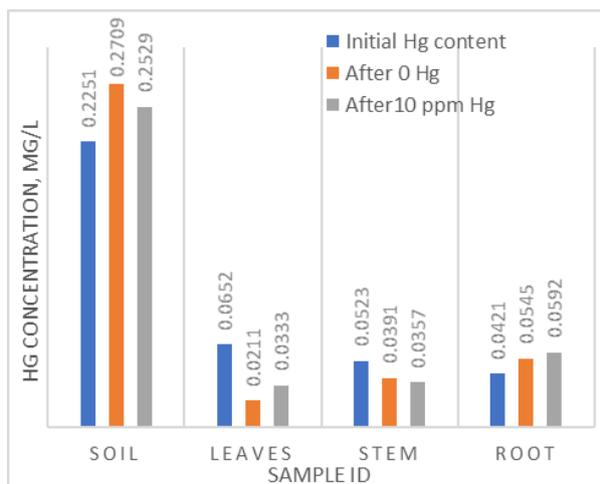
### 3.3 Uptake of Hg by the Cocoyam Plants

Table 4 displays results of Hg accumulation results in soil and plant tissues after the cultivation of *Colocasia esculenta* (cocoyam plant). The result shows that *Colocasia esculenta* is a mercury hyperaccumulator and does not show significant symptoms of phytotoxicity during the growth period. Recent study by Chayapan *et al.* (2015) indicated that, this plant could be considered a good Zn hyperaccumulator because it could concentrate in its above-ground parts with Translocation Factor > 1. Comparing *C. esculenta* with other plants, it was only *C. esculenta* that was suitable enough for the phytoremediation of aquaculture wastewater, due to its ability to accumulate and significantly reduce the concentrations of cadmium, phosphorus, and iron (Ang *et al.*, 2017).

Table 4 Concentration of Hg in Samples of Cocoyam Plants and Soil After the Study

Samples	After 0-M Hg (mg/l)	After 10-M Hg (mg/l)
Soil	0.2709	0.2529
Leaves	0.0211	0.0333
Stem	0.0391	0.0357
Root	0.0545	0.0592

Mercury was shown to be concentrated in the leaves of the plant at 0.0652 ppm before the experiment as indicated in Table 2. However, after the study, the roots of both setups had higher mercury levels in all samples compared with other areas of the plants as shown in Table 4. Fig. 6 shows mercury sorbed by soil and various plant tissues before and after the experimental setup. The results from Fig. 6 shows that the soil had a considerable amount of Hg of 0.2251 ppm before the start of the experiment. The leaves, stem and root showed 0.0652 ppm, 0.0523 ppm and 0.0421 ppm of Hg respectively at the start of the experiment. At the end of the experiment, the setup with 0-Hg solution showed an increase in Hg concentrations in the soil, stem and roots at 0.2709 ppm, 0.0391 ppm and 0.0545 ppm respectively but showed a decrease in Hg concentration of the leaves at 0.0211 ppm.



**Fig. 6 Column Distribution of Hg Concentrations in Soil and Plant Parts Analysed Before and After the Study**

According to Tangahu *et al.* (2011), phytovolatilization and transpiration is the release of a contaminant from leaves to the atmosphere as growing plants take up water along with the contaminant. The analysis shows reduction of mercury in the leaves by transpiration stream; a process that occurs as the water along with Hg compounds gets volatilised into the atmosphere at low concentrations. The atmosphere to which the leaf is exposed drives transpiration and it creates negative pressure (tension) at the leaf surface (Anon, 2013).

A similar observation was made in the 10 ppm Hg setup as compared to the initial concentrations where there was an increase in Hg concentration in the soil, stem and roots with values of 0.2529 ppm, 0.0357 ppm, and 0.0592 ppm respectively, while the leaves had 0.0333 ppm, indicating a decrease. About 98 percent of the water taken up by roots may be lost through transpiration (Petruzzello, 2020). It is no wonder that mercury loss occurred greatest in the leaves for both setups.

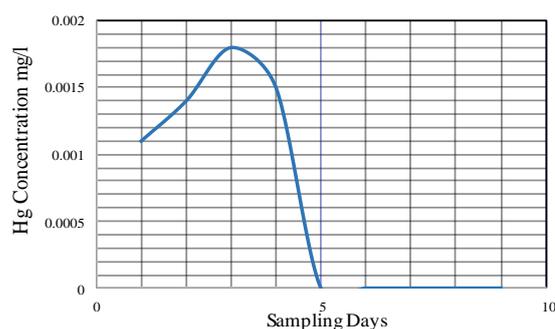
Hg compounds that may not be volatilised get stored in the cells of leaves. However, food prepared by plant leaves along with these compounds are transported by phloem cells to other plant parts, through a translocation process. An increase in the total water potential and turgor pressure in the phloem tissues drives the movement of substances, including the Hg compounds from the leaves downwards to other plant parts and an eventual deposition in the soil (Anon, 2013). This could explain the increase of mercury in the stem, roots, and soil samples of both setups.

