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Removal and Accumulation of Cadmium and Lead by *Typha latifolia* Exposed to Single and Mixed Metal Solutions

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Abstract We investigated the effect of Cd and Pb on the growth of the aquatic macrophyte *Typha latifolia*; the removal from the solution and the accumulation of these elements by the plant were also studied. Thus, small plants of *T. latifolia,* collected from a noncontaminated site, were exposed for 10 days to Cd and Pb, in a single solution or in mixture solutions, at two concentrations of the metals (5 and 7.5 mg/L). Our results showed that *T. latifolia* removed effectively Cd and Pb from solutions and was able to accumulate these metals in the roots and, to a lesser extent, in the leaves. Our findings suggested a synergistic effect of Cd and Pb with respect to the toxicity to *T. latifolia*. Additionally, Cd diminished the Pb absorption by *T. latifolia.* Our results confirmed, using scanning electron microscopy, the internalization of Cd and Pb in *T. latifolia*.

The heavy metals pollution of soils and waters is considered as one of the most serious problems worldwide because these elements are toxic, not biodegradable, and can be incorporated into the food chain. In aquatic ecosystems, mixtures of heavy metals are usually found and their uptake by plants is considerably influenced by synergistic or antagonistic interactions among these elements. Synergism refers to the phenomenon in which two or more agents acting together create an effect greater than the sum of the independent effects. By contrast, antagonism is a phenomenon by which two or more agents in combination have an overall effect that is less important than the sum of their individual effects. Additionally, these interactions might refer to the ability of an element to avoid or increase the absorption of other elements by the roots (Kabata-Pendias 2000); however, the mechanisms controlling these processes remain to be understood. Cadmium (Cd) and lead (Pb) are released into the environment by mining, wastewater and industry, representing a serious threat to human health (Paradiso et al. 2008; Sharma and Dubey 2005). In plants, the exposure to toxic concentrations of Cd and Pb to single treatments causes oxidative stress, growth inhibition, chlorosis, browning of root tips, disturbance of photosynthesis, reduction of water and nutrient uptake and inhibition of enzymatic activities (Paradiso et al. 2008; Sharma and Dubey 2005) and, finally, death.

Mercury (Hg), Cd, and Pb are considered as priority pollutants due to their toxicity and impact to the environment (Volesky 1994). Therefore, there is a considerable interest in the development of low-cost, effective, affordable, and environmentally friendly solutions for the treatment of sites contaminated by heavy metals, taking into consideration the interactions among these elements. The use of aquatic plants has been shown as an attractive alternative in the remediation of aquatic ecosystems polluted by heavy metals (Manios et al. 2003; Sasmaz et al. 2008). According to Boyd (1970), the aquatic macrophytes used in any treatment system should meet several criteria: rapid growth, easy spreading, high pollutant uptake capacity, and easy harvesting. *Typha latifolia* (cattail) is an

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emergent macrophyte; it is a perennial plant belonging to the Thyphaceae family, which grows in swamps, lakes and lagoons. These plants have the advantages of growing under varied climatic conditions and accumulate heavy metals under natural conditions or from contaminated environments. With respect to the last one, recently we have reported that plants of *T. latifolia,* growing in an artificial lagoon containing municipal and industrial wastewaters, showed the potential to extract Pb, Cd, Cr, Mn, and Fe and accumulate these metals mainly in its roots (Carranza-Álvarez et al. 2008).

In the aquatic macrophytes, the mechanisms involved in the accumulation of heavy metals are partially understood and could vary among species. Suñe et al. (2007) have studied the Cd and Cr uptake by *Pistia stratiotes* and *Salvinia herzogii* and have observed that this involved a fast stage and a slow stage. They have explained the fast mechanism by adsorption, chelation, and ion exchange; the slow stage seemed to be different between species and was explained by biological (metal translocation to the aerial parts) or chemical (metal precipitation at the plant root) processes. There are also differences in the accumulation of heavy metals depending on their chemical behavior and the metal concentrations, even for the same plant species. Some plant species have developed mechanisms for the accumulation of heavy metals, such as the formation of a coordination complex of heavy metals with organic acids (citrate, oxalate, malate), proteins (metallothioneins), small peptides (glutathione, phytochelatins), and amino acids (cysteine); finally, these coordination complexes are transported toward vacuoles and the cell wall (Hall 2002), sites where the heavy metals can be stored without affecting the plant physiology.

Most of studies using macrophytes to remove heavy metals from solutions refer to the removal of one element and few reports have been focused on the removal of binary mixtures of metals (Saygideğer and Doğan 2004; Shukla et al. 2007; Sinha et al. 2003). The goals of the present study were (1) to investigate the toxic effects of Cd and Pb in single and combined treatments on *T. latifolia*, (2) to determine the removal of Cd and Pb from single and binary mixtures and their accumulation by *T. latifolia*, and (3) to confirm the internalization of Cd and Pb in *T. latifolia* roots, previously exposed to these metals, using scanning electron microscopyl with an energy-dispersive X-ray (EDX).

