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Bio-Accumulation of Lead and Cadmium by Radish (*Raphanus sativus*) and Cress (*Lepidium sativum*) under Hydroponic Growing Medium

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ABSTRACT: In order to investigate the accumulation and bio-absorption of lead and cadmium in radish and cress, the present study has been conducted in a completely randomized design in three replicates in a hydroponic growing medium. The first factor includes the plant type at two levels (radish and cress), and the second factor is consisted of lead (Pb) (first experiment) at two levels (50 and 100 mg/L), cadmium (Cd) (second experiment) at one level (10 mg/L), and a combination of lead and cadmium (third experiment) again at two levels. After 23 days, roots and aerial parts of both plants have been dried for 48 hours at 70°C in an oven. Then, half gram (0.5 g) of the dried templates has been used to measure the accumulation of Pb and Cd by means of an atomic absorption spectrometer. The highest amount of Pb in radish and crest roots belong to 100 mg/L concentration and the combined Cd (10) + Pb (100) mg/L treatment, respectively, and the highest amount of Cd occurs in Cd (10) + Pb (50) for radish roots and in Cd (10) + Pb (100) combination for cress. Moreover, the Translocation Factor (TF), with a value below 1 and higher bio-concentration factor (BCF) in roots, compared to the aerial part of both radish and cress, seem to be due to the low capability of these plants to transfer Pb and Cd from roots to aerial part. There is a high potentiality for lead accumulation in the roots that prevent its transfer to the aerial part.

Keywords: Vegetables, heavy metals, hydroponic cultivation, translocation factor.

INTRODUCTION

With the expansion of global industrialization, one of the significant and most evident environmental problems is the presence of heavy metals in human food chain. Not only do these metals diminish the quality of food but also they influence the health of human consumers, using such foodstuff in their diet. Therefore, monitoring these pollutants in the human food chain is an essential priority to reduce their side effects (Ping et al., 2011). Heavy metals have a significant role, due to their toxic effects, accumulation, and high stability in the body of organisms (Banaee et al., 2015; Banaee et al., 2019). These metals are absorbed by the soil, pollute farmlands, and eventually enter food chains, and may even reach the toxic threshold for plants, animals, or humans (Ghaderi et al., 2012;

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Karbassi et al., 2014). Although some of these elements are essential for plants in minimal amounts, levels higher than the standard limit could be hazardous for both plant and animal life (Sharma et al., 2008). Plants are one of the main ways of transferring heavy metals to the human food chain and biological cycles. The way these elements are distributed and where they are accumulated in different plant organs is of high account, because their distribution is not the same in different organs. Usually, their accumulation is lower in seeds and fruits, compared to the leaves and roots (Eghbal et al., 2019). However, the ability of a plant to move and transfer heavy metals depends on the type of element, plant organ, and even the plant's age (Outfly et al., 2006). Vegetables can absorb high amounts of nitrate, anion, and heavy metals. In concentrations higher than the physiological demand of vegetables, these compounds not only cause toxic effects, but may enter food chains also, leading to biomagnification, posing a potential threat to human health (Singh et al., 2010). Since heavy metals are difficult to decompose, they can accumulate in different plant organs such as stems, roots, and leaves, there to enter and accumulate in human body and finally cause chronic and severe diseases (Asdeo & Loonker, 2011). Lead is one of the major heavy metals that is widely distributed in water, soil, and air. It brings different health problems in humans (Khodakarami et al., 2010). Lead toxicity can be attributed to its imitation of some metabolic behaviors of calcium and prevention of certain enzymes' activity (Parsa doost et al., 2007). The significance of cadmium (Cd) among other toxic elements is that it can be accumulated in great amounts in plant organs without displaying any signs of toxicity in the plant, itself (Nazemi et al., 2010). Soil and water pollution with heavy metals is a major environmental issue in human societies that reduces the performance and quality of crops and sustainability of agricultural products, not to mention people's health in a community (Maleki & Alasvand Zarasvand, 2008).

Several studies have been carried out on the accumulation and concentration of heavy metals in vegetables and plants in aquatic and terrestrial environments: For instance, Rooniasi and Parvizi Mossaed (2016) investigated the rate of heavy metals in different parts of consumed vegetables in Karaj, Iran. Their results indicated that there was a higher concentration of chromium, manganese, and iron in the leaves of spinach, onion, cabbage, and lettuce, compared to their stems and roots, with the latter showing the lowest concentration of these metals. This can be attributed to the high translocation of these metals to aerial part, especially leaves. Zoufen et al. (2016) studied absorption and accumulation of zinc in *Malva* in a hydroponic environment. Bolandnazar et al. (2016) studied the influence of cadmium and zeolite on the growth properties of cress and radish in a hydroponic environment. Toulabi et al. (2014) and Zaer et al. (2018) studied the accumulation of heavy metals in roots and aerial parts of radish and lettuce, respectively.

