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Phytoremediation of lead by a wild, non-edible Pb accumulator *Coronopus didymus* (L.) Brassicaceae

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ABSTRACT

Coronopus didymus was examined in terms of its ability to remediate Pb-contaminated soils. Pot experiments were conducted for 4 and 6 weeks to compare the growth, biomass, photosynthetic efficiency, lead (Pb) uptake, and accumulation by *C. didymus* plants. The plants grew well having no visible toxic symptoms and 100% survivability, exposed to different Pb-spiked soils 100, 350, 1500, and 2500 mg kg^{-1}, supplied as lead nitrate. After 4 weeks, root and shoot concentrations reached 1652 and 502 mg Pb kg^{-1} DW, while after 6 weeks they increased up to 3091 and 527 mg Pb kg^{-1} DW, respectively, at highest Pb concentration. As compared to the 4 week experiments, the plant growth and biomass yield were higher after 6 weeks of Pb exposure. However, the chlorophyll content of leaves decreased but only a slight decline in photosynthetic efficiency was observed on exposure to Pb at both 4 and 6 weeks. The Pb accumulation was higher in roots than in the shoots. The bioconcentration factor of Pb was > 1 in all the plant samples, but the translocation factor was < 1. This suggested *C. didymus* as a good candidate for phytoremediation of Pb-contaminated soils and can be used for future remediation purposes.

Abbreviations: BCF: bioconcentration factor; PCs: phytochelatins; ROS: reactive oxygen species; TF: translocation factor

KEYWORDS
Accumulation; bioconcentration factor; Pb-contaminated soil; remediation; translocation factor

1. Introduction

The contamination of soils by metal(loid)s is one of the serious issues in the world. Anthropogenic activities like electroplating, smelting, mining, excessive use of fertilizers, traffic have caused the discharge of metal(loid)s in the environment (Sidhu 2016). Lead (Pb), one of the most wide spread inorganic pollutant, is released in the environment from the burning of coal, vehicular exhausts, electric batteries, paints, gasoline, sewage sludge, explosives, and metallurgical activities (Sharma and Dubey 2005). Pb has been ranked second in the priority list of hazardous substances (ATSDR 2015). Pb in plants has no physiological relevance and the plants growing in soils containing Pb can still accumulate it in edible tissues and impart serious threat to our foods (Ramesar *et al.* 2014). It retards various metabolic processes like photosynthesis, respiration, uptake of water, nitrogen metabolism, nutrient uptake (Sharma and Dubey 2005) and thus induces oxidative stress by generating reactive oxygen species (ROS) in plants (Sidhu *et al.* 2016, 2017a).

During the past few decades, both conventional and non-conventional strategies have been proposed for the remediation of contaminated soils. The fundamental objectives for the remediation of soils are: (i) to alleviate or lessen the concentration of metal(loid)s from the contaminated soils. (ii) To reinstate the chemical and biological traits of the contaminated soils so as to sustain its fertility and maintain soil life. The conventional cleanup methods like soil excavation, vitrification, solidification, burial, stabilisation, incineration, soil washing, soil flushing, electro-kinetic systems and landfill are often expensive, laborious, disturb the native soil microflora and demand the segregation of the contaminated sites (Ali *et al.* 2013). In this regard, a non-conventional, *in situ* practice like phytoremediation is a promising, green alternative approach to restore the polluted soils contaminated with metal(loid)s (Ali *et al.* 2013; Sidhu et al. 2017a, 2017b). Besides, the inception of green cover on the polluted soils lemmatizes the risk of heavy metal movement through water percolation and wind erosion (Amer *et al.* 2013). Phytoextraction and phytostabilization are the important strategies adopted by the plant species to remediate the soils contaminated with metal(loid)s. These strategies are affordable, cost-effective, sustainable, and environmentally safe.