Materials and Methods

Plant Material

Plants (35 ± 5 cm long) of *T. latifolia* collected from ponds not contaminated with metals were transported in plastic bags to the laboratory and washed with running tap water. Plants were maintained in a greenhouse at 25–28°C and 60% of humidity. Finally, the plants were grown in glass boxes with aeration, containing a nutritive solution of Tricel 20-amino (Cosmocel, Monterrey, México) at 1 g/L supplied with 20% of each of the following:, nitrogen, phosphorus, and potassium.

Experimental Design

Small plants were grown as described earlier for about 6 weeks to allow good root development before each experiment. Plants of similar weight (51.6 ± 4.3 g/ plant, wet mass) and length (roots: 12–15 cm; aerial parts: 60–62 cm) were used for the experiments. Three plants were selected as a control to measure their initial concentrations of Cd and Pb. Plants were inserted in an upright position in glass boxes of $25 \times 25 \times 30$ cm containing 4 L of deionized water; the pH of the solution and the ionic strength (I) were adjusted to 5.7 and 0.01 M, respectively. Results obtained in our laboratory using in vitro cultures of *Larrea tridentata* showed that these conditions were the optimum to remove Pb (Bocanegra-Salazar 2004). Plants were exposed for 10 days to individual and binary mixtures of Cd and Pb at concentrations of 5 and 7.5 mg/L. Cd and Pb, of analytical grade, were supplied as $Cd(NO_3)_2$ and $Pb(NO_3)_2$, respectively (Fluka Chemical Co., Milwaukee, WI). The concentrations of trace elements used in our study were calculated to exceed the maximum concentrations permitted by Mexican laws for agricultural use (NOM-CCA-032-ECOL/1993) and to surpass the levels considered as phytotoxic Cd (0.5 mg/kg) and Pb (5 mg/kg) (Markert 1992). We performed chemical modeling using the MINEQL + program (Schecher and McAvoy 1994) to predict whether Pb and Cd were available for plants, calculating their limit of solubility and estimating their dissolved chemical species under the physicochemical characteristics of water (pH and I). Each treatment was performed in two experiments in triplicate. Previous to the experiments, the glass boxes were cleaned with HNO_3 3% (v/v) for 48 h and thereafter washed with deionized water. Controls were prepared using plants ($n = 3$); none of the controls was exposed to metals and their roots were submersed in deionized water. Additional chemical controls were simultaneously performed by adding metal solutions to glass boxes without plants to check the loss of metals from the experimental solutions due to the adsorption on the vessels wall.

Samples Processing and Determination of Heavy Metals by AAS

Water samples (8 mL each) were taken in triplicate from all solutions at 0 h and every 24 h for 10 days, acidified with

20 μL/mL of 0.02 N HNO_3, and analyzed for Cd and Pb concentrations by atomic absorption spectrophotometry with graphite furnace (AAS-GF; Varian SpectrAA 220Z). As described by Zhu et al. (1999), elements such as Cd and Pb can partially bind to negatively charged sites in roots. This adsorption can be determined by using the chelator agent EDTA. After 10 days of exposure, plants were removed from the solutions, washed thoroughly with distilled water, and rinsed by immersion in a solution of 0.01 M EDTA for 10 min to eliminate the metals adsorbed to the roots. The concentrations of desorbed metals were analyzed by AAS-GF. The relative vegetal growth was determined by dividing the fresh weight (g) of the plant at the end of the experiment by the initial fresh weight (g) of plants. The length of the longest leaf on each plant was measured at day 0 (prior to the addition of metals to solutions) and at day 10. Plants were cut and the roots and leaves were processed separately, oven-dried at 70°C for 18 h, and ground in a Wiley mill for 2 min. The treated plants were preserved in high density polyethylene (HDPE) bottles at room temperature and protected from light and dust. The plants were digested following the procedure reported by Carranza-Álvarez et al. (2008). Metal concentrations in water samples were taken every 24 h; EDTA solutions and digestions of plant samples were determined by AAS using an air–acetylene flame (AAS-F; Varian SpectrAA 220FS) or graphite furnace (AAS-GF; Varian-SpectrAA 220Z). A reference plant material *Lagaroshipon major* (CBR, Reference material No. 60) and blanks were analyzed by triplicate to determine the accuracy of the determinations. The recovery rate for the reference plant sample ranged between 90% and 110%. The detection limits for the analytical method were 0.01 and 0.02 mg/kg for Cd and Pb, respectively. The quality control for the analytical procedures was assured by the analysis of a certified water sample for trace elements (TM-DWS, National Water Research, Canada); the recovery for the certified water was 100 ± 15%.

