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The potential value of bedding begonia in phytoextraction of chromium, lead and cadmium

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ABSTRACT

Bedding begonias (*Begonia cucullata* Hort.) are cultivated primarily for their aesthetic appeal. Boasting beautiful leaves and lively, colourful flowers, these plants can significantly enhance any garden space. They also have the capacity to produce a large biomass, suggesting their suitability for phytoextraction purposes. This study aims to evaluate the effectiveness of bedding begonia in removing Cr, Pb, and Cd from artificially polluted substrates, with concentrations varying from 100 mg/kg to 500 mg/kg for Cr and Pb, and from 20 mg/kg to 100 mg/kg for Cd. The phytoextraction potential was estimated using bioaccumulation (BAF) and translocation (TF) factors analysis. The current study demonstrated that bedding begonia can successfully grow in substrates enriched with Cr, Pb, and Cd. BAF values < 1 for both Cr and Pb were detected regardless of contamination levels, indicating that this species has limited capacity to restore soils contaminated with these metals. On the other hand, BAF and TF values for Cd were greater than 1 at all contamination levels, implying their potential to remove Cd from polluted soils.

Keywords: *Begonia cucullata* Hort., bioaccumulation, heavy metals, soil remediation.

INTRODUCTION

Soil contamination by heavy metals has become a major concern worldwide primarily because of its harmful effects on human health and the environment (Li et al., 2019). Elevated levels of heavy metals in soil affects agricultural productivity, leads to various health issues, and hinders sustainable development. It also damages soil ecosystems and disrupts ecological balance by allowing heavy metals to enter the food chain (Madanan et al., 2021; Vasilachi et al., 2023).

Chromium (Cr), lead (Pb), and cadmium (Cd) are among the most hazardous heavy metals due to their high degree of toxicity and environmental persistence (Aveiga et al., 2023). Toxic amounts of Cr in the human body can cause numerous disorders or diseases, including irritations, burns, and ulcers in the stomach and small intestine (Shin et al., 2023), while exposure to toxic levels of Pb can damage the brain and central nervous system potentially causing coma, convulsions or some other neurologic disorders (Sanders et al., 2009). Cd is also known to exert toxic effects on the kidneys and the skeletal, respiratory, and reproductive systems (Rafati Rahimzadeh et al., 2017).

Cr, Pb and Cd are generally present in the environment at low levels. However, their concentrations in the ecosystems, particularly in the soils, have risen sharply in recent decades primarily due to the rapidly growing industrial activity, accompanying inadequate waste disposal and the improper use of fertilizers and pesticides in agriculture (Amini et al., 2024). In this regard, it is of utmost importance to take appropriate remediation measures to reduce soil contamination by Pb, Cd, and Cr. Phytoremediation is a promising technique that reduces or stabilizes heavy metals and other pollutants in soils using plants (Ratnawati et al., 2024). There are five basic types of phytoremediation, each with different mechanisms for remediating soils polluted by heavy metals: phytoextraction, phytostabilization, phytovolatization, phytodegradation, and phytofiltration (Lone et al., 2008).

Phytoextraction refers to the processes when certain plant species absorb pollutants, in particular heavy metals, from contaminated soils and transfer them into harvestable above-ground organs (Parzych and Sobisz, 2024). This technique is both efficient and eco-friendly, as it does not require specialized equipment for its implementation, making it a practical and valuable option for the remediation of soils contaminated with heavy metals (Sarwar et al., 2017; Tan et al., 2023). For effective phytoextraction, plant species should exhibit significant tolerance to heavy metals, a brief life cycle, substantial biomass production, and an enhanced ability to absorb them (Yan et al., 2020).

