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Original Research

Uptake and Translocation of Hexavalent Chromium by Selected Species of Ornamental Plants

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Abstract

The uptake and translocation of hexavalent chromium (Cr (VI)) by four ornamental plant species was investigated. *Aptenia cordofolia* L., *Brassica juncea* L., *Brassica oleracea* L., and *Alyssum maritima* L. species were planted in peat growth medium and exposed to Cr (VI) with irrigation water in a range of concentrations from 0.05 to 1 $mmol \cdot l^{-1}$ for 10 weeks. The results found in this study indicated that the Cr (VI) concentrations in irrigation water significantly affected the Cr uptake and translocation capacities and the growth responses of all four plants. The increases in the concentration of the Cr (VI) in the irrigation water increased the accumulation and translocation of Cr in the root and shoot of the plants. The Cr concentrations found in the shoots of tested plants were relatively low in comparison with the plants classified as Cr-hyperaccumulators. The Cr accumulation in the shoot of tested plants was recorded in the order of *Alyssum maritima* L. > *Aptenia cordofolia* L. > *Brassica oleracea* L. > *Brassica juncea* L., for the root the order was *Brassica juncea* L. > *Brassica oleracea* L. > *Alyssum maritima* L. > *Aptenia cordofolia* L.

Keywords: phytoremediation, Cr-accumulation, bioconcentration factor

Introduction

Recently, contamination of the environment by Chromium (Cr), especially hexavalent chromium (Cr (VI)), has become a major area of concern worldwide [1] because of its extremely high toxicity, mutagenicity, and carcinogenicity [2]. Cr and its compounds are being used in a wide variety of manufacturing processes, including leather processing and finishing, the production of refractory steel, drilling muds, electroplating cleaning agents, catalytic manufacture, and the production of chromic acid and specialty chemicals. These anthropogenic activities have led to the widespread contamination that Cr shows in the environment and have increased its bioavailability and biomobility [3]. Cr (VI) contamination in soils mainly results from the discharge of chromium-containing waste and wastewater from ore refining, production of steel and alloys, metal plating, tannery, wood preservation, and pigmentation [4].

Cr compounds are highly toxic to plants and are detrimental to their growth and development [3], but some plants have demonstrated the ability to uptake, translocate, and tolerate high concentrations of Cr that are toxic to other plants.

A number of conventional remediation technologies have been used to clean up Cr-contaminated soils, sediments, and waters [5]. However, these methods suffer from high costs associated with energy and chemical consumption [6]. Phytoremediation, a technology based on the use of plants to assimilate, accumulate, and/or degrade contaminants from contaminated soil, water, sediments, and air, has gained interest during the last decades [7-9]. The use of metal-accumulating plants to clean soil and water contaminated with toxic metals is the most rapidly developing component of this environmentally friendly and cost-effective technology [10, 11].

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The uptake and translocation of Cr by plants has been studied extensively either in hydroponics or in soils contaminated with Cr. Little attention has been given to the effects of elevated Cr concentration in irrigation waters on plant uptake and translocation of Cr [1, 12, 13]. A limited number of studies were found about metal-accumulating ornamental plants that can be used for remediation of contaminated soils and waters as well. It will have great and practical significance to screen out remediation plants from ornamental resources [14].

The objective of this study was to evaluate the uptake and translocation capacity of Cr by selected ornamental plants that were exposed to Cr (VI) through irrigation water. Selected plant species are widely used for ornamental purposes in Adana.

Experimental Procedures

The pot-culture experiment was carried out in the lab of the Department of Environmental Engineering, University of Cukurova in Adana. Four ornamental plants that were adapted to regional climatic conditions and frequently used in restoration work were selected for the study. The seedlings of *Aptenia cordofolia* L., *Brassica juncea* L., *Brassica oleracea* L., and *Alyssum maritima* L. used in the experiment were obtained from a local greenhouse. The root of seedlings was cautiously washed with distilled water after rinsing with tap water. Then the seedlings with similar biomass were transplanted into plastic pots (d: 15 cm, h: 17 cm) containing natural peat soil. Table 1 presents the characteristics of the peat soil used.

