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Bioremediation of Soil Contaminated with Lead and Cadmium by Using Plant Indian Mustard and Canna

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Abstract. The current study focused on comparing two types of plants, *Brassica juncea L* and *Canna generalis*, in the bioremediation of soil contaminated with heavy metals, as well as evaluating the plant contamination with lead and cadmium according to global pollution standards. The experiment was carried out in the shade of the College of Agriculture at Al-Qadisiyah University, using a clay soil mixture collected from the agricultural departments of the directorate of Agriculture in Al Diwaniyah province, to assess the efficiency of Indian mustard and canna plants in the bioremediation of heavy metal-contaminated soil. Four levels of lead and cadmium concentrations were added to the soil before planting as nitrates for each element and left for 10 days to reach equilibrium. Indian mustard and canna plants were planted on 9/9/2023, and the total concentration of heavy metals was estimated before planting and after the experiment ended on 16/12/2023. The root and shoot parts were washed with tap water and then with distilled water, dried, and ground for digestion to determine their ability to absorb heavy metals as a key factor for phytoremediation according to the standards of plant pollution represented by the biological accumulation coefficient (BAC), the biological concentration factor (BCF), and the translocation factor (TF). The results show an increase in the concentration of lead and cadmium in the shoot and root parts of both Indian mustard and canna plants within increasing levels of addition. Indian mustard plants generally showed good accumulation of cadmium in their root part, exceeding a BCF value, while their ability to transfer lead and cadmium from the root part to the shoot part was weak. As for the canna plant, the results indicated its weak capacity to transfer lead from the roots to the shoot part, and it demonstrated superiority over Indian mustard in accumulating cadmium, due to higher values of BCF, BAC, and TF.

Keywords. Bioremediation, Heavy metals, Soil Contaminated.

1. Introduction

Environment pollution is increasing as a result of massive economic development and rapid expansion of many fields, such as agriculture and industry. Heavy metal pollution is a global issue due to health risks associated with metal contamination. Their risk increases when they remain in the soil or are exposed to any chemical changes, leading to contamination of plants and crops consumed by humans, negatively affecting their health (Li *et al*., 2023). Heavy metals well-known environmental pollutants

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owing to their toxicity, refer to a group of comparatively dense and harmful elements, even in very low concentrations, which possess densities higher than 5 g/cm³, and largely belong to the transition elements in the periodic table with an atomic number greater than 20 (Liu *et al.,* 2009). Biologically they harm plants even in small quantities. In urban and rural environments, accumulation of one or more heavy elements beyond specified reference values poses health risks to the ecosystem, as well as to humans, animals, and plants (Wang *et al.,* 2014). Despite the negative impact of polluted soil on plants, many plant species can tolerate high concentrations of these elements without affecting their growth. These plants can be utilized in the remediation and rehabilitation of soil contaminated with heavy metals by removing or restricting the movement of pollutants in the soil or water through their chemical, biological, and physical activities. They can also be adapting to growth in heavy metal-contaminated soil through absorption, distribution, and regulation of elements within plant tissues (Sharma *et al.,* 2023).

These plant species should have high biomass, rapid growth, and active accumulators of heavy metals, metal tolerance, and an advanced root system. Indian mustard, Brassica juncea (L.) is an economically important, edible oilseed crop of Brassicaceae family, Abdel-Wahab (2020) previously pointed out its efficiency in withdrawing and accumulating some substance in its tissues. Canna generalis, commonly known as the Canna plant, belongs to the Cannaceae family, as Abdul Karim (2022) was indicated that the plant efficiently accumulates tomatoes in one harvest. The current study aims to evaluate the efficiency of *Brassica juncea L* and *Canna generalis* in remediating soils contaminated with lead and cadmium according to internationally accepted standards, represented by the biological concentration factor (BCF), biological accumulation coefficient (BAC), and translocation factor (TF).

2. Materials and Methods

The biological experiment was carried out in plastic pots in the shade belonging to the College of Agriculture-University of Al-Qadisiyah in the village of Al-Nawariyah, affiliated with the Al-Shafi'iya district, for the summer agricultural season of 2023/9/9. A mixed clay texture soil was used, taken from one of the fields of the Horticulture Station under the Department of Agriculture of Al Diwaniyah at a depth of 0-30 cm. The soil was air-dried, ground with a wooden hammer, and sieved with a 4 mm diameter sieve for planting in plastic pots with a capacity of 12 Kg, with a diameter of 28 cm, a base diameter of 23 cm, and a height of 32 cm. A portion of the soil was sieved with a 2 mm diameter sieve for chemical and physical analysis before planting, and 10 kg of soil was placed in each pot. Heavy elements were added to the soil in a homogeneous solution not exceeding the field capacity, in the form of sulfates for two elements (lead and cadmium), and left for 10 days to reach equilibrium. The Completely Randomized Design (CRD) was used in the experiment with four different plant species for heavy elements (Pb, Cd) and three replicates, resulting in a total of 24 experimental units, as follows:

2.1. The First Factor: the concentrations of elements in addition to clarity in Table 1.

Table 1. Concentrations of heavy metals used in the experiment for different treatments (mg kg^{-1}).

