The effect of arsenic and heavy metals on growth and metal accumulation by artichoke (*Cynara scolymus* L.) and savory (*Satureja hortensis* L.)

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Abstract

The present investigation assessed the effects of a metalloid (arsenic) and two heavy metals (cadmium and mercury), on the growth and metal accumulation in two medicinal plant species, artichoke (*Cynara scolymus* L.) and Savory (*Satureja hortensis* L.). The experiment was conducted hydroponically in spiked solution with different concentrations of arsenic (0, 20, 100, and 500 µM), cadmium (0, 10, 50, 250, and 500 µM) and mercury (0, 5, 25, and 50 µM) for four weeks. Under elevated arsenic and heavy metal stresses, root and shoot biomass of artichoke and savory were reduced. Shoot dry weight was significantly ($p<0.05$) decreased at arsenic supply levels of 20-500 µM, cadmium levels of 10-500 µM and mercury levels of 5-50 µM compared to the control plants. Similar response patterns to arsenic, cadmium and mercury supply levels were noted for root dry weight in the two plant species. Arsenic and heavy metal accumulated by the plants root and shoot linearly increased with increasing their supply levels. More accumulation of arsenic, cadmium and mercury was observed in roots than shoots in artichoke and savory. Artichoke had higher metalloid and heavy metal uptake, bioaccumulation factor, and root-to-shoot translocation efficiencies than those of savory. This can be attributed to a greater accumulating capacity in artichoke. Overall results indicated that metal phytoextraction using the artichoke can be applied to clean up soils moderately contaminated by arsenic, cadmium and mercury in polluted lands.

Keywords: phytoremediation; phytotoxicity; plant; toxic elements; uptake

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Introduction

Heavy metals are defined as a group of elements with a density higher than about 5 gr/cm^3 (Lottermoser, 2007). Heavy metals and metalloids are released into the environment by many anthropogenic activities including former or current mining activities, industrial emissions, the application of agricultural amendments and lime product (Pilon-Smits, 2005; Mahmood et al., 2005). Heavy metals are potential threats for human health and the environment, through their accumulation in the soil, in the food chain and locally in drinking water (Lottermoser, 2007).

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From soils to plants, heavy metals transfer depends on the following three factors: quantity (the total amount of potentially available elements), intensity (the activity as well as the ionic ratios of elements in the soil solution) and reaction kinetics (the rate of element transfer from solid to liquid phases and to plant roots) (Li et al., 2007).

Arsenic (As) is widely distributed into the nature in the form of either metalloids or chemical compounds, which causes a variety of pathogenic conditions including coetaneous and visceral malignancies (Karimi et al., 2010). There are concerns that arsenic may be absorbed by plants, particularly cereals, entering the grains and thus the food chain. The phytotoxicity of arsenic is affected considerably by the chemical form in which it occurs in the soil and by concentration of the metalloid, water-soluble form being more phytotoxic than other firmly bound forms (Karimi et al., 2010). Arsenite, As (III), is more phytotoxic than arsenate, As (V) and both are much more phytotoxic than monosodium methane arsenic acid (MSMA) (Patra et al., 2004). Due to its chemical similarity to phosphorus, arsenic participates in many cell reactions. Specific organo- arsenical compounds have been found in some organisms and arsenic has been reported to replace phosphorus in the phosphate groups of DNA. In view of the variety of reactions in plants that involve sulphydryl groups and phosphorus, arsenites and arsenates may interfere with physiological and biochemical processes which constitute growth in a number of ways (Michalak, 2006).

Cadmium (Cd) is regarded as one of the most toxic environmental pollutants and is readily absorbed by certain crops from soils (Li et al., 2011). Elevated concentrations of Cd in agricultural soils have posed a significant threat to safe food production and have therefore become a worldwide concern (Järup and Åkesson, 2009). The reduction of biomass by Cd toxicity could be the direct consequence of the inhibition of chlorophyll synthesis and photosynthesis (Zhu and He, 2008). Excessive amount of Cd may cause decreased uptake of nutrient elements, inhibition of various enzyme activities, induction of oxidative stress including alterations in enzymes of the antioxidant defense system (Krüpper et al., 2007).