Table 1. Characteristics of growth medium (peat soil).

Parameter	Value
pH	7.3
Organic content (%)	75.8
Salinity (mg/kg)	1,940
NO_3-N (mg/kg)	110
Na (mg/kg)	19
K (mg/kg)	65
Fe (mg/kg)	150
Cu (mg/kg)	45
Mn (mg/kg)	50
Zn (mg/kg)	85

Peat soil has a high content of organic matter. The organic matter content of soil plays a significant role in the mobility of Cr in soil because of the tendency of soil organic matter to reduce the mobile Cr (VI) to the relatively immobile Cr (III) [15]. Organic matter in soil increases the supply of organic carbon and protons, and stimulates of microorganisms that are considered to be the major factors enhancing the reduction of Cr (VI) to Cr (III) [16]. However, it is important to point out that there is a dynamic equilibrium among these Cr fractions in soils and the depletion of the soluble and exchangeable fractions through plant uptake and leaching losses leads to the release of the Cr from other fractions. The immobilized Cr may become bioavailable with time through the natural weathering process or through advanced decomposition of soil organic matter [16]. Besides, Cr reduction and oxidation reactions are controlled by many factors, including aeration, soil moisture content, wetting and drying, iron and manganese status, microbial activity, pH, and availability of electron donors and acceptors [15]. The present study was not intent to investigate the effects of organic matter content of soil on the mobility of Cr in soil.

Plants were irrigated with tap water and allowed to grow for 6 weeks. After that, for the duration of 10 weeks, plants were exposed to Cr (VI) through irrigation water. Plants were irrigated every other day with water (100 ml-pot) containing different concentrations of Cr (VI), whose concentrations in irrigation water were 0, 0.05, 0.25, 0.5, and 1 $mmol \cdot l^{-1}$ (0, 2.6, 13, 26, 52 $mg \cdot l^{-1}$). The growth and development responses of plants exposed to Cr (VI) through irrigation water were evaluated as plant height and measured weekly.

At the end of the experiment, plants were harvested and divided into roots, stems, and leaves. The plant parts were thoroughly rinsed in abundant distilled water and oven dried at 60ºC until reaching constant weight. The plant and soil samples were milled and digested in an acid solution. The concentrations of Cr were determined using ICP spectrophotometer (Perkin-Elmer SCIEX- ELAN-5000A).

Cr concentration in the plant parts was given as mg of Cr per kilogram of dry biomass. In order to assess the Cr (VI) phytoextraction efficiency of tested ornamentals, the bioconcentration factor (BF), defined as the ratio of metal concentration in plant shoots to metal concentration in the growth media, was calculated [17]. To evaluate the capacity of the plants to transfer Cr from roots to shoots, the translocation factor (TF) and translocation efficiency (TE %) were also computed. These indicators are described as the ratio of the metal concentration in the shoots to the metal concentration in the roots [18], and the ratio of the amount of metal accumulated in the shoots to the amount of metal accumulated in the plant [19], respectively.

The data in table and figures were given as mean ± SE of the three replicates. One-way ANOVA with the least significant difference (LSD) test was used to determine differences among Cr (VI) treatments ($p<0.05$). Statistical analysis of data was performed using SPSS 16.0.

Results and Discussion

Growth Response of Plants to Cr (VI)

For the period of the experiment, the growth responses of *Aptenia cordofolia* L., *Brassica juncea* L., *Brassica oleracea* L., and *Alyssum maritima* L. exposed to Cr (VI) through irrigation water in different concentration are shown in Fig. 1. The presence of Cr in the external environment leads to changes in the growth and development pattern of the plant [3]. Adverse effects of Cr on plant height and shoot growth have been reported [20-24]. The result obtained from different Cr (VI) treatment concentrations on growth of tested ornamentals showed inhibitory effect. All the ornamentals used in the experiment were affected to varying degrees by Cr (VI) treatment in response to growth. Only the treatment containing 1 mmol Cr (VI) concluded a complete deterioration of the *Alyssum maritima* L. seedlings.

