Phytoextraction Efficiency of Cadmium and Zinc by Arum (Colocasia esculenta L.) Grown in Hydroponics

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Cadmium (Cd) and Zinc (Zn) tolerance and phytoextraction efficiency of arum (Colocasia esculenta L.) were investigated in hydroponics. Plants were grown for 60 d in nutrient solution after addition of Cd and Zn at the levels of 0, 15, 30 and 60 μmol L⁻¹ and 0, 100, 500 and 1,000 μmol L⁻¹, respectively. Growth of arum was unaffected by low levels of metal concentration (15 μmol L⁻¹ Cd and 100 μmol L⁻¹ Zn) whereas it decreased gradually with the increase of metal concentration in solution. Concentration of metals in parts of arum increased significantly (P < 0.05) with the levels of metals in growth media. In arum shoots, Cd and Zn concentrations were 713 and 10,120 mg kg⁻¹, respectively, at their low levels in solution. These concentrations (15 μmol L⁻¹ Cd and 100 μmol L⁻¹ Zn) did not cause any growth retardation indicating that arum is a metal hyperaccumulator. Transfer factor (TF) greater than one confirmed the hyperaccumulating behavior of arum for Cd and Zn in solution. Cadmium and Zn uptake in arum shoots without growth retardation and TF of these metals in arum indicates that this plant is a suitable candidate for the phytoremediation of water contaminated with Cd and Zn.

Keywords: contamination, hyperaccumulator, metal, toxicity, water

INTRODUCTION

Heavy metals reach soils through natural pedogenic (or geogenic) processes and anthropogenic activities. Often the concentrations of heavy metals released into the soil system by pedogenic processes are low and are largely related to the origin and nature of the parent material. However, anthropogenic activities primarily associated with industrial processes, manufacturing and the disposal of domestic and industrial waste materials are the major sources of metal enrichment in soils (Adriano, 2001). Unlike pedogenic input, metals added through anthropogenic activities often have high bioavailability. Metal uptake and accumulation from soils by plants are influenced by such factors as plant species, soil metal concentration, soil properties, rapid transport within the plant, the proliferation of roots in metal hotspots within the soil etc. (Adriano, 2001). Among the heavy metals, cadmium (Cd) is non-essential to biota, more mobile and bioavailable, potentially toxic to humans at lower concentrations than those toxic to plants (Kabata-Pendias and Pendias, 1992; Singh and McLaughlin, 1999). Zinc (Zn) is essential in trace amounts for plants but its concentrations found in contaminated soils frequently exceed those required by the plant and soil organisms, and thus create danger to animal and human health (Greenland and Hayes, 1981; Alkorta et al., 2004). Cd and Zn concentrations in some industrial sites of Bangladesh are found to range from 0.1–1.8 and 53–477 mg kg⁻¹, respectively (Kashem and Singh, 1999) which are above the background level for Cd (0.01–0.2) and Zn (68 mg kg⁻¹) in soil (Domingo and Kyuma, 1983; Singh and Steinnes, 1994). However, the concentrations of Cd and Zn in vegetables grown in agricultural soils adjacent to the industrial areas of Bangladesh were observed in the range of 1.0–4.7 and 16.5–67.1 mg kg⁻¹ dry weight, respectively by Ahmad and Goni (2010) and 0.4–0.8 and 98–244 mg kg⁻¹ dry weight, respectively by Kashem and Singh (1999). These values exceed the acceptable tolerance level for FAO/WHO standard of 0.3 mg Cd kg⁻¹ dry weight and 60 mg Zn kg⁻¹ dry weight (Codex Alimentarius Commission, 1984).