Element	First Treatment T1	Second Treatment T2	Third Treatment T3	Fourth Treatment T4
Cd	Zero	5	15	25
Pb	Zero	50	100	200

2.2. The Second Factor: the type of plant Brassica juncea L

2.2.1. Canna Generalis

Young cannas seedlings were planted, one week old, at a rate of two plants per mound on 9/9/2023. After a week, thinned the plants down to one plant. Approximately 3 grams per serving of organic humic fertilizer was added to the soil in accordance with the fertilizer recommendations. After 40 days from planting, a plant stimulant, (Terra-Sorb Spanish type 7), at a rate of 2 cc per liter was added to preserve the plant from wilting. Additionally, Indian mustard seeds were sown with about 5 seeds per pot on 9/9/2023, then thinned down to two plants after 30 days from planting. Chemical fertilizer NPK was added to the soil per pot according to fertilizer recommendations, which was approximately 3 g per Serving and watering was done using tap water based on field capacity, continuing irrigation after using up to 50% of the available water.

2.2.2. Laboratory Tests

- Soil samples were taken before planting for chemical and physical analysis following the method described by Day *et al.* (1965) and Page *et al.* (1982). The total concentration of heavy metals (lead and cadmium) was determined before and after the biological experiment using the method outlined by Jones *et al*(2001) .
- After the biological experiment, plant samples were collected, washed thoroughly with water, air-dried, ground using an electric grinder, sieved through a 2 mm sieve, and subjected to digestion of the root and shoot parts using concentrated acids. The samples were then analyzed using an Atomic Absorption Spectrometer following the procedure described by Jones *et al.* (2001).

2.2.3. Calculate plant pollution standards

- Bioconcentration factor (BCF)

$$\mathrm{BCF} = [Metal]_{Root} \big/ [Metal\ ]_{Soil} \quad (1)$$

- Bioaccumulation Coefficient (BAC):

$$\mathrm{BAC} = [Metal]_{Shoot} \big/ [Metal\ ]_{Soil} \quad (2)$$

- Translocation factor (TF)

$$\mathrm{TF} = [Metal]_{Shoot} \big/ [Metal\ ]_{Root} \quad (3)$$

Table 2. Chemical and physical characteristics and properties of biological soil before planting.

Characteristics		Value	Units
Electrical Conductivity EC 1:1		3.64	DC-Siemens M^{-1}
pH 1:1		7.3	----
Cation Exchange Capacity		21.17	centimole-charge/kg^{-1} soil
Organic Matter O.M		7.9	gm kg^{-1}
Calcium Carbonate CaCO3		19.41	
Soluble Positive Ions	Calcium Ca2+	10.17	
	Magnesium Mg2+	8.42	
	Potassium K+	0.52	
	Sodium Na+	4.26	mmol L^{-1}
Soluble Negative Ion	Carbonate CO3-	Nil	
	Bicarbonate HCO3-	1.52	
	Sulphate SO42-	5.86	
	Chloride Cl1-	19.69	
Available Elements	Nitrogen N	18.00	mg kg^{-1} soil
	Phosphorus P	13.00	
	Potassium K	135.00	
Heavy Metals	Lead Pb2+	8.59	mg kg^{-1} soil
	Cadmium Cd2+	1.12	
Soil Fractions	Sand	225.00	gm kg^{-1} soil
	Silt	385.00	
	Clay	390.00	
Texture Class		Clay loam mixture	----

Characteristics	Value	Units
Apparent Density	1.45	Mg m^{-3}
Real Density	2.65	
Moisture Content at Field Capacity	1.74	cm3 cm^{-3}

2.3. Statistical Analysis

The results were statistically analyzed after conducting an experimental study using the Complete Randomized Design (CRD) with three repeats. The treatment means were compared using the Least Significant Difference (LSD) test at a significance level of 5% using SPSS software.

3. Results and Discussion

3.1. Heavy Elements in the Soil After the End of the Biological Experiment

3.1.1. Total Lead Concentration

Table 3 shows the total lead concentration in soil planted with Indian mustard and canna plants at the end of the experiment. The results of the statistical analysis indicated significant differences between the different treatments for each plant. The lead concentration in soil planted with Indian mustard was 5.67, 30.73, 56.92, and 153.05 mg Pb kg^{-1} for treatments T1, T2, T3, and T4, respectively, while its concentrations in the canna plant soil reached 6.02, 31.58, 58.43, and 129.35 mg kg^{-1} in the corresponding treatments respectively.

Table 3. Total lead concentration in the soil grown with Indian mustard and canna plants for the different treatments after the end of the experiment (mg kg^{-1} soil).

Type of plant	Treatments				Average Plant Type
	T1	T2	T3	T4	
Brassica juncea L	5.67	30.73	56.92	153.05	61.59
Canna	6.02	31.58	58.43	129.35	56.35
LSD	6.297				3.149
Average addition	5.84	31.16	57.67	141.2	
LSD	4.453				

These results indicate that the highest concentration was in the soil planted with Indian mustard plants at treatment T4, reaching 153.05 mg/kg^{-1}. This was followed by the soil planted with Canna plants, with a concentration of 129.35 mg/kg-1. It is clear that the plants with the highest lead absorption were in the soil planted with Canna plants, followed by Indian mustard plants. The average concentrations of lead in the soil for the different treatments reached 61.59 and 56.35 mg Pb kg^{-1} for Indian mustard and Canna plants, respectively. The soil planted with Canna plants differed significantly from the soil planted with Indian mustard plants. This indicates that Canna plants have a higher capacity and efficiency in absorbing lead from the soil compared to Indian mustard plants.