Considering the importance of such nutrition, consumption of contaminated vegetables in developing countries, and finally the entrance of heavy metals to human food chain, it is essential to conduct a local study in order to investigate the causes and contaminants in agricultural products. In other words, the safety of major consumed vegetables should be evaluated. Since heavy metals have a sustainable and accumulative nature in leaf vegetables, the concentration of these heavy metals should be constantly monitored and compared with standard conditions. Therefore, the paper focuses on the accumulation rate of cadmium and lead in roots and aerial part of radish and cress as two vegetable types.

MATERIALS AND METHODS

The study was conducted in 2016 at the laboratory of Natural Resources Faculty at Behbahan Khatam Alanbia University of Technology in a hydroponic system under controlled laboratory conditions (25°C, 16h light photoperiod). It was characterized by two separate factorial experiments in a completely-random basic design and with three treatments. The factors included: 1. Plant type with two varieties (Radish and Cress); 2. Different treatments including Pb (for the first experiment) at two levels (50 and 100 mg/L), Cd for the second experiment at one level (10 mg/L), and a combination of Pb and Cd (for the third experiment) at two levels {Pb (50) + Cd (10) and Pb (100) + Cd (10)}.

Radish and cress seeds were prepared, washed, and planted in 3-liter pots containing sterilized peat. They then entered growth medium conditions. One liter of distilled water with a nutritional solution was added to each pot. At the first week 10 cc and in the second week 5 cc of Hoagland nutrient solution with the following formula was added to the plan pots (Mohtadi et al., 2012):

3mM KNO_3, 2 mM $Ca(NO_3)_2$, 1 mM $NH_4H_2PO_4$,0.50 mM $MgSO_4$, 20 μM Fe(Na)-EDTA, 1 μM KCl, 25 μMH_3BO_3, 2 μM $MnSO_4$, 2 μM $ZnSO_4$, 0.1 μM CuSO 0.1, and 4 μM $(NH_4)6Mo_7O24$

Each pot contained ten plants and for each concentration, three replacements were considered. The pots were placed in a completely random design in a growth medium, at 20°C during the day and at 15°C at night and 16:8 lights: darkness photoperiod. At first, plants were planted in a hydroponic environment for 14 days and the nutrient solution was changed once a week.

Once the seeds got adapted to laboratory conditions, in order to add cadmium and lead to the growth medium of the plants and determine the treatments, cadmium nitrate and lead carbonate salts were used, respectively. Cadmium treatments had a 10 mg/L concentration, lead treatment had a 50 and 100 mg/L concentration, and the combined treatments of both elements contained (Cd 10 + Pb 50) and (Cd 10 + Pb 100) mg/L. The nutrient solution was changed every 6 days and the solution's acidity remained 5.5. All treatments were set in a 16:8 light-darkness photoperiod and at 15-20°C. After 23 days, the samples got harvested.

At the end of the treatment, radish and cress vegetables were carefully removed from water from each lab unit (pot). In order to remove cadmium and lead from the roots surface, Na_2EDTA (20 mM) was used. Roots were placed in this solution for 10 minutes at room temperature and their surface was dried with paper napkins. Then, each plant was divided into two parts: the root and the aerial part. Roots and aerial parts were separately wrapped in an aluminum foil and dried in an oven for 48 hours at 70°C. The samples' dry weight got measured by means of a digital scale (with an accuracy of 0.001 g). Then the samples were grinded and Pb and Cd accumulation was measured with an atomic absorption spectrometer (Shimadzu AA-6300). Therefore, 0.5 g of the dry powder sample was put in 10 ml acid, washed in the test tubes, and 10 cc of Nitric acid (HNO_3) was added. After 24 hours, 2 cc of hydrogen peroxide (H_2O_2) was added as well. Then, the test tubes were put in hot water baths (100°C) for 15 minutes for the samples to be solved. Once the tubes got cool, the samples were filtered via Whatman grade 42 filtration paper and the samples volume was increased to 20 mL by receiving distilled water. Following this stage, an atomic absorption device was used to read the amount of Pb and Cd separately in the solution and the obtained data were recorded (Verbruggen et al., 2009). These values were converted to actual concentrations per samples' dry weight unit (mg/Kg):

$$\text{Actual concentration} = \frac{\text{Concentration of the device} \times \text{ final volume of the sample}}{\text{Dry weight}} \quad (1)$$

Quality assurance/Quality control

In case of each metal, a recovery study was carried out to assess the accuracy and the reliability of the heavy metals' concentrations, obtained in the analysis, more precisely. Linear calibration graphs were obtained, using six consecutive blank concentration measurements for all studied metals. The limit of detection (LOD) for metals was analyzed to show that the LOD for Pb and Cd were 0.613 and 0.095 mg/kg, respectively.

