Accumulation and Phytotoxicity of Lead in *Cynara scolymus*

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Abstract

Effects of different lead concentration (0, 100, 200, 400, 600, 800, 1000 and1500 µM) on growth, pigment concentration, biochemical parameters and lead accumulation in *Cynara scolymus* L. (artichoke) were investigated. The experiment was conducted hydroponically in a lead spiked solution. The lead toxicity exhibited a decline in growth and chlorophyll content of artichoke at elevated concentrations (>100 µM). In contrast, proline and total soluble sugar increased significantly as lead concentration augmented. The accumulation of lead was found to increase in a concentration dependent manner with a maximum of 411 mg kg^{-1} at 1500 µM. Root accumulated more lead than shoot. The loss of chlorophyll content was associated with disturbances in photosynthetic capacity which ultimately results in the reduction of artichoke growth. Increase proline and total soluble sugar content suggest that compatible solutes may contribute to osmotic adjustment at the cellular level and enzyme protection stabilizing the structure of macromolecules and organelles. The higher lead uptake and root to shoot translocation efficiencies than none accumulating plants was indicative of its greater lead accumulating capacity. Collectively, our results indicate that artichoke has physiological traits associated with accumulation of lead to relative high levels and it can be useful for restoring lead-contaminated sites.

Keywords: Artichoke, Bioaccumulation, Chlorophyll pigments, Lead pollution, Proline , phytoextraction, Phytoremediation

1. Introduction

Heavy metals are contaminants of much environmental concern, as they are hazardous to humans and other biota. The presence of heavy metals in soil may be naturally occurring or due to anthropogenic activities, such as manufacturing or agricultural practices. Human activities (metallic industries, contaminated fertilizers, herbicides or insecticides, irrigation with contaminated groundwater, and use of contaminated sewage sludge) are largely responsible for the accumulation of above-ground levels of heavy metals in soils (Duruibe et al., 2007). 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 (Huang et al., 2007). Among heavy metals, lead (Pb) has been acknowledged to be the most abundant metal pollutant in the environment (Manomita et al., 2004). The annual global emission of Pb by motor vehicles and industrial plants was estimated to be 500000 tones which it can persist in the environment for 150-5000 years (Steinnes & Friedl, 2006). This metal enters agricultural soils mainly from automobiles, metal smelting plants, mines, lead-contaminated sewage sludge and industrial wastes etc., and is then transferred to the food chain (Zakrzewski, 1991). Severe Pb contamination in the soil may cause a variety of problems such as loss of vegetation, ground water contamination, and Pb toxicity in plants, animal and humans (Body et al., 1991).

Lead, a potentially toxic heavy metal with no known biological function, has attracted more and more considerable attention for its widespread distribution and potential risk to the environment. Lead exposure to plants causes effects such as the disturbance in mitosis (Liu et al., 1994), cell disturbance (Patra et al., 2004), decrease in seed germination (Xiong, 1997), induction of leaf chlorosis (Ruley et al., 2006), depression of photosynthetic rate, (Patra et al., 2004), inhibition in root and shoot growth (Liu et al., 1994), and inhibition and activation of enzymatic activities (Khan et al., 2009). Strict Pb contamination in soils may lead to a variety of environmental problems such as reduce vegetation structure and biodiversity, ground water contamination, and ultimately Pb toxicity to humans (Ruley et al., 2006). Thus, there is an urgent need for remediation of contaminated sites using an effective and environment friendly technology such as phytoremediation.

Recently phytoremediation, that is a cost effective, promising and environment friendly technology to clean up the polluted soils with green plants, has emerged as a potential in situ technology employed to clean up soils polluted by organics and heavy metals (Kramer, 2010). This strategy makes use of hyperaccumulator 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 Pb phytoextraction it should accumulate metal concentration ≥1000 mg kg^{-1} of shoot dry weight, besides having high biomass productivity (Kramer, 2010). A balance between metal accumulation and plant biomass productivity is critical for a plants species to be used in Pb phytoextraction (Huang et al., 1997). From this standpoint, plant species such as Indian mustard, pea, and corn were focused recently for Pb phytoremediation research. These species accumulate high amounts of Pb, and produce satisfactory biomass (Epstein et al., 1999). Another interesting Pb accumulators are *Sesbania drummondii* and *Matthiola flavida*, a perennial plant with greater biomass productivity than the above plant species (Ruley, 2004; Ghaderian et al., 2007). *Sesbania drummondii* grows naturally in seasonally wet places of the southern coastal plains of the United States whereas *M. flavida* grows in the old Pb/Zn mining areas of central Iran (Irankouh). They have been identified as a unique potential of Pb accumulation in aerial parts from an aqueous and arid environments (Sahi et al., 2002, Ghaderian et al., 2007).

