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EFFECTS OF CADMIUM AND ZINC ON GROWTH AND METAL ACCUMULATION OF *Mathiola flavida* BOISS

Naser Jamali[1], Seyed Majid Ghaderian[1], Naser Karimi[2*]

[1]*University of Isfahan, Department of Biology, Isfahan, Iran*
[2]*Razi University, Faculty of Science, Department of Biology, Kermanshah, Iran*

Abstract

The effects of cadmium (Cd), Zinc (Zn), and Cd–Zn on growth and their accumulation in the *Matthiola flavida* shoots were investigated. A factorial experiment with two factors (Cd and Zn) concerning four concentrations of Cd (0, 5, 10 and 20 mg L^{-1}) and four Zn concentrations (0, 10, 20 and 40 mg L^{-1}) were carried out. The shoot and root biomass of *M. flavida* growing in Cd-Zn medium decreased significantly ($p<0.01$) compared to the control. Growing in the presence of 20 mg L^{-1} Cd and 40 mg L^{-1} Zn, resulted in the highest decrease of root and shoot biomass and tolerance index compared to that at 5 mg L^{-1} Cd. At the highest Cd (20 mg L^{-1}) and Zn (40 mg L^{-1}) concentration, plant tolerance index was inhibited by 82 and 74%, respectively ($P<0.01$) compared with the control. The concentrations of Cd and Zn in the shoots of *M. flavida* were increased with increasing Cd and Zn concentration in the medium. Significant inhibitory effects of Zn on Cd concentration in the shoots occurred at levels above 10 mg Zn L^{-1}. On the other hand, the shoot Cd concentration of *M. flavida* in the combined Cd and Zn treatment group was reduced by 67.6%, relative to that of the Cd alone treatment group. Zinc concentrations in the shoots decreased with increasing rates of applied Cd. Therefore, we recognize *M. flavida* as a candidate for remediation of sites co-contaminated by Cd and Zn purposes in Iran, the more so because they are adapted to the local climate and soil conditions.

Key words: Cadmium, Interaction, *Mathiola flavida*, Phytoremediation, Zinc

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1. Introduction

The study of toxic heavy metal contamination in soils and crop plants is of major importance due to their health effects on humans and other animals (Pavel et al., 2012; Perfus-Barbeoch et al., 2002; Zheng et al., 2007). Cadmium (Cd) is highly toxic to humans, animals and plants. In plants, Cd exposure induces various symptoms of phytotoxicity due to its high mobility and severe toxicity (Gomes-Junior et al., 2006; Traina, 1999). Zinc (Zn) is a micronutrient essential for plants but can be highly toxic when present at excessive concentration, causing reduced growth, leaf chlorosis, and nutritional disturbances (Kinraide et al., 2004). Cadmium and Zn are elements having similar electronic configuration and valence and hence similar environmental properties. Zinc is often associated with Cd, and the processing and subsequent release of Zn to the environment is normally accompanied by Cd (Goyer, 1997; Verougstraete et al., 2003). Thus there is a real need for analyis of the adaptive ecophysiology, biochemistry and reliable technologies of Cd - Zn interaction in the environment (Duruibe et al., 2007).

Phytoremediation i.e. the use of plants to remediate contaminated soil or to render them harmless has been proposed as an environment friendly and cost-effective technique for soil and water remediation (Garbisu and Alkorta, 2001; McGrath and Zhao, 2003; Salt et al., 1998). Heavy metal uptake, translocation, and cellular sequestration are key factors of plant's hyperaccumulation and

* Author to whom all correspondence should be addressed: e-mail: nkarimi@razi.ac.ir; nkarimie@yahoo.com; Phone: 0098-831-8211869; Fax: 0098-831-4274545

tolerance of heavy metals. Root system is the main interface of ion exchange between plants and their environment (Goyer, 1997; Verougstraete et al., 2003). In phytostabilization, root-accumulating plants are used to reduce the mobility or bioavailability of metals, which are then stabilized in the substrate and/or accumulated in root tissue. The high root accumulation of metals may further decrease the mobility of metals in sediment. Heavy metal uptake by roots depends on both soil and crop plant factors (e.g. source and chemical form of elements in soil, pH, CEC, organic material, plant species and tissues, plant age etc.) (Casado et al., 2007; Pavel et al., 2013). Phytoextraction is a method of using plants with high shoot-accumulation ability to extract metals from soils/sediments, and it has been demonstrated to be an economically feasible method of treating polluted land (Fritioff and Greger, 2003). Interactions among the co-exist elements occurring at root surface and within the plant affect uptake and translocation (Aravind and Prasad, 2005). The association of cadmium and zinc in the environment and their chemical similarity can lead to interaction between cadmium and zinc during plant uptake, transport from roots to aboveground parts, or accumulation in edible parts.