Despite the considerable progress achieved in phytoextraction research, the application of this technique with ornamental plants has not been thoroughly explored. Ornamental plants are cultivated primarily for their aesthetic appeal, showcasing a variety of shapes, colours, and sizes that can thrive in diverse climates and landscapes. However, several studies have shown that some ornamental plants like *Amaranthus tricolor* L. and *Tagetes erecta* L. not only enhance the visual environment but also contribute to the remediation of heavy metal-polluted soils (Awad *et al.*, 2021; Biswal *et al.*, 2022). Although most ornamental plants are inedible, their use to remediate soil contaminated with toxic heavy metals such as Cr, Pb, and Cd offers significant economic, health, and environmental benefits.

Bedding begonias (*Begonia semperflorens-cultorum* Hort. synonym of *Begonia cucullata* Hort.) are tender perennials with fibrous roots, typically cultivated as annuals. They have fleshy, rounded, green or bronze leaves, and produce clusters of single or double flowers in red, pink, or white from mid-summer to autumn. Green-leaved begonias perform optimally in partial to full shade, while bronze-leaved varieties are capable of thriving in full sunlight. All types are quite resilient to drought due to their thick, waxy leaves, and they are relatively easy to grow and maintain. Begonias are highly versatile and can be planted in containers, hanging baskets, window boxes, and garden beds. They are also well-suited for growth as houseplants. Their aesthetic appeal not only enhance visual interest but also create a friendly atmosphere for both gardeners and visitors

Bedding begonias also produce high biomass and are potentially very suitable for phytoextraction. However, up to now, there has been no thorough exploration regarding the potential use of begonia plants for this purpose, particularly in soils polluted by Cd, Cr, and Pb. Therefore, this study aims to evaluate the effectiveness of bedding begonia in removing Cr, Pb, and Cd from polluted substrates, focusing on the translocation factor (TF) and bioaccumulation factor (BAF). Bedding begonias were grown in a commercial substrate artificially contaminated with various concentrations of heavy metals (ranging from 100 mg/kg to 500 mg/kg for Cr and Pb, and from 20 to 100 mg/kg for Cd).

MATERIALS AND METHODS

Plant material

The plant material used for the present study was bedding begonia to evaluate its ability to remove Cr, Pb, and Cd from artificially contaminated substrate. The seedlings were produced at the Garden centre "Flora" - Nedžarići in Sarajevo, and showed no significant differences in vigour, size, or overall appearance.

Experimental design

The research was conducted from mid-July to the end of August 2024 within a naturally ventilated greenhouse located at the experimental station of the Faculty of Agriculture and Food Sciences (Sarajevo, Bosnia and Herzegovina). One-month-old seedlings were transplanted in black plant grow bags (24 × 24 × 40 cm; one plant/grow bag) previously filled with a commercial growing substrate (Garden centre 'Flora') artificially contaminated with Cd, Cr, and Pb. The substrate contained black and white peat, wood fibre, and composted plant material, with 1 g of N-P-K

15-15-15 fertilizer per litre. The chemical properties of the growing substrate before adding the contaminants are outlined in Table 1.

Considering the basic chemical properties, the growing medium utilized is appropriate for facilitating the growth and development of begonias. The chemical analysis also revealed that all heavy metals detected in the growing medium were below the acceptable limits established by legislation in Bosnia and Herzegovina (OG FBiH, 2009). The acceptable limits for cadmium (Cd), chromium (Cr), lead (Pb) copper (Cu), zinc (Zn), and nickel (Ni) in agricultural soils are 1, 100, 100, 80, 200, and 50 mg/kg dry weight, respectively. The threshold value for Fe and Mn is not established by legislation, because they are not directly contaminant elements. However, the content of Mn and Fe in the substrate tested was significantly lower than the average values reported in scientific literature. According to Kabata-Pendias (2010), the average Mn content in soils is reported to be between 500 and 900 mg/kg, while Fe content typically ranges from 6000 to 12000 mg/kg.

Before initiating the experiment, the substrate was deliberately contaminated by incorporating a solution that contained specific heavy metals (Cr, Pb, and Cd) in different concentrations, followed by thorough mixing to achieve a consistent distribution of the heavy metal solution. The application of Cr, Pb, and Cd was carried out using potassium dichromate ($K_2Cr_2O_7$), lead nitrate ($Pb(NO_3)_2$), and cadmium chloride ($CdCl_2$), respectively.