Moreover, in order to determine these vegetables' ability in absorbing Cd and Pb, both Translocation Factor (TF) and Bio-Concentration Factor (BCF) were measured in the medium containing different concentrations of Pb and Cd via the following formulae:

$$\text{TF} = \frac{\text{Metal concentration in aerial part}}{\text{Metal concentration in root}} \quad (2)$$

(Mattina et al., 2003)

$$\text{BCF} = \frac{\text{Metal accumulation rate in a specific part}}{\text{Initial rate of metal in the planting bed}} \quad (3)$$

(Saraswet & Rai, 2009)

All experiments had three replacements with the data being analyzed by SPSS software, version 22. In order to compare the mean concentration of the elements in the samples of different treatments, one-way ANOVA (Duncan) was used, while correlation test (Pearson) at a confidence level of 0.05 helped investigating the relation between metals' concentration in both roots and aerial parts. What is more, Shapiro-Wilk test was used to see if the data were normal or not. The relevant charts were drawn in Excel.

RESULTS AND DISCUSSION

Table 1 shows a mean concentration of Pb in radish and cress in a hydroponic growth medium. Although Pb rate differed among the solutions, its accumulation level was similar in the roots of both plants. Radish roots in 100 mg/L treatment (85.64 mg/Kg) and cress roots in the combined treatment (Cd (10) + Pb (100) mg/L) had the highest rate of Pb accumulation. Therefore, an increase in metal concentration in the growth medium, induces absorption and bio-accumulation of metals to increase in the roots of both plants. The results of this experiment indicate a difference between the two plants in terms of bio-availability of Pb in the roots and aerial parts. Studies conducted on TF of Pb indicate that these two plants differ from one another in varied concentrations of Pb. The highest TF of Pb to aerial organs of radish (0.70) was observed in the combined treatment of Pb (50 mg/L) plus Cd (10 mg/L) (Table 1).

Comparing Pb accumulation in aerial parts of radish and cress shows that Pb accumulation rose in the aerial part of radish up to 50 mg/L, which was also true for the combined treatment (Cd (10) + Pb (50)). However, the greater the increase in Pb concentration in the growth medium, the lower the Pb accumulation. On the other hand, Pb accumulation in cress was still increasing in 100 mg/L concentration in the combined Pb + Cd treatment (Cd (10) + Pb (100)) (25/85 mg/Kg). In other words, the aerial parts of cress were more able to accumulate Pb in the growth medium following an increase in Pb concentration. Since the highest amount of Pb accumulation was observed in the combined Pb plus Cd treatment, it can be said that bio-accumulation of Pb increased in different parts of the plant when it was accompanied by Cd. In a research on Zn absorption and accumulation in mallow in a hydroponic medium, Zoufen et al. (2016) showed that with the passage of time an increase in Zn content in the medium, raised the amount of this metal in the aerial part. However, they found a significant decrease in the roots in concentrations over 1000 μm. This shows that different factors such as the species of the purifying plant, type, and amount of the chelator, condition and stage of plant growth, type of heavy metal, the initial concentration of the metal, acidity, etc. affect absorption efficiency and the pollutant's transfer via the plant (Singh et al., 2007).

T-test results for comparison of Pb concentration in different parts of radish and cress indicate a considerable difference between mean concentration of Pb in the roots and the aerial parts of these two plants ($P < 0.05$). Pb accumulation was higher in the roots, compared to the aerial parts. In studying the accumulation of heavy metals in roots and aerial part of radish grown in soils modified with sewage sludge, Toulabi et al. (2014) reported that radish roots showed a higher accumulation rate of heavy metals, compared to its aerial part and had a high capacity of absorbing Pb from soil. Their results were consistent with the findings of this study. Their results indicated that heavy metals, including Pb, were more prone to accumulate in plant roots, because Pb is an element that precipitates in roots as lead sulfate (Aisien et al., 2010). Roots are the base and the main route of metal absorption in aquatic plants. Although Pb could be easily absorbed by the roots (depending on the species), a small amount of it is transferred to the aerial parts (Dos Santos & Lenzi, 2000).

