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Phytoremediation of Heavy Metal Contaminated Soil by Using Some Ornamental Plants

Adedoyin D. Adepoju[1♥], Christopher O. Adejuyigbe[2], Olatunde M. Olosunde[3], and Godwin A. Ajiboye[2]

[1]Masters of Agriculture (Environmental Soil Science), Department of Soil Science and Land Management, Federal University of Agriculture, Abeokuta, Nigeria
[2]Department of Soil Science and Land Management, Federal University of Agriculture, Abeokuta, Nigeria
[3]Department of Horticulture, Federal University of Agriculture, Abeokuta, Nigeria
♥Corresponding author email: adedoyinadepoju30@gmail.com

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Abstract. This study aims to assess the effectiveness of two different varieties of ornamental plants in remediating soil contaminated with cadmium and lead. The study was a two-cycle pot experiment with three replications arranged in a completely randomized design. The treatments include ornamental plants and contamination levels. Ornamental plants include *Solenostemon scutellarioides* (L.) Codd. var. Religious radish and Red-trailing-queen; *Codiaeum variegatum* L. var. Gold dust and Oakleaf. The concentrations were P0 (Pb at 0 mg.kg^{-1}, Cd at 0 mg.kg^{-1}), P1 (Pb at 1000 mg.kg^{-1}, Cd at 2 mg.kg^{-1}), P2 (Pb at 1500 mg.kg^{-1}, Cd at 5 mg.kg^{-1}), and P3 (Pb at 2000 mg.kg^{-1}, Cd at 10 mg.kg^{-1}). Dry matter weight (DMW), bioconcentration factor (BCF), and translocation factor (TF) were determined after harvest. The results showed that all plants' DMW of shoot > DMW of root. *Codiaeum variegatum* varieties had BCF and TF of Cd higher than that of *S. scutellarioides* varieties. Similarly, *S. scutellarioides* varieties showed higher BCF and TF of Pb; however, there is a limit to how much Pb *S. scutellarioides* varieties may absorb from the soil, as BCF of Pb decreased after 1500 mg.kg^{-1} lead contamination. The study found that the ornamental plants had high TF and low BCF values at high cadmium and lead levels, indicating their role as phytostabilizers. Among the plants studied, Oakleaf was identified as the most efficient phytostabilizer for cadmium, while Religious radish proved to be the most effective for lead.

Keywords: *Codiaeum variegatum* L.; *Solenostemon scutellarioides* (L.) Codd.; phytoremediation; heavy metals

INTRODUCTION

Heavy metals do not accumulate visibly on the soil, therefore hazardous amounts may be stored undetected. When concentrations rise or metals start leaching into underground water, soil remediation becomes essential. Nevertheless, traditional soil remediation techniques like chemical stabilization and excavation are neither economical nor ecologically friendly necessitating the use of dependable eco-friendly technologies like phytoremediation, which is a straightforward, low-effort approach that is perfect for dealing with soil pollutants (Wuana and Okieimen, 2011).

Jacob *et al*. (2018) described phytoremediation as the process of using plants to absorb, concentrate, and relocate metals from root systems to aerial parts to eliminate, confine, or render contaminants harmless. However, locating readily available remedial plants in urban areas may be difficult; making ornamental plants highly appealing because they are available in these regions.

Compared to other plant species such as edible crops and medicinal plants, ornamental plants seem more suitable because they provide several benefits such as beautifying contaminated environments and financial benefits to both local people and the government (Sani *et al.*, 2016). The most important benefit is that there is no or little likelihood of entering the food chain and being ingested by people. It is admirable to observe these plants in action, particularly in contaminated urban environments, as certain ornamental plants can either accumulate or degrade contaminants when cultivated in such conditions (Liu *et al.*, 2018).