Mercury (Hg) has been considered as a highly toxic substance due to its persistent nature and magnification through the food chain in the ecosystem. Mercury is a liquid metal at ambient temperature and pressure (Chen et al., 2012). Mercury can cause brain damage, heart, and lung diseases in human beings (US Environmental Protection Agency, 2006). The absorption of organic and inorganic Hg from soil by plants is low (Patra et al., 2004) and there is probably a barrier to mercury translocation from plant roots to tops. However, Hg containing pesticide / fungicide spray residues are, in some cases, taken up by plants (e.g. rice) and translocated to edible portions. Factors affecting plant uptake include external Hg concentration and exposure time, soil or sediment organic content, carbon exchange capacity, oxide and carbonate content, and redox potential (Chen et al., 2012). The toxic action of Hg may be related to a non-specific inhibition of a variety of intracellular enzymes and several specific thiol-containing respiratory enzymes in vitro (Patra et al., 2004).

Remediation of heavy metals by plant species can be divided into three groups. Through phytoextraction metal accumulating plants are planted on contaminated soil and later harvested in order to remove metals from the soil. In Rhizofiltration roots of metal accumulating plants absorb metals from polluted effluents and are later harvested to diminish the metals in the effluent. In phytostabilization, metal-tolerant plants are used to reduce the mobility of metals, thus, the metals are stabilized in the substrate. Plants with both bioconcentration factor and translocation factor greater than one (TF and BCF>1) have the potential to be used in phytoextraction (Mc Karimi et al., 2010). Besides, plants with bioconcentration factor greater than one and translocation factor less than one (BCF>1 and TF<1) have the potential for phytostabilization (Karimi et al., 2009). Phytoextraction, i.e., the use of plants to remove pollutants (including As, Cd and Hg) from contaminated soils has been proposed as a promising technology that is both low cost and environmentally friendly (Zandsalimi et al., 2011). A general approach for phytoextraction of heavy metal contaminated soils is to make use of hyperaccumulating plants, which have the inherent potential to survive and accumulate excessive amounts of metal ions in their biomass without incurring damage to basic metabolic functions (Karimi et al., 2010). For a plant species to be efficient in phytoextraction it should accumulate As and Hg concentration ≥1000 and Cd≥100 mg kg^{-1} of shoot dry weight, besides having high biomass productivity (Zhang et al., 2009). A balance between metal accumulation and plant biomass productivity is critical for a plant species to be used in heavy metal phytoextraction (Kramer et al., 2010). From this standpoint, plant species such as *Thlaspi caerulescens*, *Arabidopsis halleri*, and *Viola baoshanensis* were focused for Cd (Zhang et al., 2009), *Pteris vitata* and *Isatis cappadocica* for As (Ma et al., 2001; Karimi et al., 2009; Kramer et al., 2010), and *Liriodendron tulipifera* for Hg (Rugh, 2001) phytoremediation, respectively.

Artichoke (*Cynara scolymus* L.) is an herbaceous perennial plant belonging to the Compositae family (Asteraceae) cultivated in the Mediterranean area. Artichoke is a fast growing plant which produces relatively high biomass (Karimi et al., 2012a). Thus this plant might be a potential candidate for phytofiltration and/or phytostabilization of heavy metal contaminated waste waters.

Satureja hortensis L. (summer savory) is an annual aromatic plant used as a valuable medicinal and spice plant worldwide. In folk medicine, savory is used for stomachache, and as stimulant, carminative, expectorant, aphrodisiac, antispasmodic and antidiarrhoeal (Ozcan, 2004; Skocibusic et al., 2006; Karimi et al., 2012b). Beside, adaptability to harsh environmental conditions, high yield and short growing period make savory as a valuable alternative crop in agriculture (Hadian et al., 2008).

To our knowledge, few reports are available on the accumulation and toxicity of heavy metals in artichoke and savory (Karimi et al., 2012a) and no work has so far been carried out to study heavy metal-induced metabolic changes therein. In the present investigation, the influence of As, Cd and Hg bioaccumulation on growth and heavy metal accumulation and translocation factor of artichoke and savory were studied. This study will be helpful in elucidating the acute toxicity and tolerance ability of As, Cd and Hg by Artichoke and savory.