The interaction between metals like Cd and Zn is varied and can be difficult to predict. For example, in *Phaseolus vulgaris* L., the effect of Cd on the accumulation of Zn depended on the tissue concentrations of Zn. It was higher in roots and lower in shoots when Cd was added to solution culture (Chaoui et al., 1997). The interaction may also depend on the nutritional status of the plant. Addition of Cd to Zn-deficient soil resulted in reduced concentrations of Zn in *Triticum aestivum* L. and *Triticum turgidum* L. var durum, whereas the addition of Cd to soils with adequate Zn either stimulated or had no effect on the uptake of Zn (Köleli et al., 2004). Podar et al. (2004) found a similar effect for *Brassica juncea* (L.) grown in Cd-contaminated soils, but Zn induced reduction in accumulation of Cd occurred only in soils supplemented with up to 340 mg Zn per kg soil; a higher dose of Zn (705 mg kg^{-1}) stimulated Cd-accumulation. It is reported that, some other crops from the Brassicaceae family (cauliflower, kale and cabbage) can also take up more metal than other plant species without visible toxicity symptoms (Zayed and Terry, 2003). Another study found no interaction between the two metals for *Glycine max* (L.) grown in Cd and Zn-amended soil (White and Chaney, 1980). Hart et al. (2002) determined that Zn and Cd are transported by a common carrier at the root plasma membrane, which has a higher affinity for Cd than for Zn. Therefore, Cd and Zn ions should experience competitive inhibition.

Matthiola flavida (Boiss.) is a species belonging to Brassicaceae which grows in the old Pb/Zn mining areas of central Iran (Irankouh), and has been identified as a new Zn/Pb-accumulator (Ghaderian et al., 2007). This plant has also exceptional abilities to tolerate and accumulate high concentrations of Pb, and the characteristics of rapid growth, asexual propagation, and perennial growth makes it an ideal plant for studying mechanisms responsible for accumulation as well as for the phytoremediation practices (Ghaderian et al., 2007). The objectives of this study were to investigate the interaction of Cd and Zn on the growth parameters of *M. flavida* including biomass production, tolerance index, and difference in Cd nd Zn uptake and translocation.

2. Material and methods

2.1. Plant culture

The seeds of *M. flavida* were collected from plants growing on old Pb/Zn mine area in Irankouh during June to Augest 2006. The Irankouh area, located in Central Iran, is a vast mountainous region with mineralized soils and several active zinc and lead mining and smelting sites (Ghazban et al., 1994). The seeds were surface sterilized and then germinated in 9 cm diameter perlite pot at 24ºC for 4 days. The uniform seedlings were feeding with modified 10% Hoagland nutrient solution containing: 0.2 mM KH_2PO_4, 0.8 mM $Ca(NO_3)_2.4H_2O$, 1 mM KNO_3, 0.4 mM $MgSO_4.7H_2O$, 15 µM FeEDDHA, 10 µM H_3BO_3, 3 µM $MnCl_2.4H_2O$, 0.2 µM $ZnSO_4.7H_2O$, 0.2 µM $CuSO_4.5H_2O$, 0.1 µM $Na_2.MoO_4.2H_2O$. Nutrient solution pH was adjusted daily to 5.8 with 0.1M NaOH or 0.1M HCl, moreover, MES-KOH was used for pH adjustment. Plants were grown in growth room with 16/8 h light/dark cycles, day/night temperature of 26/20 ˚C and light intensity approx, 280mmol $m^{-2}s^{-1}$. The nutrient solution was renewed every 3 d.

2.2. Treatments

Pre-cultured seedlings of the *M. flavida* were used for different Zn and Cd treatment. There were 48 pots with 4 plants in each. After 15 d of growth in basal nutrient solution, plants were exposed to zinc ($ZnSO_4.7H_2O$) at four different concentrations: 0 (control treatment), 10, 20 and 40 mg L^{-1} and cadmium ($CdSO_4 \cdot 8/3H_2O$) at four concentration of 0 (control treatment), 5, 10 and 20 mg L^{-1}. Each level of cadmium was combined with each level of zinc for a total of 16 treatments (4*4*1) as Cd-0 Zn-0, Cd-0 Zn-10, Cd-0 Zn-20, Cd-0 Zn-40, Cd-5 Zn-0, Cd-5 Zn-10, Cd-5 Zn-20, Cd-5 Zn-40, Cd-10 Zn-0, Cd-10 Zn-10, Cd-10 Zn-20, Cd-10 Zn-40, Cd-20 Zn-0, Cd-20 Zn- 10, Cd-20 Zn-20 and Cd-20 Zn-40.

The statistical design was a randomized block of three replicate with 4 plants per each. Plants were received 200 ml of the appropriate solution every day for 3 wk. Every third day the perlite was flashed with deionized water to prevent a potential toxic build up of nutrient salts in the substrate. At harvest, plants were divided into root and shoot fractions. Root tissue samples were rinsed twice in deionized water

to remove surface contaminants. Plants samples were air-dried in an oven at 70°C for 48 hours. Dried samples were cut with stainless steel scissors and ground in mortar to obtain homogeneous samples.

2.3. Plant analysis

For calculate plant tolerance index, the dry weight of plant samples was determined. Then tolerance indices (the mean of plant dry weight in each treatment/ mean of plant dry weight in control) × 100 were calculated (Rabie, 2005). For total Cd and Zn analysis, plant samples (0.5 g) were tuned into ash at 550°C in a muffle oven for 8 hours, digested in 3N HNO_3, and analyzed for Cd and Zn using a Shimadzu AA-6200 atomic absorption spectrophotometer.