Research on the use of ornamental plants for phytoremediation in Nigeria is limited. This study focuses on *Solenostemon scutellarioides*

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(L.) Codd (Coleus) and *Codiaeum variegatum* L. (Croton), both widely grown non-edible plants with high biomass, suggesting they could accumulate heavy metals in their roots and tissues (Okunola et al., 2021). Croton is a popular ornamental plant in Nigeria, according to Ogunwenmo *et al*. (2007) approximately 56 cultivars are housed in the Babcock University Germplasm Repository (BUGR) in Ilishan-Remos biological Garden. It has also been explored for phytoremediation of lead-contaminated soils (Herlina *et al.*, 2020; Kumar *et al.*, 2014). Coleus is an evergreen herbaceous perennial in the Labiatae family, many of the cultivars are planted as ornamentals both in tropical and temperate regions because of their beautiful leaves (Suva *et al.*, 2015). Previous studies demonstrated that coleus plants can collect and accumulate aluminum-making them viable phytoremediation plants (De León *et al.*, 2011).

Studies on various ornamental plants for phytoremediation have yielded promising results (Nanda and Pradhan, 2019). Although their mechanism to remediate heavy metals has not been reported in terms of different varieties or cultivars, therefore, this study aimed to assess the ability of two varieties of Coleus (Red Trailing Queen and Religious Radish) and Croton ornamental plants (Gold Dust and Oakleaf) to uptake cadmium (Cd) and lead (Pb) on polluted soil.

METHODS

Study Location

This study was conducted in 2021 – 2022 in a screen house at Efugo Extractive Industry, Idu Industrial layout Abuja. The laboratory analysis was carried out at Sheda Science and Technology Complex, Abuja, Nigeria.

Collection of Soil Samples and Ornamental Plants

Soil sample was collected with the aid of a shovel at a depth (0 – 30 cm). The soil was classified as non-polluted based on the WHO 1996 heavy metal permissible level standard. The samples were air-dried to prevent the loss of volatile nutrients and soil organic matter loss. Then they were sieved with a 2.0 mm mesh sieve for initial soil analysis and heavy metal determination. Sub-samples were ground and passed through a 0.5 mm sieve for the determination of organic carbon and total nitrogen.

The two plants, Croton and Coleus, were selected based on their availability in the region. Two varieties of Coleus (Religious Radish and Red Trailing Queen) and two varieties of Croton (Gold Dust and Oakleaf) were obtained from a local florist in Idu, Abuja. Stem cuttings were taken from these plants and re-cut into 10 cm lengths before being planted in polyethylene pots filled with topsoil. The seedlings of each cultivar were transplanted at 3 months with some degree of physiological uniformity.

Experimental Design

The experiment was laid out in a screen house in two successive trials. Each was a 4 x 4 factorial, arranged in a Completely Randomized Design (CRD), and replicated three times to make a total of 48 pots. The factors were: the 4 ornamental plants (Red trailing queen; Religious radish; Gold dust and Oak leaf) and the 4 levels of Pb and Cd concentration (P0: 0 $mg.kg^{-1}$ of Cd and 0 $mg.kg^{-1}$ of Pb; P1: 2 $mg.kg^{-1}$ of Cd and 1000 $mg.kg^{-1}$ of Pb; P2: 5 $mg.kg^{-1}$ of Cd and 1500 $mg.kg^{-1}$ of Pb; and P3: 10 $mg.kg^{-1}$ of Cd and 2000 $mg.kg^{-1}$ of Pb).

Experimental Setup

Soil sample of 3 kg was placed in containers and was replicated 3 times for planting. The soil samples were contaminated with Cd at 0 $mg.kg^{-1}$, 2 $mg.kg^{-1}$, 5 $mg.kg^{-1}$, and 10 $mg.kg^{-1}$ and Pb at 0 $mg.kg^{-1}$, 1000 $mg.kg^{-1}$, 1500 $mg.kg^{-1}$, and 2000 $mg.kg^{-1}$. Cd was spiked as $CdCl_2 \cdot 2.5H_2O$ while Pb was spiked as

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$Pb(NO_3)_2$. The contamination rates were chosen to be higher than the WHO Permissible limit for heavy metals. Coleus and Croton seedlings with identical growth phases; Croton plants had an average of 4 leaves and Coleus plants had an average of 15 leaves. Both plants, with an average height of 10 cm, were transplanted into the containers two weeks after soil contamination and observed for three months.

