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Meet the editor

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Contents

Chapter 7

The Efficiency of Phytoremediation of the Big-Sage Plant in Accumulating Some Heavy Metals in Their Tissues *In Vitro*

Majid Ibrahim, Mahmood Hashim and Anfas Okash

Abstract

Concerning the controlled environment and media technique in these studies, *in vitro* phytoremediation analyses might provide more precise and reliable findings. Hence, this chapter pursued to estimate the efficacy of the shoot and root organs of big-sage (*Lantana camera (L.) Czern*.) plantlets in assembling heavy metals (cadmium, cobalt, and lead) *via* the plant tissue culture technique. Many examinations achieved on the phytoremediation of the *Lantana camara* seedlings to heavy metals *in vivo* demonstrated that they were assembled in the shoot organs at a higher concentration compared with the root organs of this plant. Thus, *L. camara* can be regarded as a higher accumulation potential plant for heavy metals such as lead, chromium, cadmium, nickel, and arsenic, and a favorable plant for phytoremediation. As for the examinations executed on the effect of different levels of the heavy metals cadmium, cobalt, and lead on their assemblage and some growth traits in the shoot and root organs of the *L. camera* plantlets beneath *in vitro* culture conditions, they discovered that the assemblage of these metals in the shoot and root organs increased with the increase in the treatment level, except for the heavy metal lead, which assemblage in the roots without the shoots.

Keywords: assemblage, BCF, cadmium, cobalt, heavy metal, TF

1. Introduction

Heavy metals are a special type of toxins that cannot be damaged into non-toxic shapes. The level of these toxic heavy elements has risen dramatically since industrial development [1]. These toxic metals can get into the soil directly *via* the usage of heavy elements and are a special kind of poison that cannot be degraded into non-toxic forms. The concentrations of these toxic heavy metals have advanced dramatically since industrial evolution [1]. These toxic heavy metals can reach into the soil presently by the use of pesticides and fertilizers or indirectly because of wastewater remains, factory emissions, and fossil fuel burning, which might make soils unsuited for cultivation if this trouble aggravates and rises by surpassing certain edges [2]. In

complement to selecting out of the agricultural specialization, soils polluted with heavy elements such as chromium, arsenic, lead, cadmium, copper, zinc, mercury, and nickel assess a significant risk to resources of groundwater through heavy elements filtering. Pollution of harvests cultivated in those soils passively impacts human health and food [3, 4]. The major attraction of environmental contamination investigations is discovering creative methods to rescue the environment from pollutants' damaging impacts [5]. Phytoremediation is a term usually supplied to the mechanisms by which living higher plants can completely attribute to the chemical impacts of the soil they are grown in. In other terms, it is an environmentally suitable technique to collect heavy metals in plant tissues to recycle contaminated soils. The origin of word phytoremediation came from the Greek term "Phyto," which means the plant and the Latin term "remedium," which demonstrates cleaning or rehabilitation [6]. Phytoremediation is a low-cost and practical method for operating soil in evolving countries [7]. The plant species utilized for this purpose are also found in several plant families, such as Asteraceae, Brassicaceae, Fabaceae, Poaceae, Euphorbiaceae, Verbenaceae, and Violaceae [8].

The big-sage (*Lantana camara L.*) plant is an ornamental evergreen shrub grown as a fence plant and the attractiveness of its flowers [9]. The original home of the *L. camara* plant is the subtropical and tropical regions of the American continent and in the tropical areas of Africa and Asia. This species was spread widely almost the world through the eighteenth, nineteenth, and twentieth centuries and evolved into a select evergreen shrub [10]. Further, this shrub earlier revealed favorable findings as shrub phytoremediation [11–14].

In vitro culture techniques include being near utilized in phytoremediation investigation [15–20]. Regarding the controlled environment and media technique in these investigations, *in vitro* phytoremediation examinations might provide more precise and dependable findings. Thus, this chapter desired to estimate the effectiveness of the root and vegetative tissues of *L. camara* seedlings in assembling heavy elements (cadmium, cobalt, and lead) via *in vitro* plant tissue culture conditions.