2.4. Statistical analysis

General Linear Model analyses of variance (ANOVAs) were conducted on the dataset to compare accumulation of zinc and cadmium in shoot and root of *M. flavida*. For each ANOVA, the normality of the distribution (Kolmogorov-Smirnov) and the homogeneity of variance (Bartlett's test) were tested. ANOVAs, Tukey HSD test and all statistical analysis were conducted with Statistical software SPSS (version 10).

3. Results

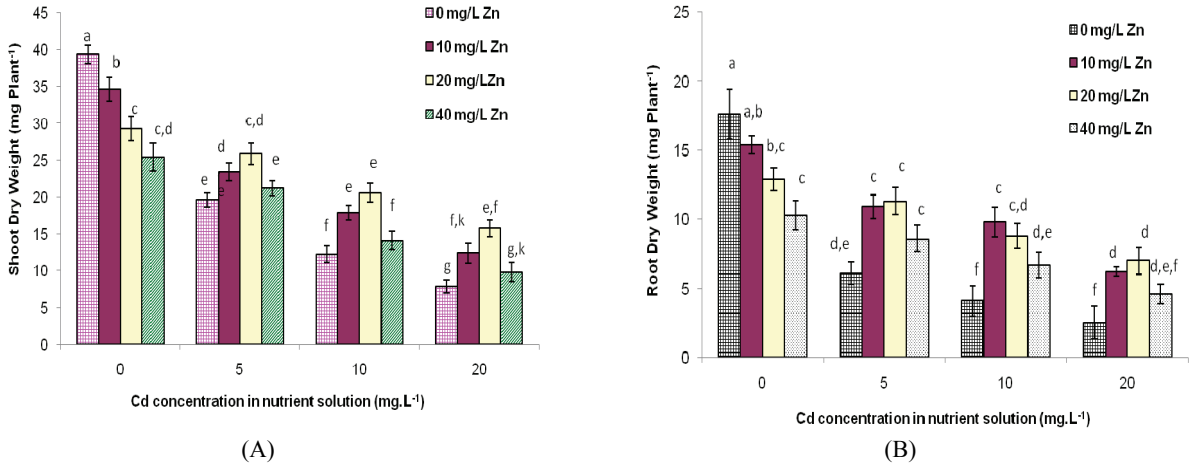
3.1. The effect of different Cd and Zn levels on plant growth

During this 21-day experiment, *M. flavida* survived in the medium exposed up to 5 mg L^{-1} Cd, showing no visual Cd toxicity symptoms such as necrosis and whitish-brown chlorosis. The toxicity symptoms became more severe with increasing Cd levels and exposure time. The leaves of *M. flavida* wilted after the plants were grown for 6 days, and the old leaves began to fall off after growing for 16 days at 20 mg L^{-1} Cd. Plant biomass and tolerance index were reduced significantly ($p<0.05$) in both shoot and roots of *M. flavida* with increasing Cd concentration in nutrient solution (Figs. 1 and 2).

The results indicated that *M. flavida* growth, measured by plant tolerance and biomass, impacted by Cd treatments at 5-20 mg L^{-1}.

As illustrated in Fig. 1A, the shoot biomass of *M. flavida* growing in Zn–Cd medium decreased significantly ($p<0.01$) compared to the control. For example shoot dry weight of *M. flavida* grown under 10 mg L^{-1} Cd + 40 mg L^{-1} Zn, or 20 mg L^{-1} Cd + 40 mg L^{-1} Zn was significantly decreased compared to the control, in which Cd-20 + Zn-40 mg L^{-1} combined treatment decreased the biomass of shoot by 75.2% compared to the control (Fig. 1A). However, shoot biomass in plants exposed to Cd level (5, 10 and 20 mg L^{-1}) was lower in comparison with once affected by Cd + Zn combined treatment. For example shoot biomass of *M. flavida* exposed to 5 mg L^{-1} Cd was 19.6 mg while the shoot biomass of plants treated with Cd 5 mg L^{-1} + Zn 10 mg L^{-1} was 23.4 mg. The root dry weight of *M. flavida* under combined concentrations of Zn and Cd in comparison with control is offered in Figure 1B. It is revealed that the dry weight of root were significantly ($p<0.05$) decreased under the various treatments compared to the control and following the similar pattern of shoot biomass reduction. Maximum (17.6 mg $plant^{-1}$) and minimum (2.5 mg $plant^{-1}$) root dry weight were both observed in control (Cd-0 + Zn-0) and Cd-20 + Zn-0 treatments, respectively (Fig.1B).

Tolerance index of *M. flavida* that expressed as: (dry weight of plant in each treatment/ dry weight of plant in control) × 100 was more sensitive to Cd exposure than Zn treatments. The lowest Cd concentration (5 mg L^{-1}) decreased tolerance index by 45% ($P<0.05$), whereas 1–10 mg L^{-1} Zn had no significant effect on its tolerance index. At the highest Cd (Cd-20 + Zn-0) and Zn (Cd-0 + Zn-40) concentration, plant tolerance index was inhibited by 82 and 37.4%, respectively ($P<0.01$) compared with the control (Cd-0 + Zn-0).