Four treatments were applied for each heavy metal assessed, including 0, 20, 50, and 100 mg/kg for Cd, and 0, 100, 250, and 500 mg/kg for Pb and Cr, with three replicates per treatment. Each treatment consisted of four grow bags/plants resulting in 142 samples.

Table 1. Chemical properties of the growing substrate before adding the contaminants

Parameter	Measure unit	Value
pH H_2O	pH	5.7
pH KCl	pH	5.3
Organic matter	%	52.9
Available forms of potassium (K_2O)	mg/100 g	43.2
Available forms of phosphorus (P_2O_5)	mg/100 g	49.5
Cd content	mg/kg	0.3
Cr content	mg/kg	5.6
Pb content	mg/kg	2.3
Cu content	mg/kg	21.7
Zn content	mg/kg	14.3
Mn content	mg/kg	130.3
Fe content	mg/kg	1186.9
Ni content	mg/kg	7.1

The air temperature and relative humidity within the greenhouse fluctuated between 19 ± 2 °C and 30 ± 2 °C, as well as from 55% to 95%, respectively. Air circulation was maintained by opening the roof vents and the main entrance during the daytime. A green shade cloth was used to prevent excessive heat buildup on warm days. Each plant/pot was watered consistently every second day. No fertilizers were applied during the experiment.

The control and heavy metal-stressed samples were collected after six weeks, and divided into aboveground and underground parts. The fresh weight was weighed immediately after harvest, while the dry weight was measured following oven drying at 60 °C until a constant weight was achieved. The plant height was measured using a ruler, while the leaf area was calculated according to Pandey and Singh (2011). For heavy metal analysis, the plant material was separately dried in an oven at 80 °C for 24 h, ground into a powder with an electric blender, and stored in paper bags in a desiccator until analysis.

Extraction of Cr, Pb and Cd from plant samples

Dry ash was used for extraction of heavy metals, including Cr, Pb, and Cd from plant samples (Lisjak et al., 2009). Briefly, 2 g of dry plant sample was placed in a crucible and ignited in a muffle furnace at 550 °C for 6 h. The ash produced was digested with a 10 mL mixture of HNO_3 and H_2SO_4 (2.5:1), followed by heating on the hot plate for 1 h at 60 °C. After cooling to room temperature, 5 mL of deionized water was added, and the mixture was filtered through quantitative filter paper (Whatman, No. 42) in a volumetric flask (50 mL). The final volume was made up to 50 ml using deionized water.

Determination of Cr, Pb, and Cd in digested sample solution

The Cr, Pb, and Cd levels in the digested sample solution were determined by atomic absorption spectrophotometry (ISO, 1998), using the Shimadzu AA-7000 device (Shimadzu Instruments, Tokyo, Japan). Working standard solutions for Cr, Pb, and Cd were made by diluting the certified stock solutions (Merck, Darmstadt, Germany) with deionized water as necessary. Heavy metal concentrations were expressed as mg/kg of plant material on a dry weight basis.

Evaluation of bioaccumulation factor

The bioaccumulation factor (BAF) indicates how effectively a plant species can take up heavy metals from its environment, and it was determined using the following equation (Ladislas et al., 2012):

$$BAF = \frac{C_{plant}}{C_{soil}} \quad (1)$$

where: C_{plant} and C_{soil} represent the heavy metal concentrations in both harvestable plant material and the soils. Values of BAF higher than 1 indicate high heavy metal accumulation in plant tissue (Ramírez et al., 2021).

Evaluation of translocation factor

Translocation factor (TF) indicates how effectively a plant species can translocate heavy metal from roots to aboveground parts, and it was determined using the following equation (Islam et al., 2020):

$$TF = \frac{C_{aboveground\ parts}}{C_{belowground\ parts}} \quad (2)$$

where: $C_{aboveground\ parts}$ and $C_{underground\ parts}$ represent the heavy metal concentrations in the aboveground plant material and roots, respectively. A TF value higher than 1 indicates that the plant has the potential for phytoextraction.

