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RESEARCH ARTICLE

Growth, accumulation and uptake of *Eichhornia crassipes* exposed to high cadmium concentrations

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Abstract
A greenhouse experiment was performed to evaluate the growth, accumulation, and uptake rate of *Eichhornia crassipes* subject to high cadmium concentrations. Three doses of Cd were added to polluted river water (1, 5, and 10 mg Cd/L), and polluted water with basal Cd concentration (0.070 mg/L) was used as a control. The experiment lasted for 7 days. Signs of stress and toxicity were visible in all treatments from day 3 of the experiment. The growth of the water hyacinth was slightly stimulated in the presence of low Cd concentration (1 mg/L), but this could also be due to the chloride and other nutrients present in the polluted water. Cd was accumulated mainly in roots, showing a maximum concentration of 1742.1 mg Cd/kg dw (10 mg Cd/L). The translocation from roots to leaves was low, with a maximum accumulation of 147.4 mg Cd/kg dw (10 mg Cd/L). The uptake rate for roots reached a maximum of 248.7 mg Cd/kg·day while the uptake rate for leaves did not saturate in the range of the studied concentrations (max. 20.8 mg Cd/kg·day). The water hyacinth showed promising results for the application in the treatment of Cd-polluted waters given its ability to tolerate high Cd concentrations in the media (up to 10 mg Cd/L) and its capacity for uptake and accumulation.

Keywords Aquatic plants · Trace elements · Water hyacinth

Introduction

Environmental pollution caused by trace elements has become a serious issue worldwide. In nature, the mobilization of metals, such as Pb, Cd, Ni, Co, Cr, Cu, or Ag, in the biogeochemical cycles is minimum. These elements are mainly found in reservoirs, but mining extraction and its subsequent processing for different applications release them to the environment (Ali et al. 2013). Urbanization, industrialization, and transportation, among other human activities, favor the dispersion of trace elements in the water and the atmosphere (Nagajyoti et al. 2010).

Cadmium (Cd) is considered a non-essential element that negatively affects all types of organisms. It is highly soluble in water and it has been classified as an element of intermediate toxicity (Sanità di Toppi and Gabbrielli 1999; Benavides et al. 2005). It is frequently used in the industry of electroplating, pigments, plastic stabilizers, and batteries, and it is a by-product of phosphate fertilizers (Lux et al. 2011; Gallego et al. 2012; Tran and Popova 2013). Cadmium alters plant growth and development by interference in the uptake, transport, and use of various elements (Ca, Mg, P, and K) (Benavides et al. 2005). It reduces the absorption of nitrates and its transport from root to shoot, affecting the water balance in the plant, and it also has negative effects on membrane phospholipids and photosynthesis metabolism (Sanità di Toppi and Gabbrielli 1999; Benavides et al. 2005; Rodríguez-Serrano et al. 2008; Tran and Popova 2013).

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Among the most industrialized and crowded areas in the world, there is a river located in Argentina that is considered one of the ten most polluted sites in the world (ECYT-AR 2011; Bernhardt and Gysi 2013). In the metropolitan area of Buenos Aires, the Matanza-Riachuelo river (MR river), a typical plain river, is subject to strong anthropogenic disturbances (Gómez 1998), in particular the lower part of the basin, called "Riachuelo." Trace elements are among the most conspicuous contaminants in water, soil, and sediments in the basin, and phytoremediation has been proposed as a likely strategy to decrease this burden (Basílico et al. 2016).