The choice of the plant is a vital characteristic to appraise in a phytoremediation-based strategy. The plant species must grow speedily having robust root–shoot system, extensive biomass and highly metal tolerant so as to accomplish a comprehensive coverage on the surface soil (Simon 2005). Members of the family Brassicaceae like *Thlaspi praecox* (Vogel-Mikuš *et al.* 2005), *Hirschfeldia incana* (Auguy *et al.* 2013) are well known for their ability accumulate high concentration of Pb in their tissues. Therefore, *Coronopus didymus*, a wild, non-edible,

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annual herb of mustard family was selected for this work. This plant species is widely distributed throughout the world and is a native of South America (Yannitsaros 1986). It grows along the road sides and gardens during winter season (October to February) in the northern parts of India. The plant grows rapidly, having profusely branched root and shoot system, less harvest time and shows high biomass production (Yannitsaros 1986). In this study, the sampling period was selected for 4 and 6 weeks, as *C. didymus* plants showed good growth and high biomass yield during this period. Furthermore, this comparative study assist to assess the time required to accumulate more Pb in the tissues of *C. didymus* from Pb-contaminated soils. To the best of our knowledge, no previous study has illustrated the tolerance and physiological impact of Pb accumulation on *C. didymus* at different time intervals. The main objective of this study was to investigate (i) the effect of Pb toxicity on the physiological attributes like growth, biomass, chlorophyll content, and photosynthetic efficiency of *C. didymus* (ii) the tolerance, uptake and accumulation potential of *C. didymus* in a series of Pb-spiked soil (100, 350, 1500, 2500 mg kg^{-1}) after 4 and 6 weeks, respectively.

2. Materials and methods

2.1. Plant material and soil samples

The seeds of *C. didymus* and soil samples were collected locally from a non-contaminated site at Panjab University campus, Chandigarh, India. Seeds were surface sterilized with sodium hypochlorite and were sown in plastic tray having 10 kg soil in a screenhouse. Soil was collected from the top soil layer (0–20 cm) from Botanical Garden, Panjab University, Chandigarh, mixed with cow dung manure (soil and manure ratio 5:1), air dried and sieved through 2 mm mesh. The selected soil was sandy loam having pH 6.69 ± 0.07, electrical conductivity 139.9 ± 1.51 μS, organic carbon 0.98 ± 0.04% and organic matter content 1.68 ± 0.07% (Walkley and Black 1934), total nitrogen 0.85 ± 0.03 mg g^{-1} (AOAC 1960), phosphorus 2.6 mg g^{-1} (Olsen *et al.* 1954) and potassium 101 mg g^{-1} (Bower and Gschwend 1952). To prevent leaching, 1 kg soil was filled in polythene bags and was kept in plastic pots (15 cm diameter and 20 cm height). The soils were spiked by four levels of Pb (100, 350, 1500, 2500 mg kg^{-1}), supplied as lead nitrate [$Pb(NO_3)_2$]. Control soil was fertilized with 200 mg N kg^{-1} soil supplied as ammonium nitrate (NH_4NO_3) so as to normalize the effect of nitrates present in Pb salt. Spiked soils were incubated for 2 weeks.

2.2. Experimental setup

15 day old *C. didymus* plants having identical size (4–6 cm long shoots and 3–6 cm long roots having 4 rosette leaves) were transplanted in Pb-spiked soils. There were four replicates of each treatment arranged in a completely randomized design. The soil moisture of each pot was maintained at 60% of the water-retaining capacity by adding distilled water as needed until harvest. In a screenhouse, plants were grown under natural light and temperature conditions (average day, 18–25°C; night, 8–15°C). Plants were harvested, 4 weeks (22–28 leaves) and 6 weeks (34–40 leaves) after Pb application in the soil. Fresh plants were separated into roots and shoots and their length was measured with centimeter scale. Plant root–shoot tissues were rigorously rinsed with running water, washed for approximately 3 min with distilled water and then oven dried at 75°C for 72 h. The dried plant tissues were weighed, recorded, grounded to powder, and sieved through 2 mm stainless mesh.