Bio-concentration factor (BCF) indicates the accumulation rate of a specific metal in the harvestable part of the purifying plant, compared to the amount available in the solution around its roots. In general, BCF has a direct relation with the purifying plant species, type of pollutant, and its concentration and bio-availability. Results from this experiment indicated a difference between the two plants in terms of bio-availability of Pb in roots and aerial parts (Table 1). Moreover, these two plants showed some differences at varied levels of Pb in terms of bio-concentration in roots and aerial parts. The highest bio-concentration of Pb in radish roots (0.85) was in 100 mg/L concentration, almost six times higher than that of the aerial parts (0.15). In case of cress, the highest BCF was in the roots (3.77) and the aerial parts (0.35) in the combined concentration of Cd (10 mg/L) plus Pb (50 mg/L) (Table 1). As can be seen in the present experiment, there was a big difference in the roots, compared to the aerial parts in terms of BCF. Other researchers have also reported similar results. The proportion of the accumulated metal in aerial part to roots is called "Translocation Factor (TF)", which signifies the ability of the purifying plant in translocating a metal or other pollutants from underground organs to aerial harvestable ones (Dos Santos & Lenzi, 2000). Studies on TF of Pb indicate that these two plants differ in varied concentrations of Pb. The highest TF of Pb to aerial organs of radish (0.70) belonged to the combined treatment of Pb (50 mg/L) plus Cd (10 mg/L). However, Pb translocation factor was below 1 in both plants, suggesting that under the applied treatments, the amount of Pb in stems and leaves of these two plants had been never equal to or bigger than its amount in the roots. These results are in concordance with the findings by Zoufen et al. (2016) in their study on Zn absorption and accumulation in mallow. As soon as Pb enters the parenchyma cells of roots and intercellular space, it comes into contact with a great amount of phosphate, carbonate, bicarbonate, and high acidity. It then exits the solution as a phosphate compound and finally deposits. Therefore, its translocation to aerial organs becomes limited.

Table 1. Comparison of the average interaction of plant and Pb for Pb-related properties

vegetable	Lead levels (mg / L)	Pb in root (mg / kg)	Pb in aerial part (mg / kg)	BCF of Pb in root	BCF of Pb in aerial part	TF of Pb
Radish	Pb(50)	18.55±1.81	7.48±0.32	0.37	0.14	0.40
	Pb(100)	85.64±0.13	15.39±2.23	0.85	0.15	0.18
	Pb(50)Cd(10)	31.56±5.7	21.99±2.9	0.63	0.43	0.70
	Pb(100)Cd(10)	55.32±7.9	16.66±0.13	0.55	0.16	0.30
	Control	5.50±0.69	3.05±0.62	-	-	0.55
Cress	Pb(50)	86.86±14.7	9.67±0.96	1.73	0.19	0.11
	Pb(100)	50.52±0.16	10.10±0.9	0.50	0.10	0.20
	Pb(50)Cd(10)	188.7±1.66	17.53±2.4	3.77	0.35	0.092
	Pb(100)Cd(10)	229.9±17.8	25.85±0.50	2.29	0.25	0.11
	Control	3.77±1.64	2.49±0.78	-	-	0.66

Although Cd concentration was the same in all treatments (10 mg/L), these two plants indicated different behaviors in terms of Cd accumulation. Cd concentration in the aerial parts of radish and cress also differed in varied treatments of the growth medium. The highest accumulation rate of Cd in aerial part of radish was in the combined concentration of Cd (10 mg/L) + Pb (50 mg/L) (112.87 mg/Kg dry weight), while the maximum amount of Cd in aerial part of cress was found in Cd (10) + Pb (100) treatment (108/25 mg/Kg). In other words, with an increase in Pb concentration in the growth medium, cress showed a higher ability to absorb and accumulate this pollutant in its aerial part. The highest value of bio-concentration of Cd in the roots and aerial parts of radish (16.03 and 11.28, respectively) was found in Cd (10) + Pb (50) treatment and the highest amount in the roots and aerial parts of cress (14.72 and 10.82, respectively) belonged to Cd (10) + Pb (100) mg/L. Translocation factor of Cd varied in these two plants. Radish had a higher ability to transfer Cd to its aerial parts (Table 2).