Phytoremediation involves the use of plants to reduce the concentration or toxic effect of different kind of pollutants (trace elements, organic compounds, and other xenobiotics) in the environment. Plants can modify contaminants in a variety of processes (removal, reduction, transformation, mineralization, degradation, etc.). This technology poses many benefits since it is efficient, cost-effective, and environmentally friendly (Ali et al. 2013). Among the plants that have been tested for phytoremediation purposes, many floating macrophytes have shown great capacity of tolerance and absorption of heavy metals. *Salvinia* (Phetsombat et al. 2006; Dhir and Srivastava 2011), *Lemna* (Khellaf and Zerdaoui 2010), *Pistia* (Sukumaran 2013), *Eichhornia* (Rezania et al. 2015), and *Azolla* (Sood et al. 2012) are among the most studied genera (Ali et al. 2013; Dixit et al. 2015; Rezania et al. 2016). Various species of floating macrophytes have been able to tolerate and absorb high Cd concentrations (> 1000 mg Cd/kg). Some examples are *Limnocharis flava* (Abhilash et al. 2009) and *Salvinia cucullata* (Phetsombat et al. 2006). In particular, the water hyacinth *Eichhornia crassipes* (Mart.) Solms has been extensively studied for its application in phytoremediation and has shown an interesting capacity for the accumulation and biosorption of heavy metals (Rezania et al. 2015). Metals, such as mercury, induce responses of oxidative stress and DNA damage in *E. crassipes* (Malar et al. 2015). Also, the water hyacinth has efficient molecular mechanisms (antioxidative enzymes) to tolerate lead accumulation in their tissues, indicating that it is a feasible plant for phytoremediation of polluted water containing lead (Malar et al. 2014).

There are several studies on the effect of cadmium on water hyacinth, but few of them explore the addition of this metal in high concentrations in polluted waters (e.g., Soltan and Rashed 2003; Hasan et al. 2007). We have previously evaluated the accumulation and tolerance of this species to copper, an essential element, under stressful conditions (Melignani et al. 2015). Since we obtained promising results, we were also interested in testing similar conditions for a non-essential element, cadmium. Both the cadmium and the water hyacinth are present in polluted water bodies with industrial and domestic effluent discharge. The tolerance described for this species under this stressful circumstance, could be applied in the treatment of industrial effluents. Therefore, the objective of this study was to evaluate the growth of water hyacinth exposed to high Cd concentrations added to polluted river water (Riachuelo water), as well as its accumulation and uptake rate in a short-term exposure experiment.

Materials and methods

Plant and water collection

Plant material (water hyacinth, *E. crassipes*) and the surficial water for the experiment were sampled from the Riachuelo section of the MR river (34° 38′ 12″ S, 58° 21′ 05″ W), Buenos Aires, Argentina, on February 2012. The plants were cleaned with tap water and acclimatized in a hydroponic system (diluted Hoagland solution in a greenhouse with natural photoperiod) for 2 months. After propagation, individuals of the second generation were selected for the experiment (April 2012).

Experimental set-up

Cadmium (as $CdCl_2 \cdot 2\ ½\ H_2O$, analytical-grade reagent) was added to the river water in three concentrations: 1, 5, and 10 mg/L (treatments Cd1, Cd5, and Cd10, respectively). The river water without Cd supplement (basal concentration: 0.07 mg/L) was used as a control (Cd0). One or two individuals of water hyacinth (200 g fresh weight) were placed in plastic reactors with 4 L of the water (3 replicates per treatment and control). The plants were exposed to the metal for 7 days under greenhouse conditions (natural photoperiod, controlled temperature 22.0 ± 1.9 °C, and pH 7.55 ± 0.24). The water volume of the reactors was kept constant by adding deionized water.

Sampling and analysis

At the beginning of the experiment, three individuals of water hyacinth were separated from the hydroponic system and three water samples were taken from each treatment in order to measure initial Cd concentrations (in plant tissue and water) and initial dry biomass of *E. crassipes*. At the end of the experiment, plants and water samples were collected from each reactor. Plants were washed, separated into roots and leaves, and oven-dried at 70 °C for 72 h. Then, they were digested with a mixture of concentrated nitric, perchloric, and clorhydric acids (10:2:5) (Soltan and Rashed 2003; Mishra and Tripathi 2008; Melignani et al. 2015). In water samples, Cd was measured without digestion. The metal was determined by flame atomic absorption spectrophotometry (flame-AAS) (detection limit for Cd 0.028 mg/L). Water physicochemical parameters were determined as described by APHA (1999). The NH_4^+ concentration was measured in water samples and the N-NH_3 concentration was estimated from this measure (NH_4^+) according to Körner et al. (2001).

Initial concentrations of Cd in water were 100 ± 10% of nominal concentrations. The initial dry weight of *E. crassipes* plants was 1.38 ± 0.12 g (mean ± standard error) for roots and 1.74 ± 0.13 g for leaves. Initial Cd content in roots was 1.32 ± 0.03 mg/kg and 1.71 ± 0.16 mg/kg in leaves. These concentrations of Cd in tissue were below the toxic limit for this metal (5–10 mg/kg) (White and Brown 2010).