The sensitivity of plants to heavy metals like Pb depends on an interrelated network of physiological and molecular mechanisms such as (i) uptake and accumulation of metals through binding to extracellular exudates and cell wall constituents; (ii) efflux of heavy metals from cytoplasm to extranuclear compartments including vacuoles; (iii) complexation of heavy metal ions inside the cell by various substances, for example, organic acids, amino acids, phytochelatins, and metallothioneins; (iv) accumulation of osmolytes and osmoprotectants and induction of antioxidative enzymes (v) activation or modification of plant metabolism to allow adequate functioning of metabolic pathways and rapid repair of damaged cell structures (Cho et al., 2003). In order to find suitable plants for removal of Pb from the contaminated environment, we need a wide range of knowledge concerning the physiological and biochemical features of potentially useful species. Preliminary surveys for biomass and mineral accumulation have indicated different responses of the plant species to nutrient supply (Bergmann et al., 2000) and literature data show also species- and metal specific strategies (Kramer, 2010).

Artichoke (*Cynara scolymus* L.) is an herbaceous perennial plant belonging to the Compositae family (Asteraceae) cultivated in the Mediterranean area. The heads of the artichoke are edible and used worldwide; the leaves are an herbal medicine recognized for a long time for their beneficial effects against liver complaints and for their antioxidant action (Gebhardt, 2001). The dry extract of artichoke is containing polyphenolic acids, flavonoids and tannins. It has some serious pharmacologic actions like stimulates the metabolization of the cholesterol in the liver and used as diuretic, tonic, depurativeand hypoglycaemic. Artichoke is a fast growing plant which produces relative high biomass. Thus this plant might be a potential candidate for phytofiltration and/ or phytostabilization of heavy metal contaminated waste waters. In a moderate climate they are successfully cultivated as annual plants from seeds sown directly to the ground or from transplants (Jiménez-Escrig et al., 2003).

The present study was undertaken to evaluate a change in the level of growth and biochemical aspects of artichoke including biomass, proline, total soluble sugar, pigment content and Pb uptake and translocation in order to contribute to an understanding of artichoke adaptation to Pb stress. Furthermore the purpose of our study was to seek the potential application of artichoke to phytoremediation of Pb-contaminated soils, sediments, and water.

2. Material And Methods

2.1 Plant material, growth conditions, and treatments

Mature seeds of artichoke were sterilized in 70% ethanol for 1 min, 0.1% mercuric chloride for 5min, followed by three washes in sterile distilled water. After sterilization, seeds were germinated into pots filled with perlite. 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 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 0.1M NaOH or 0.1M HCl. Plants were grown in growth room with 16/8 h light/dark cycles, day/night temperature of 26/20 °C and light intensity approx, 280 mmolm^{-2} $^{s-1}$. The nutrient solution was renewed every 3 d. Two weeks later the solutions were amended with eight Pb concentrations (0, 100, 200, 400, 600, 800, 1000 and 1500 µM) as $Pb(NO_3)_2$ for another 4 weeks. The seedlings were grown in a growth chamber with 14/10 h light/dark cycles; temperature was kept at 26 ºC during the day and 20 ºC during the night. Light intensity was around 280 µmol m$_{-}^{2}$ $^{s}_{-}$^{1}. 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, weighted and ground in mortar to obtain homogeneous samples.