Statistical analysis

Data generated from the study were analysed using the statistical package of SPSS 22. The differences among means of groups were performed by Analysis of variance (ANOVA) and the Fisher's LSD post hoc test was computed at a 5% significance level ($p < 0.05$).

RESULTS

The basic growth characteristics of bedding begonias grown in substrates contaminated with Cr, Pb, and Cd are given in Table 2.

The results show that high values of heavy metals in substrates are more detrimental to root growth than to shoot growth. The bedding begonias grown in the substrate with 500 mg/kg of Cr and Pb recorded the lowest root fresh mass, whereas the control plants had the highest. Between the control and heavy metal-treated plants in height, leaf area, or fresh and dry aboveground biomass no significant differences were observed.

The levels of Cr, Pb, and Cd in the roots and aboveground parts of bedding begonias cultivated on contaminated substrates are summarized in Tables 3, 4, and 5. The results are expressed in mg/kg on a dry weight basis.

The levels of Cr, Pb, and Cd in bedding begonias grown on contaminated substrates were significantly higher than those in control conditions, with uptake of these heavy metals associated with increasing levels of soil contamination.

The highest heavy metal concentration was observed for Cd (359.9 mg/kg) in the aboveground

Table 2. Growth characteristics of begonia plants cultivated on contaminated substrates

Treatments	Plant height (cm)	Leaf area (cm^2)	Fresh aboveground mass (g)	Fresh root mass (g)	Dry matter (%)
Control	34.3 ± 6.5	42.2 ± 7.7	75.1 ± 12.7	3.5 ± 0.2^{a}	2.7 ± 0.5
100 mg/kg of Cr	33.4 ± 7.0	42.3 ± 6.2	73.3 ± 24.1	3.4 ± 0.2^{a}	2.3 ± 0.8
250 mg/kg of Cr	32.8 ± 6.8	37.7 ± 6.1	63.1 ± 13.7	2.8 ± 0.4^{cd}	2.2 ± 0.6
500 mg/kg of Cr	31.1 ± 8.8	37.1 ± 10.9	64.7 ± 21.1	2.6 ± 0.4^{d}	2.4 ± 0.9
100 mg/kg of Pb	34.4 ± 6.9	42.8 ± 15.2	83.7 ± 26.3	3.1 ± 0.3^{b}	2.3 ± 1.7
250 mg/kg of Pb	31.1 ± 7.7	38.7 ± 14.9	75.8 ± 13.9	2.9 ± 0.2^{bc}	2.5 ± 0.7
500 mg/kg of Pb	29.3 ± 6.5	35.5 ± 15.4	65.5 ± 22.5	2.6 ± 0.2	2.5 ± 1.0
20 mg/kg of Cd	32.1 ± 5.9	42.0 ± 11.3	75.5 ± 27.2	3.0 ± 0.3^{bc}	2.4 ± 1.2
50 mg/kg of Cd	32.0 ± 4.1	40.9 ± 10.6	73.5 ± 26.5	3.0 ± 0.3^{bc}	2.5 ± 0.9
100 mg/kg of Cd	30.6 ± 5.1	39.4 ± 12.2	65.0 ± 24.2	2.9 ± 0.3^{bc}	2.4 ± 1.2
$LSD_{0.05}$	-	-	-	0.26	-

Note: The same letter in superscript means no significant difference within column ($p < 0.05$).

Table 3. Cr levels in begonia plants grown on Cr-contaminated substrates

Treatments	Roots	Aboveground parts
0 mg/kg of Cr	2.9 ± 1.8^{d}	1.9 ± 3.0^{c}
100 mg/kg of Cr	40.2 ± 19.3^{c}	13.0 ± 11.4^{bc}
250 mg/kg of Cr	75.2 ± 14.3^{b}	35.4 ± 10.9^{b}
500 mg/kg of Cr	254.2 ± 52.5^{a}	90.3 ± 19.7^{a}
$LSD_{0.05}$	30.3	27.9

Note: The same letter in superscript means no significant difference within column ($p < 0.05$).

