



Full Length Article

Growth Parameters and Elemental Status of Cucumber (*Cucumis sativus*) Seedlings in Response to Cadmium Accumulation

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ABSTRACT

The influence of cadmium (Cd^{2+}) on growth index and mineral composition of cucumber (*Cucumis sativus* L.) was investigated. Seedlings were grown in hydroponics media containing a nutrient solution amended with Cd^{2+} at various concentrations (0.00, 100, 150, 200 & 250 $\text{mg L}^{-1} \text{Cd}^{2+}$). Phytotoxicity of metal, quantified as growth inhibition, was observed well before there was any other change in the elemental status. After 10 days of treatment, tissue-dependent decrease of fresh mass, dry mass, lengths of both shoot and root and area of the leaf segments were correlated with concentration especially 200 and 250 $\text{mg L}^{-1} \text{Cd}^{2+}$ in the growth medium. Cucumber was tolerant to 100 $\text{mg L}^{-1} \text{Cd}^{2+}$, with a tolerance index (TI of 95%) but not to 250 mg L^{-1} (TI = 46%). Tissue concentrations of Mg, P, K Mn Cu and Zn decreased significantly in both shoots and roots at higher concentrations of Cd^{2+} . The specific areas and densities of macro and micronutrients in the chloroplast membrane of leaf segments were significantly decreased with 250 $\text{mg L}^{-1} \text{Cd}^{2+}$ treatment. A close relation between the plant organs and the elemental status in shoots and roots of cucumber plants was evident. Results indicated that cucumber plants could increase their hyperaccumulating potential and could be used to supplement human diet.

Key Words: Heavy metals; Cucumber; Elemental status; Tolerance index

INTRODUCTION

Cadmium (Cd^{+2}), a potent member of the toxic heavy metals is a major environmental pollutant released from heavy traffic, smelters and in the vicinity of sewage sludge areas (Sanita di Toppi *et al.*, 2003). In agricultural lands Cd^{2+} tends to accumulate with excessive use of phosphate fertilizers, dispersal of sewage sludge and atmospheric deposition and is readily taken up by the plants. Cd^{+2} has no physiological role in higher plants. It is one of the most toxic metal to vascular plants and considered biologically as a non essential heavy metal, although at low concentrations it was found to have stimulatory effect on growth of *Allium sativum* but at high concentrations it is extremely toxic (Liu *et al.*, 2003). Cadmium is recognized as an extremely significant pollutant due high toxicity and great solubility in water. It can accumulate in plants to level that are toxic to humans and animals, but which may not phytotoxic (Prince *et al.*, 2002).

Exposure of plants even to minute concentrations may lead to the alteration of many cellular processes and structures (Hall, 2002). One of the characteristic effects of metal poisoning, observable at an early stage is a reduction in cell proliferation and growth (Das *et al.*, 1998; Carrier *et al.*, 2003). The responses of plants to heavy metal stress,

depending on the growth stages at which they were exposed to a stress factor, have been documented in different plant species: *Brassica juncea* growth was inhibited by 0.06 $\text{mg L}^{-1} \text{Cd}^{2+}$; 0.6 $\text{mg L}^{-1} \text{Cd}^{2+}$ inhibited root and shoot growth in *Phaseolus vulgaris* and 6 mg L^{-1} was completely inhibited its germination (Haag-Kerwer *et al.*, 1999; Maksymiec *et al.*, 1994; Liu *et al.*, 2003). Besides reduction in root and shoot growth Cd^{2+} toxicity is sometimes associated with chlorosis and root damage (Maksymiec *et al.*, 1995; Drajzkiewicz *et al.*, 2003). At supra-optimal levels, Cd^{2+} is strongly phytotoxic and causes growth inhibition and even plant death, although the mechanisms involved in its toxicity are still elusive (Das *et al.*, 1998). Other important but less well understood factors that may influence plant nutrition, include changes in root morphology of primary root, poor development of lateral roots and shoot root ratio in response to Cd^{+2} treatment (Moral *et al.*, 1994). Cd^{+2} toxicity is also correlated with disturbances in the uptake and distribution of macro and micronutrients in plants (Gussarson *et al.*, 1996). In the present study, the dose-response effect of a 10 days Cd^{2+} exposure on the growth parameters and elemental status in different plant organs of 15-days-old cucumber plantlets were examined. Cucumber was chosen because it is the most important economic crops in Saudi Arabia and other countries of the world.