(A) (B)

Fig. 1. Shoot (A) and root (B) dry weight of *M. flavida* treated with different concentration of Cd (0-20 mg L^{-1}) and Zn (0-40 mg L^{-1}). Bars represent standard error (S.E.) of three replicates

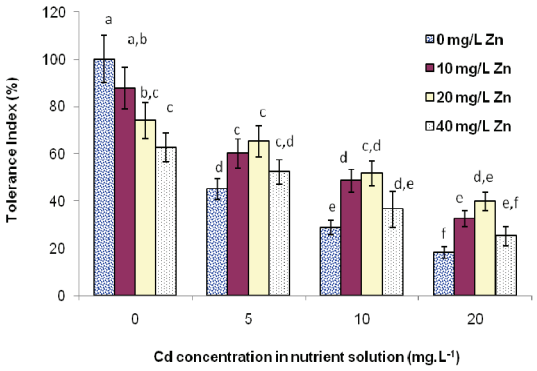


Fig. 2. Tolerance index of *M. flavida* treated with different concentration of Cd (0-20 mg L^{-1}) and Zn (0-40 mg L^{-1}).

In this relevance, with the presence of 5 mg L^{-1} Cd, increasing Zn concentration from 1 to 10 mg L^{-1} increased tolerance index of *M. flavida* significantly ($P<0.05$), whereas Cd + Zn combined treatment at Cd-5 + Zn-40 decreased *M. flavida* tolerance index by 52 % compared with the control (Fig. 2).

3.2. Cadmium accumulative characteristics of M. flavida

The accumulation of Cd in the *M. flavida* shoot was increased with increasing Cd concentrations in the medium when only Cd was present (Fig. 3A). They reached 51, 58 and 124 mg kg^{-1} in shoot dry weight, at single Cd treatments of 5, 10, and 20 mg L^{-1} respectively.

The total amount and distribution of Cd accumulated in *M. flavida* under joint stress of Cd and Zn are shown in Fig. 3A. When Zn level was at 40 mg L^{-1}, Cd concentration in the shoots decreased by 27.5%, 45% and 76% at Cd-5, Cd-10 and Cd-40 respectively, compared to (Cd-5+Zn-0). Compared to the low concentration of Zn (10 mg kg^{-1}), the concentration of Cd in the shoots was reduced by 32.6–73.5% at the high level treatment of Zn (40 mg kg^{-1}). The result indicated that the high concentration of Zn had toxic effects on plant Cd uptake (Fig. 3A).

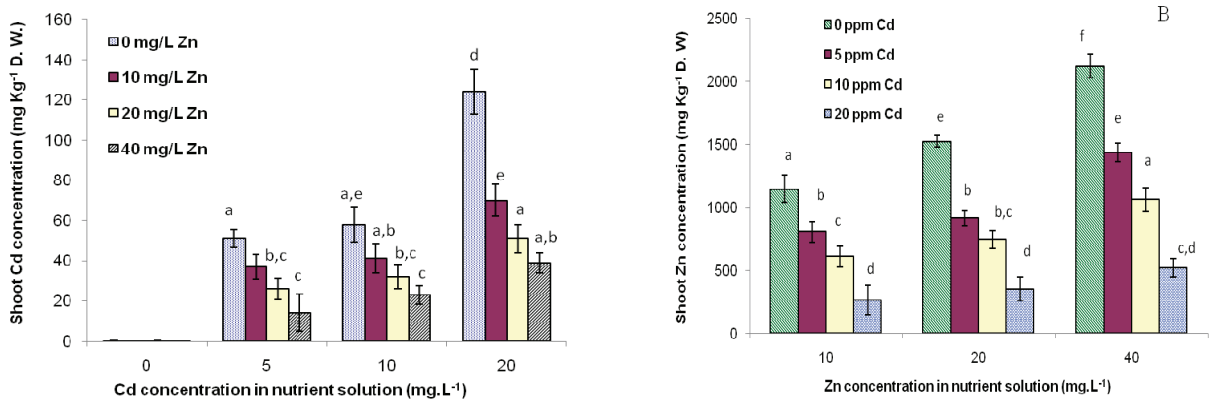
3.3. Zn uptake and partitioning in the M. flavida under Cd and Zn treatments

The total amount of Zn and its distribution in *M. flavida* are shown in Figure 3B, the Zn concentration was affected by different cadmium and zinc treatments. It is revealed from Figure 3B that a highest decrease of Zn in *M. flavida* was occurred under combined effect of 20 mg L^{-1} Cd and 10 mg L^{-1} Zn.

3.4. Cd and Zn Interactions in the M. flavida

Phytotoxicity of *M. flavida* was observed in the 10 and 20 mg L^{-1} Cd treatments when Zn supply was 0 mg L^{-1}. The symptoms of phytotoxicity were chlorosis symptoms and necrotic spots of leaves. Increasing Zn supply alleviated as phytotoxicity. Shoot and root dry weights were affected significantly by either Cd or Zn treatments (Fig. 1). Cd and Zn accumulation was demonstrated clearly in this experiment, with Cd and Zn concentrations in the shoots reaching up to 124 and 2150 mg kg^{-1} dry weight, respectively (Figs. 3A and B). Increasing Zn concentration in nutrient solution decreased shoot concentrations of Cd significantly ($P < 0.01$), in which the effect was proportionally larger in the 40 mg L^{-1} Zn. For example, in the 10 mg L^{-1} Cd treatment, increasing Zn from 0 to 40 mg L^{-1} decreased shoot Cd concentration by 57%. In the 20 mg L^{-1} Cd treatment, increasing Zn from 0 to 40 mg L^{-1} decreased shoot Cd concentration by 69%.