2.2 Determination of photosynthetic pigments

Chlorophyll-a and -b contents in wheat leafs were determined after growing on amended hydroponic culture with Pb. Chlorophyll-a and -b were determined spectrophotometrically. Leaf was cut into small pieces leaving away the midribs, mixed thoroughly and 0.25 g of the leaf was taken into a mortar to grind them finely by pastel with 25 ml of 80% cold acetone for 2 min. A small amount of Na_2CO_3 was added to the leaf before grinding to check degradation of pigments during grinding. The homogenate was filtered through filter paper (Whatman No.1) and was made a volume of 25 ml with 80% cold acetone. The optical density of each solution was measured at 663 and 645 nm against 80% acetone blank in 1.5 cm cell. Specific absorption coefficient method of Arnone (1949) was used to calculate the amount of chlorophyll-a, -b and total. The content of the photosynthetic pigments was calculated with the formula:

$$[chl\ a] = 0.0127 * A663 - 0.00269 * A645 * v/w$$
$$[chl\ b] = 0.0229 * A645 - 0.00468 * A663 * v/w$$

[chl total] = 0.02021 * A645 + 0.00802 * A663 * v/w
-A663, A645, A440 is the absorbance,
-V is the volume of the solvent,
- W is the mass tissue

2.3 Estimation of Proline content

Proline concentration was determined using the method of Bates et al. (1973). Fresh leaves (300 mg) were homogenized in 10 ml of aqueous sulphosalicylic acid (3%). The homogenate was centrifuged at 9000 × g for 15 min. A two ml aliquot of the supernatant was mixed with an equal volume of acetic acid and ninhydrin and incubated for 1 h at 1000°C. The reaction was terminated on ice bath and extracted with 4 ml of toluene. The extract was vortexed for 20 s and the chromophore containing toluene was aspirated from the aqueous phase and absorbance determined photometrically at 520 nm (Tomas 302, USA) using toluene for a blank.

2.4 Extraction and analysis of total soluble sugar

For determination of total soluble sugar content, 50 mg of dry shoot powder was extracted using 10 cm^3 of ethanol: distilled water (8:2; v/v), and supernatant was collected after twice centrifugation at 1 480 *g*. Total soluble sugar content was estimated calorimetrically using phenol sulfuric acid method described by Dubois et al. (1956).

2.5 Pb analysis

At harvest, dried shoots and roots were ground in a stainless steel miller. The powdered dry materials were digested in HNO_3 and H_2O_2, 3:1 proportion through block digestion as described by Meharg and Jardin (2003). The concentrations of heavy metals were determined using the atomic absorption spectrophotometry (Shimadzu AA-680). Reference standard for calibration of the AAS was made using 1000 mg l^{-1} (Beach leaves material FD8, Commission of the European Communities, Joint Research Centre ISPRA).

2.6 Statistical analysis

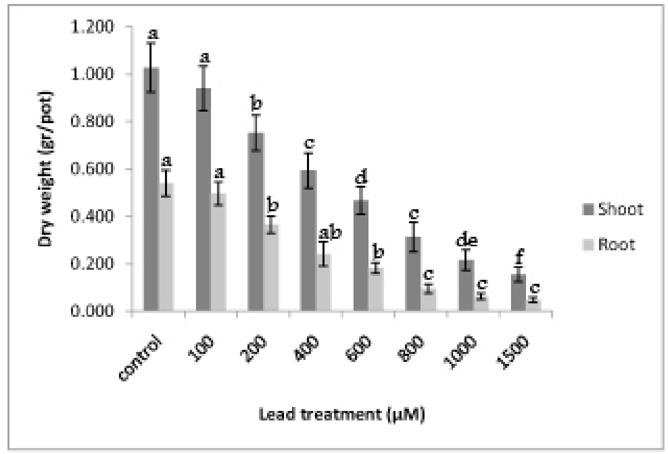
The results were analyzed statistically by the SPSS 16. One-way ANOVA was performed to test the significant differences for all measurable variables. Duncan's multiple range (DMRT) test was performed to compare among the groups for significant differences. All the values presented in this paper were the means of three replicates.

3. Results

3.1 Effects of Pb on plant growth

Fig. 1 depicts the effect of Pb on plant growth, as shown by the root and shoot biomass. There were no significant differences in root biomass at 100 µM Pb compared to the control. However, significantly reduced root biomass ($P<0.05$) was observed in case of plants grown in the presence of Pb supply levels of 200-1500 µM compared to the control. Similar response patterns to Pb supply levels were noted for shoot dry weight in artichoke. It survived in the medium exposed up to 100 µM Pb, showing no visual Pb toxicity symptoms such as necrosis and chlorosis. The maximum root dry weight decreased with increasing Pb supply levels from 400 µM and dramatically decreased at Pb levels higher than 800 µM (Fig. 1). The maximum shoot dry weight at 1000 µM was only about 9% of the control. It appears that artichoke has optimal growth at Pb levels as high as 200 µM in term of both shoot and root dry matter production.