It is therefore, important to develop methods to cleanup Cd and Zn contaminated soils. Phytoremediation, where hyperaccumulators are used to take up large quantities of pollutants from contaminated soils has been touted as a promising alternative for the generally expensive and disruptive conventional remediation techniques to reduce environmental health risks posed by Cd and Zn contaminated sites (McGrath et al., 2002). To date, about 700 species of plants have been reported to be hyperaccumulators of different contaminants (Xi et al., 2010), of which a good number of species have been considered as Cd and Zn hyperaccumulators (Raskin and Ensley, 2000). However, successful phytoextraction requires that these plants are capable of producing high biomass while accumulating large amounts of contaminants in the biomass from the soil (Liu et al., 2015). In the present investigation, we select a common and locally popular plant species arum (Colocasia esculenta L.). This plant is widely distributed in Bangladesh and can grow in both dry and marshy conditions. It has deep roots and long shoots. It possesses the...
characters of high biomass, easy cultivation, extensive competitive ability and strong resistance to environmental stresses. There are several studies that have demonstrated the metal tolerance and phytoextraction efficiency of arum (*C. esculenta*, *C. antiquorum*) and other plant species to various heavy metals such as Cd, Zn, Pb etc. (Yanqu et al., 2005; Kashem et al., 2008; Castiglione et al., 2009; Wang et al., 2009; Kashem et al., 2010; Kim et al., 2011; 2013; Kashem et al., 2013; Chayapan et al., 2015a; 2015b; Madera-Parra et al., 2015; Nahar and Alam, 2015; Islam et al., 2016a; 2016b). Chayapan et al. (2015b) investigated phytoremediation potential of Cd and Zn by wetland plants, *C. esculenta*, *Schott.* , *Cyperus malaccensis* Lam. and *Typha angustifolia* L., grown in hydroponics. They reported that all the three plants were Cd hyperaccumulator while only *C. esculenta* was Zn hyperaccumulator. Kashem et al. (2008; 2013) conducted both hydroponics and soil experiment in Japan with a different arum species (*C. antiquorum*) and found that this plant had strong tolerance to Cd in the nutrient solution and soil culture and strong accumulation capability of Cd in its body. Madera-Parra et al. (2015) assessed the accumulation of Cd (II), Hg (II), Cr (VI) and Pb (II) in *Gynnerium sagittatum*, *C. esculenta* and *Heliconia psittacorum* planted in constructed wetlands treating synthetic landfill leachate. They concluded that the evaluated plants demonstrate their suitability for phytoremediation of landfill leachate and all of them can be categorized as metals accumulators. Mechanisms of heavy metals tolerance and accumulation in plants were investigated by several researchers (Zhigang et al., 2006; Kim et al., 2011; 2013; Ken et al., 2012). Metallothioneins (MTs) and MT-like proteins have been found in various plant species including *C. esculenta*. Metallothioneins appear to play important roles in maintaining the homeoeostasis of essential transition metals, detoxifying toxic metals through binding, and sequestering excess amounts of both essential and nonessential heavy metal ions (Kim et al., 2013). Kim et al. (2011) reported that MT-like gene, CeMT2b isolated from *C. esculenta* increased Cd and Zn tolerance in *Escherichia coli* and tobacco plants during Cd stress where CeMT2b functions as an efficient Cd binding chelator. Kim et al. (2013) isolated another MT-like gene, pCeMT, and reported that overexpression of the pCeMT gene not only imparted enhanced Cd, Cu, and Zn tolerance but also increased Cd, Cu, and Zn accumulation in *E. coli* and tobacco plant through homoeostasis of essential metals such as Cu and Zn and detoxification of toxic metals such as Cd by metal binding. In our previous hydroponics and soil study, it was shown that *C. esculenta* L. had strong tolerance to Pb in the nutrient solution and soil culture and strong accumulation capabilities of this metal in its body (Islam et al., 2016a; 2016b). Hydroponics provides potential to examine metal tolerance and magnitude of metal accumulation in plant species with greater precision than soil studies (Gruppen et al., 2006). In the present paper, Cd and Zn tolerance and phytoextraction efficiency of arum grown in nutrient solution containing different levels of Cd and Zn were studied.