A concentration increase is noticed in response to an increase in the amount of lead added to the soil, regardless of the concentration of lead added. The average lead concentrations in the soil were 5.48, 31.16, 57.67, and 141.2 mg Pb kg^{-1} soil for treatments T1, T2, T3, and T4, respectively. This is consistent with findings by Karim *et al*. (2022) and Talib (2023) who indicated an increase in total lead concentration in the soil with higher levels of lead addition. When comparing the total lead concentration in the study soil and both plants under treatment T3 with the guidelines of the World Health Organization and the Food and Agriculture Organization (WHO & FAO, 2007), it was significantly reduced to within the permissible limits of 100 mg Pb kg^{-1} soil. This indicates the ability of those plants to absorb lead and accumulate it in their tissues.

3.1.2. Total Cadmium Concentration

The results in Table 4 show the concentrations of total cadmium in the soil planted with Indian mustard and canna plants, with significant differences for the four treatments of each plant. The concentrations of cadmium in the soil planted with Indian mustard were 66.0, 3.04, 5.36, and 19.05 mg Cd kg^{-1} soil for treatments T1, T2, T3, and T4, respectively. Whereas the concentrations of cadmium in the soil planted with canna plants were 0.23, 2.25, 4.4, and 6.65 mg kg^{-1} for the above treatments.

Table 4. Total cadmium concentration in the soil grown with Indian mustard and canna plants for the different treatments after the experiment (mg kg^{-1} soil).

Type of plant	Treatments				Average Plant Type
	T1	T2	T3	T4	
Brassica juncea L	0.66	3.04	5.36	19.05	7.30
Canna	0.23	2.25	4.04	6.65	3.29
LSD	1.102				0.551
Average addition	0.45	2.65	4.70	12.85	
LSD	0.779				

The results above show that the highest concentrations were in the soil planted with Indian mustard, 19.05 mg Cd kg^{-1} soil for treatment T4, followed by the soil planted with canna which 6.65 mg Cd kg^{-1} soil for the same treatment, indicating the high ability of canna plants to absorb cadmium compared to Indian mustard. The average cadmium concentrations for the different treatments were 7.30 and 3.29 mg Cd kg^{-1} soil for Indian mustard and canna plants respectively. Statistical analysis results indicate that adding different concentrations of cadmium had a significant effect on increasing the total cadmium concentration in plant soil with increasing addition levels, reaching 0.45, 2.65, 4.70, and 12.85 mg Cd kg^{-1} soil for treatments T1, T2, T3, and T4 respectively. This is consistent with the findings of Alawsy *et al.* (2024) who showed an increase in cadmium concentrations with increasing added concentrations to the soil.

3.2. Heavy Metals in Plants After the End of the Biological Experiment

3.2.1. Heavy Metals in Plant Roots

The results in Table 5 show that, the concentrations of lead in the roots of Indian mustard and canna plants after the experiment. These results show significant differences within each plant among the different treatments. Lead concentrations in Indian mustard were 2.83, 11.61, 27.6, and 47.1 mg Pb kg^{-1} soil for treatments T1, T2, T3, and T4, respectively. Meanwhile, lead concentrations in canna plants were 3.00, 18.57, 30.31, and 50.47 mg Pb kg^{-1} soil for the aforementioned treatments.

These results indicated that the highest concentration of lead was found in the root system of the canna plant at 50.47 mg/kg^{-1} under treatment T4, followed by the root system of the Indian mustard plant at 47.1 mg/kg^{-1} at the same level. This is consistent with the findings of Olga *et al.* (2009), who suggested an increase in lead concentration in the root system of plants with an increase in soil concentration, especially after observing significant differences between the various treatments in lead concentration in the root total compared to plants grown in lead-free soil.

Statistical analysis results indicate significant differences in the average concentrations of lead in the soil between the canna plant and Indian mustard plant soil. The lead concentration in canna soil was 25.59 mg Pb kg^{-1} soil, compared to 22.28 mg Pb kg^{-1} soil in Indian mustard plant soil. This suggests that the canna plant has a higher capacity and efficiency in absorbing and accumulating lead in the root system compared to the Indian mustard plant, highlighting canna's higher ability to absorb lead from contaminated soil compared to the Indian mustard plant.

The increase in the root system volume of canna plants compared to Indian mustard plants leads to enhanced absorption of readily available lead from the soil, drawing and accumulating it in the roots. This is consistent with the findings of Evans *et al.* (2003), who demonstrated that an increase in the root system volume of plants leads to increased secretion in the root zone, which in turn reduces soil reactivity and increases the availability of lead in the soil, consequently increasing the amount of lead absorbed by the plant and accumulating it in the root zone.

Table 5. The concentration of lead in the root system of Indian mustard and canna plants for different treatments after the end of the experiment (mg Pb kg^{-1} dry matter).

Type of plant	Treatments				Average Plant Type
	T1	T2	T3	T4	
Brassica juncea L	2.83	11.61	27.60	47.10	22.28
Canna	3.00	18.57	30.31	50.47	25.59
LSD		2.369			1.184
Average addition	2.91	15.09	28.95	48.79	
LSD		1.675			

However, the impact of the added lead concentrations on the soil is evident from the above results, showing significant differences between the different treatments. The highest concentration was in treatment T4, followed by T3 and T2, reaching 48.79, 28.95, and 15.09 mg kg^{-1} respectively, compared to the reference sample T1, which was 2.91 mg kg^{-1}. When comparing the lead concentrations in the root system with the globally allowed concentrations in plants according to the FAO, and WHO (2007) organizations, which is 5 mg kg^{-1}, we notice that all concentrations in the plants have exceeded the critical limits allowed. However, these plants did not show any signs of growth deficiency or toxicity, indicating that they are all lead-accumulating plants.