Fig.1. *Root and shoot biomass of (artichoke) after 4 weeks grown on hydroponic solution with different Lead concentration. All values are mean of three replicate ±S.E.*



3.2 Effect of Pb on photosynthetic pigments

The most important photosynthetic pigment is chloroplast consist of two types of chlorophylls, chlorophyll-a and chlorophyll-b. The contents of Chl-a, Chl-b and total Chl all displayed decreasing trend with the increase of Pb concentration (0–1500 µM) (Fig. 2). The mean chlorophyll-a contents in the leaves of the artichoke was 0.808, 0.801, 0.762, 0.710, 0.687, 0.602, 0.576 and 0.512 mg g^{-1} in control, 100, 200, 400, 600, 800, 100 and 1500 µM of Pb treatments, respectively while chlorophyll-b contents were 0.692, 0.691, 0.643, 0.605, 0.536, 0.442, 0.335 and 0.316 mg g^{-1}, respectively. At higher level of Pb treatment (1500 µM), Chl-a, Chl-b and total Chl declined by 63.37%, 45.71% and 54.94%, respectively (Fig. 2). The mean chlorophyll content in the leaves of did not affect significantly up to 200 µM of Pb.

3.3 Effect of Pb on free proline accumulation

The results pertaining to the effect of Pb on proline content is presented in figure 4. The 100 and 200 µM of Pb did not significantly effect on the proline content of artichoke. There was an almost linear increase in proline accumulation with increasing concentrations of Pb from 100 to 1500 µM, with the greatest increase in proline content in medium contain 400 µM Pb (Fig. 3). However, Pb induced stress in 800 to 1500 µM had difference effects on proline accumulation in artichoke. 1500 µM Pb increased proline content to 359% of the control.

Fig.2. *Effect of different concentration of Pb (0-1500 μM) on chlorophyll a, chlorophyll b and total chlorophyll content of content of (artichoke) All values are mean of three replicate ±S.E.*

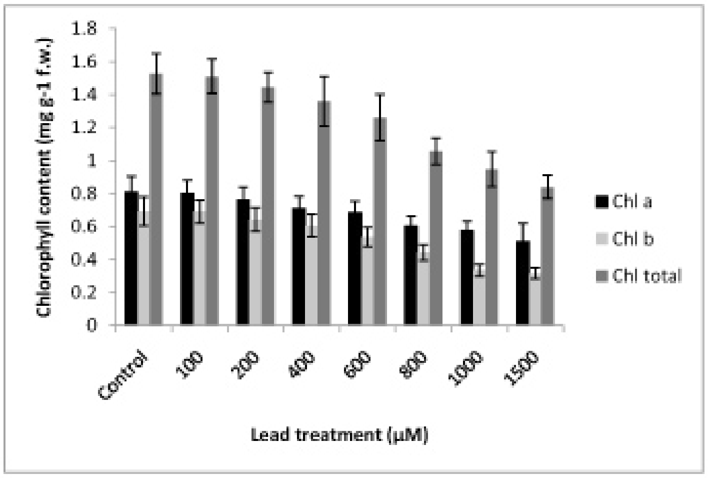
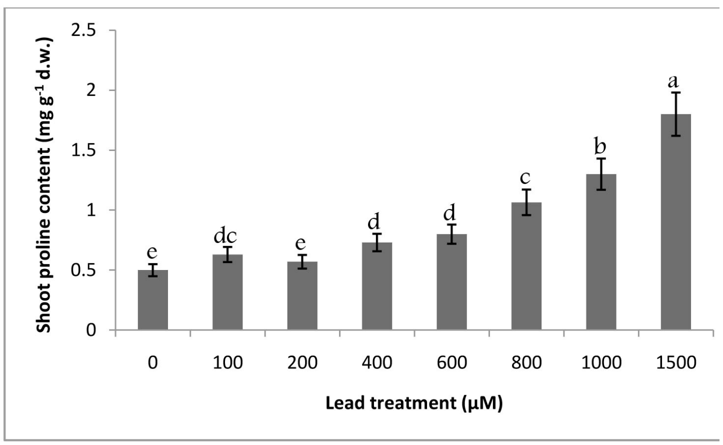