Growth parameters such as number of leaves, leaf area, plant height, and stem girth were measured bi-weekly. The plants were harvested at 12 weeks after transplanting and were separated into two compartments, viz. roots and shoot and their dry matter weight was determined and prepared for heavy metal analysis. In the second trial, seedlings with identical growth phases were transplanted into treated pots with varied amounts of Pb and Cd concentrations that remained in the soil after harvesting in the first trial. The layout and techniques were the same as in the previous trial.

Soil Analysis

Initial soil analysis was carried out on the soil samples and the soil pH was determined in water (1:1) using a glass electrode pH meter (Hendershot *et al.*, 2007). The particle size was determined using the hydrometer method (Ashworth *et al.*, 2001). Total Nitrogen was determined by the macro-kjeldahl digestion method (Bremner, 1996). Exchangeable cations were extracted with 1N NH_4OAc (pH 7.0), Potassium and Sodium were determined using flame photometers while Calcium and Magnesium were determined by atomic absorption spectrophotometer (Spark, 1996). Exchangeable acidity (Aluminum and Hydrogen) was determined by KCl extraction method (Coscione *et al.*, 1998). Organic carbon was determined using the dichromate wet oxidation method (Schumacher, 2002).

Heavy Metal Determination in Ornamental Plants

Each plant sample was divided into two parts: shoot (leaf and stem) and root. The portions that had been separated were cleaned with distilled water and dried at 70ºC. Dry digestion was performed by putting one gram of sample (shoot and root) into porcelain crucibles. The temperature of the muffle furnace was gradually increased from room temperature to 450°C in 1 hour. The weighed samples were then ashed for 4 hours in the muffle furnace at 450°C. After cooling, each residual received 5mL of HNO_3. The mixture was transferred to a 25 mL volumetric flask and filled to volume. The blank analysis followed the same procedure. According to Tuzen (2003), lead and Cd concentrations were evaluated using an atomic absorption spectrophotometer.

Heavy Metal Determination in Soil

Mehmet's (2008) approach was used to analyze the lead and cadmium in the soil. One gram of dried soil was obtained and digested at 230ºC with 15 ml of HNO_3 and 25 ml of $HClO_4$ until it was entirely turned to ash. The digested solution was filtered and diluted to a volume of 50 ml in a volumetric flask. An atomic absorption spectrophotometer was used to determine lead and Cd concentrations, and the same approach was used for the blank analysis.

Phytoremediation Indices

Translocation Factor (TF): indicates the efficiency of the plant to translocate the accumulated heavy metals from roots to shoots. It is the ratio of the concentration of heavy metal in shoots (stem and leaves) to that in their roots (Herlina *et al.*, 2020). It is calculated following the equation:

$$TF = \frac{metal\ concentration\ in\ shoot}{metal\ concentration\ in\ root} \ldots 1)$$

Bioconcentration Factor (BCF): important in the selection and evaluation of plants for the

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phytoremediation of heavy metals and can be represented according to the following equation: (Abolghasem *et al.*, 2016):

$$\mathrm{BCF} = \frac{\text{metal concentration in plant tissues}}{\text{metal concentration in the soils}} \ldots 2)$$

Note: the concentration of the metal from plant tissues comprises both roots plus shoots.

Statistical Analysis

The means of significant treatment were separated using Least Significant Difference (LSD) at a 5% level of probability using GenStat 9th edition.