Table (6) shows significant differences between the four treatments of the concentration of cadmium in the root system of Indian mustard and canna plants. The cadmium concentrations in the roots system of Indian mustard were 0.76, 3.31, 5.52, and 19.36 mg Cd kg^{-1} dry matter for treatments T1, T2, T3, and T4 respectively. While the cadmium concentrations in the roots of canna plants were 0.28, 2.95, 4.47, and 6.69 mg kg^{-1} dry matter for treatments T1, T2, T3, and T4 respectively.

The results showed that the highest concentrations were in the Indian mustard plant roots, 19.36 mg/kg dry matter for treatment T4, followed by the canna plant roots at a concentration of 6.69 mg/kg dry matter under the same treatment. Statistical analysis revealed significant differences in the average concentration of cadmium in the root system of Indian mustard and canna plants, with the highest values in Indian mustard at 7.24 mg/kg dry matter compared to an average concentration of 3.60 mg/kg dry matter in canna plants. This indicates the ability of Indian mustard to absorb and accumulate cadmium in the root system compared to canna plants. This is consistent with the results of Alexander *et al.* (2008) who indicated that some crops have a large root system with a high surface area that increases root exudates. By incorporating organic humic fertilizer, the soil reactivity can be reduced, leading to increased availability of essential nutrients and heavy elements. Additionally, the use of organic humic fertilizer may contribute to the lowering of soil pH, which can then be absorbed and accumulated in the root system of plants. The high cadmium levels in the root system may also be attributed to its formation of complexes with proteins found in root cells as suggested by Popoval (2008).

This aligns with the findings reported by Alexander et al. (2008), suggesting that certain crops possess a significant root system with a high surface area that enhances root exudates. This, in turn, can decrease soil reactivity when organic humic fertilizer is applied, leading to increased availability of essential nutrients. Moreover, the addition of organic humic fertilizer may also play a role in lowering soil pH, facilitating the absorption and accumulation of heavy elements in the plant root systems.

Table 6. The concentration of cadmium in the root system of Indian mustard and canna plants for different treatments after the end of the experiment (mg Cd kg^{-1} dry matter).

Type of plant	Treatments				Average Plant Type
	T1	T2	T3	T4	
Brassica juncea L	0.76	3.31	5.52	19.36	7.24
Canna	0.28	2.95	4.47	6.69	3.60
LSD		0.55			1.184
Average addition	0.52	3.13	4.99	13.02	
LSD		0.39			

However, regarding the impact of the added concentrations of cadmium element, a statistically significant increase in cadmium concentrations in the roots is observed with the increase in the added concentrations to the soil. The cadmium concentration averages in the root system were 0.52, 3.13, 4.99, and 13.02 mg kg^{-1} dry matter for the four treatments T1, T2, T3, and T4 respectively. Yobouet *et al.* (2010) who stated that the increase in absorbed cadmium levels is attributed to its enhanced availability in the soil, leading to its uptake by the plant and accumulation in the root. When comparing the cadmium concentration in the root system with the globally permitted concentrations in plants, it exceeded the critical limits set by the World Health Organization and the Food and Agriculture Organization (WHO & FAO, 2007) at 0.2 mg $Cd.kg^{-1}$ dry matter, attributing this to the high levels added to the soil before cultivation.

3.2.2. Concentration of Heavy Metals in Plant Shoots

The results in Table 7 show an increase in the concentration of lead in the vegetative system of both plants with increasing addition levels. The highest concentration was in treatment T4, with a lead concentration of 25.52 mg kg^{-1} dry matter in the vegetative system, compared to the control sample T1, which had a concentration of 0.7 mg kg^{-1} dry matter in the vegetative system. This is consistent with Ouda (2018) showed, that increasing the concentration of added lead in the soil before planting contributes to its readiness in the soil, leading to increased absorption by the plant, resulting in a higher concentration in the total green mass.

The results indicate significant differences in the interaction between plant type and different treatments. The highest concentration was in treatment T4 for Indian mustard plants, with a lead concentration of 27.09 mg/kg dry matter in the vegetative system, compared to canna plants where the concentration was 23.96 mg/kg dry matter under the same treatment. Significant differences in lead concentrations, with the average lead concentration in the vegetative system of Indian mustard plants, being 13.8 mg/kg dry matter compared to its concentration average in the canna plant, which was 12.63 mg/kg dry matter. This demonstrates the efficiency and ability of Indian mustard plants to absorb and accumulate lead in the vegetative system compared to canna plants. This is consistent with Al-Salman *et al*. (2011) who showed the variations in plants' capacity to absorb and accumulate heavy elements in their tissues.

Table 7. The concentration of lead (Pb) in the shoots of plants grown for different treatments at the end of the experiment.

Type of plant	**Addition Level**				**Average Plant Type**
	0	**50**	**100**	**200**	
Brassica juncea L	0.65	9.25	18.23	27.09	13.8
Canna	0.75	9.2	16.63	23.96	12.63
LSD	1.644				0.822
Average addition	0.70	9.23	17.43	25.52	
LSD	1.162				

When comparing these concentrations for all transactions and both plants against the criteria established by the World Health Organization and the Food and Agriculture Organization (WHO & FAO, 2007), they are found to have exceeded the critical limit of 5 mg/kg dry matter, except for the comparison sample, which averaged 0.7 mg/kg^{-1}dry matter. This is due to the increased concentration in the soil that is absorbable by the plants, resulting from the addition of high levels of lead before cultivation, as indicated by Azite and Seid (2008), who showed that an increase in heavy metal concentrations in the soil affects its fertility and the absorption by the growing plants in it.