The bioconcentration factor (BCF) for the plants tested in this work was calculated as proposed by Zayed et al. (1998), as follows:

$$BCF = [Me]_P/[Me_0]_S$$

where $[Me]_P$ is the metal concentration (mg/kg) in the plant tissues at harvest (end of the experiment) and $[Me_0]_S$ is the initial concentration (mg/L) of the metal in the experimental solution.

Analyses of Scanning Electron Microscopy with an EDX

Parallel experiments were carried out exposing plants of *T. latifolia* to single and mixed solutions of Cd or Pb at 100 mg/L under the conditions described previously. After 3 days, plants were removed from the solution and the tip roots were separated, directly frozen at –20°C and lyophilized (Freeze Dry System, Labconco) for 18 h. Samples were glued to aluminum holders and sputter-coated with gold using a current of 40 A and placed for 20 s in an Ar atmosphere using a Cressington Sputter Coater 108 auto. The tip roots were studied using a scanning electron microscope (SEM; FEI XL30 SFEG with an EDX microanalysis system), with an acceleration voltage of 10 kV. EDX studies were carried out on the samples to obtain their elemental composition.

Statistical Analysis

The mean metal concentrations in the plants exposed to Cd and Pb are reported in milligrams per kilogram based on dry weight. The normality of the analyzed data was checked by the chi-square test; the Bartlett's test was used for the evaluation of homogeneity of variances. Where necessary, the difference between two sets of samples was determined by a Student's *t*-test on the normalized data by logarithmic transformation. Results were considered significantly different when the calculated *p*-values were ≤ 0.05. All calculations were done employing the JMP 5.1 program (SAS Institute Inc, Cary, NC).

Results and Discussion

Effects of Cd and Pb on the Growth of *T. latifolia* Exposed to a Single Metal or Metal Mixture Solutions

Figure 1 shows the effects of Cd and Pb on the relative growth and leaves elongation of *T. latifolia* exposed for 10 days to single metal (Cd or Pb) or mixture (Cd and Pb) treatments. The fresh weight of plants treated with Cd or Pb in single solutions did not differ significantly with respect to the control ($p \geq 0.05$). However, the relative growth of plants exposed to a mixture of Cd and Pb at 5 and 7.5 mg/L decreased significantly ($p \leq 0.05$) as follows (Fig. 1a): by 16% when they were exposed to a mixture of 5 mg/L of each metal and by 25% when the plants were grown in solutions containing 7.5 mg/L Cd and 7.5 mg/L Pb. Additionally, there was a significantly decrease ($p \leq 0.05$) in leaf elongation of the plants with increasing metal concentrations in both single and binary treatments (Fig. 1b). The maximum decrease in leaf elongation (78%) was found in plants treated with the combination of Cd and Pb at 7.5 mg/L (Fig. 1b), compared with the control. In addition, symptoms of toxicity, such as fragility, chlorosis in leaf, and browing and twisting of roots, occurred only in *T. latifolia* plants treated with binary mixtures of Cd and Pb. Our findings suggest that Cd and Pb exerted a synergistic effect concentration dependency on toxicity of *T. latifolia*. Similar results were reported by other authors. The relative growth of plants of *Ceratophyllum demersum*, *Hygrophila difformis*, *Cabomba caroliniana*, and *Ludwigia hyssopifolia* growing in solutions containing Pb at 10 mg/L for 15 days decreased by 20% (Yaowakhan et al. 2005). However, *C. demersum* exposed to Pb at 5 mg/L for 7 days did not affect its relative growth (Mishra et al. 2006). The relative growth pf plants of *Eichhornia crassipes*, *Veronica anagallis*, and *Ranunculus aquatilis* growing in solutions containing 4–7.5 mg/L Cd for 12–14 days decreased by 20–24% (Lu et al. 2004; Saygideğer 2000). Exposure to both Cd and Pb in solution affected the growth of *Lemna minor* and *C. demersum* more than the single treatments to Cd or Pb (Saygideğer and Doğan 2004).

The apparent no correlation among values obtained with relative growth and leaves elongation, might be, in part, because the relative growth represents to the whole plant, whereas leaves elongation only represents ~10% of the fresh weight of the plant. Leaves elongation might be also affected by the chlorosis.