The concentrations of Zn in the shoots of *M. flavida* are shown in Fig. 3B. Increasing Cd concentration in the solution decreased the concentration of Zn in the shoots significantly ($P< 0.05$), independent from the Zn supply level in the medium (10-40 mg L^{-1}). In the treatment with 20 mg L^{-1} of Cd, a Zn concentration in the shoots was 524 mg kg^{-1}, which decreased 4 –folds compared to the treatment without Cd addition. Therefore, the interaction effects in *M. flavida* were considered strongly antagonistic with Cd in the presence of Zn.



(A) (B)

Fig. 3. Shoot Cd (A) and Zn (B) concentration of *M. flavida* treated with different concentration of Cd (0-20 mg L^{-1}) and Zn (0-40 mg L^{-1}). Bars represent standard error (S.E.) of three replicates

4. Discussion

Cd and Zn are considered to have competition interaction in case of conventional plant species especially in hyperaccumulators (Peris et al., 2007).In the present study, we compared effects of Cd and Zn and the interaction of these heavy metals on *M. flavida* plants growth, tolerance and these heavy metals accumulation. *M. flavida* is species from Brassicaceae family which grows naturally around Pb/Zn mining area in Iran with high ability of Zn and Pb accumulation (Ghaderian et al., 2007). Therefore, the study of interaction between a nutrient and a non-essential element may be important for understanding, analyzing and improving the defense strategies through various parameters.

It is revealed that during the time exposure to Cd and Zn, biomass of plant shoots and roots were decreased significantly ($P < 0.05$) at the threshold concentration of plant growth inhibition under the various Cd and Zn treatments compared to the control. Toxicity symptoms such as chlorosis and necrotic spots were observed in plants grew at 10 mgL^{-1} and 20 mgL^{-1} Cd respectively. Positive interactions between Zn and Cd were noted under Cd+ Zn combined treatment in *M. flavida*. Cadmium toxicity in the shoot was alleviated by Zn treatment, thus these results may approved hypothesis that Zn protects plants from Cd toxicity by competing with Cd in plant cellular metabolism (Sawidis, 2008; Shaw et al., 2004). Similar pattern was also reported in Cd/Zn hyperaccumulator *Sodium alfredii* (Ye et al., 2003) when exposed to combination of Cd–Zn treatments. Furthermore, de la Rosa et al. (2004) studies on *Salsola kali* showed that Zn in higher application had protective effects on Cd toxicity up to 20 mg L^{-1}.

Shoots Cd and Zn concentrations increased as substrate Cd and Zn doses increased (Figs. 3A and B). Different plant species and varieties have great variations regarding to the interaction of Cd and Zn (Grant and Bailey, 1997). The inhibitory effect of Cd and Zn on each other was reflected directly by analysis of metal accumulation in *M. flavida*. Zn supplement (40 mg L^{-1}) to Cd treated plants (20 mg L^{-1} Cd) reduced (up to 75%) the accumulation of Zn in comparison with those just treated with 40 mg L^{-1} Zn. Therefore, Cd decreases Zn uptake and accumulation in *M. flavida.* Simultaneously the Cd accumulation can be influenced by increasing Zn supply (Adriano, 1986; Nan et al., 2002). Results from the present work showed that Cd toxicity in the shoot of *M. flavida* was alleviated by Zn treatment, which this was accompanied by a corresponding decrease in shoot concentrations of Cd. Cadmium concentration in shoots decreased significantly with increasing Zn application to the medium (Fig. 3). The presence of Cd also reduced the accumulation of Zn in the roots of *Silene vulgaris* (Moench) Garke grown hydroponically for only 3 days in concentrations of Cd and Zn that ranged 0–60 μM for Cd and 1–400 μM for Zn (Sharma et al., 1999). In contrast, a combination of 2–5 μM Cd and 10–25 μM Zn in solution culture increased the accumulation of Zn in roots of *P. vulgaris* L. after 14 days (Chaoui et al., 1997).

The effect of Cd on accumulation and toxicity of Zn is apparently complex and depends on plant species, chemical speciation of Cd, growth medium and the experimental conditions. Due to the strong influences of soil and soil solution chemistry on metal bioavailability, one cannot expect Cd-accumulation under greenhouse or hydroponic conditions to reflect accurately the situation under field conditions. Hewitt (1996) hypothesized that, elements which have similar characteristics in physical and chemical properties act as antagonistic. Zn and Cd have many physical and chemical similarities as they both belong to group II of the periodic table. They are usually found together in the ores and compete with each other for various ligands (Aravind and Prasand, 2005). The fact that Cd is a toxic heavy metal and Zn is an essential element makes this association interesting as it raises the possibility that the toxic effects of Cd may be reducing by Zn (Hart et al., 2002). Cadmium acts as a Zn analogue and is transported across the plasma membrane via a Zn transport systems (Hart et al., 2006; Ullrich-Erebius et al., 1989). Once inside the cytoplasm Cd competes with Zn, for example replacing Zn in reactive enzymatic and receptor proteins which lead to inactivate their functions (Das et al., 1997, Sawidis, 2008; Shaw et al., 2004). These results support the observations that the nutritional status of the plant will affect the processes involved in metal uptake and translocation.