Materials and Methods

Plant material, growth conditions, and treatments

Mature seeds of artichoke were sterilized in 70% ethanol for 1 min, 0.1% mercuric chloride for 5 min, followed by three washes in sterile distilled water. After sterilization, seeds were germinated into pots filled with perlite. The uniform seedlings were fed 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 FeEDHA, 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 0.1 M NaOH or 0.1 M HCl. Plants were grown in growth room with 16/8 h light/dark cycles, day/night temperature of 26/20 °C and light intensity approximately 280 mM(photons)$m^{-2}s^{-1}$. The nutrient solution was renewed every 3 d. Two weeks later, the solutions were amended with different As, Cd and Hg concentrations as NaH_2AsO_4, $CdCl_2.4H_2O$ and $HgCl_2$, respectively. Artichoke and savory were subjected to different concentrations of As (0, 20, 100, 500 µM), Cd (0, 10, 50, 250, 500 µM) and Hg (0, 5, 25, 50 µM) for four weeks.

The plants were grown in a greenhouse (Razi University, Kermanshah, Iran) with 14/10 h light/dark cycles; temperature was kept at 26 °C during the day and 20 °C during the night. Light intensity was around 280 mM(photons)$m^{-2}s^{-1}$. The experimental design was a randomized block of three replicates with 4 plants per each. Plants received 200 ml of the appropriate solution every day for 3 weeks. Every third day the perlite was flushed (washed out) 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, weighted and ground in a mortar to obtain homogeneous samples.

Element analysis

Arsenic analysis

At harvest, dried shoots and roots were ground in a stainless steel miller. The powdered dry materials of shoots and roots were digested through the method described by (Meharg and Jardine 2003). The ground plant samples (0.5 g) were placed in a digestion tube and mixed with 2.5 ml of concentrated nitric acid. The digest was allowed to stand overnight and then 2.5 ml of concentrated H_2O_2 was added. The tubes were then placed on a digestion block and heated at 100 °C until frothing stopped, and then heated at 140 °C until the solutions became clear. The tubes were then heated to 180 °C to boil off the nitric acid. On cooling, the residue was taken up in 10 ml of a solution containing 10% HCl, 5% ascorbic acid and 10% KI. Concentrations were measured in duplicate by using Shimadzu spectra AA-680 and hydride generator Atomic Absorption Spectrophotometer (WHG 103A).

Heavy metal analysis

For Hg analysis, 0.5 g samples were triplicately digested with 6 ml HNO_3, 0.5 ml HF and 1 ml H_2O_2. The tubes were then placed on a digestion block and heated at 100 °C until frothing stopped, and then heated at 140 °C until the solutions became clear. Cold vapor technique was used for mercury analysis employing Shimadzu spectra AA-680 and hydride generator Atomic Absorption Spectrophotometer (WHG 103A). The procedure described in European Standard EN 1483 (European standard EN, 1483, 1997) was followed using a solution of 3% $NaBH_4$ in 1% NaOH as a reducing agent. For Cd analysis, the powdered dry materials were digested in HNO_3 and H_2O_2, 3:1 proportion through block digestion. Cd analysis was conducted with atomic absorption spectrophotometer AA-680.

Standard materials for chemical analysis were purchased from Merck and the calibration curve fit (at least five standard concentrations) was of $R^2>0.97$ in all cases. The method's recovery of As (0.79 ± 0.08 mg/kg) from certified reference material (Beach leaves material FD8, Commission of the European Communities, Joint Research Centre ISPRA) was not significantly different from the certified reference value (0.76 ± 0.1 mg/kg). The mean As concentration in blank digests was 0.08 µg/l and the detection limit for As in plant tissue was 0.05 µg/l.

The bioaccumulation coefficient (BC), or enrich factor, was described as (Liu et al., 2009); Tanhan et al. 2007): BC = the heavy metal concentration in the whole plant / the heavy metal concentration in the medium. The translocation factor (TF) indicated the ability of plants to translocate heavy metals from the roots to the shoots. TF from heavy metal concentration was calculated as (Liu et al., 2009): TF = the heavy metal concentration in shoots / the heavy metal concentration in roots. The tolerance index (TI) to grow in the presence of a given concentration of metal, calculated as: TI = dry weight of the plants growing in cadmium supplies / dry weight of the plants growing in control.