2.3. Analysis of Pb in the plant tissues

The concentration of Pb in plant tissue was determined by atomic absorption spectroscopy (Contra 700; Analytic Jena AG, Jena, Germany) following wet digestion in oven dried tissue (100 mg) in 10 ml mixture of $HNO_3/HClO_4$ (4:1, *v/v*) at 140°C. The concentration of Pb in plant tissue was expressed in mg kg^{-1} DW. The content of Pb in soil was determined by using DTPA-extractable fraction of metal measured in terms of acido-soluble fractions (Lindsay and Norvell 1978).

2.4. Analysis of chlorophyll content and photosynthetic efficiency (F_v/F_m)

Total chlorophyll content was measured from the leaves of the tested species, as per Hiscox and Israelstam (1979) and was determined using the equation of Arnon (1949). F_v/F_m of PS II for both treated and control leaves was measured using OS-30p pulse modulated chlorophyll fluorometer (Opti Sciences, US).

2.5. Analysis of BCF and TF

Bioconcentration factor (BCF), Translocation factor (TF) of Pb in *C. didymus* were determined as per by (Sidhu *et al.* 2017a, 2017b). BCF and TF values play a key role to determine the capacity of a plant species for remediation of metal-contaminated soils. The plant species with both (BCF and TF > 1) have the potential to extract metal(loid)s in their aerial parts and are employed for phytoextraction. Besides, the plant species with (BCF > 1 and TF < 1) have the potential to accumulate high metalloid concentrations in their roots and are used for phytostabilization. The bioconcentration factor is the ratio of metal concentration in plant roots to that in the soil. The bioconcentration factor (BCF) = $C_{\text{root}}/C_{\text{soil}}$ translocation factor is the ratio of metal concentration translocated in shoots to that present in root part of the plants. Translocation factor (TF) = $C_{\text{shoot}}/C_{\text{root}}$.

2.6. Statistical analysis

The data presented were means of five replicates. All the data were analyzed by one-way analysis of variance (ANOVA), and then treatment means were compared after applying *post hoc* Tukey's test at $P \leq 0.05$ or Dunnett's test at $P \leq 0.05$ and $P \leq 0.01$. The statistical analyses were performed using SPSS software version 16.0 (SPSS Inc., Chicago, IL).

3. Results and discussion

3.1. Effect of Pb on plant growth

In this work, the root and shoot length of *C. didymus* significantly ($P \leq 0.05$) enhanced in a concentration-dependent

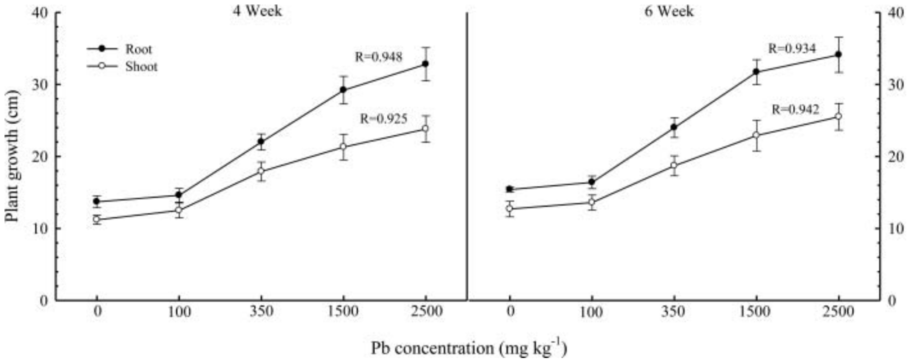

Figure 1. . Effect of Pb on root and shoot length of *C. didymus* after 4 and 6 weeks. Vertical bars along each data point represent the standard deviation of the mean. R represents correlation between the Pb concentrations in soil and growth of *C. didymus* at $P \leq 0.05$.