The effect of Zn on the accumulation of Cd depended on the dose provided. When Cd and Zn were present together in low concentrations, 40–47% lower concentrations of Cd were measured in shoots as compared to the concentrations found in tissues from plants grown with Cd only (Fig. 2a). Others have reported that addition of Zn to hydroponic culture decreased Cd-accumulation (Hart et al., 2005; Lombi et al., 2001; McKenna et al., 1993). In Zn-deficient soil (Oliver et al., 1994) and soil with 0.145 mg kg^{-1} Cd (Choudhary et al., 1995), addition of Zn (up to 20 mg/ha and 30 mg kg^{-1}, respectively) also reduced the uptake of Cd in mature plants. This means that the ability of metal uptake by the plants not only rests upon the concentrations of heavy metals but also relates to their combinations (Zhou, 1995). Not only can Zn affect the uptake and translocation of Cd, but it appears to vary in effect depending on the relative amounts of Cd and Zn present in the soil. In particular, the Zn-status of the plant may be very important. The addition of Cd to a Zn-deficient soil may result in further accumulation of Cd in the plant, in part due to the higher affinity of the Cd/Zn transporter for Cd (Hart et al., 2002). In contrast, adequate Zn-nutrition may help protect the plant from Cd-toxicity (Köleli et al., 2004) and more

Cd may be immobilized in the root tissues. Either Zn- or Cd-toxicity will cause impaired physiological functions, which may result in uncontrolled uptake of toxic metals. As with the effect of Cd on accumulation of Zn, the effect of Zn on accumulation of Cd is apparently complex and differs from relative metal concentration. As discussed above, the nutritional status of the plant will affect the processes involved in metal uptake and translocation.

The plant, *M. flavida*, accumulated a maximum of 124 mg Cd kg $^{-1}$ dry mass in shoots when cultivated for 21 days in hydroponic medium. The tolerance of *M. flavida* to Cd and Zn is greater than that observed for many nonaccumulating plant species, which have a threshold concentration for phytotoxicity between 5 and 100 mg kg^{-1} dry weight (Solís-Domínguez et al., 2007).

Generally, Cd and Zn accumulation were determined by their concentration in plant tissue and biomass production. Increased of the Cd and Zn concentration in this study could be explained by two sides. On the one hand, the *M. flavida* growth as morphological characters and biomass production was nearly unaffected by the increase of Cd and Zn concentration in medium and there were few visible symptoms of withered leaves and chlorosis (Fig. 1). On the other hand, the Cd and Zn concentrations in *M. flavida* tissue were significantly increased with increasing Cd and Zn levels in the nutrient solution (Fig. 3).

Cadmium tolerance in higher plants should in general be defined as the natural or artificially given capacity, regulated by interacting genetic and environmental factors, to bear high levels of Cd exposure for a long time, without appreciable detrimental effects on metabolism (Ghosh and Singh, 2005). Thus, the development of 'real' Cd tolerance should be a long-term process (possibly years) and involve modifications in the genetic patrimony of the plant. Therefore, an ideal plant for phytoextraction application should have high metal tolerance and high accumulation capacity in its tissues (especially in harvestable parts) (Shi and Cai, 2009). Furthermore, the biomass production of the plant, which limited the actual phytoextraction application in contaminated field is an important factor for determining tolerant plants.

The phytoremediation efficiency is determined by the amount of metal transported to the aboveground tissues, and the aboveground biomass of the hyperaccumulating plant. The results presented here show that *M. flavida* is fast growing plant and it could extract relatively large amount of Zn or Cd in their aboveground part in comparison with plants growing on Cd or Zn contaminated area (*Sorghum sp*; *Iris sp, Atriplex halimus*, *Echinochloa polystachya* and some populations of *Sedium alfredii*), which shows it possibly used for phytoremediation of Cd or Zn contaminated area (Deng et al., 2007; Han et al., 2007; Nedjimi and Daoud, 2009; di Toppi et al., 1999).

Fast-growing plant as the examined *M. flavida* exhibited higher phytoextraction efficiency with higher biomass production but relative lower cadmium concentration in comparison with some species of hyperaccumulator plants (Figs. 1-3). The results at least partly demonstrated the hypothesis that fast-growing plant had the higher remedying efficiency compared with the other slow-growing hyperaccumulators.

5. Conclusions

The results indicated that *M. flavida* had the relative tolerance to high levels of Cd and Zn which it tolerate up to 20 and 40 mg L^{-1} Cd and Zn respectively.

Interactions between Zn and Cd led to a decrease in Zn and Cd uptake when the metals co-occurred in high concentrations, likely due to the competition between Cd and Zn. The ability of *M. flavida* to withstand the high concentrations of Cd and Zn, high tolerance ability and short growing cycle suggests that this plant has a mechanism to detoxify the Cd and Zn. This could make it possible because of its higher robustness and Cd accumulation capacity, potential candidates for phytoremediation purposes in Iran, and in addition to that, because they are adapted to the local climate and soil conditions.