2. Botanical description of big sage (*L. camara* L.)

The *Lantana* genus has been described as shrubs of different species as the difference is in flower size, leaf shape and color, stem thorns, growth rates, shade tolerance, toxicity to organisms, chromosome number, and DNA content [21]. The big sage plant belongs to the family Verbenaceae, which includes 100 genera and about 2000 species. The genus Lantana has about 150 species that fall into the group of ornamental plants. As for its flowers, they are small in size and grouped in the form of small bouquets, ranging from 20 to 30 flowers in one inflorescence (**Figure 1**), as well as its fruits are of small size, and its seeds are solid and stone [22]. The *Lantana* shrub is characterized by ribbed stems covered with hairs and curved and sharp spines. It has opposite leaves, aromatic with a strong smell when crushed. This plant has cluster flowers of different colors; they may be white, yellow, pink, red, or orange. Its fruits are cluster aggregate, and each fruit contains a single seed inside it, which at the beginning of its growth takes a bright green color, and then turns to a blackish-purple color when it ripens [23]. These shrubs have many uses in the fields of health, as the oil extracted from the leaves and flowers of this plant has the property of acting as an antimicrobial and as a fungicide or insecticide to combat nematodes [9, 24].

Figure 1.
*The big-sage (*Lantana camara (L.) Czern*.) flowers.*

3. *In vivo* phytoremediation of *L. camara* for heavy-metal-polluted soil

One of the studies on the plants of *L. camara* and *Datura inoxia* planted on polluted sites such as industrial landfill areas, waste dumping areas, and mining mines indicated that they play a major role in controlling the accumulation and disposal of heavy metal pollutants [25].

A study was conducted on the phytoremediation of *L. camara* L. for soils contaminated with heavy metals resulting from factory wastes in the city of Bhopal in India. It was found that the leaves of *Lantana camera* plant had accumulated the largest amount of heavy metals in them compared with its branches. Chromium, lead, cadmium, and nickel accumulated in leaves at a concentration of 242.7, 262.2, 49.4, and 34.8 mg kg^{-1}, respectively, while the contents of heavy metals above accumulated in the vegetative branches were 72.3, 88.4, 28.8, and 22.8 mg kg^{-1}, respectively [13].

The study was maintained by Deepa et al. [26] to research the possibility of *L. camara* for the phytoremediation and accumulation of arsenic and nickel in the root and vegetative parts. The soil and plant samples utilized in this investigation were obtained from areas nearby Koradi Lake, the Northern of Nagpur, and then examined for arsenic and nickel levels. The accumulated heavy metals were analyzed utilizing an inductively connected plasma atomic emission spectrometer device. The arsenic and nickel concentrations in the soil were 2.29 mg L^{-1} and 58.344 mg L^{-1}, respectively.

The capability of plants to accumulate heavy metal from the soil was estimated by the bioconcentration factor, whereas their capability to translocate heavy metal from roots to vegetative parts was estimated by the translocation factor. On the basis of bioconcentration factor and translocation factor data, *L. camara* was determined as the phytoremediator for arsenic and nickel in contaminated soil. Nickel accumulated higher than the arsenic concentration in *L. camara*. These heavy metals accumulated in vegetative parts with more concentration compared with roots in this plant. Therefore, *L. camara* may be considered as an accumulator plant to nickel higher than arsenic heavy metal and a promising plant for phytoremediation.

4. *In vitro* phytoremediation of *L. camara* for some heavy-metal-polluted media

4.1 The aim of study

The effect of different concentrations of some heavy metals (cadmium, cobalt, and lead) on the vegetative and root growth characteristics of big sage (*L. camara* L.) plants under *in vitro* conditions and their efficiency in accumulating these elements [27].

4.2 Materials and methods

The study was conducted in the Plant Tissue Culture Laboratory, College of Agriculture, University of Basrah, Basrah, Iraq. The seeds of the local cultivar of the big sage (*L. camara* L.) plant obtained from Basrah nurseries were used. The fruits were soaked in sterile distilled water for 30 minutes to facilitate the removal of the fruit pulp. Then, the seeds were placed in a sterilizing solution of sodium hypochlorite at a concentration of 1.05% with the addition of three drops of Tween-20 for 20 minutes. Then, it was washed with distilled and sterile water thrice [27].

4.2.1 Preparation of nutrient medium

The nutrient medium was prepared from ready-made MS salts [28] at a concentration of 4.43 g L^{-1} obtained from Cassion Lab, USA (**Table 1**). Other chemicals were added to the MS medium (**Table 2**). The pH was adjusted to 5.7–5.8 with a solution of sodium hydroxide (NaOH) or hydrochloric acid (HCl) 0.1 N. Then add the agar at a concentration of 6 g L^{-1}. Then complete the MS to 1000 ml with distilled water. Then, the medium was heated to 90°C. After the medium became homogeneous and clear, the nutrient medium was poured into culture tubes of dimensions 2.5 × 18 cm (Pyrex) with a volume of 20 ml for each culture tube. Then, the tube nozzles were blocked with medical cotton, and the nozzles were wrapped with aluminum foil [27].