### 3.4 The Reduction of Hg in the Solution

Table 5 shows the results of liquid samples that were analysed using ICP-MS. Fig. 7 also shows the reduction of mercury from the solution as the days went by. It can be deduced from the figure that, there was a reduction to 0.011 ppm after the first day, increased to 0.014 ppm on the second day and peaked at 0.018 ppm after the third day. On the fourth day, the concentration of Hg in solution decreased to 0.015 ppm, and then reduced drastically to 0 ppm after the fifth day. No traces of mercury were observed in the solutions after the fifth day to the end of the experiment. After the plant had fully adapted to the new environment, original leaves withered and fell off as new leaves were seen to have sprouted out. Although the concentrations were not varied nor the period extended, it could be deduced that, as the days went by, the roots picked up mercury from the soil and transported it to its various parts and thereby reducing the mercury concentration in the solution to 0.

**Table 5 Mercury Results of Liquid Samples Taken**

Sample ID	Results (mg/l)
D1	0.0011
D2	0.0014
D3	0.0018
D4	0.0015
D5	<0.00014
D6	<0.00014
W1	<0.00014
W3	<0.00014
W4	<0.00014



**Fig. 7 Reduction of Mercury in Solution Samples**

### 3.5 The Translocation Factor (TF)

The translocation factor (TF), also known as the shoot-root quotient, describes a plant's ability to translocate a metal from soil to root or its roots to the upper parts of a plant (Ramkrishna *et al.*, 2015). The mercury that was sorbed by roots in soils was distributed across the cell membrane of the shoot

and leaves. The calculated TF values are shown in Table 4.

**Table 4 Translocation Factor of Mercury in *Colocasia esculenta***

Sample ID	TF Soil to Root	TF Root to Stem	TF Root to Leaves
0 Mercury	0.20	0.72	0.39
10 ppm Mercury	0.23	0.60	0.56

Mercury is toxic to plants depending on the level of contamination; however, the cocoyam plant could accumulate it without showing obvious negative effects on its growth and flowering. In the 0-Hg setup, TF of the metal from soil to root right through to the leaves was found to be in the order: Root-Stem (0.72) > Root-Leaves (0.39) > Soil-Root (0.20), while in that of the mercury-contaminated soil, TF was found in the sequence of Root-Stem (0.60) > Root-Leaves (0.56) > Soil-Root (0.23). It was also deduced from the table that, TF from Root to Stem had the highest affinity for mercury in both setups. The TFs observed indicate the bioavailability of mercury in soil and the fact that *C. esculenta* can accumulate and deposit mercury from the soil to its upper plant parts. It is, however, imperative to note that mercury found in food has the potential to cause severe health complications to the consumer. It is for this reason that the Joint FAO/WHO Expert Committee on Food Additives (JECFA) has provided an ambient standard (Tolerable Weekly Intake (TWI) of mercury in the total diet of an individual) to be 1.6 µg/kg body weight to regulate the consumption of foods contaminated with mercury (Kim *et al.*, 2012). The average amount of mercury calculated in the 10-ppm cocoyam plant being 0.0427 ppm (42.7 µg/kg body weight) is greater than the standard value of 1.6 µg/kg body weight, and that suggests a high toxicity of the plant used in this study.

#### 4 Conclusions and Recommendations

In this paper, the toxicity of *Colocasia esculenta* (cocoyam) plants grown on mercury-contaminated soil has been examined. According to the results, cocoyam plant is a hyperaccumulator for Hg. TF was calculated and showed higher accumulation of Hg in the stem than all other plant tissues. The amount of Hg in solution decreased after the cultivation of *Colocasia esculenta*, indicating that mercury translocates from soils to roots of plants and further stores in the above plant parts.

It was established that cocoyam plant is prone to phytotoxicity in mercury-contaminated environment and exposes consumers to numerous health threats. The present findings contribute to

environmental awareness as it questions the consumption of *C. esculenta* (cocoyam plant) after phytoremediation and recommends that measures be put in place to ensure the safety of living organisms where this plant is grown and used for phytoremediation.

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## Authors



**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.



**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.



**R. Ntiri-Bekoh** is currently reading MSc in Engineering Management at the University of Mines and Technology, (UMaT) Tarkwa, Ghana. He holds a BSc in Minerals Engineering from UMaT. His research interest include mineral processing, extractive metallurgy and phytoremediation.



**G. 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, environmental biohydrometallurgy, acid mine drainage issues and precious minerals beneficiation.