Growth estimation, cadmium translocation and uptake rate

The parameters for growth estimation and metal translocation in tissue were calculated as described earlier (Melignani et al. 2015). The relative growth rate (RGR, day^{-1}) was calculated as: $RGR = (\ln DWf - \ln DWi)/t$, where DWf = dry weight at the end of the experiment (g); DWi = initial dry weight (g); and t = duration of the experiment (days). The growth stimulation percentage (GS, %) (modified from the growth inhibition percentage equation; Park et al. 2011) was estimated as $GS = (RGRt/RGRc - 1) \times 100$, where $RGRt$ = relative growth rate for treatment x and $RGRc$ = relative growth rate for respective control. The bioconcentration factor (BCF) was calculated as $BCF = Cr/Cw$, where Cr = Cd concentration in roots (mg/kg dw) and Cw = Cd concentration in water (mg/kg). The translocation factor (TF) was estimated as $TF = Cl/Cr$, where Cl = Cd concentration in leaves (mg/kg dw).

The capacity of *E. crassipes* for Cd uptake was estimated as the metal uptake rate for roots or leaves (UR, mg/kg day) according to Singh and Agrawal (2007): $UR = (Cf - Ci)/t$, where Cf = final Cd concentration in biomass (roots or leaves) (mg/kg dw) and Ci = initial Cd concentration in biomass (roots or leaves) (mg/kg dw). A functional relation was investigated between the uptake rate and the Cd concentration in water and a linear regression analysis was performed. Data were tested for normal distribution (Shapiro–Wilks' test) and for homogeneity of variance (Levene's test). Metal concentrations were scaled when the relation between both variables was not linear. The test was compared at a level of $p < 0.05$.

Statistical analysis

Data were statistically analyzed with the ANOVA test. Normality and homogeneity of variance were checked with Shapiro–Wilks' test and Levene's test, respectively. When the assumptions were not satisfied, a natural-log transformation of the data was applied. Tukey's test was performed to differentiate between treatments. The significance level of comparison for all tests was $p < 0.05$.

Results

The physicochemical characteristics of the river water used in the experiment are shown in Table 1. The level of ammonium and trace elements (Cu, Cd, Cr, Ni, and Pb) exceed the national water quality guidelines for the protection of aquatic life (National Law No. 24051 on Hazardous Waste) (Argentina 1991). Also, the level of Cd exceeds the international water quality guidelines for the protection of aquatic life (μg Cd/L: 0.15–0.40, DWAFF 1996; 0.06–0.80, ANZECC and ARMCANZ 2000; 0.09–1.0, CCME 2014; 0.25–2.0, USEPA 2016). Thus, the water used for this experiment is considered as polluted.

From the third day of the experiment, leaves and petioles in all treatments showed loss of turgor. Leaves showed invaginations in their lamina. Chlorosis and dry leaves were also evident from the third day, but only in treatment Cd10.

Table 1 Initial physicochemical characteristics of Riachuelo water and reference value (designated use: protection of aquatic life, as stated in the Argentinian National Law No. 24051 on Hazardous Waste)

Parameter	Value[1] (mg/L)	Reference value[2] (mg/L)
Macronutrients		
Ca	55.95	–
K	13.33	–
Mg	26.78	–
N-NH_4^+	14.03	1.37
NO_2^-	0.014	0.06
NO_3^-	0.18	–
SRP (as orthophosphate)	1.70	–
SO_4^{-2}	72.30	–
Micronutrients		
Cl	255.85	–
Cu	0.033	0.002
Fe	0.62	–
Na	150.00	–
Zn	0.073	–
Non-essential heavy metals		
Cd	0.070	0.0002
Cr	0.073	0.002
Ni	0.17	0.025
Pb	0.073	0.001
Other physicochemical parameters		
Alkalinity (as CO_3^{-2})	543.76	–
TOC (total organic carbon)	15.22	–
DOC (dissolved organic carbon)	9.52	–
pH	7.14	–