4.2.2 The proliferation of L. camara *plantlets under* in vitro *culture conditions*

Sterilized seeds of the big sage plant were cultured in MS medium without the addition of hormones to obtain seedlings from which the shoot tips are taken as explants for subsequent experiments. The regenerated shoots of the *L. camara* were produced from branch proliferation on MS medium supplemented with 0.6 mg L^{-1} BA and 0.1 mg L^{-1} NAA after 8 weeks of culturing (**Figure 2A**). Then, these proliferated shoots were rooted by growing them on an MS medium supplemented with

No.	Inorganic salts	Concentration (mg L^{-1})
1	Calcium chloride	332.02
2	Ammonium nitrate (NH_4NO_3)	1650
3	Magnesium sulfate ($MgSO_4$)	80.70
4	Boric acid (H_3BO_3)	6.2
5	Cobalt chloride ($CoCl_2.6H_2O$)	0.025
6	Cupric sulfate ($CuSO_4.6H_2O$)	0.025
7	Manganese sulfate ($MnSO_4.H_2O$)	16.90
8	Potassium iodide (KI)	0.83
9	Potassium nitrate (KNO_3)	1900
10	Potassium phosphate (KH_2PO_4)	170
11	Sodium molybdate ($Na_2MoO_4.2H_2O$)	0.25
12	Zinc sulfate ($ZnSO_4.7H_2O$)	8.60
Iron source		
13	Sodium EDTA (Na_2-EDTA)	37.26
14	Ferric sulfate ($FeSO_4.7H_2O$)	27.80

Table 1.
Inorganic nutrient components of MS medium [28].

No.	Inorganic salts	Concentration (mg L^{-1})
1	Sucrose	30,000
2	Glycine	1
3	Thiamin-HCl	1
4	Pyridoxin-HCl	1
5	Nicotinic	1
6	Adenine sulfate	40
7	Sodium hydrogen orthophosphate	170
8	Poly vinyl pyrrolidone (PVP)	1000
9	Phyto-agar	6000

Table 2.
Inorganic nutrient components of MS medium [27].

1.0 mg L^{-1} naphthalene acetic acid (NAA) and 0.1 mg L^{-1} benzyl adenine (BA) (**Figure 2B**). The plantlets having three pairs of leaves per plantlet were utilized in the accumulation of heavy metal investigations [27].

4.2.3 Heavy metal accumulation in root and vegetative part experiment

Plantlets were cultivated on the MS media supplemented with 0.0, 0.2, 0.4, 0.6, and 0.8 mg L^{-1} of Co ($CoCl_2.6H_2O$), Cd ($CdCl_2.2H_2O$), or Pb ($Pb(NO_3)_2$) [27]. After 30 days of cultivating, the subsequent data were registered:

1. Estimation of heavy metals content in the root and vegetative parts, cobalt, cadmium, and lead, according to Ref. [29] utilizing an atomic absorption spectrophotometer device (Phoenix-986 model) at wavelengths of 228.8, 240.7, and 283.3 nm, for Co, Cd, and Pb, respectively.

2. The bioconcentration factor (BCF) was estimated by the subsequent equation: BCF = Heavy metal concentration in vegetative and root parts/heavy metal concentration in MS medium [30].

3. The translocation factor (TF) was estimated by the following equation: TF = Heavy metal concentration in vegetative part/Heavy metal concentration in root part [30].

The investigations were designed by utilizing a randomized complete design. Each treatment included 10 replications (10 plantlets). The data were analyzed by utilizing analysis of variance with the statistical program SPSS Version 22. The treatments were compared between them utilizing the revised least significant difference test (R-LSD) at a probability level of 5% [31].

4.3 The heavy metal accumulation in *L. camara*

4.3.1 The heavy metal accumulation in vegetative organs

The increase in cadmium concentration that was added to the MS medium caused a significant increase in cadmium accumulation in the vegetative parts of the *L. camara* plant after 4 weeks of cultivating (**Table 3**) [27]. The 0.8 mg L^{-1} cadmium was significantly greatest than other treatments (0.192 mg kg^{-1} cadmium). This finding is in accord with the findings acquired by Kališová-Špirochová et al. [16], who investigated cadmium assembly in *Helianthus annuus*, *Populus tremula* × *tremuloides*, and *Zea mays*, and Milusheva et al.'s [19] investigation on *Petunia* × *hybrida* and *Ageratum houstonianum via* tissue culture technique. The findings also agree with the findings acquired by [32] when investigating the phytoremediation possibilities of the *Brassica juncea (L.) Czern*., where an accumulation in cadmium concentration in the vegetative parts was noticed when the added concentration enhanced.