Table 8 shows the statistical analysis results of the concentration of cadmium of Indian mustard and canna plants, indicating significant differences between the four treatments for each plant. Cadmium concentrations in Indian mustard were 0.53, 1.47, 3.67, and 6.38 mg/kg^{-1} for treatments T1, T2, T3, and T4 respectively. For canna plants, cadmium concentrations were 0.38, 3.09, 5.06, and 8.98 mg/kg^{-1} for treatments T1, T2, T3, and T4 respectively. The highest cadmium concentration was 8.98 mg/kg^{-1} in the canna plant at treatment T4, followed by Indian mustard with 6.38 mg/kg^{-1} under the same treatment. These increases in the treatments is normal as a result of adding the element at high levels to the soil, which led to increased soil pollution and the transfer of the element to the vegetable parts of the plants.

Table 8. The concentration of cadmium in the shoots of plants grown for different treatments at the end of the experiment.

Type of plant	Treatments				Average Plant Type
	T1	T2	T3	T4	
Brassica juncea L	0.53	1.47	3.67	6.38	3.01
Canna	0.38	3.09	5.06	8.98	4.38
LSD	0.5202				0.2601
Average addition	0.45	2.28	4.37	7.68	
LSD	0.3679				

The results of the statistical analysis, the superiority of the canna plant in accumulating the element cadmium in the vegetative system, as its concentration of 4.38 mg/kg-1 dry weight compared to the Indian mustard plant, with a concentration in the vegetative system of 3.01 mg/kg^{-1} dry weight. These results agree with Chojnocha *et al.* (2005) indicated, that plants growing in soil contaminated with heavy metals extract these elements from the soil and accumulate them within their tissues compared to plants growing in uncontaminated soil. However, each plant has its unique behavior in its ability to absorb and accumulate toxic elements.

As for the effect of the added concentrations of cadmium element to the soil, an increase in cadmium concentrations is observed with the increase in the added concentrations for both plants, as the concentrations averaged 0.45, 2.28, 4.37 and 7.68 mg kg^{-1} dry matter for treatments T1, T2, T3, and T4 respectively. Sandalio *et al.* (2001) and Al-Aryani (2005), indicated that as the concentrations of added cadmium in the soil increase, its concentration in plant parts also increases. This is consistent with the findings of a study conducted by Talib (2023), which showed that the increase in cadmium concentrations in plants is directly proportional to the added concentrations of cadmium in the soil.

When comparing the cadmium concentrations in the vegetative parts of the cultivated plants with the globally permitted concentrations according to the Food and According to the World Health Organization of 0.2 mg kg^{-1} dry matter, it is evident that both plants (Indian mustard and canna) have exceeded the globally permissible limits and have not shown any signs of growth deficiency or toxicity, indicating that the plants used in the experiment are accumulators of cadmium.

3.3. Plant Pollution Standards

3.3.1. Bioconcentration Factor (BCF)

The BCF refers to the efficiency of plants in extracting and accumulating heavy elements from the soil and accumulating them in its tissues of various parts. It represents the relationship between the concentrations of the heavy element in the root system to its total concentration in the soil, the greater its value than one in the plant, the more appropriate it is for plant extraction (Sajad *et al*., 2019). The results of Figure 1 show BCF values that ranged from 0.31-0.50 and 0.39-0.59 for lead for both plants (Indian mustard and canna) respectively.

We observed that all values were less than one. The highest value was in treatment T2 for the canna plant at 0.59, while the highest value for the Indian mustard plant was in the comparison treatment at 0.50. The lowest values were in the final treatment T4 for both Indian mustard and canna plants at 0.31 and 0.39 respectively. This is attributed to the difference in the root system mass of the plants at the additive levels, in addition to the increase in total lead concentration in the soil with increasing addition levels. This indicates a slow movement of the lead element in the soil and its weak ability to transfer within the root system. These results are consistent with Abd Al-Wahab (2020) when comparing the bioconcentration factor values of lead in Indian mustard plants, which were found to be less than one. However, Abdel Karim (2022) who found that the bioconcentration factor values of lead in canna plants were greater than one. This is likely due to differences in conditions such as soil texture, reaction degree, and organic matter content as well as calcium carbonate. Lead ions become poorly soluble at high pH reaction degrees while their adsorption on clay minerals and oxide surfaces increases. Therefore, lead is considered one of the heavy elements least mobile in soil under basic and reducing conditions (Elkhatib, 2008).

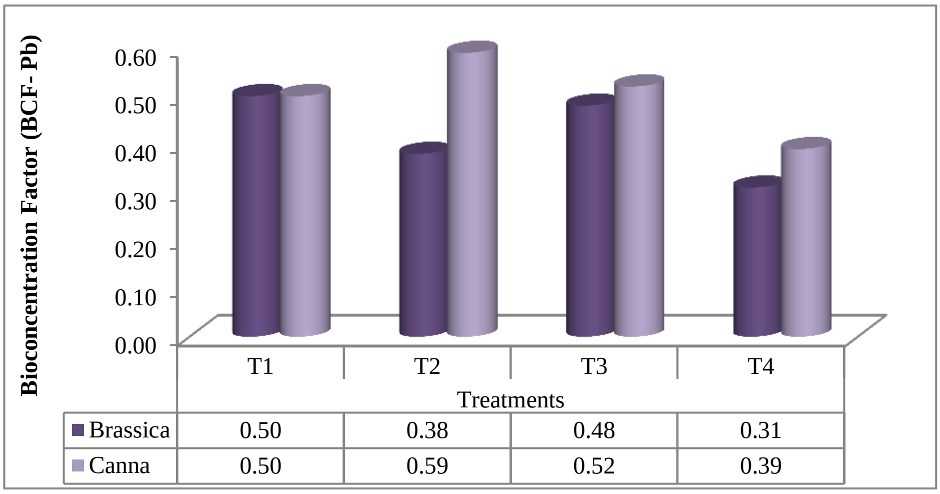

Figure 1. Bioconcentration factor values for lead for Indian mustard and canna plants.