Removal of Cd and Pb *by T. latifolia*

The percentage of Cd and Pb removed from single or binary mixture solutions by *T. latifolia* is shown in Fig. 2. In all of the experiments, the heavy metals concentration decreased in the solution as the exposure time increased. *T. latifolia* showed a total removal efficiency of 41% and 38% at concentrations of 5 and 7.5 mg/L Cd in single solutions, respectively (Fig. 2a, c). In addition, *T. latifolia* removed 89% (5 mg/L) and 84% (7.5 mg/L) of Pb in single solutions (Fig. 2a, c). By contrast, the plants removed 38% of Cd and 87% of Pb from a binary mixture of 5 mg Cd/L + 5 mg Pb/L (Fig. 2b) and 32% of Cd and 80% of Pb when these elements were combined at concentrations of 7.5 mg/L (Fig. 2d). A nonsignificant decrease ($p \geq 0.05$) in Cd and Pb concentrations was observed in control glass boxes without plants at all of the tested concentrations (data not shown), indicating that the decrease observed in the heavy metals concentrations in the solutions was mainly due to adsorption/absorption by the plants. Our results suggest that the Pb removal efficiency of *T. latifolia* is high when this element is in both single and binary treatments. The removal efficiency for Cd and Pb did not show a significant difference ($p \geq 0.05$) when the concentrations of the metals varied under single and mixed treatments, suggesting that the initial concentration of Cd and Pb was independent of the total removal efficiency of *T. latifolia*. Our results are in agreement with other studies. Plants of *E. crassipes* exposed to several concentrations of Cd in single treatments showed that the initial concentrations of this element were independent of its total removal efficiency (Lu et al. 2004). These authors also indicated that *E. crassipes* removed over 90% of Cd when exposed to concentrations of 4 mg/L for 12 days. Yaowakhan et al. (2005) showed that the removal of Pb by *C. demersum*, *H. difformis*, *C. caroliniana*, and *L. hyssopifolia* was dependent on the dissolved metal

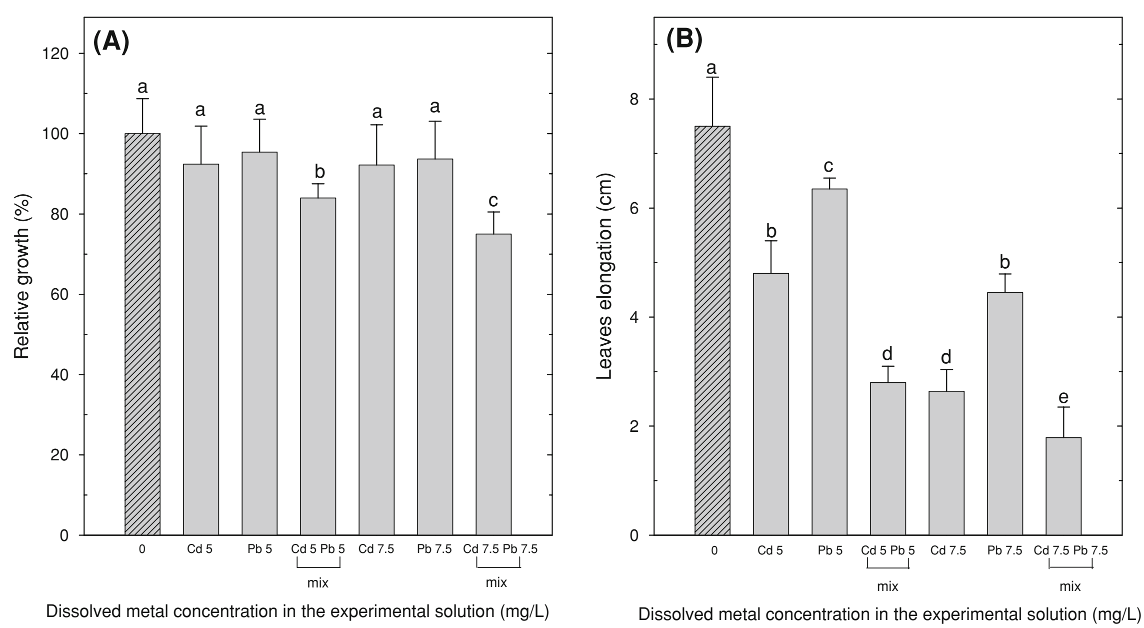

Fig. 1 Effects of Cd and Pb treatments on the growth (**a**) and the leaf elongation (**b**) of *T. latifolia* exposed for 10 days to single and binary treatments. The results are presented as the mean ± standard deviation (SD) of two independent experiments done in triplicate. *Different letters* among treatments indicate a significant difference according to the ANOVA test ($p < 0.05$). The word "*mix*" denotes the presence of Cd and Pb together in the solution

concentration. These plants showed a removal efficiency of 80%, 70%, 50%, and 30%, respectively, at 9 days of exposure at 10 mg/L of Pb.