In general, the growth of plants based on the height recorded weekly increased with time at the first couple of weeks of the experiment for the treatments containing low Cr (VI) concentration. Then, the inhibitory effects of Cr (VI) on plant growth were observed with those in the corresponding controls. In *Aptenia cordofolia* L., the heights of the plant decreased significantly ($p<0.05$) with the increase of Cr (VI) concentration in the irrigation water compared with the controls. However, the height of the plants did not differ significantly ($p<0.05$) between the 0.05 and 0.25 mmol, as well as 0.5 and 1 mmol treatments. The presence of Cr (VI) in the irrigation water significantly inhibited ($p<0.05$) the growth of *Brassica juncea* L. compared with the controls, except the 0.05 mmol treatment. Within the range of 0.25-1 mmol Cr (VI) concentration, the growth of the plants was not significantly affected ($p<0.05$) compared with each other. In both *Brassica oleracea* L. and *Alyssum maritima* L., the presence of Cr (VI) in the irrigation water significantly reduced ($p<0.05$) the plant growth rates compared with the corresponding controls. However, no significant differences ($p< 0.05$) were observed in plant heights between the Cr (VI) treatments, excluding the 0.05 mmol Cr (VI) treatments for *Alyssum maritima* L.

Cr (VI) Uptake and Translocation

Fig. 2 presents the Cr concentrations in the roots and shoots of four ornamentals plants exposed to Cr (VI) through irrigation water in a range of concentrations from 0.05 to 1 $mmol\cdot l^{-1}$ for 10 weeks. The results demonstrated that root and shoot Cr concentrations were affected by the varying Cr (VI) concentrations in irrigation water. The increases in the concentration of the Cr (VI) in the irrigation water significantly increased ($p<0.05$) the concentration of Cr in the roots and shoots of all tested plants.

The highest concentrations of Cr measured in the roots and shoots of *Aptenia cordofolia* L. were 110.10 and 103.38 $mg\cdot kg^{-1}$, respectively. Significant difference ($p<0.05$) was observed between the Cr (VI) treatments in the concentration of Cr in roots and shoots of plants, except the 0.05 mmol treatments and the controls for shoots.

A similar trend was observed between *Brassica juncea* L.and *Brassica oleracea* L. in terms of the Cr concentrations and their variation in roots and shoots of the plants under all treatments. The maximum Cr concentrations reached in roots and shoots were 222.40 and 35.89 $mg\cdot kg^{-1}$ for *Brassica juncea* L. and 207.10 and 62.48 $mg\cdot kg^{-1}$ for *Brassica oleracea* L., respectively. No significant differ-