Demonstrating the results in Figure 2, the values of the bioconcentration factor for cadmium in the root system of the plants used in the experiment were between 1.02 - 1.15 for Indian mustard and 1.01 - 1.31 for canna consecutively. It was noticeable that all values were greater than one, indicating that both Indian mustard and canna plants are capable of absorbing cadmium from the soil through their root systems. This agrees with the findings of Somaratne and Weerakooon (2012), who showed that the increased accumulation of cadmium reflects the ability of these plants to transfer the element from the soil to the root system, as well as their high susceptibility to develop mechanisms to tolerate high levels of heavy metals. This is consistent with Abdel Karim (2022), the bioconcentration factor value for cadmium in canna was more than one, categorizing it as a cadmium-accumulating plant in the root system.

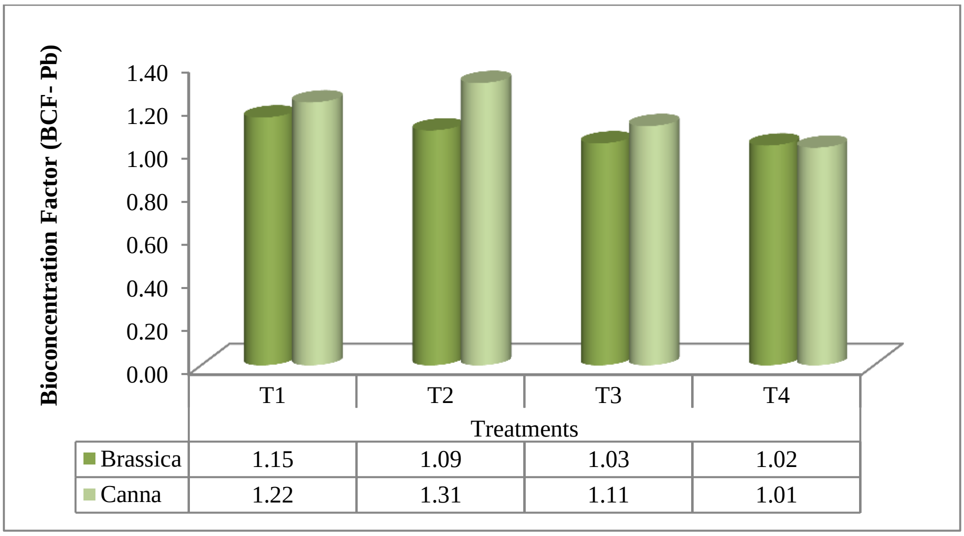

Figure 2. Cadmium bioconcentration factor values for Indian mustard and canna plants.

3.3.2. Bioaccumulation Coefficient (BAC)

The bioaccumulation factor refers to the ratio between the concentrations of the heavy element in the plant's green parts to its total concentration in the soil. Figure 3 shows the values of the bioaccumulation factor for lead in the green parts of Indian mustard and hemp plants, ranging between 0.11-0.32 and 0.12-0.29 for both plants respectively. All values were found to be less than one, indicating that both Indian mustard and canna plants have moderate lead accumulation, that is agrees with Malayeri *et al.* (2008), who referred to plants with a bioaccumulation factor ranging from 0.1-1 as moderate accumulating plants. While, these results differ from Abd Al-Wahab (2020) who, studying the bioaccumulation factor values for lead in Indian mustard plants, found it to be a weak accumulator in the green parts. This may be attributed to the limited movement of lead in the soil unless suitable conditions are present such as an appropriate reaction degree, leading to its precipitation in the form of carbonates, phosphates, and hydroxides at high reaction degrees (Elkhatib, 2008).

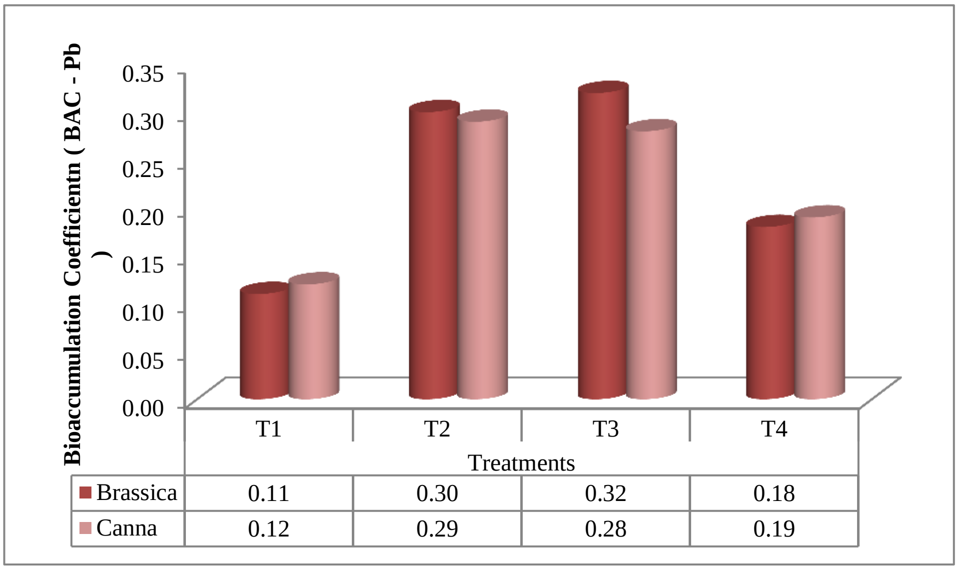

Figure 3. Values of lead bioaccumulation coefficient for Indian mustard and canna plants.