Fig.3. *Effect of different concentration of Pb (0-1500 μM) on proline content of artichoke. All values are mean of three replicate ±S.E*



3.4 Effect of Pb on total soluble sugar

Lead increased the contents of total soluble sugar in artichoke comparing to that of control (Fig. 4). The maximum carbohydrate content was obtained at 1000 and 1500 μM Pb compared with controls which it reached 60.35 and 73.25 mg gr^{-1} dry weight respectively. The mean total soluble sugar content of artichoke did not affect significantly up to 200 μM of Pb L^{-1}.

3.5 Lead accumulation in root and shoots

The Pb concentrations in the roots and steams of artichoke grown in perlite supplemented with $Pb(NO_3)_2$ are shown in Figure 5. Lead concentration in the plant is significantly affected by both the Pb content supplied in the growth medium and the plant tissue. Lead supply slightly increased root and shoot Pb concentrations in two cultivars with increasing Pb in nutrient solution (Figure 5, $P < 0.01$). In all Pb treatments, the concentration of Pb in the roots was always greater than that in the shoots. In artichoke the highest Pb concentration were reached 411in roots and 277.32 mg kg^{-1} at shoots under the 1500 μM treatment, respectively (Fig. 5). Phytotoxicity was observed in the 100 and 1500 mg μM treatments. The visibale symptoms of phytotoxicity include chlorotic spots, necrotic lesions etc.

Fig.4. *Total soluble sugar content of artichoke under Pb stress (0-1500 μM). Means ± SE of three replicates.*

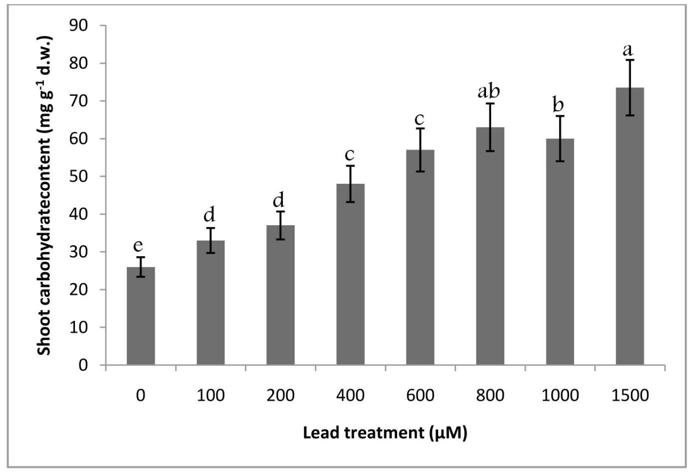
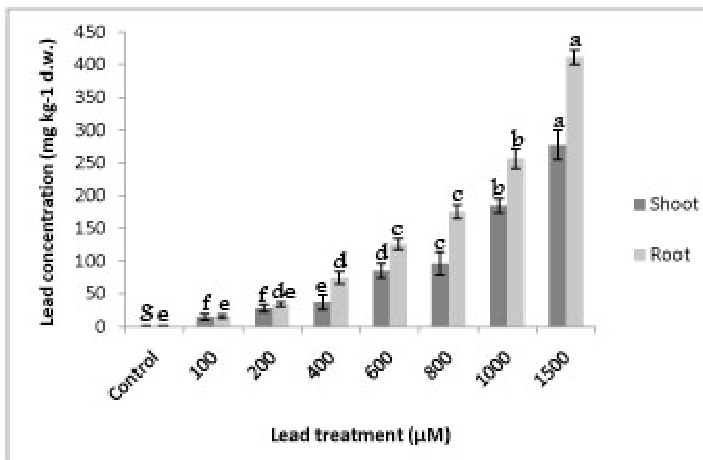


Fig.5. *Lead concentration in the roots and shoots of artichoke treated with different Pb concentrations (0-1500 μM) doses for 4 wk. All values are mean of three replicate ±S.E.*