MATERIALS AND METHODS

Plant growth and Cd²⁺ treatment. Seeds of different Cucumber species were screened for germination response to Cd²⁺ (data not shown). *Cucumis sativus* L. was the most tolerant species. Seeds were surface sterilized by immersing in 0.1 % HgCl₂ for two min washed with five changes of sterile distilled water and soaked in continuously aerated distilled water for 24 h in darkness. Twelve seeds were sown in each pot (15 cm diameter x 20 cm height), filled with moistened vermiculite. All pots were placed in a growth chamber under 70-80% RH with 16/8 h day/night cycle and controlled temperature of 28/26°C. Light intensity was 1500 μmol m⁻² s⁻¹ at the top of plants supplied by a mixture of fluorescent and incandescent lamps. Each pot was irrigated with 250 mL distilled water at first, then occasionally with a certain amount of water in order to keep the soil water content constant for seven days. Thereafter all plants were watered on alternate days with half strength Hoagland solution.

Experimental design. Fifteen-days-old *Cucumis sativus* seedlings of a uniform size were carefully taken from the pots to avoid any injury to the roots and placed in sponge support collars. Collars were then fitted into holes in the tops of glass bottles containing 500 mL continuous aerated Hoagland's solution supplemented with various concentrations of Cd²⁺. Individual Cd²⁺ treatments were a control, with Hoagland nutrient solution (0 mg L⁻¹ Cd²⁺) and four Cd²⁺ concentrations 100, 150, 200 and 250 mg L⁻¹ using CdCl₂. These concentrations were chosen on the basis of preliminary experiments, the lowest one being below the toxicity threshold and the highest one above. The pH of the nutrient solution was buffered to pH 6.0 and kept constant during the experiment. All solutions were changed every 3 days during 10 days of experiment to maintain the metal concentrations. All bottles were placed in a growth chamber under the same conditions. After 10 days of Cd²⁺ treatment, plants were harvested and washed twice with distilled H₂O and then washed with deionised water. Shoots were separated from roots and blotted dry. Leaf area was determined using a moving belt electronic planimeter (Delta. T Devices, Burwell, UK). The samples were oven-dried, at 65°C for 48 h, to obtain the constant dry weight and then ground to a fine powder.

Growth measurements. Roots from control and Cd²⁺ treated plants were sampled (8–10 plants) and maximum root or seedling length was measured. Growth was expressed relative to control plants and data given were the average of at least ten replicates, relative growth inhibition was calculated according to the following expression, in which HM is the heavy metal treatment and C is the control:

Relative growth inhibition (%) = $[(\text{root/seedling length}_{\text{C}} - \text{root/seedling length}_{\text{HM}}) / \text{root/seedling length}_{\text{C}}] \times 100$. The tolerance index (TI), at different individual concentrations of Cd²⁺ treatments was calculated by dividing the root length at different metal concentrations by that obtained in the control

solution, as suggested by Wilkin (1978). The following equation was used:

$TI (\%) = 100 \times (\text{root length in metal treatment}) / \text{root length in the control}$.

Total metal accumulation rate, expressed as μ g⁻¹DW day⁻¹, was calculated as

Accumulation rate = $([\text{metal}]_{\text{shoot}} \times DW_{\text{shoot}} + [\text{metal}]_{\text{root}} \times DW_{\text{root}}) / 10 \times (DW_{\text{shoot}} + DW_{\text{root}})$.

Macronutrient and micronutrient determination. Harvested Plants were partitioned into leaves and roots and ashed in a muffle furnace at 500°C for 6 h. The ash was digested in a mixture of eight mL¹ M HNO₃ and four mL of 2 M HCl in a sand bath at 110°C, until the volume was reduced to approximately three mL (Salt *et al.*, 1995). The solution was then adjusted to pH =3 with NaOH in a final volume of 50 mL. The concentration of Cd²⁺ and other elements were determined by atomic absorption spectrophotometer (Perkin Elmer 2380 AAS) using an air-acetylene flame.

Analytical electron microscopy (X-ray microanalysis). The concentrations of Na, Mg, P, K, Ca, Mn, Fe, Zn and Cu in chloroplastic membrane, were determined by X-ray microanalysis according to Fritz (1989) and described by Godbold and Jentschke (1998). Leaf samples were rapidly frozen in a liquid propane isopentane (3:1, v/v) mixture cooled in liquid nitrogen. Samples were freeze-dried, infiltrated with ether and embedded in styrol-butylmethacrylate. Sections (1 μm thick) were cut. The concentrations of elements of chloroplast membrane were determined using a Philips EM 420 electron microscope equipped with an energy-dispersive X-ray detection system (SILI). The accelerating voltage was 120 kV, the diameter of the analyzed area was 250 nm and the standard detection time 30 live seconds. Spectra were recorded with a slow scan camera and processed. Concentrations of the elements were calculated from the peak intensities (Fritz & Jentschke, 1994). On each section 10 randomly selected spots of chloroplast membrane were analyzed and arithmetically averaged. The precision of the measurements was increased by addition of the spectra (300 live seconds total detection time per sample).