### MATERIALS AND METHODS

The experiment was carried out in the net house of the Department of Soil Science of the University of Chittagong, Bangladesh in autumn under natural light conditions (27–28°C, 12/12 h light/dark cycle, 70% relative humidity). Healthy and uniform size plantlets of arum (*Colocasia esculenta* L.) (approximately 5–6 cm in height, 1–1.5 cm in diameter. 2 leaves/plantlet) with well formed root system were collected from the agricultural field near the University of Chittagong Campus. The plantlets were tightly set in the holes in the central position of plastic covers using foam and were placed above the 15-L plastic pots containing 10-L half-strength nutrient solution. The composition of half-strength modified Hoagland and Arnon (1950) nutrient solution (standard solution) was: 3.0 mmol L⁻¹ KNO₃; 2.0 mmol L⁻¹ Ca(NO₃)₂; 0.5 mmol L⁻¹ NH₄H₂PO₄; 1.0 mmol L⁻¹ MgSO₄; 10 mmol L⁻¹ Fe-EDTA; 1.5 mmol L⁻¹ H₃BO₃; 0.25 mmol L⁻¹ MnSO₄; 0.1 mmol L⁻¹ CuSO₄; 0.2 µmol L⁻¹ ZnSO₄; and 0.025 µmol L⁻¹ H₃MoO₄. Two weeks after transplanting, Cd at the levels of 0, 15, 30 and 60 µmol L⁻¹ as 3CdSO₄.8H₂O (ACS Grade, Sigma-Aldrich Co., Ltd., USA) and Zn at the levels of 0, 100, 500 and 1,000 µmol L⁻¹ as ZnSO₄.7H₂O (ACS Grade, Sigma-Aldrich Co.) were separately added to the half-strength nutrient solution. There were three replicates of each treatment and each replicate consisted of one plantlet. The level of the solution was maintained by adding deionized water and renewing once every 7 d. The pH level of the solutions was adjusted to 5.5 daily either with 1 M NaOH or 1 M HCl using a digital pH meter. Plants were harvested 60 d after addition of metals in nutrient solution. Plants were then washed with tap water and then deionized water. The fresh weight of plants was measured. Then the plants were separated into dead leaves, normal leaves, stems, rhizomes and roots. All plant parts were oven dried at 68°C for 72 h. After measuring their dry weights, the plant parts were ground using a stainless steel grinder. The plants parts were digested with HNO₃–HClO₄ (3:1) mixture. Around 0.5 g of plant samples were taken in digestion tube. Almost 20 times HNO₃ was added for each sample and was heated at 100°C continuously for 10 h on digestion block. After cooling (over night 7 h), additional 5 mL HNO₃ was added and again heated for 11 h at 140°C for 7 h. After cooling (over night 7 h), 5 mL HClO₄ was added and again heated for 11 h at 140°C. Then the digested samples were cooled and were volume in 50 mL volumetric flask and stored in 50 mL acid washed plastic bottle (Piper, 1942). Cadmium and Zn in the digests was measured using atomic absorption spectrophotometer 240 AA (Agilent Technologies, Australia). Reagent blank were used where appropriate to ensure accuracy and precision in the analysis of Cd and Zn. The transfer factor (TF) was calculated as the ratio of metal concentration in shoots to those in roots of plant (Baker et al., 1994). The TF of Cd and Zn was measured by dividing the concentration of each of these metals in shoots to those in roots of arum grown in nutrient solution. All results are presented on dry weight.
Zn concentration in the nutrient solution increased from mal leaves, stems, rhizomes and roots, respectively when the corresponding values at the highest Cd application rate (15 μmol L⁻¹) in normal leaves, stems, rhizomes and roots, respectively and the Cd application rates applied in nutrient solution. At the lowest rate of Cd application (15 μmol L⁻¹) significant (P < 0.05) increase in Cd concentration was 1, 6, 15, 2 and 8 mg plant⁻¹ in the dead leaves, normal leaves, stems, rhizomes and roots, respectively. Cadmium accumulations in the whole plant were 32, 50 and 106 mg plant⁻¹ at Cd levels in the solution were 15, 30 and 60 μmol L⁻¹, respectively. Cadmium accumulation in different parts of plant decreased in the order: stems > roots > normal leaves > rhizomes > dead leaves, 247 to 1,727 mg kg⁻¹ in the stems, 41 to 109 mg kg⁻¹ in the rhizomes and 500 to 1,717 mg kg⁻¹ in the roots when Cd levels in nutrient solution increased from 15 to 60 μmol L⁻¹ (Fig. 1). In the whole plant, Cd concentration was 194, 462 and 1,091 mg kg⁻¹, respectively at solution Cd levels of 15, 30 and 60 μmol L⁻¹. The corresponding increases of Zn were from 5,615 to 13,993, from 2,104 to 6,001, from 2,401 to 7,688, from 190 to 1,200 and from 4,554 to 8,856 mg kg⁻¹ in dead leaves, normal leaves, stems, rhizomes and roots, respectively when Zn concentration in the nutrient solution increased from 100 to 1,000 μmol L⁻¹ Zn (Fig. 2). In the whole plant, Zn concentration was 2,088, 3,262 and 5,905 mg kg⁻¹, respectively at Zn levels of 100, 500 and 1,000 μmol L⁻¹ in nutrient solution.

Similar to Cd concentration, the accumulation of Cd based on concentration and dry weight of plant significantly (P < 0.05) increased in different parts of plant with the Cd application rates supplied in nutrient solution. At the lowest rate of Cd application (15 μmol L⁻¹), Cd accumulation was 1, 6, 15, 2 and 8 mg plant⁻¹ in the dead leaves, normal leaves, stems, rhizomes and roots, respectively and the corresponding values at the highest Cd application rate (60 μmol L⁻¹) was 4, 19, 60, 3 and 20 mg plant⁻¹ in the dead leaves, normal leaves, stems, rhizomes and roots, respectively. Cadmium accumulations in the whole plant were 32, 50 and 106 mg plant⁻¹ at Cd levels in the solution were 15, 30 and 60 μmol L⁻¹, respectively. Cadmium accumulation in different parts of plant decreased in the order: stems > roots > normal leaves > rhizomes > dead leaves, 159 to 890 mg kg⁻¹ in the stems, 41 to 109 mg kg⁻¹ in the rhizomes and 500 to 1,717 mg kg⁻¹ in the roots when Cd levels in nutrient solution increased from 15 to 60 μmol L⁻¹ (Fig. 1). In the whole plant, Cd concentration was 194, 462 and 1,091 mg kg⁻¹, respectively at solution Cd levels of 15, 30 and 60 μmol L⁻¹. The corresponding increases of Zn were from 5,615 to 13,993, from 2,104 to 6,001, from 2,401 to 7,688, from 190 to 1,200 and from 4,554 to 8,856 mg kg⁻¹ in dead leaves, normal leaves, stems, rhizomes and roots, respectively when Zn concentration in the nutrient solution increased from 100 to 1,000 μmol L⁻¹ Zn (Fig. 2). In the whole plant, Zn concentration was 2,088, 3,262 and 5,905 mg kg⁻¹, respectively at Zn levels of 100, 500 and 1,000 μmol L⁻¹ in nutrient solution.

**RESULTS**

**Effects of Cd and Zn on plant growth**

There were no visible symptoms of toxicity in any part of arum at the lowest Cd treatment (15 μmol L⁻¹), but the morphological parameters of plant such as the plant height, plant width, number of leaves, plant fresh weight and plant dry weight were decreased significantly (P < 0.05) at the highest Cd treatments (60 μmol L⁻¹) (Table 1). The similar trends were also found with Zn treatments where no visible symptoms of toxicity of plant were found at the lowest Zn treatment (100 μmol L⁻¹) while a significant (P < 0.05) decrease in morphological parameters of plant were found at the highest Zn treatment (1,000 μmol L⁻¹) (Table 2).