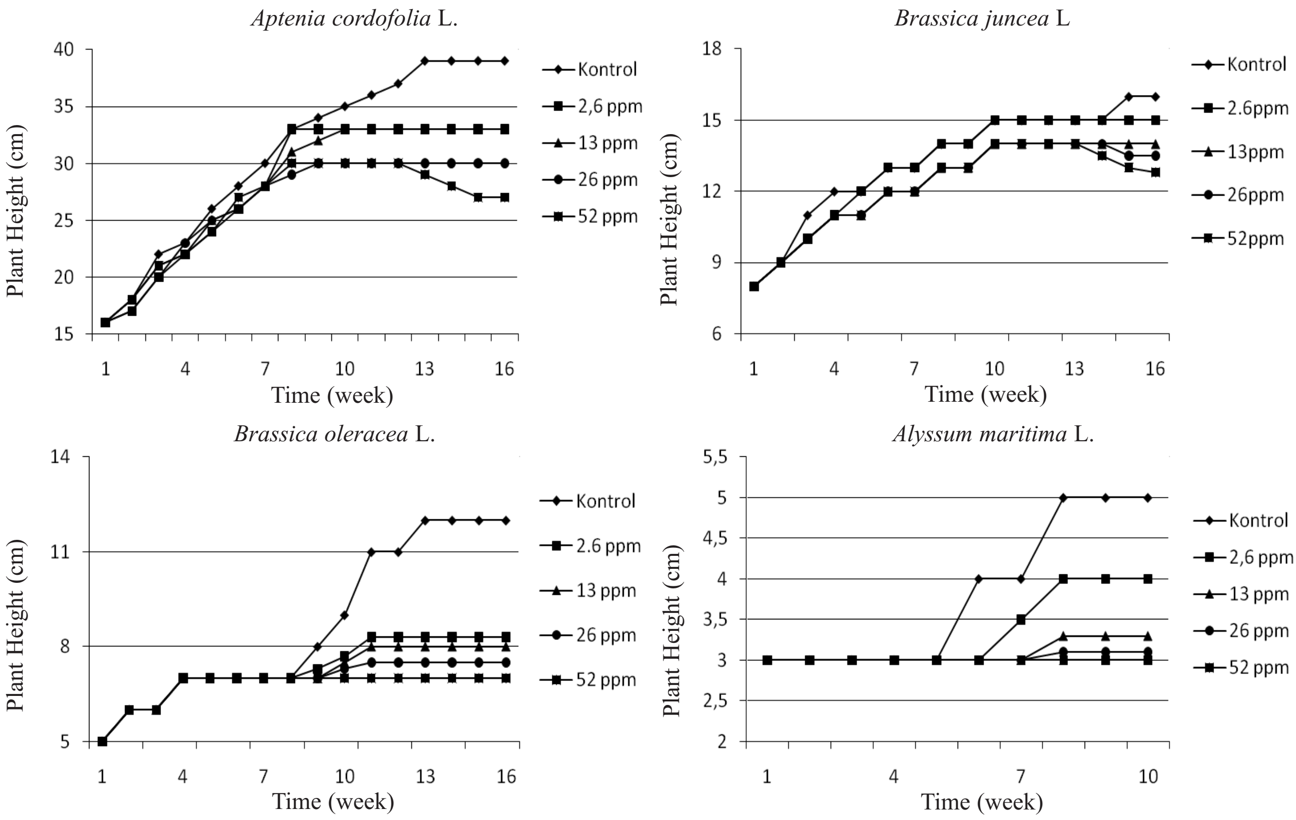

Fig. 1. The growth responses of tested ornamentals exposed to Cr (VI) through irrigation water in different concentrations for sixteen weeks.

ences ($p<0.05$) were observed in the Cr concentrations in roots of the plants between 0.05 and 0.25 mmol Cr (VI) treatments. The increases in the concentration of the Cr (VI) in the irrigation water were not significantly increased by ($p<0.05$) the concentration of Cr in shoots under the 0.05 and 0.25 mmol treatments compared with the controls for *Brassica oleracea* L. For *Alyssum maritima* L., the maximum Cr concentrations measured in roots and shoots were 123.65 and 234.42 mg·kg^{-1}. In terms of the Cr concentrations in roots and shoots, significant differences were found between Cr (VI) treatments. However, *Alyssum maritima* L. plants exposed to 0.25 mmol Cr (VI) demonstrated a significant decrease, as compared with the 0.05 mmol Cr (VI) treatments, in Cr concentrations in roots.

The success of phytoextraction depends on shoot biomass, shoot metal concentration and bioavailable concentration of metal in the growing media. Therefore, translocation factor (TF), translocation efficiency (TE %), and bioconcentration factor (BF), were calculated and presented in Table 2. The results showed that the Cr concentrations in the roots for all tested ornamental plants excluding *Alyssum maritima* L. were higher than in the shoots under all treatments. The translocation factor was affected by Cr (VI) treatment concentrations. The increases in the concentration of Cr (VI) in irrigation water stimulate the translocation of Cr to the shoot of the plants. Among the tested ornamentals, *Alyssum maritima* L. had the highest ability to uptake Cr into their roots and transfer them to the shoots. The maximum value for the TF found was 1.91 for *Alyssum maritima* L. For others, the TF values were found lower than 1, indicating the low mobility of Cr from the roots to the shoots. However, it should be noted that the TF values found for *Aptenia cordofolia* L. was very close to 1 (Table 2).