manner (Figure 1). After 4 weeks, root and shoot length at highest level (2500 mg kg^{-1}) enhanced ($P \leq 0.05$) significantly by 139.4% and 112.5%, respectively, compared to the control (Figure 1). On the parallel, Pb exposures for 6 weeks boosted the root and shoot length by 121.4% and 100.8% over the respective control (Figure 1). It is worth noting, however, that the plants grew vigorously even at the exposure to the higher Pb level and showed 100% survivability both after 4 and 6 weeks. The exact reason for the increased growth of *C. didymus* is not yet clear. However, the increased growth may be accredited to the rapid growth of the plants after the rosette stage. Another reason may be attributed to the phenomenon called hormesis in which a stimulatory effect in growth is noticed under the physiological toxic doses of heavy metal ions (Poschenrieder *et al.* 2013). Such triggered effect is an adaptive plant response followed by slight disturbance in the cellular homeostasis (Calabrese and Baldwin 2003). The results were in line with the findings reported by (Meeinkuirt *et al.* 2013) and (Sidhu *et al.* 2017a, 2017c). This might be correlated with the potential to retain Pb in active non-metabolic regions like cell wall and vacuole that facilitate the growth of the plants without any hindrance. In contrast, a declined plant growth (root-shoot length) of some Pb accumulators with elevated Pb concentrations was observed in *Sesbania grandiflora* by Malar *et al.* (2014a) and in *Eichhornia crassipes* by Malar *et al.* (2014b). However compared to 4 weeks, percent increase in plant growth was slightly declined after 6 weeks. This probably might be due to the expenditure of extra energy to combat Pb induced stress in the plant tissues or might be due to the restriction in cell division and cell elongation that impart ultrastructural alterations in the tissues of *C. didymus* plants. Another reason might be attributed to the formation of more Pb soluble fractions in the soil that promoted the Pb toxicity by reducing the chlorophyll content and PS-II activity. Based on these growth traits, it is possible to proclaim that *C. didymus* has the ability to withstand and tolerate stress induced by Pb excess.

3.2. Effect of Pb on plant biomass yield

During the whole experiment, the dry biomass yield of *C. didymus* plants increased linearly in a dose-dependent manner as indicated in Figure 2. After 4 weeks of growth, the root and shoot dry biomass incremented ($P \leq 0.05$) significantly by ~6%, 15%, 27%, 36% and by ~2%, 7%, 14%, 21%, respectively, compared to the control at concentration range from 100 to 2500 mg kg^{-1} Pb treatment (Figure 2). The root and shoot biomass after 6 weeks was enhanced by ~1–32% and ~2–20% with respect to the control, over 100–2500 mg kg^{-1} Pb treatment (Figure 2). The increased biomass yield might be attributed to the emergence of phytochelatins (PCs) in plants (Mishra *et al.* 2006) or might be due to the precipitation of Pb–phosphate deposits in the plant tissues that induces detoxification mechanism or antagonistic reaction between Pb and phosphate (Cotter-Howells *et al.* 1999) or might be due to the fertilization by nitrates spiked in the soil as lead nitrate. Our results were in agreement with the observations reported in *Thysanolaena maxima* and *Vetiveria zizanioides* (Meeinkuirt *et al.* 2013) and two cultivars of *Ricinus communis* under Pb stress (Zhang *et al.* 2016). On the contrary, conflicting results regarding the strong pessimistic effects of Pb on plant biomass have been reported. The root and shoot biomass production of both metallicolous and non-metallicolous ecotypes of *Dianthus carthusianorum* declined on exposure to Pb (Wójcik and Tukiendorf 2014). Malar *et al.* (2014b) observed decrease in biomass yield of *E. crassipes* under Pb stress. In general, increase or decrease in biomass might be due to the variation in plant species, time duration of metal stress, and experimental conditions especially soil type, microbial community and reaction of Pb with the components present in the soil. Compared to 4 weeks, the percent increase in biomass production was declined slightly after 6 weeks. The reason probably correlated with the elevated Pb uptake and accumulation in plant tissues with increased time duration, causing an inhibitory effect on biomass yield. Nevertheless, higher biomass production of *C. didymus* indirectly expresses its capability to withstand Pb stress.