RESULTS AND DISCUSSIONS

Soil Physical and Chemical Properties

The initial analysis of the experimental soil before contamination revealed an alkaline pH of 8.58. The total nitrogen content was 2.11%, while the organic carbon content was 1.47%, which was considered moderate. Overall, the abundance of exchangeable cations was Ca (7.1) > Mg (2.5) > K (0.4) > Na (0.11) cmol/kg. The initial concentration status of Pb and Cd was as follows: Pb (11) > Cd (0.5) mg/kg, and both were within the WHO 1996 acceptable limit. The soil textural class was sandy loam. The alkaline nature of the soil did not interfere with the experiment because it was allowed to cure for two (2) weeks after heavy metal contamination before transplanting, which reduced the pH and made the heavy metals available for plant uptake; additionally, previous research has shown that basic pH does not impair plants' potent ability to remove heavy metals (Azeez *et al.*, 2013). A post-analysis of the soil after harvest was not conducted, as the focus of the study was primarily on the ornamental plants.

Dry Matter Weight

Exposure of plants to heavy metals at a high rate leads to severe damage to various metabolic activities consequently leading to the death of plants. This is one of the reasons why dry weight serves as an indicator of the tolerance ability of plants to adverse environments. The results of the impact of the lead and cadmium contamination on the dry matter weight (DMW) of the selected ornamental plants are presented in Table 1. In both trials, the study indicated that soil treated with P3 had the lowest DMW of shoot and root, with no significant difference between P2 and P1. Uncontaminated soil had higher DMW of shoot and root, whereas P3 and P2 treated soil had identical DMW of root. The order of DMW of the shoot in both trials is Oakleaf > Religious Radish > Red trailing queen > Gold dust. However, the order of DMW of root in both trials was quite different, in the first trial: Religious Radish > Red trailing queen > Oak Leaf > Gold dust while in the second trial: Oakleaf, > Religious radish > Red trailing queen > Gold dust. In both trials, it was seen that Gold dust responded more negatively to the contaminations, while Oakleaf and Religious radish had a quite positive response.

In this study, the dry matter of the ornamental plants decreased at higher cadmium and lead concentrations which indicated the adverse effect of Cd and Pb on dry matter production specifically at higher concentrations, a similar finding was reported by Alaboudi et al. (2018). Auda and Ali (2010) reported that a decrease in plant biomass might be related to heavy metal toxicity which may have inhibited their nutrient uptake (especially nitrate), photosynthesis, and transpiration.

It can be deduced from the results that the heavy metal contamination effect was more pronounced in the root of *C. variegatum* varieties and the shoot of *S. scutellarioides* varieties with Religious Radish had the highest dry matter weight (DMW) of the root while the DMW of the shoot was highest in Oakleaf. It has been reported that lead toxicity inhibits root growth in *Sedum alfredii*, *Pharagmites australis* (Wang *et al.*, 2013), and *Zea mays* (Hussain *et al.*, 2013), which affects the uptake of lead by the studied plants. When both Cd and Pb were utilized as pollutants in soil, Alaboudi

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et al. (2018) found that Cd was more effective at reducing sunflower dry matter than Pb because sunflowers absorb a significant amount of Cd into their shoots and roots. Previous research has also revealed that Pb toxicity reduces shoot and root growth in *Codiaeum variegatum* L. plants (Herlina, 2020a). In line with this, the findings of this study suggest that *S. scutellarioides* varieties can absorb more Pb while *C. variegatum* varieties absorb more Cd.

Table 1. Effects of cadmium and lead soil contamination on dry matter weight (DMW) ornamental plant

	First Trial		Second Trial	
Ornamental Plant	Shoot (g)	Root (g)	Shoot (g)	Root (g)
C.V OL	24.13	11.18	35.83	15.69
C.V. GD	19.63	11.11	30.18	13.96
S.S. RR	22.80	11.41	35.26	15.27
S.S. RTQ	19.69	11.39	32.46	14.81
LSD 5%	4.00	ns	4.20	ns
Contamination				
P0	28.50	13.69	40.59	16.63
P1	22.45	11.56	34.18	13.53
P2	20.21	9.64	31.72	12.55
P3	15.10	8.18	27.21	11.45
LSD 5%	3.87	1.59	4.10	0.823
Interaction				
P x C	8.01	3.17	8.41	3.36