[1] Mean of three replicates

[2] Argentinian National Law No. 24051 on Hazardous Waste, Regulatory Decree No. 831/93, Annex II, Table 2

Table 2 Dry weight of *E. crassipes* roots and leaves, relative growth rate (RGR) and growth stimulation percentage (GS) of plants after 7 days of Cd exposure

Treatments	Roots (g)	Leaves (g)	RGR (day^{-1})	GS (%)
Cd0 (control)	3.34 ± 1.09 a	3.50 ± 0.99 a	0.100 ± 0.009 a	–
Cd1	3.70 ± 0.63 a	4.07 ± 0.96 a	0.121 ± 0.007 b	22 ± 4 a
Cd5	1.72 ± 0.36 b	3.54 ± 0.33 a	0.102 ± 0.019 ab	3 ± 12 b
Cd10	1.42 ± 0.67 b	3.52 ± 0.33 a	0.102 ± 0.018 ab	2 ± 12 b

Values expressed as mean ($n = 3$) ± std. error. Different letters under the same column indicate significant differences ($p < 0.05$) among treatments

Cd0 control (no metal addition), *Cd1* supplemented with 1 mg Cd/L, *Cd5* supplemented with 5 mg Cd/L, *Cd10* supplemented with 10 mg Cd/L

Growth estimation

Final dry weight of root and leaf biomass, relative growth rates (RGR) and growth stimulation percentage (GS) are shown in Table 2. Root biomass was reduced by half in treatments Cd5 and Cd10 ($F = 20.65$, $df = 3$, $p = 0.0004$). In contrast, leaf biomass did not show significant differences from the control in any treatment ($F = 1.20$, $df = 3$, $p = 0.3685$). The RGR showed a slight increase in treatment Cd1 ($F = 4.44$, $df = 3$, $p = 0.0407$), consistent with growth stimulation (22%) ($F = 10.34$, $df = 2$, $p < 0.0114$).

Cadmium accumulation

Table 3 shows the Cd concentration in roots and leaves, the bioconcentration factor (BCF) and the translocation factor (TF). Cd accumulated principally in roots, increasing with metal concentration in the medium. It seemed to stabilize at the highest Cd dose (10 mg/L). The maximum concentration in roots was 1000x that of the control (1742.1 mg Cd/kg dw; $F = 86.83$, df = 3, $p < 0.0001$). Cd accumulation in leaves also increased with metal concentration in water, although not as much as in roots. The maximum concentration in leaves was 100× that of the control (147.1 mg Cd/kg dw; $F = 108.09$, $df = 3$, $p < 0.0001$). BCF were higher in treatments than in control (max. 1233.9; $F = 557.35$, $df = 3$, $p < 0.0001$), while TF were lower than unity (TF < 1) ($F = 101.40$, $df = 3$, $p < 0.0001$) (Table 3).

Cadmium uptake rate

The Cd uptake rate for roots and leaves of the water hyacinth showed different functional relations. The relation between the uptake rate for roots and the metal concentration in water adjusted to a logarithmic function, reaching an uptake rate of 248.7 mg Cd/kg·day (Fig. 1) in the concentration range studied. Given that the relation between the variables was logarithmic, the Cd concentrations in water were scaled using a logarithmic transformation to run the linear regression analysis (functional relation: $p < 0.01$; lack of adjustment: $p = 0.15$; $R^2 = 0.95$). As for leaves, the relation between the uptake rate and the Cd concentration in water adjusted to a linear function (Fig. 2). The metal concentrations in leaves adjusted to an increasing linear function and reached an uptake rate of 20.8 mg Cd/kg·day in the range of the assayed concentrations (0–10 mg Cd/L).

Discussion

Contrary to expected, the growth of the water hyacinth was not severely affected by Cd exposure in the concentration range studied. Despite the observed toxicity symptoms and the decrease in root biomass, there was no unfavorable impact on the RGR. In fact, there was growth stimulation in one of the treatments (1 mg Cd/L). This growth could also be due to the presence of chloride (added as $CdCl_2 \cdot 2\ ½\ H_2O$) and other nutrients present in the polluted water from Riachuelo river.