3.3. Effect of Pb on photosynthetic apparatus

Chlorophyll is an important indicator of plant photosynthetic efficiency. Pb stress conferred negative effects on the chlorophyll content and photosynthetic activity of *C. didymus* plants. The content of chlorophyll declined in shoots of *C. didymus* on exposure to varied Pb treatments. After 4 weeks, the chlorophyll content reached minimum (7.59 μg/mg dw) at highest Pb concentration and was reduced by ~1–38%, respectively, over the control with the successive addition of Pb from 100 to 2500 mg kg^{-1}, whereas after 6 weeks, compared to the control,

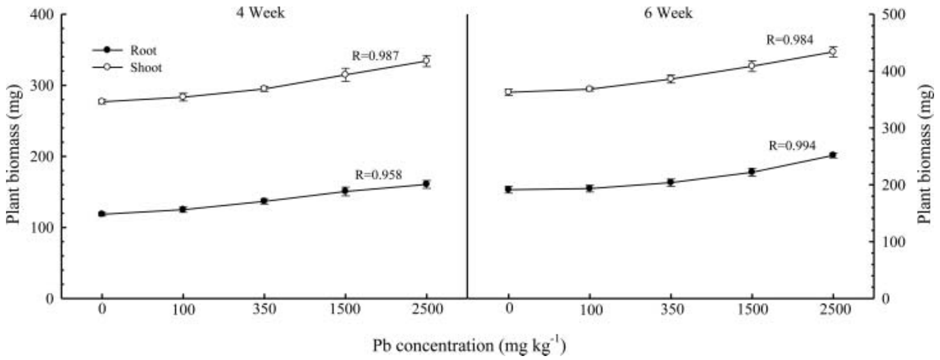

Figure 2. Effect of Pb on root and shoot biomass of *C. didymus* after 4 and 6 weeks. Vertical bars along each data point represent the standard deviation of the mean. R represents correlation between the Pb concentrations in soil and root-shoot biomass of *C. didymus* at $P \leq 0.05$.

it was declined by ~47% at 2500 mg kg^{-1} Pb treatment (Figure 3). The results indicated the pessimistic effect on chlorophyll content. This might be attributed to the interference of Pb with the photon–electron transport and hampering the activity of protochlorophyllide reductase (Aibibu *et al.* 2010). The other reason probably correlated with the higher accumulation of Pb in shoots that interferes and interact with –SH group of enzymes involved in the synthesis of chlorophyll (Shu *et al.* 2012), degeneration of chlorophyll by enhanced chlorophyllase activity (Sharma and Dubey 2005). Our results were in agreement with the findings reported in *Brassica napus* (Shakoor *et al.* 2014) and in *Coronopus didymus* (Sidhu *et al.* 2017c). Similarly, Malar *et al.* (2014b) revealed the decrease in photosynthetic pigment contents in leaves of *E. crassipes* under Pb stress. On the parallel, induction of Cd and Zn excess result a declined pigment concentration in *Brassica juncea* (Ebbs and Uchil 2008). F_v/F_m is an indicator of photosynthetic efficiency in plants. The normal and healthier plants have F_v/F_m ratio of 0.8 or above. In our results, the plants exposed to Pb stress have F_v/F_m ratios > 0.7. After 4 and 6 weeks of plant growth, a slight decline in F_v/F_m values to 0.76 and 0.75, respectively, was noticed at the highest Pb treatment (Figure 3). The results were in line with the findings on *Sesbania drummondi*, where F_v/F_m values were not significantly affected by Pb accumulation (Ruley *et al.* 2006). It is presumed that if a plant species under Pb stress retains a high F_v/F_m values for normal growth and metabolism, then this species may have efficient tolerance and accumulation mechanism for mitigating Pb from the contaminated soils (Ruley *et al.* 2006). On the contrary, Pb exposure adversely affects the photosynthetic machinery in *E. crassipes* (Malar *et al.* 2014b). This might suggest that high Pb levels in plant inhibit δ-aminolevulinic acid dehydratase which retards photosynthetic efficiency by reducing the chlorophyll content. In our work, the chlorophyll content of *C. didymus* plants decreased, but the plants maintained relatively good F_v/F_m ratios and growth, thus exhibited a strong ability to counteract Pb stress.