The results in Figure 4 indicate the bioaccumulation factor for cadmium element in the vegetative system of Indian mustard and canna plants, ranging between 0.33-0.80 and 1.25-1.65 respectively for both plants. The highest values were in sample T1 with 0.80 and 1.65 for Indian mustard and canna plants respectively.

The results in this figure, it is evident that the bioaccumulation factor values of cadmium in Indian mustard plants were less than one, indicating these plants have a moderate accumulation of cadmium in their vegetative mass. On the other hand, for canna plants, the results showed an increase in bioaccumulation factor (BAC) values as they were greater than one for all treatments. This indicates the process of absorption and translocation of cadmium from soil to roots and then to the vegetative mass. Therefore, canna plants are considered high accumulators of cadmium in their vegetative mass, which is in agreement with Malayeri *et al.* (2008), who showed that plants with bioaccumulation factors ranging from 1-10 are classified as high accumulators, while those ranging from 0.1-1 are considered moderate accumulators as seen in Indian mustard plants. Hence, canna plants possess a higher capability for cadmium accumulation in their vegetative mass compared to Indian mustard plants.

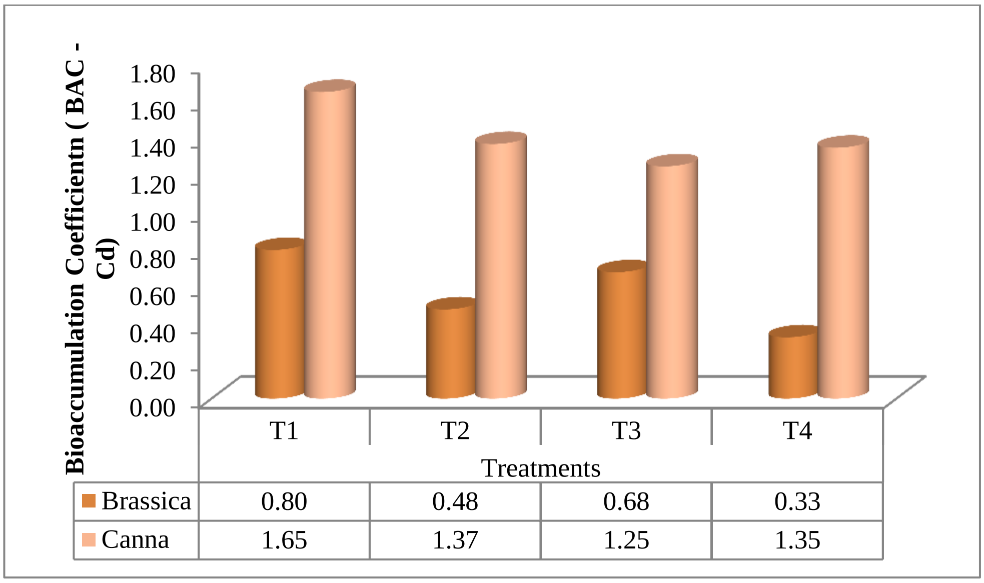

Figure 4. Cadmium bioaccumulation coefficient values for Indian mustard and canna plants.

3.3.3. Translocation Factor (TF)

The indicator of a plant's ability to transfer heavy elements from the root system to the shoot system, and plants that have a transfer coefficient greater than one are known as plants capable of translocating elements from the roots to the shoot system (the stems and leaves) and accumulating them in their tissues (Ansari *et al.,* 2015).

The results of Figure 5 indicate the values of the translocation coefficient for lead in Indian mustard and canna plants, ranging between 0.23 - 0.80 and 0.25 - 0.55 for both plants respectively. The highest values were under treatment T2 at 0.80 for Indian mustard, while in the canna plant; its highest value was under treatment T3 at 0.55.

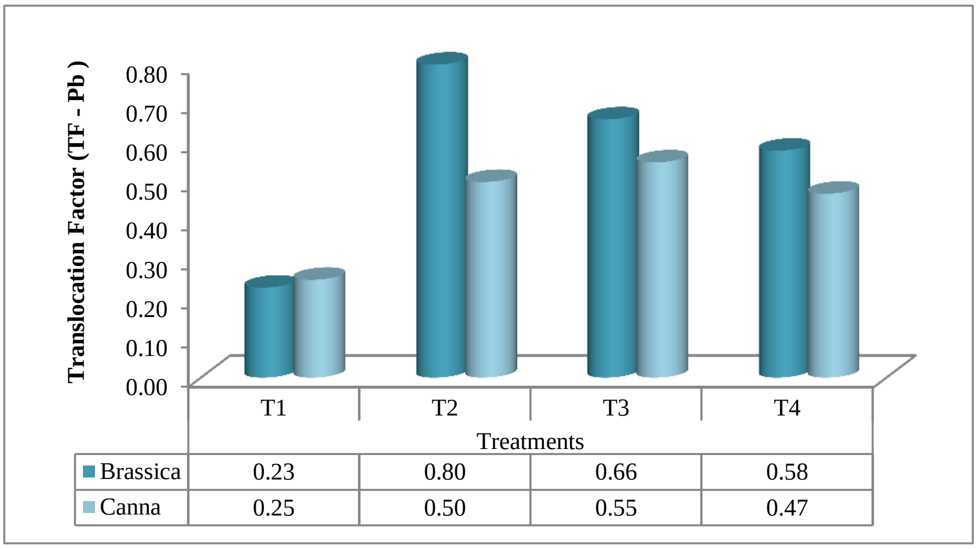

Figure 5. Values of the translocation factor of lead for Indian mustard and canna plants.