Table 4. Pb levels in begonia plants grown on Pb-contaminated substrate

Treatments	Roots	Aboveground parts
0 mg/kg of Pb	2.4 ± 1.1^{c}	1.4 ± 0.2^{c}
100 mg/kg of Pb	101.2 ± 19.7^{b}	61.4 ± 22.1^{b}
250 mg/kg of Pb	111.5 ± 19.6^{b}	110.1 ± 19.6^{a}
500 mg/kg of Pb	169.4 ± 20.1^{a}	114.8 ± 22.7^{a}
$LSD_{0.05}$	16.5	18.3

Note: The same letter in superscript means no significant difference within column ($p < 0.05$).

Table 5. Cd levels in begonia plants grown on Cd-contaminated substrates

Treatments	Roots	Aboveground parts
0 mg/kg of Cd	1.4 ± 0.6^{d}	1.2 ± 0.2^{c}
20 mg/kg of Cd	62.4 ± 13.7^{c}	74.1 ± 23.6^{c}
50 mg/kg of Cd	107.2 ± 21.7^{b}	204.1 ± 161.6^{b}
100 mg/kg of Cd	137.9 ± 41.1^{a}	359.9 ± 122.9^{a}
$LSD_{0.05}$	25.9	96.9

Note: The same letter in superscript means no significant difference within column ($p < 0.05$).

plant parts in the growing medium contaminated with 100 mg/kg Cd. The order of accumulation of heavy metals in the aboveground parts of bedding begonias was found to be Cd > Pb > Cr for all cases of substrate contamination except control treatment.

The concentrations of Cr and Pb were higher in the roots than in the aboveground parts, regardless of the level of substrate contamination. In contrast, Cd levels were higher in the aboveground parts than in the roots for all substrate contamination. The bioaccumulation factors are given in Table 6.

The BAF values for both Cr and Pb in all cases were less than 1 which implies that bedding begonia have a limited ability to absorb these heavy metals. On the other hand, the BAF values for Cd were greater than 1 at all contamination levels, implying their potential to remove Cd from polluted soils. Translocation factors are given in Table 7.

Results presented in Table 7. indicate that bedding begonia has a low ability to relocate Cr and Pb from roots to above-ground tissues, and they cannot be considered suitable for restoration of soils contaminated with these heavy metals. On the other hand, the observed TF values for Cd in this study suggest that bedding begonia can translocate Cd from roots to aboveground parts in high amounts. In this light, bedding begonia could be one of the plants of interest in phytoextraction.

DISCUSSION

The bedding begonias grown in the substrates artificially contaminated with Cr, Pb, and Cd showed similar analysed features compared to those planted on the non-contaminated growing medium. There was no significant variation in plant height, leaf area, or fresh aboveground biomass between the control and heavy metal-treated plants. Only the fresh root mass showed a significant variation. The bedding begonias cultivated in a substrate containing 500 mg/kg of Cr and Pb exhibited the lowest fresh root mass (2.6 g), which is 25.7% less than observed in the control plants (3.5 g). Numerous studies have also shown that roots exhibit a higher susceptibility to heavy metal toxicity compared to shoots (Oncel et al., 2000; Sofo et al., 2022; Jorjani and Karakaş, 2023). Hajmoradi and Kakaei (2021) reported that the accumulation of heavy metals in the root tissues negatively impacts the rate of mitosis in the meristematic zones, thereby causing a reduction in