3.4. Pb uptake and accumulation in plant tissues

Pb uptake and accumulation in roots and shoots of *C. didymus* exhibited a linear increase in response to increased Pb exposure (100–2500 mg kg^{-1}) in the soil medium as depicted in Figure 4. After 4 weeks, the Pb concentration was significantly enhanced ($P \leq 0.05$) from 42 to 1652 mg kg^{-1} DW in roots and 27 to 502 mg kg^{-1} DW in shoots (Figure 4). However after 6 weeks, the Pb concentration was dramatically increased from 113 to 3091 mg kg^{-1} DW in roots and 35 to 527 mg kg^{-1} DW, respectively, in shoots (Figure 4). Compared to 4 weeks, the root Pb concentration was almost doubled in 6 week old plants. This might be attributed to long time exposure of plant roots with the Pb-contaminated soil. Additionally, Pb concentration in the plant roots was approximately 3–6 times that in the shoots probably because roots

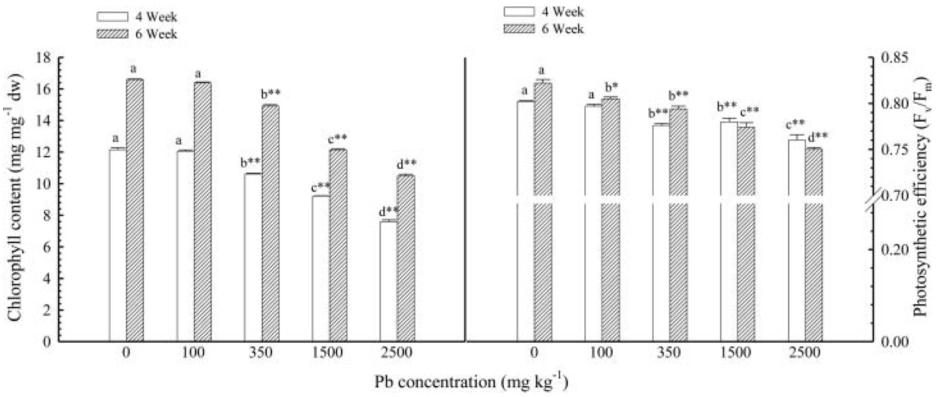

Figure 3. Effect of Pb on chlorophyll content and photosynthetic efficiency of *C. didymus* after 4 and 6 weeks. Vertical bars along each data point represent the standard error of the mean. Different alphabets represent significant difference at $P \leq 0.05$, after applying *post hoc* Tukey's test. ** represent significant difference at $P \leq 0.01$ over control, after applying Dunnett's test.

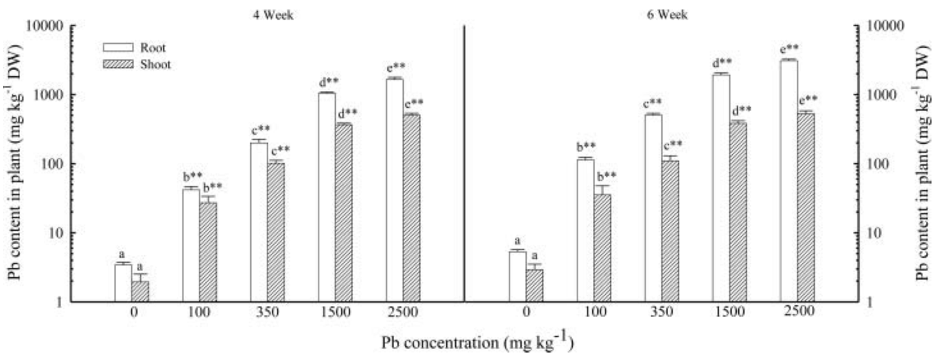

Figure 4. Pb content in root and shoot tissues of *C. didymus* after 4 and 6 weeks. Vertical bars along each data point represent the standard error of the mean. Different alphabets represent the significant difference at $P \leq 0.05$, after applying *post hoc* Tukey's test. ** represent significance at $P \leq 0.01$, over control after applying Dunnett's test.