Statistical analyses. Data shown are means of five replicates for each treatment. Analysis of variance between treatments means was carried out with the SPSS software using an ANOVA General Factorial Test. Duncan's post hoc test was used.

RESULTS

Growth response and Cd²⁺ accumulation. The determined parameters, growth of shoot and root, shoot/root ratio and leaf area were used to determine the response of cucumber plant to different levels of Cd²⁺. The toxic effect of Cd²⁺ was apparent at the high concentration (250 mg L⁻¹) and obviously caused a significant decrease in all growth parameters and therefore seemed to be detrimental to the

cucumber plant under stress (Fig. 1a & b). On the other hand, plants treated with low concentration (100 mg L⁻¹) showed an insignificant decrease ($P > 0.05$) in fresh and dry weights and leaf area relative to the control. Suppressive effect of Cd²⁺ was more pronounced at 200 and 250 mg L⁻¹, being the most detrimental, since the fresh weights of shoot and root at 200 mg L⁻¹ were less than 44 and 56%, respectively relative to control. The corresponding values for 250 mg L⁻¹ were 56 and 68%, respectively (Fig. 1a & b). Also increasing concentrations of Cd²⁺ produced a significant growth inhibition measured as dry weight. At 250 pp Cd²⁺ concentration reduction in dry weigh of root reached to 77% in comparison with untreated seedlings, the corresponding value for shoot was 48% (Fig. 1b).

It was interesting to note that the greatest adverse effect of Cd²⁺ was greater on root than shoot. As a consequence, the shoot/ root ratio relative to the control was increased by about 29 and 38% at 200 and 250 mg L⁻¹, respectively for fresh weight. The corresponding values for dry weight were 91 and 127%, respectively (Fig. 1b). At that time roots contained Cd²⁺ about 1.297 and 1.993 mg g⁻¹ DW, respectively compared to 0.198 and 0.295 mg g⁻¹ DW in shoots (Fig. 3b). The relative growth inhibition was significantly increased with increasing Cd²⁺ concentration, increased 2.6 fold increase at 250 mg L⁻¹ Cd²⁺ concentration (Fig. 2a).

A change in color of roots from white to brown was observed especially with higher concentrations of Cd²⁺ (data not shown). Decrease in the fresh and dry weights of shoots and roots were closely related to the decrease recorded for the leaf area, which provoked a depression in the leaf area by 26 and 40%, respectively in the plants grown in presence of 200 and 250 mg L⁻¹ Cd²⁺ concentrations (Fig. 1b). Analysis of variance showed a significant effect of Cd²⁺ on shoot height and root length. Remarkably, exposure of plants to Cd²⁺ at 200 mg L⁻¹ in 10 d resulted in a significant reduction in the length of roots and height of the shoot by about 41 and 30% respectively. The corresponding value for 250 mg L⁻¹ were 54 and 42%, respectively (Fig. 1d).

The tolerance index (TI), based on root length for different concentrations of Cd²⁺ treatments, indicated that the higher concentrations of Cd²⁺ were more toxic to cucumber than the lower ones. At 100 mg L⁻¹ Cd²⁺ the TI was 85%, whereas at 250 mg L⁻¹ the TI was less than 46%. In addition, the TI of cucumber was about 60% at 200 mg L⁻¹ Cd²⁺ (Fig. 2c).

The total amount of Cd²⁺ taken up and translocated was lower in shoot than in root. The bioconcentration factor (BCF) differed according to Cd²⁺ treatment (Fig. 3a). The highest value of BCF was observed in the root. Comparing the lowest and highest Cd²⁺ treatments BCF ranged from 392 to 1484 in the root and 43 to 152 in shoots. In addition the total accumulation rate of Cd²⁺ was very low at lower concentration compared with those of the higher treatments. The concentration of Cd²⁺ content in different plant organs was significantly correlated with Cd²⁺ concentrations (Fig.