Accumulation of Cd and Pb by *T. latifolia*

The mass of Cd and Pb in the solution after the experiments, the EDTA-extractable (adsorbed) metals, and accumulated (absorbed) metals by *T. latifolia* are shown in Fig. 3. Considering that a fraction of Cd and Pb removed by *T. latifolia* might have been adsorbed to the vegetal surface, the roots were washed with EDTA to remove the adsorbed metals. Our results indicated that the highest Cd content in both single and combined metals treatments was found in the solution after the experiments. In the case of Pb, the highest content of this element was found in the plant, in both single and binary mixtures. Our findings showed that in binary mixtures, the content of Pb in plant decreased ($p \leq 0.05$) by 30–40% but increased ($p \leq 0.05$) sixfold to sevenfold in EDTA-extractable solution, compared to single treatments, whereas the content of Cd in the three studied systems was not affected by the presence of Pb. This might suggest that Cd competes with Pb for the same transporter and, therefore, Cd might present more affinity than Pb for the site of union in the roots, resulting in a decrease of the content of Pb absorbed and accumulated by the plant. Thus, our results might indicate that Cd exerts an antagonistic effect on Pb absorption in *T. latifolia.* The effect of the interaction of Cd and Pb on their uptake by aquatic plants is not well understood yet. Our results agree with Saygideğer and Doğan (2004). They reported an antagonist effect between Cd and Pb when both were in the solution; Cd decreased the Pb accumulation by *C. demersum* in comparison to treatments with Pb alone. However, our findings disagree with those of Georgieva et al. (1997); they showed that Pb was a stronger antagonist on Cd accumulation in *Pisum sativum* plants. Moreover, it was shown that Pb decreased the Cd content in the protist *Euglena gracilis* exposed to a binary mixture of these heavy metals (Mendoza-Cózatl et al. 2006). More research

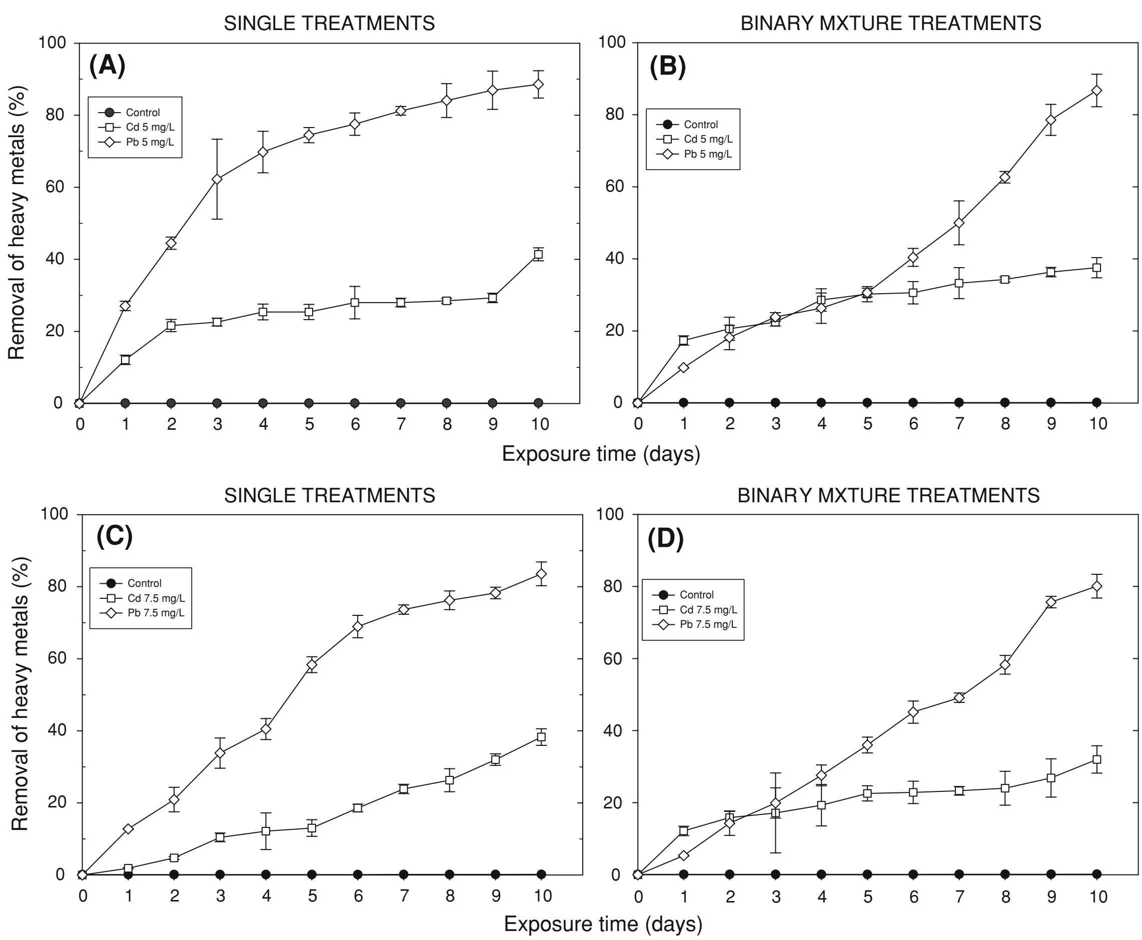

Fig. 2 Removal of Cd and Pb by *T. latifolia* from single (**a**, **b**) and binary (**c**, **d**) mixtures in solution. Plants were exposed for 10 days at the indicated concentrations in single and binary treatments with Cd and Pb. The results are presented as the mean ± SD of two independent experiments done in triplicate

is needed to better understand the interaction between Cd and Pb in order to propose the factors that explain this behavior or the mechanisms that can be enhanced to increase the capacity of this plant to accumulate Cd and Pb when both elements are present in the solution.