Table 3 Cd concentration in roots and leaves, bioconcentration factor (BCF) and translocation factor (TF) in *E. crassipes* after 7 days of metal exposure

Treatments	Cd in roots (mg/kg dw)	Cd in leaves (mg/kg dw)	BCF	TF
Cd0 (control)	1.77 ± 0.49 a	1.48 ± 0.83 a	25.2 ± 7.0 a	0.826 ± 0.287 a
Cd1	748.4 ± 136.8 b	9.73 ± 3.02 b	1233.9 ± 333.0 b	0.013 ± 0.003 b
Cd5	1580.2 ± 358.6 c	51.1 ± 29.2 c	846.3 ± 149.7 c	0.033 ± 0.026 c
Cd10	1742.1 ± 327.7 c	147.4 ± 95.5 d	774.8 ± 82.5 c	0.084 ± 0.049 d

Values expressed as mean ($n = 3$) ± std. error. Different letters under the same column indicate significant differences ($p < 0.05$) among treatments

Cd0 control (no metal addition), *Cd1* supplemented with 1 mg Cd/L, *Cd5* supplemented with 5 mg Cd/L, *Cd10* supplemented with 10 mg Cd/L

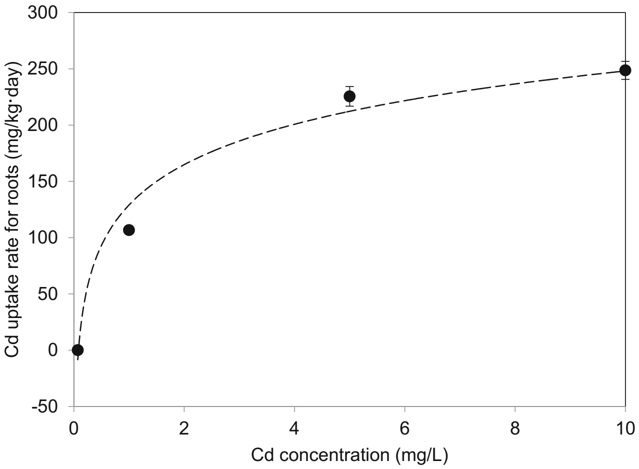

Fig. 1 Cd uptake rate for roots of *E. crassipes* in function of Cd treatments after 7 days of metal exposure. References: error bars = standard error (mean of three replicates); dash line = functional relation

These results agree with observations for this species in assays under similar conditions (El-Leboudi et al. 2008; Lu et al. 2004; Hasan et al. 2007) (a summary of the references is presented in Table 4). A few cases registered growth decrease at 1 mg Cd/L (Delgado et al. 1993; Smolyakov 2012).

Cd accumulation in the water hyacinth was considerably high, especially in roots. Cd concentrations in treated roots in this assay (740–1750 mg Cd/kg dw) exceeded several values reported for this species under similar conditions (Mazen and El Maghraby 1997; Soltan and Rashed 2003; El-Leboudi et al. 2008; Aisien et al. 2010). Similar or larger Cd concentrations in roots were also reported (Muramoto and Oki 1983; Kay et al. 1984; Lu et al. 2004; Hasan et al. 2007). The bioconcentration factors obtained in this experiment (774.8–1233.9) are higher (Lu et al. 2004; Eid et al. 2019) or in the order (Hasan et al. 2007; Aisien et al. 2010) of the ones reported in bibliography.

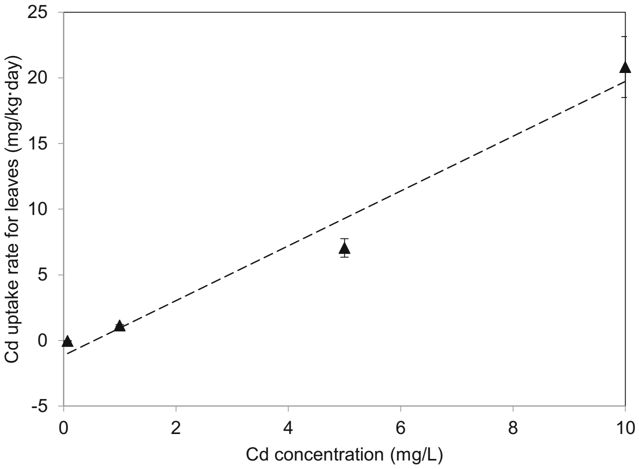

Fig. 2 Cd uptake rate for leaves of *E. crassipes* in function of Cd treatments after 7 days of metal exposure. References: error bars = standard error (mean of three replicates); dash line = functional relation