**Cadmium and Zn concentrations and their accumulations in arum plant**

The concentrations of Cd and Zn in different parts of arum increased significantly (P < 0.05) with increasing their levels in the nutrient solution (Figs. 1, 2). In control treatment, concentration of Cd was not detected in any parts although a small content of Zn was found in arum roots (7 mg kg⁻¹) and shoots (leaves plus stems) (5 mg kg⁻¹) and these values were not shown in table and figure. Cadmium concentrations in plant increased from 307 to 1,582 mg kg⁻¹ in the dead leaves, 159 to 890 mg kg⁻¹ in the normal leaves, 247 to 1,727 mg kg⁻¹ in the stems, 41 to 109 mg kg⁻¹ in the rhizomes and 500 to 1,717 mg kg⁻¹ in the roots when Cd levels in nutrient solution increased from 15 to 60 μmol L⁻¹ (Fig. 1). In the whole plant, Cd concentration was 194, 462 and 1,091 mg kg⁻¹, respectively at solution Cd levels of 15, 30 and 60 μmol L⁻¹. The corresponding increases of Zn were from 5,615 to 13,993, from 2,104 to 6,001, from 2,401 to 7,688, from 190 to 1,200 and from 4,554 to 8,856 mg kg⁻¹ in dead leaves, normal leaves, stems, rhizomes and roots, respectively when Zn concentration in the nutrient solution increased from 100 to 1,000 μmol L⁻¹ Zn (Fig. 2).

### Table 1

| Treatment (μM) | Plant Height (cm) | Plant Width (cm) | Number of Leaves | Dead Leaves | Normal Leaves | Stems | Rhizomes | Roots | Total |
|---------------|------------------|------------------|------------------|------------|---------------|-------|----------|-------|-------|
| 0             | 88.0 ± 0.2       | 5.8 ± 0.1        | 5.0 ± 0.1        | 4.1 ± 0.2  | 5.0 ± 0.1     | 4.1 ± 0.2 | 5.0 ± 0.1 | 4.1 ± 0.2 | 5.0 ± 0.1 |
| 15            | 82.0 ± 0.5       | 5.3 ± 0.1        | 4.8 ± 0.1        | 4.1 ± 0.2  | 5.0 ± 0.1     | 4.1 ± 0.2 | 5.0 ± 0.1 | 4.1 ± 0.2 | 5.0 ± 0.1 |
| 60            | 70.0 ± 0.6       | 4.9 ± 0.1        | 3.8 ± 0.1        | 3.0 ± 0.1  | 2.9 ± 0.1     | 2.9 ± 0.1 | 2.9 ± 0.1 | 1.4 ± 0.1 | 4.0 ± 0.2 |

### Table 2

| Treatment (μM) | Plant Height (cm) | Plant Width (cm) | Number of Leaves | Dead Leaves | Normal Leaves | Stems | Rhizomes | Roots | Total |
|---------------|------------------|------------------|------------------|------------|---------------|-------|----------|-------|-------|
| 0             | 48.0 ± 0.2       | 3.2 ± 0.1        | 2.3 ± 0.1        | 2.0 ± 0.1  | 2.0 ± 0.1     | 2.0 ± 0.1 | 2.0 ± 0.1 | 2.0 ± 0.1 | 2.0 ± 0.1 |
| 15            | 46.0 ± 0.5       | 3.0 ± 0.1        | 2.5 ± 0.1        | 2.0 ± 0.1  | 2.0 ± 0.1     | 2.0 ± 0.1 | 2.0 ± 0.1 | 1.5 ± 0.1 | 3.0 ± 0.2 |
| 60            | 39.0 ± 0.6       | 2.8 ± 0.1        | 2.3 ± 0.1        | 1.7 ± 0.1  | 1.7 ± 0.1     | 1.7 ± 0.1 | 1.7 ± 0.1 | 1.2 ± 0.1 | 2.5 ± 0.2 |

Values represent the mean and standard error of 3 samples. Means with the same letters in each column are not significantly different at P = 0.05.
leaves (Fig. 3).

Accumulation of Zn was also significantly \( (P < 0.05) \) increased as did in case of Cd in different parts of arum plant with its application rates applied in nutrient solution. Accumulation of Zn increased from 21 to 37, 72 to 158, 139 to 291, 7 to 33 and 66 to 112 mg plant \(^{-1}\) in dead leaves, normal leaves, stems, rhizomes and roots, respectively when Zn concentration in solution rose from 100 to 1,000 \( \mu \)mol L \(^{-1}\). However, accumulation of Zn in the whole plant was 305, 385 and 631 mg plant \(^{-1}\) at Zn levels in the solution 100, 500 and 1,000 \( \mu \)mol L \(^{-1}\), respectively. Accumulations of Zn decreased in the order of stems > normal leaves > roots > dead leaves > rhizomes (Fig. 4).