The concentrations of Cd and Pb in *T. latifolia* growing under single and mixed metal treatments (Fig. 4) are given after subtracting the content of Cd and Pb in the control plants. Cadmium concentrations in roots ranged from 932 to 2339 mg/kg, whereas that in leaves ranged from 276 to 622 mg/kg. The maximum accumulation of this element occurred in roots at 7.5 mg/L under single treatment (Fig. 4a). Accumulation of Pb in *T. latifolia* was from 1365 to 4867 mg/kg in roots and from 272 to 927 mg/kg in leaves, and the maximum accumulation of this element was detected in the roots at 7.5 mg/L under single treatment (Fig. 4a). Our results showed that the accumulation of Cd and Pb in *T. latifolia* increased significantly ($p \leq 0.05$) when increasing the concentrations of these elements in single treatments. However, the heavy metals concentrations in *T. latifolia* decreased under binary mixtures compared to the single treatments (Fig. 4a), probably due to the toxic effects, such as a decrease on the relative growth of the plant exposed to Cd and Pb (Fig. 1).

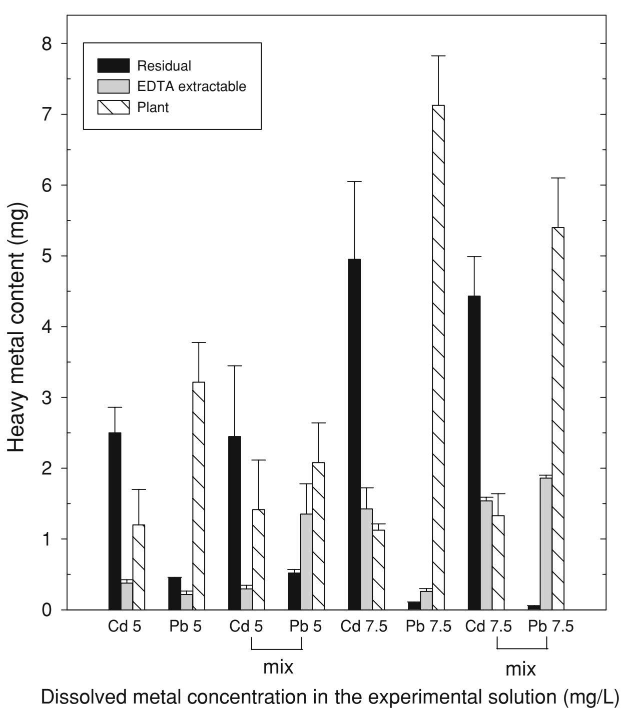

Fig. 3 Concentrations and content of Cd and Pb in the solution after the experiments, the EDTA-extractable (adsorbed metal), and the accumulated (absorbed) metals by *T. latifolia*. The results are presented as the mean ± SD of two independent experiments done in triplicate. The word "*mix*" denotes the presence of Cd and Pb together in the solution

Our findings indicated that *T. latifolia* accumulated more Pb than Cd at all of the treatments ($p \leq 0.05$) (Fig. 4a). Additionally, *T. latifolia* showed higher concentrations of Cd and Pb in the roots than in the leaves, indicating the accumulation by the roots and their transport to the aerial parts. Cd and Pb concentrations in roots were about three to eight times higher than in leaves, and the content of these two elements in the leaves was quite high (272–927 mg/kg) considering that the time of exposure was 10 days. In a previous report, Carranza-Álvarez and co-workers (2008) showed that *T. latifolia* plants 3–4 m high, collected from a wastewater lake, accumulated Cd and Pb mainly in the root (0.1–25 mg/kg Cd and 16–25 mg/kg Pb) and, to a lesser extent, the metals were translocated to the leaves (0.1–1.2 mg/kg Cd and 8.6–17 mg/kg Pb). In that lake, *T. latifolia* has been an invasive species for the last 6–8 years. Our previous results suggested that the translocation of heavy metals in this plant occurs with the increasing time of exposure. Further experiments will characterize the ability of this plant to transport elements from the roots to aerials parts. The reduction of the transport of Cd and Pb from the roots to aerials parts in some aquatic macrophytes has been attributed to the formation of a coordination complex between organic acids (Paradiso et al. 2008; Sharma and Dubey 2005). Our results concur with reports from other authors. Zhu et al. (1999) showed that *E. crassipes* supplied with 10 mg/L of Cd for 14 days accumulated 6.1 g/kg of this element in roots. Additionally, plants of *Hydrocotyle umbellata* treated with Pb at 20 mg/L for 12 days accumulated 32 g/kg of this metal in the roots (Yongpisanphop et al. 2005).