Statistical analysis

The results were analyzed statistically by the SPSS 16. The experiment was a 2×3×4 experiment (two different plants affected by three metal types at four concentrations) with three replications arranged in a completely randomized design. Treatment effects were determined by analysis of variance. Duncan's multiple range (DMRT) test was performed to compare the groups for significant differences.

Results

This experiment was conducted to determine the impacts of arsenic and heavy metals (Cd and Hg) uptake on plant growth and distribution of them in an arsenic and heavy metal contaminated hydroponic solution. Table 1 shows the biomass of artichoke and Savory shoots under contamination of As and heavy metals in nutrient solution. There were no significant differences in shoot biomass at 20 µM As, 10 µM Cd and 5 µM Hg compared to the control. It is revealed that the dry weight of shoots was significantly ($p< 0.05$) decreased at As supply levels of 20-500 µM, Cd levels of 10-500 µM and Hg levels of 5-50 µM compared to the control. The shoot dry weight of the two plant species was dramatically decreased with As, Cd and Hg levels exceeded from 20, 10 and 5 µM respectively. Similar response patterns to As, Cd and Hg supply levels were noted for root dry weight in two plant species. The maximum root dry weight decreased with increasing As and heavy metal supply levels in the medium. It appears that the two species have optimal growth at As, Cd and Hg levels as high as 100, 50 and 25 in terms of both shoot and root dry matter production, respectively. Furthermore, artichoke has higher tolerance to As and heavy metal toxicity.

Heavy metal accumulation

Arsenic accumulation

In the hydroponic experiment, root and shoot As concentrations in both species slightly increased with increasing As in nutrient solution (Fig. I, $P < 0.05$). Also in both species, the highest As concentration were reached 214.92 and 166.58 in roots and 219.61 and 106.69 in shoots under 500 µM treatments, respectively (Fig. Ia, b). Artichoke showed higher shoot As concentrations than savory ($P < 0.05$). The BC of plant species increased with the increase in As,

Table 1
Artichoke and Savory biomass and their components (means ± SD) in response to different Arsenic, cadmium and mercury supplies in hydroponic solution

Plant species	Element supply (µM)	Shoot biomass (mg plant^{-1})	Root biomass (mg plant^{-1})	Total (mg plant^{-1})
Cynara scolymus (Artichoke)	***Arsenic***			
	0.00	396.66	200.00	596.66
	20.00	380.00	176.66	556.66
	100.00	316.66	103.66	420.32
	500.00	223.33	70.00	293.33
	Cadmium			
	0.00	328.33	123.67	452.00
	10.00	361.67	106.00	467.67
	50.00	320.67	93.30	413.97
	500	162.33	16.00	178.33
	Mercury			
	0.00	380.00	200.00	580.00
	5.00	303.33	150.00	453.33
	25.00	163.33	53.33	216.66
	50.00	80.00	50.00	130.00
Satureja hortensis (Savory)	***Arsenic***			
	0.00	240.00	103.67	343.67
	20.00	276.67	147.00	423.67
	100.00	230.00	86.67	316.67
	500.00	173.33	70.00	243.33
	Cadmium			0.00
	0.00	138.37	98.33	236.70
	10.00	116.00	65.23	181.23
	50.00	83.00	35.33	118.33
	500	8.70	7.30	16.00
	Mercury			
	0.00	210.00	160.00	370.00
	5.00	160.00	86.67	246.67
	25.00	96.67	66.67	163.34
	50.00	73.33	40.00	113.33

whereas BC was higher in artichoke than that of savory (Table 2). These results suggest that artichoke has a high ability to absorb As and translocate it to shoots. Phytotoxicity was observed in 500 µM As treatments. In contrast, TF and TI decreased significantly as concentration of As increased (Table 2).