are the primary sites for metal outburst that help the plant to combat Pb toxicity effectively. The results were in accordance with the observations reported in *Sesuvium portulacastrum* and *Brassica juncea* that showed high Pb concentration in roots in a dose-dependent manner (Zaier *et al.* 2010). Danh *et al.* (2009) reported that *Vetiveria zizanioides* accumulate Pb about 1% in roots and only a small amount of Pb 0.4% is translocated to the shoots. In another study, *Celosia cristata pyramidalis*, an ornamental plant accumulated Pb ~3-times more in roots than the shoots (Cui *et al.* 2013). This could be attributed to the formation of insoluble Pb precipitates with the phosphates, carbonates and bicarbonates present in the intercellular root spaces (Brennan and Shelly 1999) thus reduces the translocation of Pb from roots to the upper aerial parts of the plants (Cunningham and Berti 2000). In this study, *C. didymus* plants did not exhibit Pb concentration >1000 mg kg^{-1} in the shoots at any Pb treatment, the threshold level for hyperaccumulator plants. Meanwhile, hyperaccumulator plants contain $>$ 100 mg kg^{-1} Cd, >1000 mg kg^{-1} Ni, Pb or Cr and $>$ 10,000 mg kg^{-1} Zn or Mn in their aerial parts (Pollard *et al.* 2002). Nevertheless, the potential of *C. didymus* to tolerate and accumulate high Pb concentration in the roots makes it a probable Pb-accumulator plant species. Similar findings regarding accumulation of Pb in the roots were reported in *Juglans regia* (Marmiroli *et al.* 2005); in *Vetiveria zizanioides* (Andra *et al.* 2009) and in *Scirpus grossus* (Tangahu *et al.* 2013). This might be attributed to the profusely branched root system having high biomass yield, which in turn enhanced the surface area for Pb precipitation and adsorption, consequently facilitating its uptake and accumulation in roots. Another reason might be correlated with the synthesis of phytochelatins and formation of Pb–phytochelatin complexes within the vascular tissues of the roots of plants (Andra *et al.* 2009) or probably due to the formation of ligno-cellulosic structures in the roots that assist the plants to scavenge Pb effectively (Marmiroli *et al.* 2005). Thus, *C. didymus* may be regarded as a useful wild, non-edible plant species for phytoremediation of Pb-contaminated soils. Although it lemmatizes the mobility of free Pb ions from roots to the shoots and immobilise Pb in the roots. Similar to our findings, phytoremediation of Pb was reported in *Hirschfeldia incana* (Auguy *et al.* 2013) and *Sesbania grandiflora* (Malar *et al.* 2014a) from Pb-contaminated soils. Our findings suggested that *C. didymus* has the potential to accumulate relatively high concentration of Pb in its tissues and it may be used for remediation of Pb-contaminated soils.

3.5. Bioconcentration factor (BCF) and Translocation factor (TF)

BCF and TF are the two important factors required to evaluate the accumulation potential of a given plant species for metal(loids). By comparing BCF and TF, the potential of plant species to uptake heavy metals and translocating them to the upper aerial parts can be compared. BCF depicts the plant ability to absorb metal(loids) from the soil. BCF values of Pb for both 4 and 6 week *C. didymus* plants were $>$ 1 at all the concentrations. After 4 and 6 weeks, BCF value at 2500 mg kg^{-1} Pb concentration was found to be 1.07 and 1.30, respectively (Table 1). BCF value $>$ 1 indicates the plant potential for remediation of metal contaminated soils. However, the BCF values were declined with the increasing Pb concentrations. Similarly, decrease in BCF values were reported by Mertens *et al.* (2005) with enhanced metal concentrations in