The BCF is a useful parameter for evaluating the ability of plants in accumulating heavy metals with respect to the initial concentration of heavy metals in the substrates (Zayed et al. 1998). The BCFs were calculated for Cd and Pb uptake by *T. latifolia,* under single and binary treatments, and are given in Fig. 4b. The BCFs of Cd were in the order of 186 to 312 in roots and from 55 to 82 in leaves of *T. latifolia,* and the highest BCF of this element occurred when Cd was supplied at concentration of 7.5 mg/L (Fig. 4b). The BCFs of Pb in roots ranged from 273 to 648, whereas in the leaves, the BCFs ranged from 54 to 123; the maximum BCF was obtained in roots treated with 7.5 mg/L Pb. Other studies have reported that *E. crassipes* and *H. umbellata* exposed to Cd (10 mg/L) and Pb (20 mg/L) showed BCFs in roots of 600 and 1600, respectively (Yongpisanphop et al. 2005; Zhu et al. 1999). According to Zayed et al. (1998), BCFs less than 300 represent a poor accumulator of heavy metals, whereas BCF values between 300 and 800 indicate moderate accumulation and BCFs greater than 800 represent a good accumulator. In the experimental conditions of this study and from the BCFs

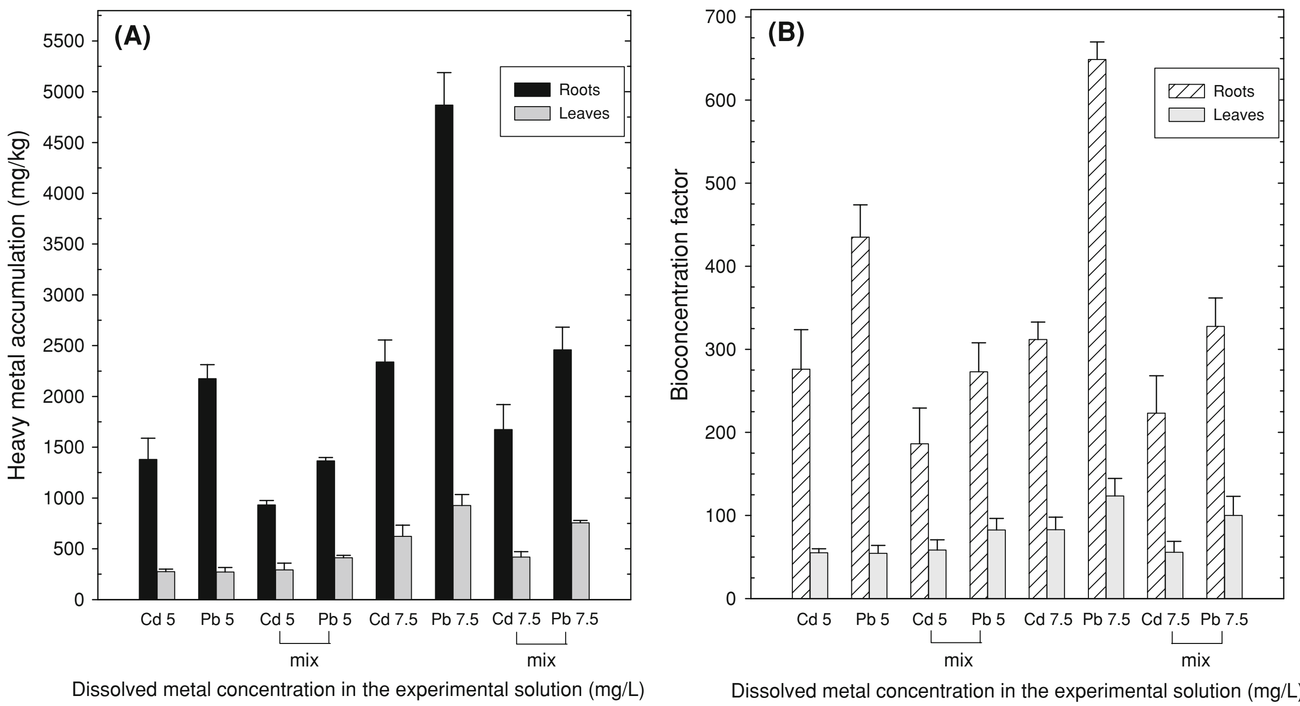

Fig. 4 Mean Cd and Pb concentrations in the roots and leaves of *T. latifolia* (**a**) and the BCFs calculated for the *T. latifolia* roots and leaves (**b**) exposed to Cd and Pb at the indicated treatments. The results are presented as the mean ± SD of two independent experiments done in triplicate. The word "*mix*" denotes the presence of Cd and Pb together in the solution

obtained, *T. latifolia* can be considered a moderate accumulator of Cd and Pb. However, this plant is probably better defined as a good accumulator of Cd and Pb, considering that this macrophyte presents the ability to accumulate high concentrations of heavy metals from contaminated environments over long times of exposure (Carranza-Álvarez et al. 2008). Additionally, this plant has a well-developed root–rhizome system, its harvesting is easy, it presents high rates of growth and high biomass production, and is widely distributed in aquatic environments.