4. Discussion

Heavy metals including lead are thought to be one of the most dangerous environmental stresses which impede growth and development of plants (Cobbett, 2000). Excessive concentrations of Pb result in phytotoxicity through interrupt activities of several essential enzymes, various aspects of the photosynthetic processes, uptake of essential nutrients, and the ultrastructure and water usage of cells (Manomita et al., 2004). *C. scolymus* L. is species from compositae family which grows naturally around Pb/Zn mining area in Iran with relative high ability of Zn and Pb tolerance (Karimi, unpublished data). Therefore, this study was performed in hydroponic condition to investigate the effects of Pb on physiological and biochemical parameters, uptake and resistance abilities of artichoke. This study would be important for understanding, analyzing and improving the defense strategies through various parameters.

The most common effect of Pb toxicity in plants is stunted growth, chlorotic spots, necrotic lesions and alteration in the activity of many key enzymes of various metabolic pathways (Manomita et al., 2004). The reduction in plant growth during stress is due to low water potential, hampered nutrient uptake and secondary stress such as oxidative stress. Further Pb can also disturb microtubule organization in meristematic cells (Eun et al., 2000). Our observations on the growth of artichoke, assessed in terms of dry weight of root and shoot, have revealed that the low level of Pb (100 µM) does not affect the root and shoot dry weights significantly, suggesting that the species is able to tolerate low doses of Pb. High doses (200-1500 µM), however, proved toxic, causing significant reduction in the dry weights of both the plant parts. This reduction could possibly be related to high Pb accumulation in plant tissues, since the plant may have to use energy to cope with the high Pb concentration in the tissues (Yang et al., 2000).

The greater impact of Pb was observed on the root growth as compared to shoot, because the plant roots are the first point of contact for these toxic compound in the medium (Elloumi et al., 2007). Reduced root and shoot growth in response to Pb exposure has been reported by a number of investigators in other plants (Manomita et al., 2004).The reduction of shoot height due to Pb exposure can be an important consideration for rice cultivation as reduced shoot height will decrease rice leaf area, net photosynthesis (Marin et al., 1993), and ultimately rice yield. A few cases of increase in the plant biomass due to metal pollutants have been reported in the literature, but these were from experiments using low concentrations of metals (Ruley et al., 2006).

Plant growth is inhibited as a consequence of reduction in leaf photosynthetic rate under heavy metal (Tang & Miller, 1991; Rodriguez-Serrano et al., 2009). Long term exposure to lead results in reduced leaf growth, decreased photosynthetic pigments, changed chloroplast structure, and decreased enzyme activities for CO_2 assimilation (Parys et al., 1998; Shearan & Singh, 1993). The decline in chlorophyll content in plants exposed to Pb stress is believed to be due to (a) inhibition of important enzymes, such as δ-aminolevulinic acid dehydratase (ALA-dehydratase) (Padmaja et al., 1990) and protochlorophyllide reductase (Van Assche & Clijsters, 1990) associated with chlorophyll biosynthesis; (b) strong oxidation of photochemical apparatus (Singh et al., 1997) and (c) impairment in the supply of Mg^{2+}, Fe^{2+}, Zn^{2+} and Mn^{2+} (Van Assche and Clijsters 1990; John et al., 2009). In this study, chlorophyll-a chlorophyll- b and total chlorophyll of artichoke plants were decreased with increasing Pb concentration in medium. Similar decrease in chlorophyll content under heavy metal stress was reported earlier in cyanobacteria, unicellular chlorophytes (*Chlorella*), gymnosperms, such as *Picea abies* and angiosperms, such as *Zea mays*, *Quercus palustrus* and *Acer rubrum* (Cho et al., 2009). The decrease in chlorophyll content was also reported in sunflower (Zengin & Munzuroglu 2006) and in almond (Elloumi et al., 2007).