**Distribution of Cd and Zn in arum plant**

Distribution of Cd and Zn (percent of the total uptake) in arum parts varied significantly \( (P < 0.05) \) among the treatments irrespective of metals (Tables 3, 4). In case of Cd, 70% and 78% of total Cd was found in the shoots at 15 and 60 \( \mu \)mol L \(^{-1}\) Cd in the solution, respectively. In the plant roots, the distribution of Cd was opposite to that found in other parts of the plant at the two rates of Cd used. At 15 \( \mu \)mol L \(^{-1}\) Cd, 24% of total Cd was found in roots, but the proportion went down to 19% at 60 \( \mu \)mol L \(^{-1}\) Cd in the nutrient solution (Table 3).

Distribution pattern of Zn in plant was similar to that of Cd in plant. However, there was no rate effect on the distribution of Zn in shoots and roots of arum plant (Table 4). In average, about 76% and 20% of the total Zn were found in the shoots and in the roots of arum irrespective of rates of Zn in the nutrient solution. On an average, translocation of Cd and Zn from roots to shoots were 74 and 76% of total Cd and Zn, respectively which indicated that major portion of metals were translocated from roots to shoots irrespective of their application rates. Among the metals, the mobility was higher for Zn while lower for Cd which had reflection on the TF values for the same metals.

The TF values ranged from 1.4 to 3.1 in the metals added treatments. In general, TF values in the two metals increased with their application rates in solution. The TF values were relatively lower in the case of Cd (1.4 to 2.4) while higher for Zn (2.2 to 3.1) (Tables 3, 4).

**DISCUSSION**

Hyperaccumulation refers to plants that can accumulate more than 100 mg kg \(^{-1}\) Cd or 10,000 mg kg \(^{-1}\) Zn in any part of their aboveground tissues (based on DW) (Baker and Brooks, 1989; Chaney et al., 1997). In addition, the other two criteria, the concentrations of Cd and Zn in shoots is 10\(^{-5}\) times more than that in plants from non-polluted areas (Cd 1 mg kg \(^{-1}\) and Zn 60 mg kg \(^{-1}\)) (FAO/WHO, 1976) and the TF > 1 (Baker and Brooks, 1989; Baker et al., 1994). In the present study *C. esculenta* L. could be considered as a Cd and Zn hyperaccumulator according to all three indicators. It showed that this plant had high Cd and Zn concentration in its shoots (Cd 713 mg kg \(^{-1}\) and Zn 10,120 mg kg \(^{-1}\)) and a TF > 1. The criterion TF > 1 was established under conditions of experiments using hydroponics, and was considered as a physiological definition by Baker and Whiting (2002). Minerals require specific transporter proteins to be exported from the root endodermis into the root xylem (Ernst, 2005; Pilon-Smits, 2005). So, plants with TF > 1 and plants with TF < 1 may possess different internal physiological and molecular
mechanisms to accumulate and tolerate metals (Baker and Whiting, 2002). Based on TF values, the strategic response of plants to heavy metals can be divided into accumulation and exclusion (Baker, 1981; Wang et al., 2009). It has been shown in several studies that Cd tolerant plants must be able to prevent the absorption of excess Cd, or detoxify the Cd after it has been absorbed (Jiang et al., 2001). Metallothioneins (MTs) and MT-like proteins have been found in various plant species including *C. esculenta*. These proteins favor the transport of metals from roots to shoots (Iqbal et al., 2015).

Several studies demonstrated the metal tolerance and phytoextraction efficiency of arum plant to various heavy metals such as Cd, Pb and Zn (Kashem et al., 2008; 2010; Kim et al., 2011; 2013; Kashem et al., 2013; Chayapan et al., 2015a; 2015b; Madera-Parra et al., 2015; Islam et al., 2016a; 2016b). Chayapan et al (2015b) reported that *C. esculenta* L. Schott, *Cyperus malaccensis* and *Typha angustifolia* could accumulate > 100 mg kg⁻¹ of Cd in their aboveground part while only *C. esculenta* L. Schott could accumulate > 10,000 mg kg⁻¹ of Zn in its aboveground part with TF < 1 for Cd and TF > 1 for Zn. Madera-Parra et al. (2015) reported that *G. sagittatum*, *C. esculenta* and *H. psittacorum* could tolerate and accumulate high heavy

![Fig. 3](image1.png)  
**Fig. 3** Cadmium accumulations in arum plant parts grown in hydroponics. Bars with the same letters within the plant parts are not significantly different from each other at *P* < 0.05.

![Fig. 4](image2.png)  
**Fig. 4** Zinc accumulations in arum plant parts grown in hydroponics. Bars with the same letters within the plant parts are not significantly different from each other at *P* < 0.05.

### Table 3  Effect of Cd application on the Cd distribution and TF of arum plant grown in hydroponics.

| Treatment Cd (μmol L⁻¹) | Cd Distribution ¹ | TF |
|-------------------------|-------------------|----|
|                         | Dead Leaves | Normal Leaves | Stems | Rhizomes | Roots |    |
| 0                       | nd          | nd            | nd    | nd       | nd    | 0  |
| 15                      | 3.4 ± 0.1a  | 18.6 ± 0.2b   | 47.6 ± 0.2b | 6.1 ± 0.1a | 24.3 ± 0.3a | 1.4 |
| 30                      | 3.5 ± 0.1a  | 20.6 ± 0.4a   | 48.6 ± 0.2b | 4.6 ± 0.1b | 22.6 ± 0.2b | 2.0 |
| 60                      | 3.3 ± 0.1a  | 17.6 ± 0.3b   | 57.3 ± 0.6a | 2.8 ± 0.1c | 19.0 ± 0.3c | 2.4 |

¹ Values represent the mean and standard error of 3 samples. Means with the same letters in each column are not significantly different at *P* < 0.05.