Notes: C.V.GD: *Codiaeum variegatum* var. gold dust, C.V. OL: *Codiaeum variegatum* var. oak leaf; S.S.RR: *Solenostemon sucutellarioides* var. red trailing queen, S.S.RTQ: *Solenostemon sucutellarioides* var. religious radish; P0: Pb concentration at 0 mg kg^{-1}, Cd at 0 mg kg^{-1}, P1: Pb concentration at 1000 mg kg^{-1}, Cd at 2 mg kg^{-1} P2: Pb concentration at 1500 mg kg^{-1}, Cd at 5 mg kg^{-1} P3: Pb concentration at 2000 mg kg^{-1}, Cd at 10 mg kg^{-1}

Phytoremediation Indices

Bioconcentration factor

The results of the ornamental plants accumulating the heavy metal into their tissues in both trials are shown in Table 2. In the first trial, results showed the BCF of Cd in *C. variegatum* cultivars (Gold dust and Oakleaf) were greater than 0.7, and were significantly greater than *S. scutellarioides* cultivars (Red trailing queen and Religious radish), while the BCF of Pb in Red trailing queen (0.717) and Religious radish (0.833) were observed to be significantly higher than in Gold dust and Oakleaf.

The BCF increased with increasing rate of heavy metal contamination, soil treated with P3 had BCF of Cd and Pb > 1 and was significantly higher than other treatments, there was no significant difference observed between P2 and P1. The findings from the residual effect trial indicate that the BCF of Cd and Pb followed a similar pattern as the first trial for both contamination and plants, however with lesser values.

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Table 2. Effects of cadmium and lead soil contamination on the bioconcentration factor (BCF) of the ornamental plants

Ornamental Plant	First Trial		Second Trial	
	Cadmium	Lead	Cadmium	Lead
C.V OL	0.709	0.431	0.477	0.25
C.V. GD	0.707	0.49	0.507	0.221
S.S. RR	0.39	0.833	0.169	0.8
S.S. RTQ	0.411	0.717	0.158	0.614
LSD 5%	0.282	0.232	0.23	0.15
Contamination				
P0	0.075	0.078	0.125	0.084
P1	0.421	0.633	0.131	0.557
P2	0.789	0.726	0.441	0.595
P3	1.071	1.034	0.613	0.65
LSD 5%	0.268	0.212	0.201	0.35
Interaction				
P x C	ns	0.299	ns	ns

Notes: C.V.GD: *Codiaeum variegatum* var. gold dust, C.V. OL: *Codiaeum variegatum* var. oak leaf; S.S.RR: *Solenostemon sucutellarioides* var. red trailing queen, S.S.RTQ: *Solenostemon sucutellarioides* var. religious radish; P0: Pb concentration at 0 mg kg^{-1}, Cd at 0 mg kg^{-1}, P1: Pb concentration at 1000 mg kg^{-1}, Cd at 2 mg kg^{-1} P2: Pb concentration at 1500 mg kg^{-1}, Cd at 5 mg kg^{-1} P3: Pb concentration at 2000 mg kg^{-1}, Cd at 10 mg kg^{-1}

The proportional relationship between BCF and the rate of heavy metal contamination is similar to the findings of Ramana et al. (2014). BCF of cadmium in *C. variegatum* varieties (Gold dust and Oakleaf) were higher than in *S. scutellarioides* varieties (Red trailing queen and Religious radish), while the BCF of Pb in coleus varieties (Red trailing queen and Religious radish) were higher than in croton varieties (Gold dust and Oakleaf). This is consistent with the research of Herlina et al. (2020b), which shows that *C. variegatum* plants have low BCF of Pb which ranges from 0.40 to 0.60. However, in both trials, the individual ornamental plants' overall BCF of Cd and Pb was less than 1. According to Herlina et al. (2020a), when a BCF value is less than 1, the plant is considered a phytostabilizer, and if the BCF value is more than 1, the plant is said to be a phytoextractor.