Cd accumulation in leaves was not as high as in roots, although it showed considerable levels (9.5–150 mg Cd/kg dw). Many reports indicate higher values of Cd accumulation in *E. crassipes* leaves (Muramoto and Oki 1983; Mazen and El Maghraby 1997; Soltan and Rashed 2003; Hasan et al. 2007). Some authors reported similar values for this species (Soltan and Rashed 2003; Lu et al. 2004; Hasan et al. 2007; Aisien et al. 2010). It is possible that the water hyacinth was not able to translocate large amounts of toxic metals to the leaves as an exclusion strategy for the protection of the photosynthetic apparatus (Benavides et al. 2005; Kirkham 2006; Gallego et al. 2012; Tran and Popova 2013). Consistently with Cd accumulation in leaves, the translocation factor was low in all treatments (less than one), meaning that Cd remained mostly in roots. This result is consistent with the reported in bibliography for Cd in water hyacinth (Kamari et al. 2017; Eid et al. 2019).

The pattern of Cd uptake rate for roots obtained in this experiment was different from that of leaves. The uptake rate for roots seemed to reach its maximum capacity when Cd concentration in the medium was 5 mg Cd/L, suggesting that Cd uptake for *E. crassipes* roots saturates at this level of Cd in the medium, under the conditions of this experiment. On the other hand, the uptake rate for leaves showed an increasing trend, indicating that Cd concentrations in leaves do not saturate in the concentration range studied and the uptake rate for leaves has not reached its threshold, under the conditions of this experiment. Wolverton and McDonald (1978) reported a similar uptake rate for roots of *E. crassipes* after 24 h of Cd exposure (281 mg Cd/kg) and a lower uptake rate for leaves (6.1 mg Cd/kg) at 0.1 mg Cd/L.

The toxicity effects observed in this experiment (symptoms of chlorosis, dehydration, and brown color in leaves and petioles) are among the frequent toxicity symptoms in plants due to Cd exposure. They include inhibition and abnormalities in general growth, reduction of elongation of shoots and roots, leaf curling, and chlorosis (Tran and Popova 2013). Consistently with the results of this experiment, other authors reported symptoms of chlorosis after 2–4 days (Soltan and Rashed 2003; Hasan et al. 2007) under similar Cd concentrations. Damage in leaves and petioles was also observed (O'Keeffe et al. 1984), as well as necrosis (Delgado et al. 1993) and red-brown patches on leaves and stunted stems (Davis et al. 1978).

Some authors reported reaching the threshold of symptom toxicity for *E. crassipes* in the culture medium at 1 mg Cd/L (Hasan et al. 2007). White and Brown (2010) informed an accumulation of 5–10 mg Cd/kg dw as the critical leaf concentration of Cd in crop plants, that is, above which yield decreases 10%. Although the phytotoxic signs were visible in all treatments, the Cd concentrations bioaccumulated during this experiment, both in roots and leaves, exceeded these limits (9–1750 mg Cd/kg dw).

Table 4 Results obtained in this study in contrast with similar assays reported in bibliography for *E. crassipes* (unless stated otherwise). References: * = approximate value (taken from figure); DW = dry weight; FW = fresh weight; m = metal mixture; i = 1/TF