The highest mean concentration of Cd in radish roots was found in Cd (10) + Pb (50) treatment and the greatest amount of Cd accumulation in cress roots belonged to Cd (10) + Pb (100) treatment. Although Cd rate was constant in the growth medium, alterations in Pb concentration in growth medium made a difference in bio-concentration of plant roots. An increase in Pb concentration in radish growth medium did not increase the Cd in roots. With an increase in Pb concentration up to 100 mg/L, the accumulation of this pollutant rose in cress roots as well. Radish roots accumulate more Pb, compared to cress, which is probably due to dense roots and greater number of rhizomes in radish. Results indicate that the amount of Cd accumulated in aerial part of radish and cress was lower than the amount accumulated in the roots. These results were in concordance with those of Rarnos et al. (2002), who reported that Cd was easily absorbed from the surface of plant roots, moving towards the woody tissues, and accumulating in the upper parts. Thus Cd concentration in the aerial part would be more than the underground parts (tuber or root). This was, however, in contrast with the findings of Ghobadi and Jahangard (2016) in their research on Cd, Zn, and Mn concentration in the roots, stems, and leaves of spinach and tomato in Hamedan, Iran. They observed higher accumulation of such metals in the leaves, compared to the roots. Nonetheless, results from the present study were in concordance with previous studies on bio-accumulation capacity of radish (*Raphanus sativus* L.) in absorbing Pb

(Mohammadipour & Asadi Kapourchal, 2012) and cress capacity in absorbing Cd (Torabian & Mahjouri, 2002). In this regard, researchers believe that the plant species makes a significant difference in the absorption rate. For instance, some plants such as alfalfa distribute Cd in the roots and some others like lettuce distribute it in the leaves (Aravind & Prasad, 2005). Studying the interaction between Cd and Zn in *Matthiola flavida Boiss* indicated that an increase in Cd concentration in the growth medium increased its accumulation in the plant (Mohtadi & Hoshyari, 2016), just like the results of the present study.

These results suggest that bio-concentration of this pollutant was greater in the roots, compared to the aerial parts. Since bio-concentration of Cd occurred more in the roots and aerial parts of radish, compared to cress, it can be said that the former was better at accumulating Cd and Pb. However, bio-concentration factor has a direct relation to the amount of metal in the solution, and comparing two different plants in relatively similar conditions is acceptable in terms of bio-availability of these elements for plant purification. Translocation factor of Cd differed in these two plants (Table 2). As such, radish had a higher ability to transfer Cd to its aerial parts. The highest amount of Cd translocation to aerial part of radish (1.60) was observed in Cd 10 mg/L treatment and the mean Cd translocation factor by cress was 0.36 (Table 2). Cd transfer to aerial part was limited since Cd bonds to the cell wall of the root.

Figures 1 and 2 compare the mean concentration of Pb and Cd in the roots and aerial parts of radish in different treatments. According to one-way ANOVA test, there was a significant difference between the mean concentration of Pb in radish roots and mean concentration of Cd in roots and aerial parts of radish in different treatments ($P < 0.05$). Only, there happened no significant difference in the mean concentration of Pb in aerial parts of radish between Cd (10) + Pb (100) and Pb (100) treatments at 0.05 ($P > 0.05$). Lack of a significant difference between these two treatments is due to the fact that Pb concentration remained the same in the growth medium of both treatments. Moreover, Pb concentration in aerial parts of radish was lower than its concentration in the roots; therefore, the aerial parts did not absorb much Pb with no remarkable difference found between these two treatments.

Table 2. Comparison of the average interaction between the plant and Cd for Cd-related properties

vegetable	Cd levels (mg / L)	Cd in root (mg / kg)	Cd in aerial part (mg/kg)	BCF of Cd in root	BCF of Cd in aerial part	TF of Cd
Radish	Cd(10)	31.77±2.8	51.05±3.2	3.17	5.10	1.60
	Pb(50)Cd(10)	160.35±0.2	112.85±0.04	16.03	11.28	0.70
	Pb(100)Cd(10)	73.42±0.61	38.02±0.90	7.34	3.80	0.51
	Control	2.73±0.76	1.95±0.62	-	-	0.71
Cress	Cd(10)	27.11±0.13	6.55±1.9	2.71	0.65	0.24
	Pb(50)Cd(10)	87.55±0.17	11/26±0.8	8.75	1.12	0.13
	Pb(100)Cd(10)	147.21±1.21	108.2±0.25	14.72	10.82	0.73
	Control	2.24±0.85	1.51±0.57	-	-	0.67