Cadmium accumulation

Cadmium concentration in artichoke and savory plants showed the same order (root > shoot) (Fig. I, C & D). Cadmium concentrations in shoot and root increased with the increase in cadmium supply in the nutrient solution. In addition, cadmium concentrations in both shoot and root were higher in artichoke compared with those in savory. Additionally, BC of both plant species increased with the increase in cadmium, whereas BC was higher in artichoke than that in savory (Table 2). The highest cadmium supply

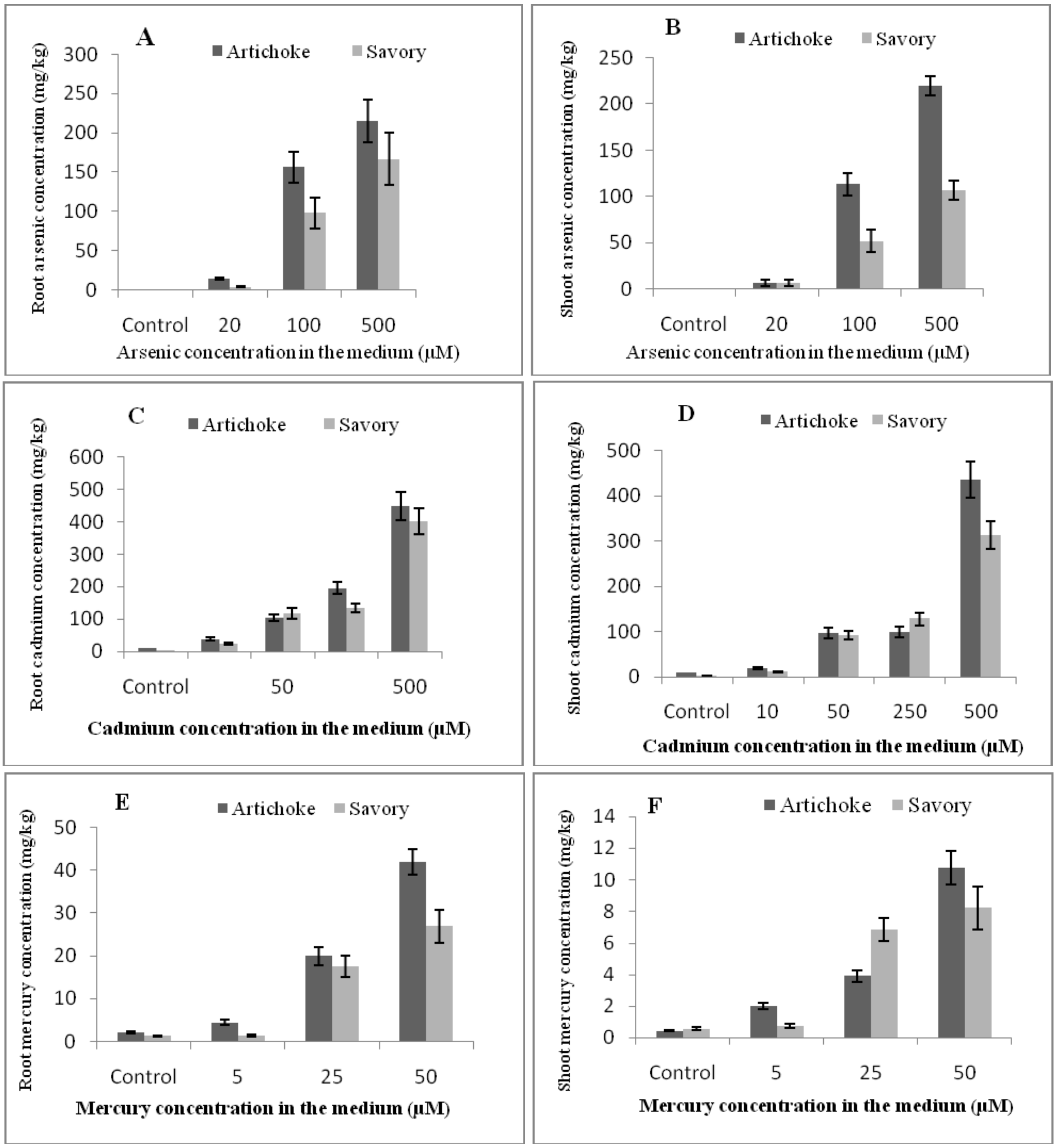

Fig. I. Root and shoot accumulation of arsenic (A, B), cadmium (C, D) and mercury (E, F) affected by different As, Cd and Hg concentration in the Artichoke and Savory. Values are means ± S.E (n=3).

significantly decreased TF and TI of studied plants in the medium. TI of savory was lower compared with artichoke the treated with 10-500 μM cadmium supplies.