Among the tested ornamentals, the maximum values for the translocation efficiency (TE %), demonstrating the percentage of accumulated Cr translocated from the roots to the shoots of the plant, were 80.87 and 96.69% for *Aptenia cordofolia* L. and *Alyssum maritima* L., respectively.

The bioconcentration factor (BF), as an indicator of phytoextraction efficiency, for all tested plants and Cr (VI) treatments, were lower than 1, excluding *Alyssum maritima* L. for the 0.05 mmol Cr (VI) treatment. The BF values decreased with increasing Cr (VI) concentration in the irrigation water for *Alyssum maritima* L. and *Brassica juncea* L., but for *Aptenia cordofolia* L. and *Brassica oleracea* L. they showed a u-shape trend.

Conclusions

The results found in this study indicated that increases in the concentration of the Cr (VI) in irrigation water sig-

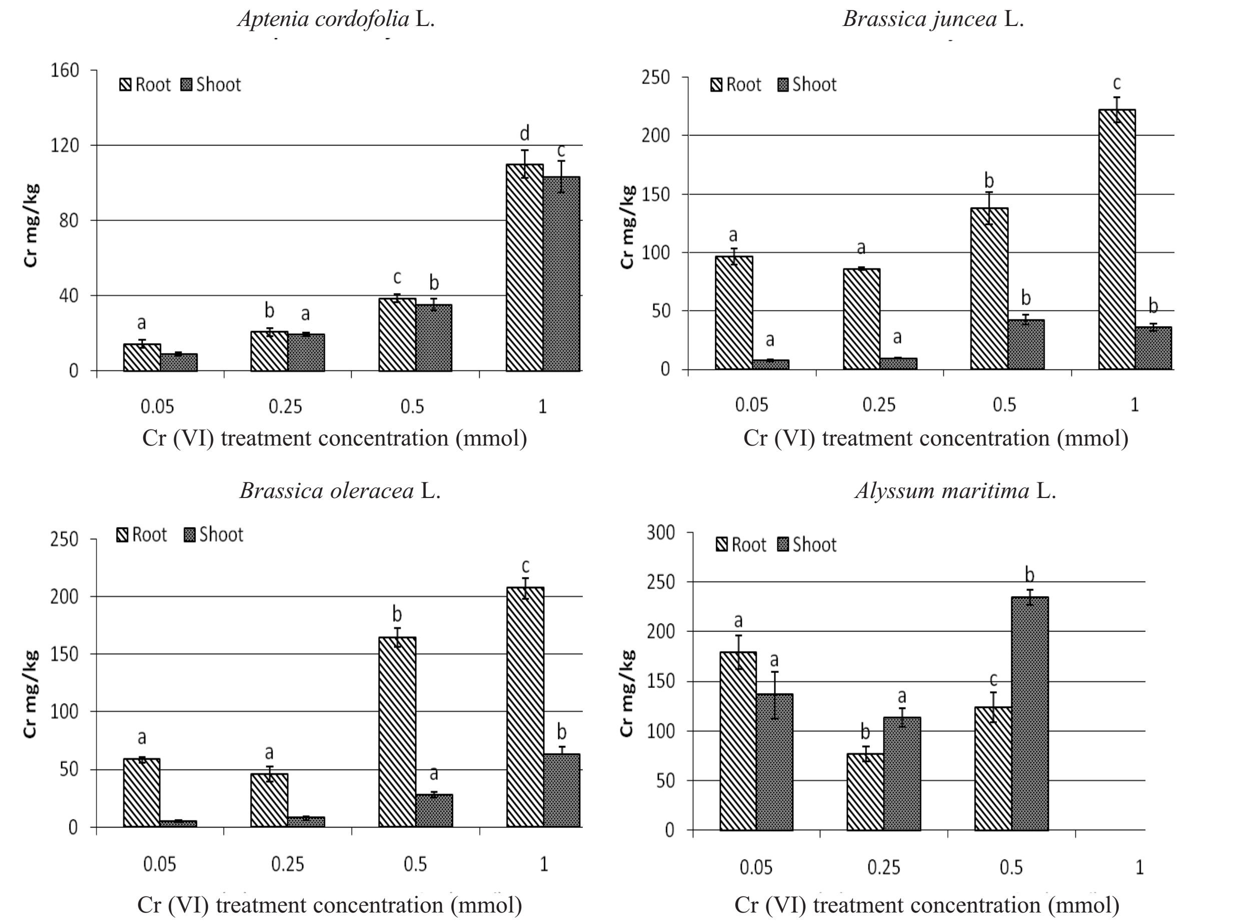

Fig. 2. Cr (VI) treatment concentration effects on the Cr concentrations in roots and shoots of four ornamentals. All values are mean (n=3). Vertical lines represent SE. In each series, different letters following the vertical bars indicate significantly different values (ANOVA and LSD test $p<0.05$).

Table 2. The translocation factor (TF), translocation efficiency (TE %), and bioconcentration factor (BF) for tested ornamentals exposed to Cr (VI) through irrigation water in different concentrations.

	Cr (VI) Treatment Concentration (mmol)	Translocation Factor (TF)	Translocation Efficiency (TE %)	Bioconcentration Factor (BF)
Aptenia cordofolia L.	0.05	0.63 (0.04) a	74.93 (0.50) a	0.24 (0.03) a
	0.25	0.96 (0.16) b	77.83 (1.88) a	0.11 (0.01) b
	0.5	0.93 (0.14) b	78.63 (3.73) a	0.13 (0.01) b
	1.0	0.94 (0.01) b	80.87 (1.25) a	0.23 (0.02) a
Brassica juncea L.	0.05	0.08 (0.01) a	13.18 (2.44) a	0.18 (0.02) a
	0.25	0.11 (0.01) b	19.35 (1.65) b	0.06 (0.01) b