Parallel to cadmium, the assemblage of cobalt in the vegetative parts raised significantly with the enhancement of its concentration in the MS medium after

Figure 2.
Micropropagation of Lantanta camara *shrub; A—shoot multiplication; B—rooting shoots [27].*

Treatment concentration of Cd, Co, or Pb (mg L^{-1})	Accumulated heavy metal concentration (mg kg^{-1})		
	Cd	Co	Pb
0.0	—	—	—
0.2	0.015	0.055	—
0.4	0.063	0.180	—
0.6	0.132	0.228	—
0.8	0.192	0.326	—
R-LSD P ≤ 0.05	0.018	0.044	—

Table 3.
In vitro *accumulation of cadmium, cobalt, and lead in the vegetative organs of the* Lantana camara *shrub [27].*

4 weeks of cultivating (**Table 3**). The 0.8 mg L^{-1} cobalt registered the most increased cobalt accumulation among the examined concentrations reaching 0.326 mg kg^{-1}. No indications of toxicity were detected in the plants, which show that the *L. camara* is a phytoremediator that accumulates heavy metals without impacting its growth. These findings were alike to Al-Wahaibi's [33] findings, which indicated that assembling heavy metals in these plants is a natural direction for them.

Regarding lead accumulation, there was no lead assemblage in the vegetative parts in any the examined concentrations (**Table 3**). Comparable findings were registered in other plant species where lead assemblies were in the root parts instead of the vegetative parts [34].

4.3.2 Heavy metal accumulation in the root organs

Cadmium and cobalt concentrations of roots significantly accumulated with each rising in cadmium and cobalt concentrations in the MS medium (**Table 4**). The treatment of 0.8 mg L^{-1} concentration of cadmium or cobalt caused the highest metal accumulation reaching 0.318 mg kg^{-1} cadmium and 0.312 mg kg^{-1} cobalt.

Furthermore, lead assembled in root parts was noticed under 0.6 and 0.8 mg L^{-1} lead only, with the last recording the highest lead amount reaching 0.627 mg kg^{-1} lead (**Table 2**). The findings of the current investigation oppose previous results on different plant species, as they noticed the assemblage of lead in both vegetative and root parts [15, 16, 18, 20].

Treatment concentration of Cd, Co, or Pb (mg L^{-1})	Accumulated heavy metal concentration (mg kg^{-1})		
	Cd	Co	Pb
0.0	—	—	—
0.2	0.099	0.013	—
0.4	0.148	0.117	—
0.6	0.198	0.166	0.501
0.8	0.318	0.312	0.627
R-LSD P ≤ 0.05	0.018	0.044	0.052

Table 4.
In vitro *accumulation of cadmium, cobalt, and lead in the root organs of the* Lantana camara *shrub [27].*

4.3.3 Bioconcentration factor (BCF)

Bioconcentration is the concentration of a specific heavy element in the tissues of a plant in comparison with the plant's enclosing concentration of that element [27]. Accordingly, BCF is a necessary indicator of the response of plants to the existence of heavy metals in their environment and a direct indicator of the phytoremediation possibilities. The highest bioconcentration factor values for the cadmium and cobalt examined elements were noticed under 0.8 mg L^{-1} concentration for both metals, with 0.32 and 0.4 in cadmium and cobalt investigations, respectively (**Table 5**). Cadmium BCF under 0.8 mg L^{-1} concentration was significantly more increased than that of 0.4 mg L^{-1} concentration of this metal. Nevertheless, no significant differences were registered between cd BCF values under 0.2, 0.6, and 0.8 mg L^{-1} concentrations of cadmium. Furthermore, there were no significant differences in BCF factor between 0.4, 0.6, and 0.8 mg L^{-1} concentrations of cobalt (**Table 5**). The present results are alike to those of findings in Ref. [32] for the BCF factor of cadmium in *B. juncea (L.) Czern*.

As for the lead treatments, 0.6 mg L^{-1} Pb concentration registered the highest bioconcentration factor data; regardless, there was no significant distinction between bioconcentration data under 0.6 and 0.8 mg L^{-1} concentrations of lead (**Table 5**).