Location	Studied metal dose (mg Cd/L)	Duration (days)	Cd in roots (mg/kg)	Cd in aerial tissue (mg/kg)	UR roots (mg/kg·day)	UR leaves (mg/kg·day)	Visual symptoms	RGR	BCF	TF	Reference
Argentina	**10**	**7**	**1742.1**	**147.4**	**248.7**	**20.8**	**Loss of turgor and invaginations in leaves (3 d)**	**0.102**	**774.8**	**0.084**	**Present study**
Argentina	**5**	**7**	**1580.2**	**51.1**	**225.6**	**7.05**	**Loss of turgor and invaginations in leaves (3 d)**	**0.102**	**846.3**	**0.033**	**Present study**
Argentina	**1**	**7**	**748.4**	**9.73**	**106.7**	**1.15**	**Loss of turgor, invaginations in leaves and chlorosis (3 d)**	**0.121**	**1233.9**	**0.013**	**Present study**
Nigeria	1	7	470–540*	60–90*	-	-	-	-	550–700*	-	Aisien et al. 2010
UK	0.5	23	-	15	-	-	Red-brown patches on leaves and stunted stems	-	-	-	Davis et al. 1978 (*Hordeum vulgare*)
Spain	5	24	-	-	-	-	Necrosis	Productivity drastically reduced	-	-	Delgado et al. 1993
Egypt	1.25	5–10	5.66–7.08	4.04–4.82	-	-	Yellowish coloration and relatively sluggish leaf growth	DW increase	3.06–5.66	-	El-Leboudi et al. 2008
India	4-6	6–8	1590–2117	700–940	-	-	Leaf chlorosis (4 d)	-	650–675 (16 d)	-	Hasan et al. 2007
India	1	6–8	401–491	103.6–148.6	-	-	-	-	662 (16 d)	-	Hasan et al. 2007
USA	5	21–42	5776–6507	229–431	-	-	Poor root development and leaf chlorosis (10 d)	80% growth reduction and RGR decrease (21 d)	-	-	Kay et al. 1984
USA	1	21–42	1258–1311	57–94	-	-	Poor root development and leaf chlorosis (10 d)	> 60% growth reduction and 80% RGR reduction (21 d)	-	-	Kay et al. 1984
Thailand	4	8	2044	113.2	-	-	-	Growth decrease	540* (whole plant)	-	Lu et al. 2004
Thailand	1	8	450*	18*	-	-	-	-	410* (whole plant)	-	Lu et al. 2004
Egypt	15	10	700*	350*	-	-	-	-	-	-	Mazen & El Maghraby 1997
Japan	4	8	2380	632	-	-	-	FW decrease	-	-	Muramoto & Oki 1983
Japan	1	8	1190	157	-	-	-	FW increase	-	-	Muramoto & Oki 1983
USA	1–100	3	-	-	-	-	Leaf and stem damage	-	-	-	O'Keeffe et al. 1984
Russia	0.05	8	56–260	18–70	-	-	Root shedding	Growth decrease	1000*-5200	3-4*^{i} (= 0.25-0.33)	Smolyakov 2012
Egypt	10^{m}	7	635	485	-	-		-	60*		

Table 4 (continued)

Location	Studied metal dose (mg Cd/L)	Duration (days)	Cd in roots (mg/kg)	Cd in aerial tissue (mg/kg)	UR roots (mg/kg·day)	UR leaves (mg/kg·day)	Visual symptoms	RGR	BCF	TF	Reference
							Yellow leaves (2 d); partial wilting (10 d)			1.5*^{i} (= 0.66)	Soltan & Rashed, 2003
Egypt	5^{m}	8	630	95	-	-	Yellow leaves (4 d)	-	125*	6.5*^{i} (= 0.15)	Soltan & Rashed, 2003
Egypt	1^{m}	10	615	30	-	-	-	-	600*	20.5*^{i} (= 0.048)	Soltan & Rashed, 2003
USA	0.01–0.1	1	39.1–281	6.1	281	6.1	-	-	-	-	Wolverton & McDonald 1978

Conclusions

The water hyacinth *E. crassipes* showed interesting results regarding its capacity to accumulate and tolerate Cd, a non-essential element, in tissues beyond the toxicity limit estimated for this element, without major impact on growth parameters. The results suggest that the water hyacinth is able to tolerate the metal in its roots, while it excludes Cd from the leaves. Thus, *E. crassipes* showed a very satisfactory performance regarding Cd incorporation from polluted stream water supplemented with Cd in doses above the threshold toxicity for plants in the culture medium. Several rivers in the Pampean region (Castañé et al. 1998; Magdaleno et al. 2001; Magdaleno et al. 2014) receive industrial effluents containing Cd concentrations above the legal discharge limits (0.1 mg/L) (ACUMAR 2017). Therefore, these are promising results for the application of the water hyacinth in treatments of industrial effluents and leaching of open air dump where batteries and electronic devices are discarded.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

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