Table 6. Bioaccumulation factor values (BAF) of bedding begonias

Treatment	BAF	Treatment	BAF	Treatment	BAF
0 mg/kg of Cr	0.36	0 mg/kg of Pb	0.64	0 mg/kg of Cd	3.49
100 mg/kg of Cr	0.16	100 mg/kg of Pb	0.67	20 mg/kg of Cd	3.71
250 mg/kg of Cr	0.16	250 mg/kg of Pb	0.47	50 mg/kg of Cd	3.89
500 mg/kg of Cr	0.21	500 mg/kg of Pb	0.24	100 mg/kg of Cd	3.38

Table 7. Translocation factor values (TF) of bedding begonia plants

Treatment	TF	Treatment	TF	Treatment	TF
0 mg/kg of Cr	0.66	0 mg/kg of Pb	0.58	0 mg/kg of Cd	0.86
100 mg/kg of Cr	0.32	100 mg/kg of Pb	0.63	20 mg/kg of Cd	1.19
250 mg/kg of Cr	0.47	250 mg/kg of Pb	0.96	50 mg/kg of Cd	1.90
500 mg/kg of Cr	0.36	500 mg/kg of Pb	0.68	100 mg/kg of Cd	2.61

root growth and biomass. A significant reduction in root growth in plants cultivated in heavy metal-contaminated soils was previously confirmed by Pant and Tripathi (2014) and Angulo-Bejarano et al. (2021).

In this study, the bedding begonias showed no visible symptoms of heavy metal toxicity regardless of the level of substrate contamination and can be classified as a plant species with a remarkable ability to grow successfully in substrates rich in Cr, Pb, and Cd. From an ecological point of view, these data are very valuable because they indicate that this plant can be used to increase the aesthetic value of areas polluted by heavy metals.

The study's results showed that the uptake of Cr, Pb, and Cd by bedding begonia corresponded to the increasing level of substrate contamination, with higher accumulation of Cr and Pb in the roots than in the above-ground parts, regardless of the level of substrate contamination. This finding is in agreement with Sharma et al. (2004) who observed that Pb and Cr disrupt essential physiological processes in leaves, prompting plants to either prevent or reduce the movement of these elements from the roots to aerial parts.

The effectiveness of bedding begonia in removing Cr, Pb, and Cd from contaminated substrates was evaluated using the BAF and TF. Yoon et al. (2006) suggest that a plant species is suitable for phytoextraction if both BAF and TF are greater than 1 for at least one heavy metal. As shown in Table 6, the BAF and TF values for both Cr and Pb in bedding begonia were found to be below 1, regardless of the levels of substrate contamination. These results suggest that bedding begonia utilizes various mechanisms to limit the uptake of Cr and Pb from the growing medium and restrict their movement from the roots to the aerial parts. Achieving this can involve multiple strategies, such as complexing metals with organic compounds that are synthesized and released from the roots, or by sequestering Cr and Pb in various intracellular compartments of root cells (Emarverdian et al., 2015). In light of the above, bedding begonia does not appear to be a suitable candidate for phytoextraction of Cr and Pb from contaminated soil or other growth medium. It is visible that Cd BAF values were above 3 at all substrate contamination levels except control, indicating its strong ability to remove Cd from contaminated soil (Table 6). According to Huang et al. (2020), root cells take up Cd through plasma membrane transporters that are also responsible for the absorption of some essential nutrients, including calcium, magnesium, iron, and zinc. This explains why many plants can easily absorb Cd from the soil (Sun et al., 2022). The TF values for Cd in bedding begonia were high, with a range from 0.86 in control plants to 2.60 in those grown in a substrate with 100 mg/kg of Cd. This result suggests that this plant may be a promising species for the remediation of soils contaminated with Cd. Future studies will be necessary to confirm this hypothesis.

CONCLUSIONS

The current study demonstrated that bedding begonia can successfully grow in substrates enriched with Cr, Pb, and Cd. However, the BAF and TF values for Cr and Pb suggest that this plant is not a viable candidate for the removal of these heavy metals from polluted soils. In contrast, the plant demonstrates high BAF values for Cd across all levels of substrate contamination, except for the control group, indicating its substantial capability to remove Cd.

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