### Table 4  Effect of Zn application on the Zn distribution and TF of arum plant grown in hydroponics.

| Treatment Zn (μmol L⁻¹) | Zn Distribution ¹ | TF |
|-------------------------|-------------------|----|
|                         | Dead Leaves | Normal Leaves | Stems | Rhizomes | Roots |    |
| 0                       | nd          | nd            | nd    | nd       | nd    | 0  |
| 100                     | 6.8 ± 0.2a  | 23.6 ± 0.5a   | 45.9 ± 0.9a | 2.2 ± 0.0c | 21.6 ± 0.9a | 2.2 |
| 500                     | 6.4 ± 0.1a  | 24.6 ± 0.9a   | 44.7 ± 0.4a | 3.6 ± 0.2b | 20.7 ± 0.7a | 2.6 |
| 1,000                   | 5.9 ± 0.1b  | 25.0 ± 1.1a   | 46.1 ± 1.2a | 5.2 ± 0.3a | 17.8 ± 0.1b | 3.1 |

¹ Values represent the mean and standard error of 3 samples. Means with the same letters in each column are not significantly different at *P* < 0.05.
metals like Cd (II), Hg (II), Cr (VI), and Pb (II), and still showed healthy growth in constructed wetlands treating synthetic landfill leachate. Kashem et al. (2008; 2013) investigated Cd tolerance and phytoextraction efficiency of a different arum species (C. antiquorum) grown in hydroponics and soil culture and found that this plant could accumulate >100 mg kg\(^{-1}\) of Cd in its shoots in both the media. They mentioned arum as a Cd hyperaccumulator as the value >100 mg kg\(^{-1}\) is considered to be the accepted threshold value for Cd hyperaccumulator (Baker and Brooks, 1989). In our previous hydroponics and soil experiments, C. esculenta L. was exposed to 0, 50, 200 and 400 μmol L\(^{-1}\) of Pb for 60 d and 0, 300, 600 and 1,200 mg kg\(^{-1}\) of Pb for 105 d in nutrient solution and soil culture, respectively. Lead concentration in shoots of this plant found >1,000 mg kg\(^{-1}\) with TF >1 at 50 μmol L\(^{-1}\) and 1,200 mg kg\(^{-1}\) of Pb in nutrient solution, respectively. These concentrations (50 μmol L\(^{-1}\) and 1,200 mg kg\(^{-1}\) of Pb) did not cause any growth retardation which indicated that arum was a Pb hyperaccumulator plant (Islam et al., 2016a; 2016b).

There are many scientists who are always searching new plants for the purpose of phytoremediation. It showed that Kashem et al. (2010) found 26,400 mg kg\(^{-1}\) dry weight of Zn in the shoots of Arabidopsis halleri ssp. Gennifera at 1,000 μmol L\(^{-1}\) of Zn in nutrient solution. Yang et al. (2006) found Zn concentration in the shoots of the Sedum alfredii Hance about 20,000 and 29,000 mg kg\(^{-1}\) at 1,000 μmol L\(^{-1}\) and 1,600 mg kg\(^{-1}\) in the nutrient solution and soil experiments, respectively. It found that Silene viscida, Lysimachia deltoids, Picris hieracioides L. subsp. Japonica krylv and Corydalis petrophila Franck could accumulate 236, 212, 145 and 330 mg kg\(^{-1}\) of Cd, respectively while Silene viscida and Gentiana sp. and Populus alba accumulate 11,155 and 19,710 and 32,000 mg kg\(^{-1}\) of Zn, respectively from heavily polluted mining sites (Yanqun et al., 2005; Castiglione et al., 2009; Wang et al., 2009). In comparison to these, C esculenta L. can be classified as a good hyperaccumulator as this plant could accumulate 713 mg kg\(^{-1}\) of Cd and 10,120 mg kg\(^{-1}\) of Zn without growth retardation when treated with 15 and 100 μM of Cd and Zn.

It is important to select a phytoextraction plant with high metal accumulation capability and is also compatible with mechanized cultivation practice and local weather conditions. However, it is unfortunate that some of the best hyperaccumulator are relatively small in size, grow very slowly and making it difficult to harvest them mechanically and limiting the metal extraction that can be achieved (Xu et al., 2004).

In the present study C. esculenta L. with many roots can absorb and accumulate substantial amounts of Pb and it is possible to harvest the entire plant including roots. It is fast growing, easily propagated, easy to manage and capable of growing in both dry and marshy conditions. This plant appears to possess the potential to provide a novel technique for the remediation of Pb in contaminated soil and water.

**CONCLUSION**

The results of this study indicate that the growth of arum was unaffected by low application levels of Cd and Zn in nutrient solution. The concentrations of these metals found in shoot tissue and the TF of these metals in arum plant indicated that this plant has an excellent potential for Cd and Zn phytoextraction. If plant uptake under field soil conditions is similar to that observed in this experiment, then this plant could be used to decontaminate soil moderately contaminated with Cd and Zn. Future studies need to be conducted with different types of arum species in both hydroponics and soil media.