4.3.4 Translocation factor (TF)

The translocation factor means the level of contaminants assembled in the shoot organs of a plant to those in the root organs [27]. The most increased translocation value in the cadmium investigation was noticed under 0.6 mg L^{-1} cadmium level (0.67), which was significantly more increased than further levels (**Table 6**). This finding indicates the efficacy of *L. camara* in the translocation of cadmium from the root organs to the shoot organs. Alike findings were acquired by [35] for the transport of cadmium in *Populus alba* and *Morus alba* trees.

About cobalt, the MS medium with a level of 0.2 mg L^{-1} cobalt was significantly excellent compared with the other treatments with a translocation factor value reaching 4.23.

Furthermore, the TF of lead for all treatments was equal to zero since no lead assemblage was noticed in the shoot organs (**Table 6**).

It was apprised that the perfect plant for phytoremediation should be capable to absorb and assemble heavy metals from contaminated soils and have specific

Treatment concentration of Cd, Co, or Pb (mg L^{-1})	Bioconcentration factor (BCF)		
	Cd	Co	Pb
0.0	—	—	—
0.2	0.29	0.17	—
0.4	0.26	0.37	—
0.6	0.28	0.33	0.42
0.8	0.32	0.40	0.39
R-LSD $P \leq 0.05$	0.06	0.20	Non-significant

Table 5.
In vitro *bioconcentration factor (BCF) of Cd, Co, and Pb in* Lantana camara *shrub [27].*

Treatment concentration of Cd, Co, or Pb (mg L^{-1})	Translocation factor (TF)		
	Cd	Co	Pb
0.0	—	—	—
0.2	0.15	4.23	—
0.4	0.43	1.54	—
0.6	0.67	1.37	—
0.8	0.60	1.05	—
R-LSD P ≤ 0.05	0.05	2.80	—

Table 6.
In vitro *translocation factor (TF) of Cd, Co, and Pb in* Lantana camara *shrub.*

characteristics such as deep and dense roots, large biomass, and rapid growth [36]. This study findings revealed that big sage (*L. camara* L.) could be an active phytoremediator in soils contaminated with cadmium and cobalt because of the suitable translocation factors of these heavy metals.

4.4 The impact of different concentrations of some heavy metals on some growth indicators of *Lantana camera* under *in vitro* culture conditions

4.4.1 Cadmium (Cd)

The data in **Table 7** indicate that there is no significant effect of the heavy metal cadmium concentrations in plantlet height, compared with the control treatment. It is also noted from the same table that there is no significant effect in each of the characteristics of the leaf numbers and the shoot dry weights among all treatments. While the addition of the cadmium heavy metal to the MS medium had a significant effect, as the plantlets treated with a concentration of 0.8 mg L^{-1} were significantly superior in the total shoot fresh weights, reaching 0.461 g, compared with the other treatments [27].

The data of the phytoremediation in **Table 7** for the *Lantana camera* plant show that there is no significant effect of different cadmium concentrations among all treatments in each of the shoot numbers $plantlet^{-1}$, leaf area (cm^2), and total chlorophyll content of the leaves (mg.100 g^{-1} fresh weight) (**Figure 3**).

The reason may be attributed to the use of plants to absorb these heavy metals from the culture media and translocate them to the vegetative organs or convert them into volatile compounds using the phytovolatilization technique. This technique exploits the ability of some plants to convert some heavy elements into volatile compounds for disposal [38].

The reason for this may be because the plant is a natural phytoremediator, as it can accumulate the contaminant, break it down, or assemble it in its biomass, and it is characterized by being a fast-growing plant and having a large biomass and having a widespread root system [39].

The data in **Table 8** show the effect of cadmium on the root growth indicators of the *L. camara* plantlets. It is noted that there are no significant differences in the number of main roots per plantlet in all treatments. It is also observed from the same table that there were no significant differences among all cadmium treatments in each of the root length and dry weight characteristics, while the data are shown in the same table

Cd concentration (mg L^{-1})	Plantlet height (cm)	Leaf numbers per plantlet	Fresh weight of vegetative parts (g)	Dry weight of vegetative parts (g)	Shoot numbers per plantlet	Leaf area (cm^2)	Total chlorophyll content (mg 100 g^{-1} FW)
0	7.27	4.00	0.113	0.035	2.67	1.80	1.424
0.2	7.47	10.67	0.233	0.030	4.00	2.63	1.746
0.4	10.23	5.33	0.170	0.026	2.67	1.93	2.029
0.6	9.03	8.67	0.240	0.025	2.67	2.40	1.857
0.8	10.13	7.67	0.461	0.048	3.33	2.37	2.042
R-LSD ($p \leq 0.05$)	NS*	NS	0.150	NS	NS	NS	NS

NS: Non-significance.