Fig. 1. Mean increase in fresh and dry weight of shoot and root (A & B), shoot:root ratio and shoot and root length for cucumber after 10 days treatment with various Cd²⁺ concentrations. Values are mean ± SD (n=3). Significant differences (P ≤ 0.05) between treatments according to the LSD test are shown by an asterisk

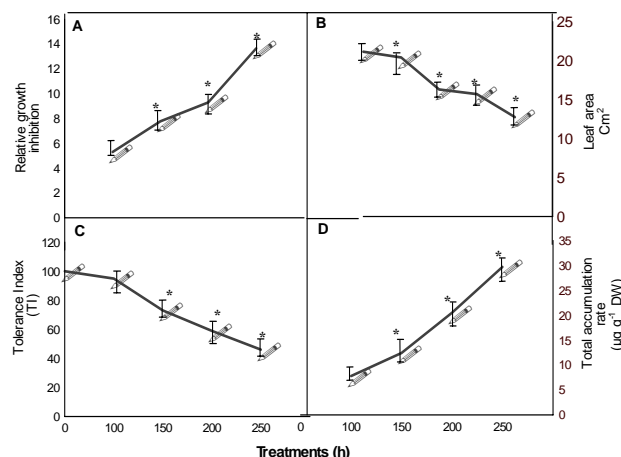
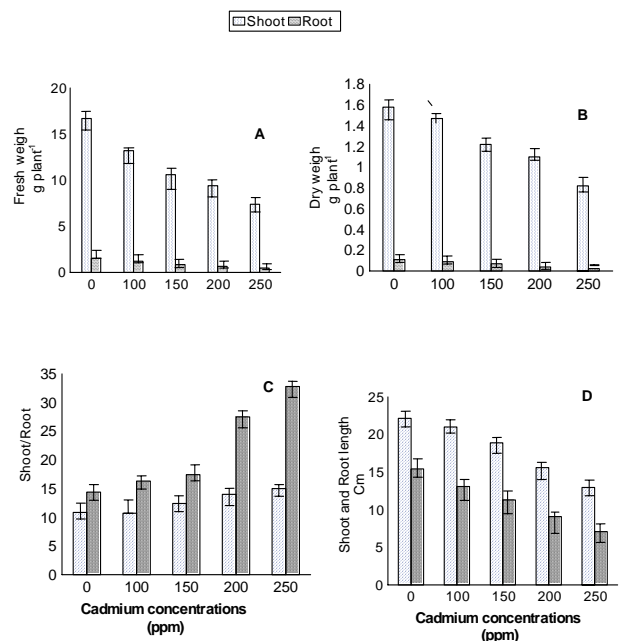


Fig. 2. Relative growth inhibition (A) leaf area (B), Tolerance index (c) and Total accumulation rate (D) of control and CD²⁺ stressed plants of cucumber subjected to various concentration of CD²⁺ for 10 d. Each value represents the mean ± SE of five replicates. Significant differences (P ≤ 0.05) between treatments according to the LSD test are shown by an asterisk



3b). The concentration of Cd²⁺ at 100 and 250 mg L⁻¹ treatments ranged from 0.392 to 1.993 mg g⁻¹ DW in the root and from 0.043 to 0.295 mg g⁻¹ DW in the shoot, respectively ($p < 0.05$). However, with 250 mg L⁻¹ Cd²⁺

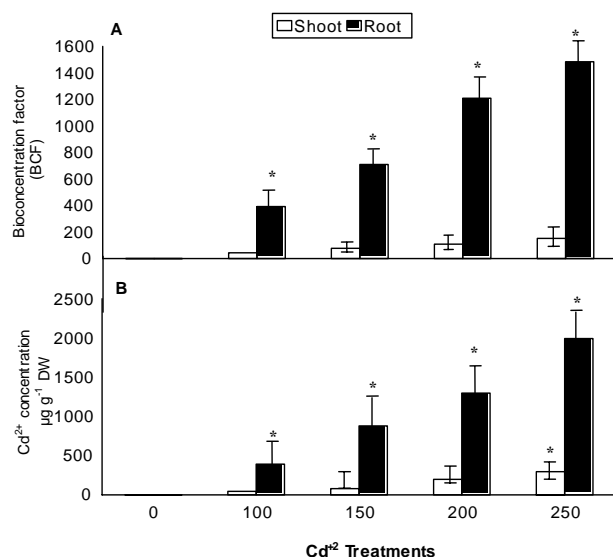
Table I. Effect of Cd²⁺ treatment on macro and micronutrient contents of shoots and roots from *Cucumis sativus* (cucumber) plants. Values are mean of four replicates. Values followed by the same letter are not significantly different (p≤0.05) as determined by Duncan's multiple range test