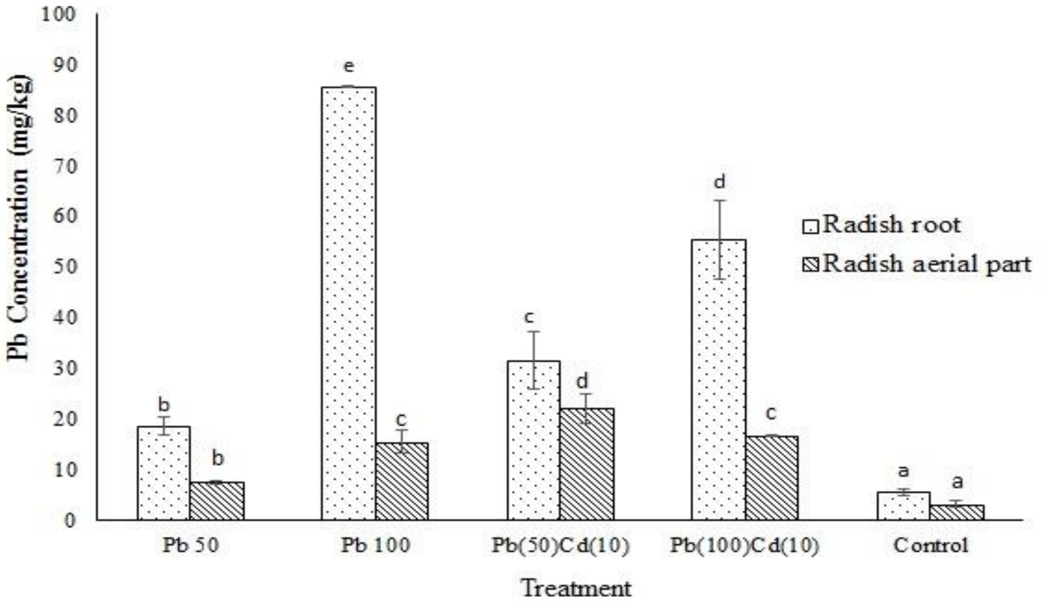

Fig. 1. Comparison of mean Pb concentration in the roots and aerial parts of radish in different treatments

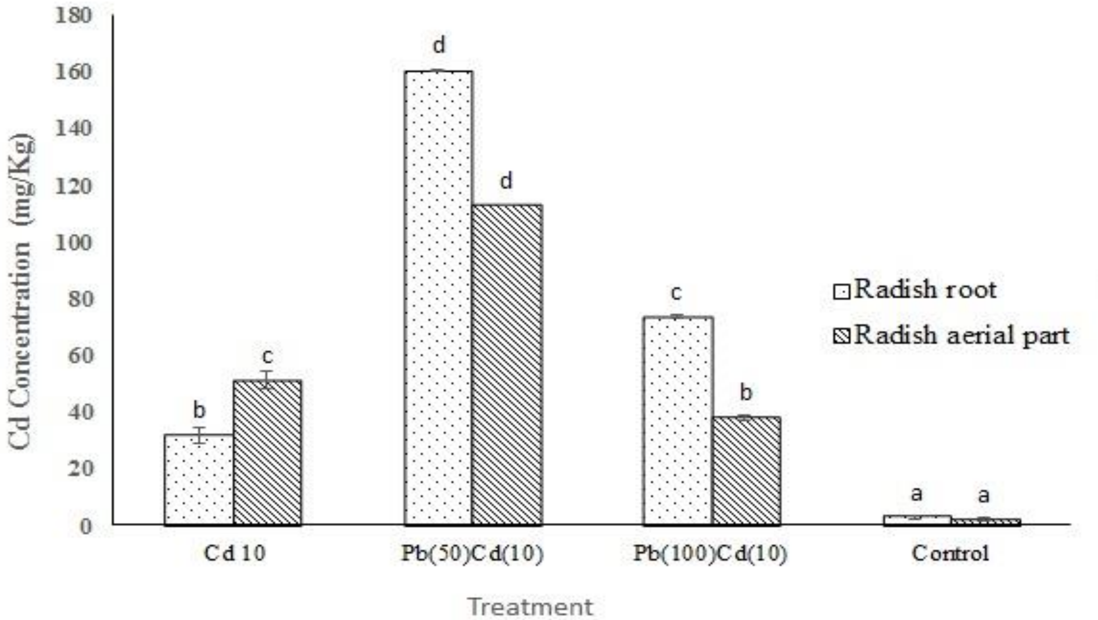

Fig. 2. Comparison of mean Cd concentration in the roots and aerial parts of radish in different treatments

Figures 3 and 4 depict the comparison of the mean concentration of Pb and Cd in roots and aerial parts of cress among different treatments. According to one-way ANOVA test, the difference at 0.05 ($P < 0.05$) was significant for mean concentration of both Cd and Pb among various treatments. As for the aerial parts of Cress, Cd showed a significant difference in varied treatments; however, in case of Pb there was not any significant difference between 50 and 100 mg/L ($P > 0.05$).