Table 7.
Effect of different concentrations of cadmium on some vegetative growth of Lantana camara *shrub [37].*

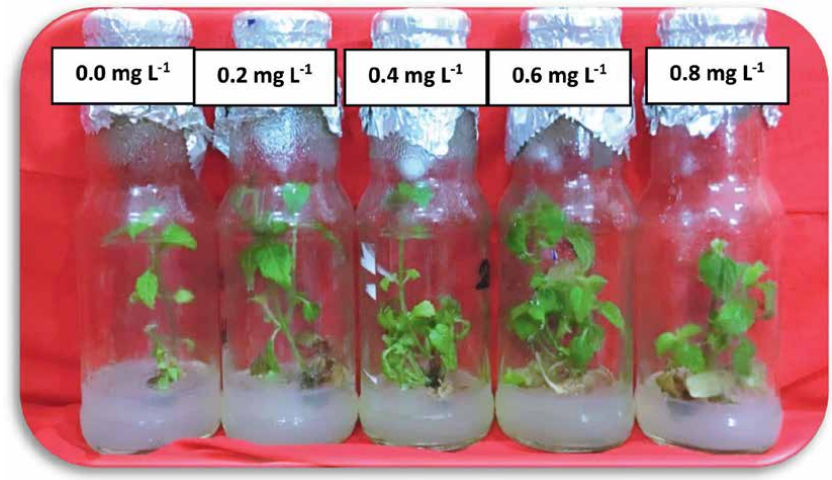

Figure 3.
Effect of different concentration of cadmium on plantlet growth of Lantana camara *shrub [37].*

Cd concentration (mg L^{-1})	Root numbers per plantlet	Root length (cm)	Fresh weight of root parts (g)	Dry weight of root parts (g)
0	4.33	2.57	0.026	0.009
0.2	5.67	2.77	0.050	0.021
0.4	3.33	3.77	0.041	0.010
0.6	3.67	4.70	0.062	0.011
0.8	5.00	4.87	0.114	0.015
R-LSD ($p \leq 0.05$)	NS*	NS	0.018	NS

**NS: Non-significance.*

Table 8.
Effect of different concentrations of cadmium on some root growth of Lantana camara *shrub [37].*

that there was a significant effect in the fresh weight of the roots in the MS medium to which the cadmium heavy metal was added. The MS medium supplemented with 0.8 mg L^{-1} cadmium was significantly superior in the root fresh weight, reaching 0.114 g. This is explained as the ideal concentration of *L. camara*. Despite the toxicity of the lead element, the big-sage shrub showed a phytoremediator for this heavy metal.

This can be explained by our findings is the ability of the big-sage plant to accumulate and be tolerant to cadmium heavy metal. Al-Wahaibi [40] indicated the characteristics of the accumulating plants when they absorb heavy elements, they stimulate the form of chelating compounds that surround the atoms of the contaminating elements and keep them within the vacuoles found in the cells of plant tissues.

4.4.2 Cobalt (Co)

Table 9 shows the effect of different concentrations of the heavy element cobalt on the vegetative growth indicators (**Figure 4**). The data showed that there was no significant effect on the characteristics of each of the plant's height (cm), leaf numbers, and the fresh and dry weights of the shoots (g) among all treatments [27].

Co concentration (mg L^{-1})	Plantlet height (cm)	Leaf numbers per plantlet	Fresh weight of vegetative parts (g)	Dry weight of vegetative parts (g)	Shoot numbers per plantlet	Leaf area (cm^2)	Total chlorophyll content (mg 100 g^{-1} FW)
0	7.27	4.00	0.113	0.0260	2.67	1.80	1.424
0.2	7.50	8.33	0.213	0.0150	2.00	1.57	1.555
0.4	6.73	5.67	0.100	0.0203	2.67	1.80	1.819
0.6	7.57	4.00	0.142	0.0167	2.33	2.70	2.019
0.8	6.73	7.00	0.112	0.0193	2.67	3.00	2.097
R-LSD ($p \leq 0.05$)	NS*	NS	NS	NS	NS	1.043	NS

NS: Non-significance.