This study provides a promising start for biomass-based phytostabilization and phytoextraction; it includes high biomass production species, and growing these species is practically easier than the production of hyperaccumulators. Therefore, *M. flavida* can be indicated as a remediant in soil contaminated with Zn and Cd.

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References

Aravind P., Prasad M.N.V., (2005), Cadmium–zinc interactions in a hydroponic system using *Ceratophyllum demersum* L.: adaptive ecophysiology, biochemistry and molecular toxicology, *Brazilian Journal of Plant Physiology*, **17**, 3-20.

Casado M., Anawar H.M., Garica-Sanchez A., Santa R.I., (2007), Arsenic bioavilability in polluted mining soil and uptake by tolerant plants (EI Caboaco mine, Spain), *Bulletin of Environmental Contamination and Toxicology*, **79**, 29-35.

Chaoui A., Mazhoudi S., Ghorbal M.H., El Ferjani E., (1997), Cadmium and zinc induction of lipid peroxidation and effects on antioxidant enzyme activities in bean (*Phaseolus vulgaris* L.), *Plant Science*, **127**, 139-147.

Choudhary M., Bailey L.D., Grant C.A., Leisle D., (1995), Effect of Zn on the concentration of Cd and Zn in plant tissue of two durum wheat lines, *Canadian Journal of Plant Science*, **75**, 445-458.

Das P., Samantaray S., Rout G.R., (1997), Studies on cadmium toxicity in plants: a review, *Environnmental Pollution*, **98**, 29-36.

de la Rosa G., Peralta-Videa J.R., Montes M., Parsons J.G., Cano-Aguilera I., Gardea-Torresdey J.L., (2004), Cadmium uptake and translocation in tumbleweed (*Salsola kali*), a potential Cd-hyperaccumulator desert plant species: ICP/OES and XAS studies, *Chemosphere*, **55**, 1159-1168.

Deng D.M., et al., (2007), Zinc and cadmium accumulation and tolerance in populations of *Sedum alfredii*, *Environmental Pollution*, **147**, 381–386.

Duruibe J.O., Ogwuegbu M.D.C., Egwurugwu J.N., (2007), Heavy metal pollution and human biotoxic effects, *International Journal of Physical Sciences*, **2**, 112-118.

Garbisu C., Alkorta I., (2001), Phytoextraction: a cost-effective plant-based technology for the removal of metals from the environment, *Bioresource Technology*, **77**, 229-236.

Ghaderian S.M., Hemmat G.R., Reeves R.D., Baker A.J.M., (2007), Accumulation of lead and zinc by plants colonizing a metal mining area in Central Iran. *Journal of Applied Botany and Food Quality*, **81**, 145-150.

Ghazban F., McNutt R.H., Schwarcz H.P., (1994), Genesis of sediment hosted Zn–Pb–Ba deposits in the Irankuh district, Esfahan area, west-central Iran, *Economic Geology*, **89**, 1262-1278.

Ghosh M., Singh S.P., (2005), A comparative study of cadmium phytoextraction by accumulator and weed species, *Environmental Pollution*, **133**, 365-371.

Gomes-Junior R.A., Moldes C.A., Delite F.S., Pompeu G.B., Gratao P.L., Mazzafera P., Lea P.J., Azevedo R.A., (2006), Antioxidant metabolism of coffee cell suspension cultures in response to cadmium, *Chemosphere* **65**, 1330–1337.

Goyer R.A., (1997), Toxic and essential metal interactions, *Annual Review of Nutrient*, **17**, 37–50.

Grant C.A., Bailey L.D., (1997), Effects of phosphorous and zinc fertilizer management on cadmium accumulation in flaxseed, *Journal of the Science of Food and Agriculture*, **73**, 307–314.

Han Y.L., Yuan H.Y., Huang S.Z., Guo Z., Xia B., Gu J., (2007), Cadmium tolerance and accumulation by two species of Iris, *Ecotoxicology*, **16**, 557–563.

Hart J.J., Welch R.M., Norvell W.A., Clarke J.M., Kochian L.V., (2005), Zinc effects on cadmium accumulation and partitioning in near-isogenic lines of durum wheat that differ in grain cadmium concentration, *New Phytologist*, **167**, 391-401.

Hart J.J., Welch R.M., Norvell W.A., Kochian L.V., (2002), Transport interactions between cadmium and zinc in roots of bread and durum wheat seedlings, *Physiologia Plantarum*, **116**, 73-78.

Hart J.J., Welch R.M., Norvell W.A., Kochian L.V., (2006), Characterization of cadmium uptake, translocation and storage in near-isogenic lines of durum wheat that differ in grain cadmiumconcentration, *New Phytologist*, **172**, 261-271.

Hewitt E.J., (1966), *Sand and Water Culture Methods Used in the Study of Plant Nutrition,* C.A.B., Farnham Royal, England.

Kinraide T.B., Perler J.F., Parker D.R., (2004), Relative effectiveness of calcium and magnesium in the alleviation of rhizotoxicity in wheat induced by copper, zinc, aluminum, sodium, and low pH, *Plant and Soil*, **259**, 201–208.

Köleli N.S., Eker S., Cakmak I., (2004), Effect of zinc fertilization on cadmium toxicity in dururn and bread wheat grown in Zn deficient soil, *Environmental Pollution*, **131**, 453-459.