All values in this figure were less than one in Indian mustard and canna plants, indicating their inability to transport the lead element from the root to the aerial parts. This is in agreement with El-Etebi (2007) who demonstrated the transfer process of the heavy element from the root system to the upper parts of the plant depends on the nature of the heavy element, plant type, and its tolerance to high concentrations of these heavy elements. Al-Salman *et al.* (2011) mentioned the variation in

plants' ability to absorb and accumulate heavy elements in their tissues. Abdel Baqi (2000) indicates that the movement of lead from the root to the shoot system is slow, reaching up to 3% of its concentration in the root system. Consequently, lead accumulates in the roots leading to a decrease in the translocation factor (TF) values. These results also corroborate with Ouda (2018), who demonstrated a decrease in the local translocation factor values of lead in plants due to its delayed movement from the root system to the shoot system because of its high atomic weight. Also, Abd AL-Wahab (2020) showed the slow lead translocation process in Indian mustard plants when studying the local translocation factor. Based on this, both plants show a low ability to translocate lead within the plant, with generally higher translocation factor values observed in Indian mustard compared to canna plants.
The results in Figure 6 revealed the transfer coefficient (TF) values for cadmium in Indian mustard and canna plants, ranging from 0.33 -0.69 and 1.05 -1.36 respectively. The highest values were under treatment T1, reaching 1.36 and 0.69 in canna and Indian mustard plants respectively.

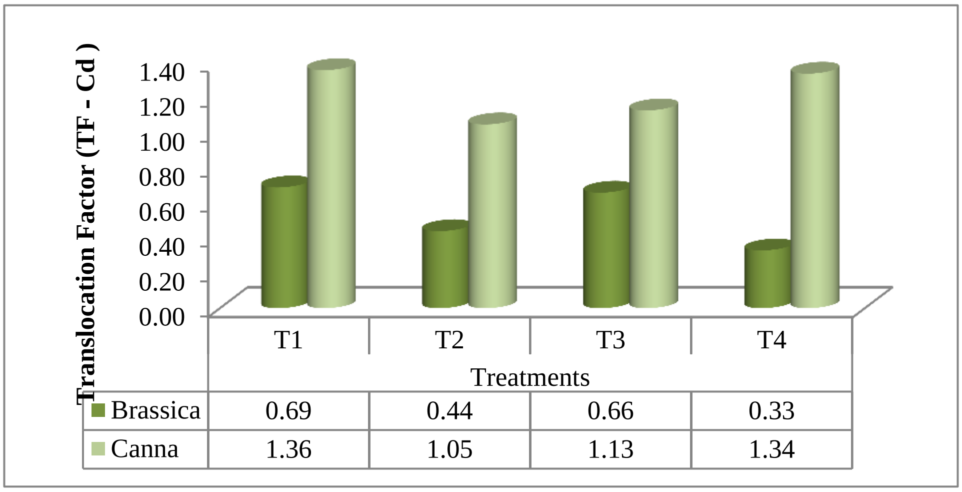

Figure 6. Values of the translocation factor of cadmium for Indian mustard and canna plants.

These results indicate that the transfer coefficient in the Indian mustard plant for all levels was less than one, suggesting the inability of the Indian mustard plant to transfer cadmium from the root to the aerial parts. This agrees with Elkhatib (2008) who mentioned that the plants' absorption process of heavy elements from polluted soil through their root system spread in the polluted soil and the subsequent transfer of the heavy element to the aerial parts primarily depends on the crop's suitability and type, its tolerance to high concentrations of pollutants, as well as the nature of the heavy element and its behavior in the soil. This is also consistent with the findings of Abd Al-Wahab (2020), which indicated the inability of Indian mustard plants to transfer the cadmium element from the root to the aerial parts. This is likely due to a strong relationship between the amount absorbed of Cd^{+2} ions by the plant roots and the concentration of free cations in the soil solution (Elkhatib, 1998).
As for the canna plant, we noticed that all the values of the localization transfer coefficient for cadmium were greater than one. This indicates the efficiency of the canna plant in transporting the element from the roots to the upper parts of the plant, meaning that cadmium is a mobile element within the canna plant. This agrees with Hussain *et al.* (2021) have shown regarding the transfer of cadmium to plant biomass due to its high solubility in the soil, which promotes its uptake within the plant.

Conclusions

- Through our current study results, we have found an increase in concentrations of lead and cadmium in the soil, as well as in the root and shoot of both Indian mustard and canna plants, due to the elevated levels of lead and cadmium sulfate additions to the study soil. Both plants show poor ability for lead translocation within the plant.

- Indian mustard plants, in general, exhibited a good accumulation of cadmium in their root system, surpassing a bioconcentration factor (BCF). Canna plants outperformed Indian mustard in cadmium accumulation and are considered cadmium-accumulating plants due to higher values of both BCF and bioaccumulation factor (BAC), as well as translocation factor (TF).

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