Phytostabilization is described as the process of reducing the mobility of contaminants in the soil through adsorption onto roots, adsorption, and accumulation by roots, or precipitation within the root zone (Vankateswarlu *et al.*, 2016). According to Antoniadis et al. (2016), root exudates alter rhizosphere chemistry and increase plant tolerance to metals. The effects of root exudates on the mobilization of metal species are diverse, and the effects of various plant species on metal availability are also plant species-dependent. Interestingly, Religious radish had 0.8 BCF of Pb in both trials, suggesting that the plants absorbed nearly 80% of the Pb in the soil. This suggests that this particular ornamental plant can function as a phytoextractor at high concentrations. Similar findings were reported by Salas-Luévano et al. (2017), who stated that plants such as *Amaranthus hybridus, Arundo donax, Pennisetum clandestinum, and Bothriochloa barbinodis* may be suitable for phytoextraction of arsenic because their BCF was close to one.

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The interaction between plant and contamination rate was not significant in both trials, except for BCF of Pb in the first trial and this is shown in Figure 1. It revealed that at all contamination levels, *S. scutellarioides* varieties accumulate more lead than *C. variegatum* varieties. However, *S. scutellarioides* varieties tend to have a limit for lead accumulation, as the decrease in BCF value was noted at 2000 mg/kg of Pb (P3) for both varieties (Red trailing queen and Religious radish). Chandrasekhar and Ray (2019) obtained similar results when *Scoparia dulcis* L. was exposed to varied levels of Pb; BCF value > 1 was seen in all Pb exposed plants compared to the control ($p < 0.05$), with maximal BCF in plants subjected to 200 mg/kg of the soil. However, at 1600 mg/kg of Pb, there was a considerable reduction in BCF value compared to previous levels of treatment.

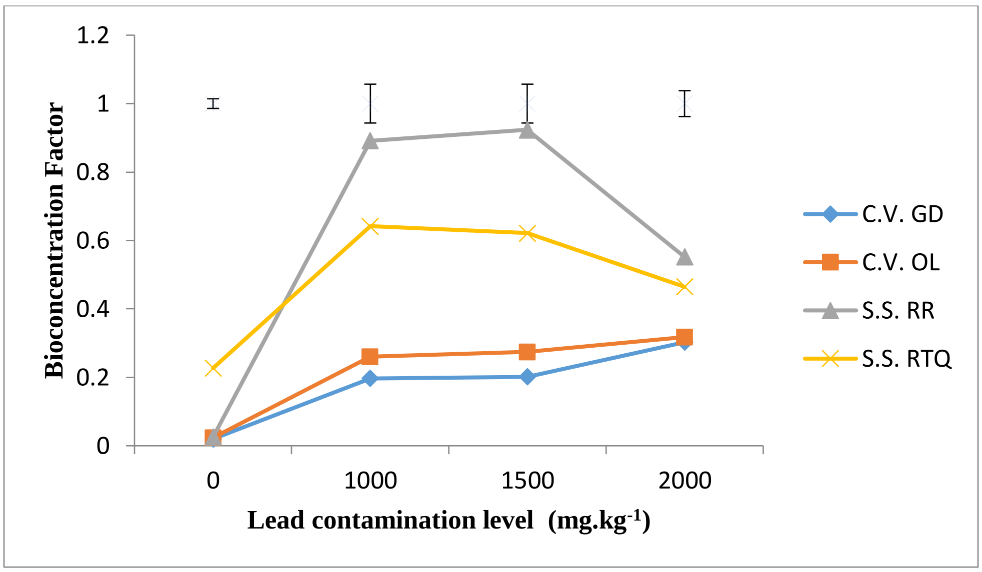

Figure 1. Interactive effect of plants and heavy metals contamination on bioconcentration factor of Lead (Pb) - (First cycle)

Notes: C.V.GD: *Codiaeum variegatum* var. gold dust, C.V. OL: *Codiaeum variegatum* var. oak leaf; S.S.RR: *Solenostemon sucutellarioides* var. red trailing queen, and S.S.RTQ: *Solenostemon sucutellarioides* var. religious radish.