Table 9.
Effect of different concentrations of cobalt on some vegetative growth of Lantana camara *shrub [37].*

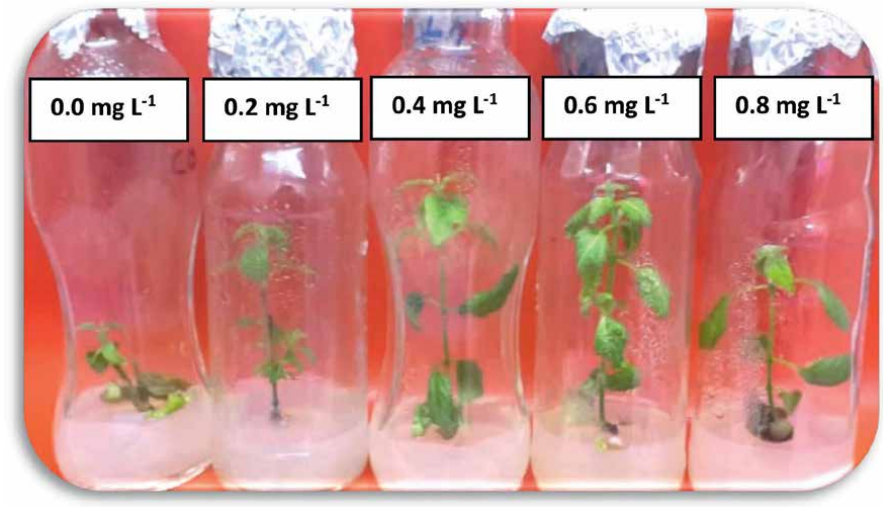

Figure 4.
Effect of different concentration of cobalt on plantlet growth of Lantana camara *shrub [37].*

Table 9 includes the effect of different cobalt heavy metal concentrations on the shoot numbers per plantlet. There was no significant effect of the element cobalt in this characteristic among all treatments. The addition of cobalt to the MS medium had no significant effect on the total chlorophyll content of leaves in all treatments.

The different concentrations of the heavy element cobalt had a significant effect on the leaf area. The treatment with 0.8 mg L^{-1} cobalt showed a significant effect on the leaf area, reaching 3.00 cm^2 compared with other treatments, except for the treatment with 0.6 mg L^{-1} cobalt, which did not differ significantly from it, reaching 2.70 cm^2.

The reason for this is that the heavy metal ions that enter the cell are associated with the chelators and companions. These chelating compounds remove the toxicity of metals by transporting minerals to the cytosol, while the companion transfer minerals to the organelles to reach the proteins that require metal. There are many chelating metal compounds and well-known chelators in plants, including phytochelatins, metallothioneins, organic acids, and amino acids [41].

The data of **Table 10** showed the effect of adding different cobalt concentrations of the MS medium on root growth indicators of *L. camara*. It was observed that there

Co concentration (mg L^{-1})	Root numbers per plantlet	Root length (cm)	Fresh weight of root parts (g)	Dry weight of root parts (g)
0	4.33	2.57	0.026	0.004
0.2	3.00	1.93	0.032	0.009
0.4	3.67	1.43	0.044	0.009
0.6	3.33	2.47	0.009	0.003
0.8	4.67	2.67	0.055	0.007
R-LSD ($p \leq 0.05$)	NS*	NS	0.028	NS

**NS: Non-significance.*

Table 10.
Effect of different concentrations of cobalt on some root growth of Lantana camara *shrub [37].*

Pb concentration (mg L^{-1})	Plantlet height (cm)	Leaf numbers per plantlet	Fresh weight of vegetative parts (g)	Dry weight of vegetative parts (g)	Shoot numbers per plantlet	Leaf area (cm^2)	Total chlorophyll content (mg 100 g^{-1} FW)
0	7.27	4.00	0.113	0.026	2.67	1.80	1.424
0.2	5.53	6.00	0.347	0.046	2.67	2.20	1.600
0.4	5.47	6.33	0.237	0.032	2.33	2.50	1.966
0.6	6.07	7.33	0.376	0.047	2.67	2.43	1.642
0.8	6.33	5.67	0.165	0.034	3.67	2.93	1.737
R-LSD ($p \leq 0.05$)	NS*	NS	NS	NS	NS	NS	NS

NS: Non-significance.

Table 11.
Effect of different concentrations of lead on some vegetative growth of Lantana camara *shrub [37].*

was no significant effect on some root growth characteristics, including the main root numbers per the plantlet, root length, and root dry weights.

The contamination of the MS medium with cobalt had a significant effect on the total root fresh weights. The treatment at 0.8 mg L^{-1} cobalt was significantly superior in this characteristic, reaching 0.055 g compared with the treatments at 0.6 mg L^{-1} cobalt and the control, which reached 0.026 g.