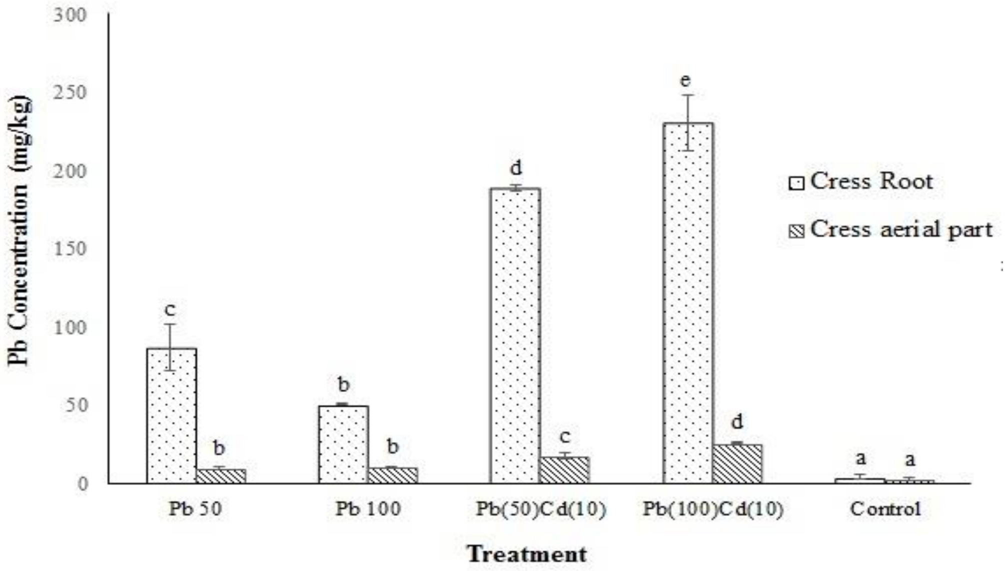

Fig. 3. Comparison of mean Pb concentration in the roots and aerial parts of Cress in different treatments

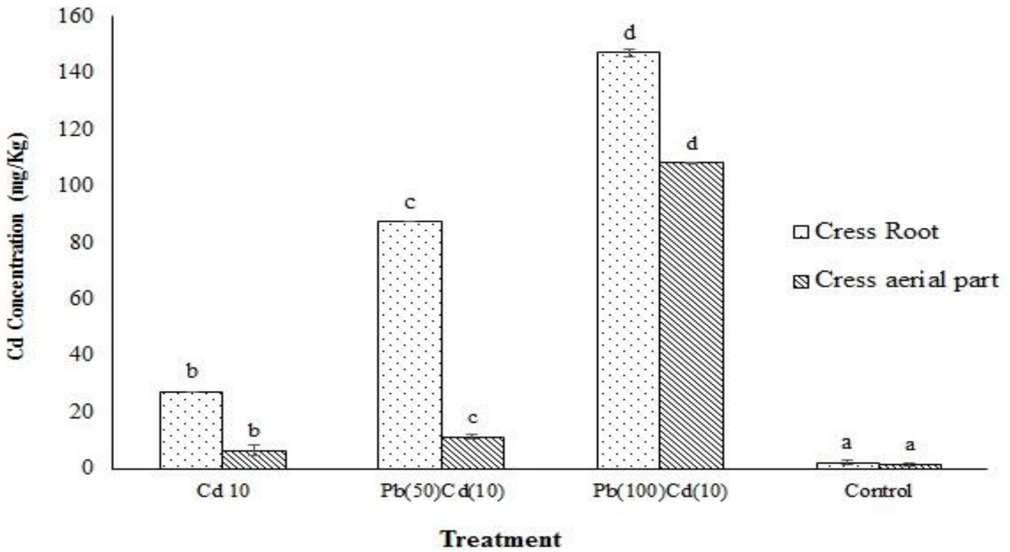

Fig. 4. Comparison of mean Cd concentration in the roots and aerial parts of Cress in different treatments

Table 3 presents the relation and correlation between mean concentration of Pb and Cd in the roots and aerial parts of radish in two combined treatments: Cd (10) + Pb (50) and Cd (10) + Pb (100), showing a significant negative correlation between Pb concentration in radish roots and Cd concentration in roots and aerial parts of radish ($P < 0.05$). Therefore, an increase in Pb amount in radish roots, reduces the Cd rate in both the roots and aerial parts, and vice versa. Since the highest accumulation rate of Pb occurred in radish roots, most absorbing areas of roots are saturated and thus other metals' absorption declines. In fact, Pb and Cd compete for being absorbed through plant tissues and disturb absorption and translocation of each other. There is a significant positive relation between Pb amount in aerial parts of radish and Cd rate in the roots and aerial parts of radish and also between Cd amount in the roots of radish and its aerial parts ($P < 0.05$).