Mercury accumulation

The Hg concentrations in the roots and stems of artichoke and savory grown in perlite supplemented with $HgCl_2$ are shown in Fig. I, E & F. Mercury concentration in the plant was significantly affected by both the Hg content supplied in the growth medium and the plant tissue. Mercury supply slightly increased root and shoot Hg concentrations in both species with increasing Hg in nutrient solution (Fig. I, E & F, $P < 0.05$). In all Hg treatments, the concentration of Hg in roots was always greater than that in shoots. In artichoke the highest Hg concentration reached 42.53 in roots and 10.74 in shoots under 50 μM As L^{-1} treatments (Fig. I). Artichoke showed higher ability for Hg accumulation than savory.

The BC of both plant species increased with the increase in Hg reaching 1.21 and 1.01 at highest concentration of Hg (50 μM) in artichoke and savory, respectively (Table 2). Moreover, the Hg toxicity exhibited a decline in TF and TI of artichoke and savory at elevated concentrations (> 10 μM). The TF and TI of artichoke regarding its

Table 2
Bioaccumulation coefficient (BC), transport factor (TF) and tolerance index (Ti) of Artichoke and Savory (means ± SD) in responce to different Arsenic, cadmium and mercury supplies in hydroponic solution.

Plant species	Element supply (μM)	BC	TF	TI
Cynara scolymus (Artichoke)	***Arsenic***			
	0.00	0.02	0.68	1.00
	20.00	0.79	0.47	0.95
	100.00	1.13	0.72	0.79
	500.00	2.21	1.02	0.56
	Cadmium			
	0.00	0.45	0.91	1.00
	10.00	0.52	0.50	1.10
	50.00	1.08	0.91	0.97
	500	2.1	0.50	0.49
	Mercury			
	0.00	0.25	0.20	1.00
	5.00	0.64	0.45	0.80
	25.00	0.97	0.19	0.43
	50.00	1.21	0.25	0.21
Satureja hortensis (Savory)	***Arsenic***			
	0.00	0.072	0.73	1.00
	20.00	0.38	1.94	1.15
	100.00	0.87	0.52	0.95
	500.00	1.24	0.64	0.72
	Cadmium			
	0.00	0.20	0.665	1.00
	10.00	0.44	0.47	0.83
	50.00	0.79	0.78	0.59
	500	1.31	0.95	0.062
	Mercury			
	0.00	0.18	0.44	1.00
	5.00	0.21	0.55	0.76
	25.00	0.76	0.39	0.46
	50.00	1.01	0.30	0.35

accumulation abilities were greater than savory at the treatments with 5-50 µM Hg supplies.

Discussion

Heavy metals and metalloids including As, Cd and Hg are thought to be the most dangerous environmental stresses which impede growth and development of plants (Patra et al., 2004). Excessive concentrations of this toxicants result in phytotoxicity through interrupting activities of several essential enzymes, various aspects of the photosynthetic processes, uptake of essential nutrients, and the ultrastructure and water usage of cells (Patra et al., 2004).

Excessive concentrations of metals result in phytotoxicity through: (i) changes in the permeability of the cell membrane; (ii) reactions of sulphydryl (–SH) groups with cations; (iii) affinity for reacting with phosphate groups and active groups of ADP or ATP; and replacement of essential ions (mainly major cations). The most common effect of Cd toxicity in plants is stunted growth, leaf chlorosis and alteration in the activity of many key enzymes of various metabolic pathways (Krüpper et al., 2007). The reduction in plant growth during stress is due to low water potential, reduction in leaf photosynthetic rate, hampered nutrient uptake and secondary stress such as oxidative stress. Furthermore, Hg and As can also disturb microtubule function in meristematic cells (Chen et al., 2012).

In our study, dry weight of artichoke and savory was affected under varied concentrations of Cd, Hg and As. The greater impact of heavy metal was observed on the root growth as compared to shoot because the plant roots are the first point of contact for these toxic compounds in the medium (Elloumi et al., 2007). Our observations revealed that the low level of As (20 µM), Cd (10 µM) and Hg (5 µM) does not affect the root and shoot dry weights significantly, suggesting that these species are able to tolerate low doses of these toxic elements.