The reason for this may be that plants exposed to high levels of cobalt, more than the permissible levels of heavy metals, show symptoms of toxicity due to excessive treatment of cobalt, which is more than what most species need. Moreover, cobalt toxicity rarely occurs when plants are exposed to low levels [42]. Therefore, the *L. camara* shrub showed tolerance for this heavy metal.

4.4.3 Lead (Pb)

The data in **Table 11** show that there are no significant differences in the characteristics of vegetative organs, plantlet height (cm), leaf numbers, and fresh and dry weights of the shoot (g) of *L. camara* shrub grown in MS media that supplemented with different concentrations of lead heavy metal (**Figure 5**) [27].

The data in **Table 11** show that there were no significant differences when the MS medium was contaminated with lead after 1 month of the experiment in each of the characteristics of the number of leaves per shoot, leaf area (cm^2), and total chlorophyll content of leaves (mg 100 g^{-1} fresh weight).

The data of **Table 12** indicate that there are no significant differences when adding lead at the different concentrations in the MS medium in each of the characteristics of the main root numbers per the plantlet, root length (cm), and the fresh and dry weights of the root parts (g).

This can be explained by the limited transport of lead through the root, as a result of the precluding caused by the Casparian strip in the root endodermis, which prevents the translocation of lead through the endodermis to the central vascular cylinder tissues.

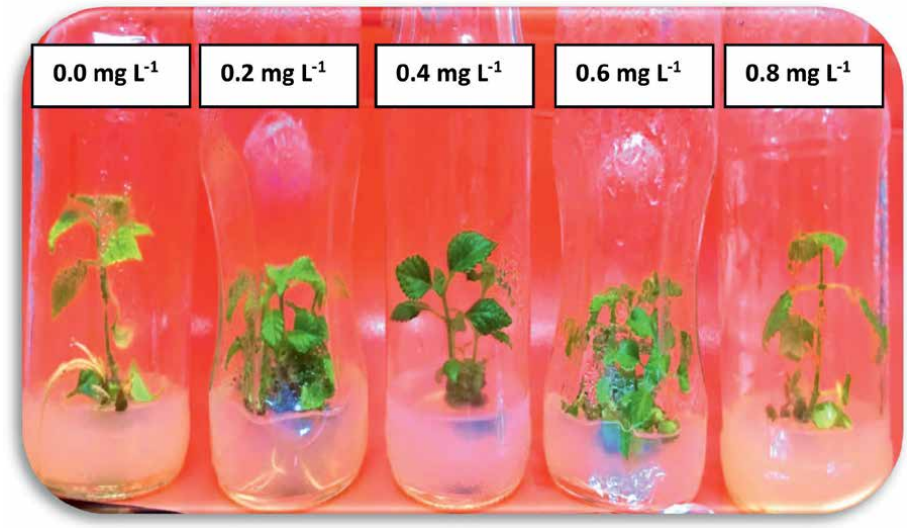

Figure 5.
Effect of different concentration of lead on plantlet growth of Lantana camara *shrub [37].*

Pb concentration (mg L^{-1})	Root numbers per plantlet	Root length (cm)	Fresh weight of root parts (g)	Dry weight of root parts (g)
0	4.3	2.57	0.026	0.0090
0.2	9.3	3.73	0.151	0.0227
0.4	4.7	5.23	0.051	0.0137
0.6	5.7	5.23	0.214	0.0293
0.8	6.0	3.63	0.036	0.0237
R-LSD ($p \leq 0.05$)	NS*	NS	NS	NS

NS: Non-significance.

Table 12.
Effect of different concentrations of lead on some root growth of Lantana camara *shrub [37].*

Whereas the accumulation of lead depends on the species, variety, and plant organ, and then increases in the accumulation within the root organs compared with the vegetative organs, and then a decrease occurs in some characteristics of the vegetative organs such as total fresh weight of the shoots when the concentration of lead is increased, which causes a difference in the characteristics of the roots at the expense of the characteristics of the vegetative parts [43].

5. Conclusions

It is concluded from the studies conducted on testing the Lantana camera plant growing in soils and tissue cultures contaminated with heavy elements that it can be exploited as a promising ornamental plant in the phytoremediation of heavy metals such as lead, cadmium, cobalt, arsenic, and nickel. The accumulations of heavy elements in the vegetative organs were higher than the root organs. The accumulation of heavy metals in the tissues of this plant did not significantly affect some growth characteristics.

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Conflict of interest

The authors declare no conflict of interest.

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