Table 1 . Bioconcentration factor (BCF), Translocation factor (TF) values of Pb in *C. didymus* plants and the remaining Pb content in soil after 4 and 6 weeks of Pb treatment

	4 Week			6 Week		
Concentration of Pb in soil (mg kg^{-1})	BCF (C_{root}/C_{soil})	TF (C_{shoot}/C_{root})	Remaining Pb content in soil (mg kg^{-1} DW)	BCF (C_{root}/C_{soil})	TF (C_{shoot}/C_{root})	Remaining Pb content in soil (mg kg^{-1} DW)
0	—	—	—	—	—	—
100	1.01	0.26	90.3±4.1a	1.09	0.31	83.1±4.6a
350	1.15	0.25	311.1±7.4b	1.45	0.22	296.4±6.9b
1500	1.16	0.22	1027.0±10.1	1.37	0.20	951.3±10.3
2500	1.07	0.20	1734.4±15.2	1.30	0.17	1641.1±14.7

soil. Nevertheless, our results were in accordance with earlier findings that showed higher BCF values in response to Pb exposure (Meeinkuirt *et al.* 2012). In another study, Lum *et al.* (2014) noticed BCF value >1 for Pb in a weed, *Kyllinga erecta* on exposure to heavy metal contaminated soils in industrial region of Douala, Cameroon. Furthermore, TF values after 4 weeks were observed to be in the range of 0.20–0.26, respectively, upon 100–2500 mg kg^{-1} Pb treatment and 0.17–0.31, respectively, at 6 weeks (Table 1). Our results revealed that TF values for both 4 and 6 week plants were < 1, and it showed that the TF of Pb from roots to shoots remained at a relatively low value. The decrease in TF values with increased Pb concentrations probably indicated the saturation level in metal uptake or its transport from root to shoot at higher concentrations. Likewise, the TF values of Pb were found to be < 1 in *S. grandiflora* (Malar *et al.* 2014a). Higher BCF (>1) values and lower TF (<1) values, clearly illustrate the potential of plant species to retain the metal in the roots. The findings of our study strongly denoted that *C. didymus* has the capability to extract Pb from the soil and store it in the roots and shoots more effectively after 6 weeks, as it exhibited greater biomass production thus, indicating its ability in phytoremediation of Pb-contaminated soils.

The findings of this study indicate that *Coronopus didymus* may be a feasible candidate for its exploitation in phytoremediation of Pb. High Pb accumulation in the roots and seemingly its capacity to tolerate and withstand high Pb concentrations in soil makes *C. didymus* an attractive plant species. The importance of this species is further incremented by the luxuriant and fast growth rate, high biomass production that this plant, being a wild, non-edible herb, can generate in natural conditions. On the contrary, *Zea mays* (Bi *et al.* 2009), *Brassica campestris* or *Triticum aestivum* (Chandra *et al.* 2009) as crop plants accumulate high concentrations of Pb in their tissues. Once Pb enters the food chain, it can be a serious concern for humans and animals (Ramesar *et al.* 2014). This concern can be minimized by consolidating *Coronopus didymus* in Pb remediation strategy, as this plant species is not a food crop and, even is not used in herbivory under natural environment. Thus, *C. didymus* a high biomass yielding annual herb that accumulate Pb in its tissues and may be employed as a promising candidate to mitigate Pb from contaminated soils.

4. Conclusions

The study concludes that *C. didymus* has an exceptional ability to accumulate Pb especially in the roots. Compared to 4 weeks, the plant showed high growth and greater biomass production in response to elevated Pb levels after 6 weeks. Extended time period ameliorate the extraction of Pb from the contaminated soils by *C. didymus* plants. As a wild, non-edible plant species, the migration of potential contaminants like Pb to enter and disturb the food chain gets decreased. Thus, *C. didymus* has emerged as a novel wild plant species that can be used efficiently in future for remediation of Pb-contaminated soils. However, further studies are required in future to assess the capacity of *C. didymus* to mitigate Pb from long-term contaminated soils under realistic field conditions.

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