High doses (500 µM of As, 500 µM of Cd and 50 µM of Hg), however, proved toxic causing significant reduction in the dry weights of both plant parts. This reduction could possibly be related to high heavy metal accumulation in plant tissues, since the plant may have to use energy to cope with the high heavy metal concentration in the tissues.

Accumulation of heavy metals in higher plants is often accompanied by induction of a variety of intracellular changes, some of which directly contribute to the metal tolerance capacity of plants (Sinha et al., 2007; Ayari et al., 2010). In the present study, As, Hg and Cd accumulation in the root and shoot of artichoke and savory increased with increasing their level in the nutrient solution. Regardless of the metal type, treatments and plant species, As, Hg and Cd accumulation was higher in roots than in shoots (Fig. I), implying that roots of studied plants are efficient barriers to As, Hg and Cd translocation to the above ground plant parts. It has been shown that heavy metals are unevenly distributed in roots, where different root tissues act as barriers to apoplastic and symplastic heavy metal transport and hence heavy metal transport to shoot is restricted. Although accumulation of heavy metal in roots is more than shoots, the translocation from root to shoot in artichoke is higher in comparison with non-accumulating plants.

Exclusion and accumulation of metal are two main tolerance mechanisms of plants in response to heavy metal pollution as declared by Reeves and Baker (2000). Due to higher As and heavy metal concentration in shoots of savory and sensitive plants (Fig. I), artichoke growing in contaminated hydroponic solution might use the accumulation mechanism. This suggests that artichoke has efficient translocation ability that transfers toxic metals from root to shoot. Cadmium concentration in plant tissue increased with the increase in heavy metal concentration in the medium, indicating that artichoke and savory have potential heavy metal phytoextraction ability, which is consistent with many results obtained for other plants (Järup and Åkesson, 2009; Ling et al., 2011).

Many previous studies have suggested that four indicators (the threshold value of toxic element, BC, TF and TI) could be used to define a heavy metal hyperaccumulator (Sun et al., 2009). The threshold value of As and heavy metals studied here were not examined. The results of the BC, TF and TI were different between artichoke and savory growing in hydroponic medium. However, phytoremediation efficiency depends on plant biomass and the ability of metal to be translocated to the shoots (Karimi et al., 2010; Ling et al., 2011). The results indicated that artichoke could translocate more cadmium from root to shoot in hydroponic medium, implying that the artichoke might display relatively high phytoremediation efficiency in nutrient solution. The results from TI could also lead to drawing similar conclusion that TI decreased less with the increase in cadmium concentration in artichoke.

An ideal plant for phytoextraction application should have high metal tolerance and high accumulation capacity in its tissues, especially in harvestable parts (Nabulo et al., 2008; Zandsalimi et al., 2011). Although a lot of studies have focused on the metal tolerance and the accumulated concentration in hyperaccumulators (Malakootian et al., 2009, Reza et al., 2010), they ignored the biomass production of plants, which can limit the actual phytoextraction application in contaminated fields. Fast-growing plants as the examined artichoke exhibited higher phytoextraction efficiency with higher biomass production but relative lower heavy metal concentration in comparison to some other species of hyperaccumulator plants (Table 2). The results at least partly demonstrated the hypothesis that fast growing plant had the higher remedying efficiency compared with the other slow-growing hyperaccumulators.

Conclusion

The present study demonstrated the reduction in root and shoot biomass and tolerance index of artichoke and savory at elevated concentrations of arsenic, cadmium and mercury. The root uptake, bioaccumulation factor and root-to-shoot translocation of As, Cd and Hg in both plant species were increased with the rise of their concentration in the growth medium. The results indicated that artichoke had the higher relative tolerance to high levels of As, Cd and Hg and it is more efficient in uptake and translocation of these elements from root to shoot than savory. The ability of artichoke to withstand the high concentrations of As, Cd and Hg, its high tolerance ability and short growing cycle suggests that this plant has a mechanism to detoxify As, Cd and Hg. The plant's robustness and, As, Cd and Hg accumulation capacity could make it a potential candidate for phytoremediation purposes.

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