Accumulation of some kind of compatible solutes is another strategy that plant adopt to withstand stress conditions (Padida & Das, 2005). Proline, an imino acid is well known to get accumulated in wide variety of organisms ranging from bacteria to higher plants on exposure to abiotic stress (Saradhi et al., 1993). Plants have been shown proline accumulation under environmental stress (Ahmad & Jhon, 2005; Ahmad et al., 2006; Ahmad et al., 2008). In artichoke, proline concentration increased considerably under Pb stress, which indicates that the overproduction of this compound is a non-specific response (Bajji et al., 2000; Errabi et al., 2007). Increase in proline content may be either due to *de novo* synthesis or decreased degredation or both (Kasai et al., 1998). It has been often suggested that proline accumulation may contribute to osmotic adjustment at the cellular level and enzyme protection stabilizing the structure of macromolecules and organelles. Then it can serve as an organic nitrogen reserve ready to be used after stress relief to sustain both amino acid and protein synthesis (Sairam & Tygai, 2004). Proline accumulation in shoots of *B. juncea* in response to Pb^{2+} toxicity has been demonstrated by John et al., (2009). Similar results of increasing proline content by Cd^{2+} was also reported by Zengin and Munzuroglu (2006) in sunflower.

It is believed that under heavy metal stress accumulation of sugar along with other compatible solutes contribute to an osmotic adjustment allow the plants to minimize sufficient storage reserves to support basal metabolism under stressed environment (Smeekens, 2000). The major functions of sugars are osmoprotection, osmotic adjustment, carbon storage, and radical scavenging (Parida & Das, 2005). Abiotic stress like salinity and heavy metals increased reducing sugars and sucrose in plants (Dubey & Singh, 1999). In this study, the concentrations of total sugars increased in artichoke shoots with increasing levels of Pb in the medium (Fig. 4). The increase in sugar concentration may be a result from the degradation of starch. Starch may play an important role in accumulation of soluble sugars in cells. It is believed that under heavy metal stress accumulation of sugars along with other compatible solutes contribute to osmotic adjustment (e.g. Bohnert et al., 1995) and/or stabilization Carbohydrates (such as glucose, fructose, and fructans) and starch accumulate under salt stress (Parida et al., 2002).

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 (Hall, 2002; Sinha et al., 2007). In the present study, Pb accumulation in the root and shoot of artichoke increased with increasing Pb level in the nutrient solution. The root and shoot accumulated up to 411 and 277 mg Pb kg^{-1} DW after 4wk of 1500 µM Pb treatments, respectively. Regardless of the treatments, the Pb accumulation was higher in root than in the shoot (Fig. 5), implying that roots of artichoke are efficient barriers to Pb translocation to the above ground plant parts. It has been shown that Pb is unevenly distributed in roots, where different root tissues act as barriers to apoplastic and symplastic Pb transport and hence Pb transport to shoot gets restricted. Although accumulation of Pb in roots is more than shoots, the translocation from root to shoot in artichoke is higher in compare with none accumulating plants. The high root to shoot translocation is an important factor affecting accumulation of this metal in aerial tissues of artichoke. Our results are in confirmation with that of John et al. (2009) who also observed higher accumulation of Pb into the roots of *B. juncea* as compared to above ground parts.

Over centuries, human industrial, mining and military activities as well as farming and waste practices have contaminated large areas of developed countries with high concentrations of lead as a key heavy metal. Obviously, there is an urgent need for alternative, cheap and efficient methods to clean up heavily contaminated industrial areas. Phytoremediation uses wild or genetically modified plants to extract a wide range of heavy metals and organic pollutants from the soil. Plants most suitable for phytoremediation are able to hyperaccumulate contaminants, possess tolerance to these chemicals, have a high biomass, and have a short growing cycle. The plant, artichoke, accumulated a maximum of 227 mg Pb kg^{-1} dry mass in shoots when cultivated for 4 wk in hydroponic medium. The tolerance of artichoke to Pb 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 (John et al., 2009). The ability of artichoke to withstand the high concentrations of Pb suggests that this plant has a mechanism to detoxify the Pb. This could make it possible because of its higher robustness and Pb 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.

5. Conclusion

Results demonstrate that artichoke thrives on a high concentration of Pb (up to 1500 µM solution). Growth and Photosynthetic efficiency as reflected by pigments content are decreased in the presence of Pb. Also, exposure of artichoke to Pb results an increase in proline and total soluble sugar content. The concentration of Pb in artichoke showed that the plant could tolerate high concentrations of Pb through detoxifying mechanisms. Therefore, artichoke can be used as a Pb accumulator in lead affected soils.

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