Analyses of SEM with an EDX

In order to confirm the internalization of Cd and Pb by the plants, SEM studies in combination with EDX were carried out in control and heavy metals-exposed plants. Due to the low sensitivity of this methodology we could not detect in *T. latifolia* the presence of Cd or Pb at the maximum dissolved concentration used in this study (7.5 mg/L), to test the removal and accumulation of these metals. Therefore, we exposed plants of *T. latifolia* for 3 days to concentrations of 100 mg/L of Cd and Pb, in single and mixed solutions, to detect the internalization of these elements by the plants. To perform the EDX analyses, the plants were separated into roots and leaves; Cd and Pb were not detected in leaves (spectrum not shown). This might be explained by the short exposition time, which was probably not enough to promote the metal translocation to the aerial parts.

On the other hand, in the roots, the EDX spectrum of the control plants revealed the content of ions, such as Cl, K, Ca, Na, and Mg (Fig. 5a). The presence of Au in all spectra corresponds to the support material used to observe the root samples. Figure 5b and d shows the EDX spectrum and the composition for each element present in *T. latifolia* roots after exposure to Cd in single (Fig. 5b) and mixed (Fig. 5d) solutions. At an intensity of 3.2 keV, the characteristic peak of Cd is shown, confirming the presence of this element inside *T. latifolia* roots. Figure 5c and d shows the Pb spectrum and the characteristic peak of this element at 2.2 keV of intensity, indicating the presence of this metal inside *T. latifolia* roots in single (Fig. 5c) and mixed (Fig. 5d) solutions. The EDX spectra showed that Cd and Pb were detected inside the roots of *T. latifolia,* indicating that this macrophyte can absorb and transport heavy metals inside the roots, which represents an important mechanism of *T. latifolia* in the accumulation of these elements. Further analyses are necessary to better characterize the internalization and accumulation of Cd and Pb by this plant.

Conclusions

Typha latifolia removes effectively Cd and Pb from solutions and is able to accumulate these metals in the roots

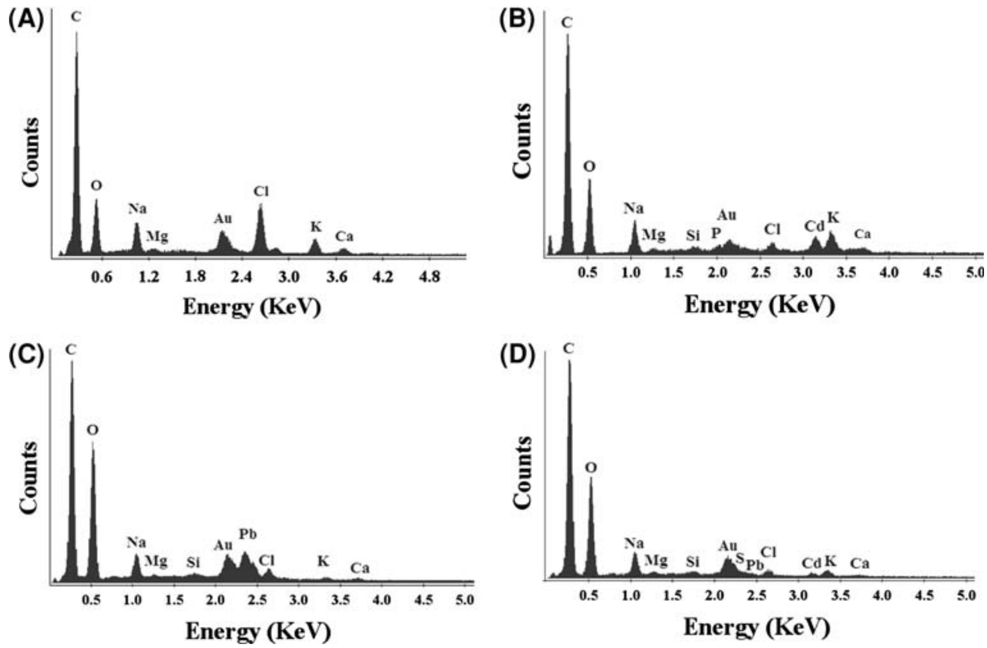

Fig. 5 Spectra of EDX taken from inner side of the primary root of control (**a**), single Cd (**b**), single Pb (**c**), and Cd and Pb (**d**) mixed exposed plants

more than in the leaves. Our results indicated that Cd and Pb presented a synergic effect on the toxicity to *T. latifolia*. Additionally, Cd affected the Pb uptake when both were in the solution. Thus, *T. latifolia* can be considered s an interesting alternative for treating polluted water systems.

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