Table 3. Correlation between the amount of heavy metals in the roots and aerial parts of radish (mg/kg) in two combined treatments of Pb (10) + Cd (50) and Pb (10) + Cd (100)

	Heavy metal			**Vegetable**			
	Cd	**Pb**		**Root**	**Aerial part**	**Root**	**Aerial part**
Radish		Pb	Root		-0.892*	-0.901*	-0.899*
			P Value		0.017	0.014	0.015
			Aerial			0.847*	0.846*
			P Value			0.034	0.031
		Cd	Root				0.900*
			P Value				0.014
			Aerial				
			P Value				

* Correlation is significant at the 0.05 level

Table 4. Correlation between the amount of heavy metals in the roots and aerial parts of cress (mg/kg) in two combined treatments of Pb (10) + Cd (50) and Pb (10) + Cd (100)

	Heavy metal			**Vegetable**			
	Cd	**Pb**		**Root**	**Aerial part**	**Root**	**Aerial part**
Cress		Pb	Root		-0.552	0.507	-0.581
			P Value		0.25	0.304	0.227
			Aerial			0.435	0.903*
			P Value			0.389	0.014
		Cd	Root				0.274
			P Value				0.599
			Aerial				
			P Value				

* Correlation is significant at the 0.05 level

The results, depicted in Table 4, indicate the relation and correlation between Cd and Pb in cress in two combined treatments of Pb (10) + Cd (50) and Pb (10) + Cd (100). There is no significant relation at 0.05 level ($P < 0.05$) between the amount of Pb in the cress roots and its amount in aerial parts, and also between Cd amount in the cress roots and its aerial part. Also, no significant relation was found between Cd amount in aerial part of cress and its amount in cress roots. There is a significant positive relation between Pb amount and Cd rate in aerial parts of cress ($P < 0.05$).

CONCLUSION

Based on the findings of this research, it seems that neither radish nor cress are capable of bio-concentration of Pb and Cd, two heavy metals in their roots and aerial parts, at least not in the laboratory conditions governing the current study. This is further exemplified by the low rate of BCF and TF factors in their aerial parts. Yet, the significant increase of BCF in the roots as well as the high concentration of these metals in the roots, could jump into the conclude that these two kinds of vegetables prevent these metals from transferring to their aerial parts. Plants may act as accumulator or excluder organisms in the challenge of environmental pollutants (Sinha et al., 2007). The present study's results showed that the roots of garden cress and radish as excluders were able to limit the transportation of Pb and Cd to the aerial parts. Although, based on the same results, radish transferred higher amount of Pb and Cd from its roots to the aerial parts, compared to cress. Similarly, the results from a research by Toulabi et al. (2014) showed that the accumulation of heavy metals in the roots and aerial parts of radish indicated that the plant's roots did accumulate higher amounts of heavy metals, compared to their aerial part. Also, the study of Zoufen et al. (2016), an evaluation of the adsorption and accumulation of zinc in Malva in a hydroponic environment in 6 treatments, showed that due to the translocation factor being lower than one (TF <1) and the bio-concentration factor being higher than one (BCF >1) in the roots, it seemed that this plant had a low ability to transfer zinc from its roots to aerial parts. In another study by Yang et al. (2020), analysis of accumulation and transformation of Mercury in eleven species of leafy vegetable shows that Hg concentration is mostly accumulated in the roots of green crops, which decreases the risk of Hg bioaccumulation in the edible parts of vegetables. Similar results have been reported by Li et al. (2020) who have analyzed accumulation and transport patterns of six phthalic acid esters (PAEs) in two leafy vegetables under hydroponic conditions.

Here, all BCFs were greater than one, indicating that the tested PAEs were readily accumulated in the plant roots. The TFs ranged from 0.0025 to 0.40, all being lower than 1 and suggesting that the tested vegetables had a poor ability to translocate individual PAEs into plant shoots from the roots.

Generally, research on the hydroponic growing medium is still in its infancy, with many knowledge gaps abounding. Therefore, this research can serve as a source and guiding tool for future studies in the field of assessing accumulation and transformation of heavy metals in the roots and aerial parts of different species of leafy vegetables in a hydroponic environment. It goes without saying that the results from these studies could be used as an effective guideline for selection of suitable leafy vegetables for both cultivation and daily consumption that minimize health risks.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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