Although both *C. variegatum* varieties (Gold dust and Oakleaf) had very low BCF of Pb tend to show a non-significant increasing pattern for the accumulation of Pb as contamination levels increased. Vargas et al. (2016) explained that plants having low BCF may be due to lower solubility of the metal in the soil, leading to lower mobility to plant roots. Xing et al. (2020) concluded that plants with low BCF of Pb values accumulate little Pb in their shoots.

Translocation Factor (TF)

The translocation factor indicates internal metal transportation from root to shoot. Table (3) shows the translocation factor of ornamental plants in both trials, which follows a similar pattern with minor variations. In the first trial, *C. variegatum* cultivars (Gold dust and Oakleaf) had TF of Cd > 1 and were significantly higher than Red trailing queen and Religious radish, similarly, Religious radish recorded TF of Pb > 1, followed by Red trailing queen (0.92), and both were observed to be

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significantly higher than Gold dust and Oakleaf. The translocation factor of Cd in ornamental plants also varied under different concentrations of heavy metal with significant difference ($p \leq 0.05$) observed to increase as soil contamination increases. However, the TF of Pb in ornamental plants under different concentrations of heavy metal was not significantly different from each other and ranged from 0.806 in soil without contamination to 0.913 in soil treated with 1000 and 10 mg/kg of Pb and Cd, respectively.

Table 3. Effects of cadmium and lead soil contamination on the translocation factor (TF) of the ornamental plants

Ornamental Plant	First Trial		Second Trial	
	Cadmium	Lead	Cadmium	Lead
C.V OL	1.136	0.746	0.84	0.652
C.V. GD	1.039	0.574	0.9	0.501
S.S. RR	0.515	1.216	0.87	0.965
S.S. RTQ	0.504	0.923	0.76	0.805
LSD 5%	0.239	0.265	ns	0.23
Contamination				
P0	0.441	0.806	0.64	0.802
P1	0.829	0.864	0.76	0.799
P2	0.947	0.875	0.93	0.765
P3	0.977	0.913	1.15	0.756
LSD 5%	0.279	ns	ns	ns
Interaction				
P x C	ns	ns	ns	ns

Notes: C.V.GD: *Codiaeum variegatum* var. gold dust, C.V. OL: *Codiaeum variegatum* var. oak leaf; S.S.RR: *Solenostemon sucutellarioides* var. red trailing queen, S.S.RTQ: *Solenostemon sucutellarioides* var. religious radish; P0: Pb concentration at 0 mg kg^{-1}, Cd at 0 mg kg^{-1}, P1: Pb concentration at 1000 mg kg^{-1}, Cd at 2 mg kg^{-1} P2: Pb concentration at 1500 mg kg^{-1}, Cd at 5 mg kg^{-1} P3: Pb concentration at 2000 mg kg^{-1}, Cd at 10 mg kg^{-1}

In the second trial there the TF of Cd of *S. scutellarioides* varieties increased leading to a non-significant difference among all the selected ornamental plants. However, both *S. scutellarioides* varieties (Red trailing queen and Religious radish) had TF of Pb 0.805 and 0.965 respectively which was significantly higher than the TF of Pb of the *C. variegatum* cultivars. Under varying heavy metal concentrations, the translation factor of Cd in ornamental plants increased as contamination increased, however, Tf of Pb in ornamental plants, decreased as the level of contamination increased.