	0.5	0.31 (0.01) c	51.79 (1.38) c	0.13 (0.01) c
	1.0	0.16 (0.02) d	36.18 (1.11) d	0.10 (0.01) c
Brassica oleracea L.	0.05	0.09 (0.01) a	30.81 (5.52) a	0.12 (0.02) a
	0.25	0.16 (0.02) b	51.10 (2.70) b	0.05 (0.01) b
	0.5	0.17 (0.02) b	46.97 (3.61) b	0.11 (0.01) a
	1.0	0.31 (0.05) c	50.57 (3.80) b	0.18 (0.02) c
Alyssum maritima L.	0.05	0.76 (0.01) a	67.69 (0.28) a	2.70 (0.27) a
	0.25	1.53 (0.28) b	92.74 (0.13) b	0.87 (0.08) b
	0.5	1.91 (0.08) b	96.69 (0.51) c	0.88 (0.03) b

All values are mean (n=3) and values in parentheses represent SE. In each series, different letters following SE values within the same column indicate significantly different value (ANOVA and LSD test $p<0.05$).

nificantly increased the concentration of Cr in the roots and shoots and stimulated the translocation of Cr to the shoots of the plants. The Cr concentrations found in the shoots of tested plants were relatively low in comparison with the plants classified as Cr-hyperaccumulators in literature [17, 25]. Therefore, the tested plants could not be classified as Cr-hyperaccumulators. On the other hand, when we considered the TF and BF values found for *Alyssum maritima* L. and *Aptenia cordofolia* L., they could be proper candidates for phytoextraction of Cr-contaminated soils that amended with high levels of organic matter. The results found in this study also show that *Brassica juncea* L. and *Brassica oleracea* L. were able to accumulate significant amounts of Cr in their roots when exposed to Cr (VI) through irrigation water in high concentrations. However, further studies are needed to improve the conclusions drawn, such as the effects of irrigation methods and different soil characteristics on the reduction and bioavailability of Cr (VI) in soil and its uptake and translocation by plants in actual field conditions.

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