Lombi E., Zhao F.J., McGrath S.P., Young S.D., Sacchi G.A., (2001), Physiological evidence for a high-affinity cadmium transporter highly expressed in a *Thlaspi caerulescens* ecotype, *New Phytologist*, **149**, 53-60.

McGrath S.P., Zhao F.J., (2003), Phytoextraction of metals and metalloids from contaminated soils, *Current Opinions in Biotechnology*, **14**, 277–282.

McKenna I.M., Chaney R.L., Williams F.M., (1993), The effects of cadmium and zinc interaction on the accumulation and tissue distribution of zinc and cadmiumin lettuce and spinach, *Environmental Pollution*, **79**, 113-20.

Nedjimi B., Daoud Y., (2009), Cadmium accumulation in *Atriplex halimus* subsp. Schweinfurthii and its influence on growth, proline, root hydraulic conductivity, *Flora*, **204**, 316–324.

Nan Z., Li J., Zhang J., Cheng G., (2002), Cadmium and zinc interactions and their transfer in soil crop system under actual field conditions, *Science of the Total Environment,* **285**, 187–195.

Oliver D.P., Hannam R., Tiller K.G., Wilhelm N.S., Merry R.H., Cozens G.D., (1994), The effects of zinc fertilization on cadmium concentration in wheat grain, *Journal of Environmental Quality*, **23**, 705-711.

Pavel V.L., Diaconu M., Bulgariu D., Statescu F., Gavrilescu G., (2012), Evaluation of heavy metals toxicity on two microbial strains isolated from soil: *Azotobacter sp*. and *Pichia sp*., *Environmental Engineering and Management Journal*, **11**, 165-168.

Perfus-Barbeoch L., Leonhardt N., Vavasseur A., Forestier C., (2002), Heavy metal toxicity: cadmium permeates through calcium channels and disturbs the plant water status, *Plant Journal*, **32**, 539-548.

Peris M., Mico C., Recatala L., Sanchez R., Sanchez J., (2007), Heavy metal contents in horticultural crops of a representative area of the European Mediterranean region, *Science of the Total Environment*, **378**, 42- 48.

Podar D., Ramsey M.H. Hutchings M.J., (2004), Effect of cadmium, zinc and substrate heterogeneity on yield, shoot metal concentration and metal uptake by *Brassica juncea*: implications for human health risk assessment and phytoremediation, *New Phytologist*, **163**, 313-324.

Salt D.E., Smith R.D., Raskin I., (1998), Phytoremediation, *Annual Review of Plant Physiology and Plant Molecular Biology*, **49**, 643–668.

di Toppi L.S., Gabbrielli R., (1999), Response to cadmium in higher plants, *Environmental and Experimental Botany*, **41**, 105–130

Sawidis T., (2008), Effects of cadmium on pollen germination and tube growth in *Lilium longiflorum* and *Nicotiana tabacum*, *Protoplasma*, **233**, 95- 106.

Sharma R.S., Panigrahi N., Kaul S.M., (1999). *Aedes aegypti* prevalence in hospitals and schools, the priority sites for DHF transmission in Delhi, *Dengue Bullten*, **23**, 109-112.

Shi G., Cai Q., (2009), Cadmium tolerance and accumulation in eight potential energy crops, *Biotechnology Advancement*, **27**, 555–561.

Shaw B.P., Sahu S.K., Mishra R.K., (2004), *Heavy Metal Induced Oxidative Damage in Terrestrial Plants*, In: *Heavy Metal Stress in Plants-Form Biomolecules to Ecosystem,* Prasad M.N.V., (Ed.), Springer-Verlag, Narosa, New Delhi, 84-126.

Solís-Domínguez F.A., González-Chávez M.C., Carrillo-González R., Rodríguez-Vázquez R., (2007), Accumulation and localization of cadmium in

Echinochloa polystachya grown within a hydroponic system. *Journal of Hazardous Material,* **141**, 630–636.

Ullrich-Erebius C.I., Sanz A., Novacky A.J., (1989), Evaluation of arsenate and vanadate associated changes of electrical membrane potential and phosphate transporting *Lemma gibba* G1*, Journal of Experimental Botany*, **40**, 119-128.

Verougstraete V., Lison D., Hotz P., (2003), Cadmium, lung and prostate cancer: a systematic review of recent epidemiological data, *Journal of Toxicology and Environmental Health, part B: Critical Review*, **6**, 227-255.

White M.C., Chaney R.L., (1980), Zinc, Cd and Mn uptake by soybean from two Zn- and Cd-amended coastal plain soils, *Soil Science Society American Journal*, **44**, 308-313.

Ye H.B., Yang X.E., He B., Long X.X., Shi W.Y., (2003), Growth response, metal accumulation of *Sedum alfredii* to Cd/Zn complex polluted ion levels, *Acta Botanica Sinica*, **45,** 1030–1036.

Zayed A.M., Terry N., (2003), Chromium in the environment: factors affecting biological remediation, *Plant and Soil*, **249**, 139-156.

Zheng N., Wang Q.C., Zheng D.M., (2007), Health risk of Hg, Pb, Cd, Zn and Cu to the inhabitants around Huludao zinc plant in China via consumption of vegetables. *Science of the Total Environment*, **383**, 81-89.