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**REFERENCES**

Adriano, D. C. 2001. Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals. Springer-Verlag, New York.

Ahmad, J. U., Goni, M. A. 2010. Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, Bangladesh. Environ. Monit. Assess. 166: 347–357.

Alkorta, I., Hernandez-Allica, J., Becerril, J. M., Amezaga, I., Albizu, I., Garbisu, C. 2004. Recent findings on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic. Rev. Environ. Sci. Biotechnol. 3: 71–90.

Baker, A. J. M., Whiting, S. N. 2002. In search of the Holy Grail II a further step in understanding metal hyperaccumulation? New Phytol. 155: 1–4.

Baker, A. J. M., McGrath, S. P., Sidoli, C. M. D., Reeves, R. D. 1994. The possibility of in situ heavy metal decontamination of polluted soils using crops of metal accumulating plants. Resour. Conserv. Recy. 11: 41–49.

Baker, A. J. M., Brooks, R. R. 1989. Terrestrial higher plants which hyperaccumulate metallic elements II a review of their distribution, ecology and phytochemistry. Biorecovery I: 81–126.

Baker, A. J. M. 1981. Accumulators and excluders II strategies in the response of plants to heavy metals. J. Plant Nutr. 3: 643–654.

Castiglione, S., Todeschini, V., Franchin, C., Torrigian, P., Gastald, D., Cicatelli, A., Rinaudo, C., Bert, G., Biondi, S., Langua, G. 2009. Clonal differences in survival capacity, copper and zinc accumulation, and correlation with leaf polyanine levels in poplar: a large-scale field trial on heavily polluted soil. Environ. Pollut. 157: 2108–2117.

Chaney, R. L., Malik, M., Li, Y. M., Brown, S. L., Brewer, E. P., Angle, J. S., Baker, A. J. M. 1997. Phytoremediation of soil metals. Curr. Opin. Biotechnol. 8: 279–284.

Chayapan, P., Kruatrachue, M., Meetam, M., Pokethitiyook, P. 2015a. Effects of amendments on growth and uptake of Cd and Zn by wetland plants, Typha angustifolia and Colocasia esculenta from Contaminated Sediments. Int. J. Phytoremediat. 17: 900–906.
PHYTOREMEDIATION OF Cd AND Zn

Chayapan, P., Krutachuee, M., Meetam, M., Pokethitiyook, P. 2015b. Phytoremediation potential of Cd and Zn by wetland plants, Colocasia esculenta L. Schott., Cyperus malaccensis Lam., and Typha angustifolia L. grown in hydroponics. J. Environ. Biol. 36: 1179–1183.

Codex Alimentarius Commission. 1984. Contaminants, Joint FAO/WHO Food standards Program (Vol. XVII, 1st ed.). Geneva: Codex Alimentarius.

Domingo, L. E., Kyuma, K. 1983. Mean and range of concentrations of selected trace elements in tropical Asian paddy soils. Soil Sci. Plant Nutr. 29: 439–452.

Ernst, W. H. O. 2005. Phytoextraction of mine wastes: options and impossibilities. Chem. Erde-Geochem. 65: 29–42.

FAO/WHO. 1976. List of maximum levels recommended for contaminants by the joint FAO/WHO codex Alimentarius Commission. 2nd series, CAC/FAL, 3: 1–8.

Greenland, D. J., Hayes, M. H. B. (Eds.) 1981. The Chemistry of Tannins. John Wiley & Sons Ltd., New York, p 593–619.

Islam, M. S., Kashem, M. A., Osman, K. T. 2016a. Phytoextraction efficiency of lead by arum (Colocasia esculenta L.) grown in hydroponics. Open J. Soil Sci. 6: 113–119.

Islam, M. S., Kashem, M. A., Osman, K. T. 2016b. Phytoextraction efficiency of lead by arum (Colocasia esculenta L.) grown in soil. Int. J. Soil Sci. 11: 130–136.

Jiang, W., Liu, D., Hou, W. 2001. Hyperaccumulation of cadmium by roots, bulbs and shoots of garlic (Allium sativum L.). Bioreasour. Technol. 76: 9–13.

Kabata-Pendias, A., Pendias, H. 1992. Trace metals in soils and plants. CRC Press, Boca Raton, Florida, p 295.

Kashem, M. A., Huq, S. M. I., Singh, B. R., Kawai, S. 2013. Cadmium tolerance and phytoextraction efficiency of Arum (Colocasia antiquorum) grown in spiked Cd contaminated soil. Int. J. Env. Prot. 3: 1–5.

Kashem, M. A., Singh, B. R., Kubota, H., Sugawara, R., Kitajima, N., Kondo, T., Kaiwa, S. 2010. Zinc tolerance and uptake by Arabidopsis halleri ssp. gemmifera grown in nutrient solution. Environ. Sci. Pollut. Res. 17: 1174–1176.

Kashem, M. A., Singh, B. R., Huq, S. M. I., Kawai, S. 2008. Cadmium phytoextraction efficiency of arum (Colocasia antiquorum), radish (Raphanus sativus L.) and water spinach (Ipomoea aquatica) grown in hydroponics. Water Air Soil Poll. 192: 273–279.