Translocation factor value is influenced by antagonistic and synergistic properties of metals which then affects the absorption and distribution of metals in plants (Eid and Shaltout, 2014). *Codiaeum variegatum* varieties had TF of Cd > 1 and *S. scutellarioides* varieties had TF of Pb > 1. If the TF is less than 1, it means that most heavy metals are accumulated in the root, while if the TF is more than 1, then the heavy metals are

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displaced from the root to the canopy (Herlina *et al*. 2020a). This affirms the reason why there was more Pb content in the root of *C. variegatum* varieties and more Cd content in the root of *S. scutellarioides* varieties. The translocation factor of metal excluder plants is < 1 whereas metal accumulator plants have TF >1 (Majid *et al.*, 2012). It can also be said that the *C. variegatum* plants (Gold dust and Oakleaf) are Cd accumulators while *S. scutellarioides* plants (Religious radish and red trailing queen) are Pb accumulators.

The BCF and TF are key indicators of phytoremediation potential exhibited by plant species. In this study, the results showed that *C. variegatum* varieties (Gold dust and Oakleaf) had high TF and low BCF at higher Cd concentrations and *S. scutellarioides* varieties (Religious radish and Red trailing queen) had high TF and low BCF at higher Pb concentrations. A similar report on BCF < 1 and TF > 1 was observed in *Dyera costulata* by Ghafoori et al. (2011). This is also similar to the findings of Hossain et al. (2022), in which the BCF value is less than 1 and the TF value is found to be greater than 1 in studied plants, it means that the plants can actively take up metals from the soil and can accumulate them in their aerial parts, as a result, can be good phytostabilisers. The high TF and low BF further suggest that the plants can reduce the potential harm that these heavy metals could cause to the physiology and biochemistry of their roots by mobilizing the metals from their roots to their shoots (Zacchini *et al.*, 2009).

Variance was seen in each cultivar's responses to the Cd and Pb contamination. *C. variegatum* var. Oakleaf had higher TF and BCF of Cd than Gold dust. However, Gold dust can uptake more Pb than Oakleaf. Also, *S. scutellarioides* varieties (Religious radish) had higher TF and BCF of both metals than Red trailing queen. Mehes-Smith et al. (2013) explained that variation occurs between species, varieties, populations, and clones for tolerance and accumulation of metals because plants have to modify their physiological processes to be able to survive in the environment in which they grow.

CONCLUSION

This study indicated considerable accumulative ability and translocation by the ornamental plants to assimilate higher amounts of Cd and Pb. *Solenostemon sucutellariodes* (L.) Codd. prefers Pb, while *Codiaeum variegatum* L. prefers Cd. Oakleaf (*Codiaeum variegatum* L.) has the strongest remediation potential for Cd and Religious radish (*Solenostemon sucutellariodes* L.) has the strongest remediation potential for Pb. The plants showed high TF and low BCF which indicates that the selected plants achieved phytoremediation by both increasing the uptake of metals in their roots and decreasing their sequestration in their roots. This also implies that the tested ornamental plants are phytostabilizers of Pb and Cd. Therefore, they can limit the accumulation of Cd and Pb in biota and minimize their leaching into underground waters. This study has demonstrated that not all cultivars of a particular ornamental plant are suitable for phytoremediation and has identified one effective variety from each ornamental plant tested. The findings highlight the need for further research into other varieties of *Codiaeum variegatum* L. and *Solenostemon scutellarioides* (L.) Codd to identify the most effective cultivars for phytoremediation.

This study suggests that factories near farmlands and residential areas should use ornamental plants like *Codiaeum variegatum* L. (Oakleaf) and *Solenostemon scutellarioides* (L.) Codd. (Religious radish) to control heavy metal leaching into underground water. It also suggests regular packing of trimmed leaves to

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prevent decomposition and heavy metals from returning to the soil. Residues can be treated using extraction methods or pyrolysis for high reduction rate, by-product utilization, low secondary pollution, and cost-effectiveness.

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