Kashem, M. A., Singh, B. R. 1999. Heavy metal contamination of soil and vegetation in the vicinity of industries in Bangladesh. Water Air Soil Poll. 115: 347–361.

Kim, Y. O., Jung, S., Kim, K., Bae, H. J. 2013. Role of pCAMT, a putative metallothionein from Colocasia esculenta, in response to metal stress. Plant Physiol. Biochem. 64: 25–32.

Kim, Y. O., Patel, D. H., Lee, D. S., Song, Y., Bae, H. J. 2011. High cadmium-binding ability of a novel Colocasia esculenta metallothionein increases cadmium tolerance in Escherichia coli and tobacco. Biosci. Biotechnol. Biochem. 75: 1912–1920.

Liu, D., Li, S., Islam, E., Chen, J., Wu, J., Ye, Z., Peng, D., Yan, W., Lu, K. 2015. Lead accumulation and tolerance of Moso bamboo (Phyllostachys pubescens) seedlings: applications of phytoremediation. J. Zhejiang Univ-Sci B. (Biomed & Biotechnol.) 16: 123–130.

Madera-Paara, C. A., Peka-Salamanca, E. J., Peka, M. R., Rousseau, D. P. L., Lens, P. N. L. 2015. Phytoremediation of Landfill Leachate with Colocasia esculenta. Gynura sagittatum and Heliconia psittacorum in Constructed Wetlands. Int. J. Phytoremediat. 17: 16–24.

McGrath, S. P., Zhao, F. J., Lombi, E. 2002. Phytoremediation of metals, metalloids and radionuclides. Adv. Agron. 75: 1–56.

Nahar, K. K., Alam, S. K. S. 2015. Physical and chemical parameters and trace metal flux in water, soil and plant samples collected from industrial effluent affected areas in and around Dhaka city. Bangladesh J. Bot. 44: 237–244.

Pilon-Smits, E. A. H. 2005. Phytoremediation. Annu. Rev. Plant Biol. 56: 15–39.

Piper, C. S. 1942. Soil and Plant Analysis. Hassell Press, Adelaide.

Raskin, I., Ensley, B. D. (Ed.). 2000. Phytoremediation of toxic metals: using plants to clean up the environment. John Wiley & Sons Ltd., New York, p 303.

Ren, Y., Liu, Y., Chen, H., Li, G., Zhan, X., Zhao, J. 2012. Type 4 metallothionein genes are involved in regulating Zn ion accumulation in late embryo and in controlling early seedling growth in Arabidopsis. Plant Cell Environ. 35: 770–789.

Singh, B. R., McLaughlin, M. J. 1999. Cadmium in soils and plants. In “Cadmium in Soils and Plant” (ed. by Mclaughlin, M. J., Singh, B. R.), Kluwer Academic, USA, p 257–267.

Singh, B. R., Steinnes, E. 1994. Soil Processes and Water Quality (ed. by Lal, R., Stewart, B. A.), Lewis publishers, Chelsea, p 233–237.

Wang, S. L., Liao, W. B., Yu, F. Q., Liao, B., Shu, W. S. 2009. Hyperaccumulation of lead, zinc, and cadmium in plants growing on a lead/zinc outcrop in Yunnan Province, China. Environ. Geol. 58: 471–476.

Xi, X. Y., Liu, M.Y., Huang, Y., Chen, Y., Zhang, Y. 2010. Response of flue-cured tobacco plants to different concentration of lead or cadmium. 4th International Conference on Bioinformatics and Biomedical Engineering (iCBBE). June, Chengdu, p 1–4.

Xu, S. G., Chen, Y. X., Reevs, R. D., Baker, A. J. M., Lin, Q., Fernando, D. R. 2004. Manganese uptake and accumulation by the hyperaccumulator plant Phytolacca acinosa Roxb. (Phytolaccaceae). Environ. Poll. 131: 393–399.

Yang, X. E., Li, T. Q., Long, X. X., Xiong, Y. H., He, Z. L., Stoffella, P. J. 2006. Dynamics of zinc uptake and accumulation in the hyperaccumulating and non-hyperaccumulating ecotypes of Sedum alfredii Hance. Plant Soil 284: 109–119.

Yanqun, Z., Yuan, L., Jianjun, T. C., Haiyan, C., Li, Q., Schvartz, C. 2005. Hyperaccumulation of Pb, Zn and Cd in herbaceous grown on lead/zinc mining area in Yunnan, China. Environ. Int. 31: 755–762.

Zhigang, A., Cuijie, L., Yuangang, Z., Yejie, D., Wachter, A., Madera-Paara, C. A., Peña-Salamanca, E. J., Peka, M. R., Rousseau, D. P. L., Lens, P. N. L. 2015. Phytoremediation of Landfill Leachate with Colocasia esculenta. Gynura sagittatum and Heliconia psittacorum in Constructed Wetlands. Int. J. Phytoremediat. 17: 16–24.

McGrath, S. P., Zhao, F. J., Lombi, E. 2002. Phytoremediation of metals, metalloids and radionuclides. Adv. Agron. 75: 1–56.