Treatment [ppm]		P (mg g ⁻¹ DM)	K (mg g ⁻¹ DM)	Ca (mg g ⁻¹ DM)	Mg (mg g ⁻¹ DM)	Cu (μg g ⁻¹ DM)	Zn (μg g ⁻¹ DM)	Fe (μg g ⁻¹ DM)	Mn (μg g ⁻¹ DM)
0	shoot	3.64 ± 0.41 ^a	54.70 ± 0.06 ^a	225.8 ± 5.72 ^a	49.7±0.09 ^a	112 ± 3.26 ^a	136±3.45 ^a	174±7.21 ^a	57±0.08 ^a
	root	2.77 ± 0.25 ^a	42.00 ± 0.07 ^a	139.8 ± 3.87 ^a	57.8±0.05 ^a	143 ± 4.01 ^a	163±4.21 ^a	487±23.34 ^a	67±0.09 ^a
100	shoot	2.97 ± 0.39 ^b	48.00 ± 0.08 ^a	94.2 ± 2.98 ^b	46.7±0.08 ^a	124 ± 4.58 ^b	120±2.87 ^b	205±3.12 ^b	50±0.06 ^a
	root	2.73 ± 0.26 ^a	41.30± 0.069 ^a	143.1 ± 4.41 ^a	52.6±0.06 ^a	183 ± 6.25 ^b	159±3.97 ^a	665±31.2 ^a	64±0.08 ^a
150	shoot	2.71 ± 0.26 ^b	41.00± 0.07 ^b	158.1 ± 4.23 ^c	43.2±0.07 ^b	138 ± 4.13 ^{bc}	102±2.40 ^{bc}	198±2.97 ^b	44±0.05 ^{ab}
	root	2.68 ± 0.24 ^a	40.90± 0.06 ^{ab}	136.8 ± 3.96 ^{ab}	48.6±0.08 ^b	165 ± 5.25 ^{bc}	130±3.45 ^c	555±25.8 ^a	62±0.07 ^a
200	shoot	2.27 ± 0.22 ^c	33.40 ± 0.04 ^c	136.2 ± 3.67 ^c	34.8±0.06 ^c	174 ± 6.23 ^c	78±1.95 ^d	180±2.45 ^c	38±0.05 ^b
	root	2.30 ± 0.21 ^c	33.00± 0.04 ^c	140.9±4.23 ^{ab}	35.3±0.06 ^c	138 ± 4.21 ^c	110±2.11 ^d	331±20.1 ^b	60±0.07 ^{ab}
250	shoot	2.04 ± 0.20 ^c	28.40± 0.03 ^c	106.3 ± 2.33 ^d	26.8±0.02 ^d	167 ± 5.52 ^{cd}	59±1.02 ^d	145±1.98 ^d	29±0.04 ^c
	root	1.99 ± 0.17 ^c	19.70± 0.02 ^c	138.7± 3.21 ^{ab}	26.0±0.02 ^d	117 ± 4.65 ^{cd}	93±1.96 ^d	287±17.9 ^{bc}	43±0.06 ^c

treatment, Cd²⁺ content in the roots was about seven times higher than in the shoot (Fig. 3b).

Effect of different concentrations of Cd²⁺ on the elemental status. Cadmium was mainly accumulated in roots (Fig. 3b) and the nutrient composition of some elements in roots and shoots were modified by the Cd²⁺ treatment (Table I). The content of Zn in leaves was decreased very significantly as a result of Cd²⁺ treatment. The content of Fe did not change significantly in roots while in leaves except a significant decrease was detected only with 250 mg L⁻¹ Cd²⁺. The content of Mn in leaves decreased highly, but in roots a significant decrease was only detected with 250 mg L⁻¹ Cd²⁺. In its turn, Cu content showed similar changes in both roots and leaves. The contents of macronutrients were also altered by Cd in both

Fig. 3. Changes in bioconcentration factor (BCF) (A) and concentration of Cd²⁺ of cucumber seedling (B) subjected to different concentration of Cd²⁺ for 10 d. The control for these measurements was non-stressed plants. Each value represents the mean ± SE of five replicates. Significant differences (P≤0.05) between treatments according to LSD test are shown by an asterisk



leaves and roots (Table I). The content of Ca was significantly reduced in leaves but did not show significant changes in roots, while the content of Mg was significantly reduced in roots and leaves. The contents of P and K showed a significant reduction in leaves due to Cd²⁺ treatment, while in roots decreases in both were only significant at 200 and 250 mg L⁻¹ Cd²⁺ (Table I).

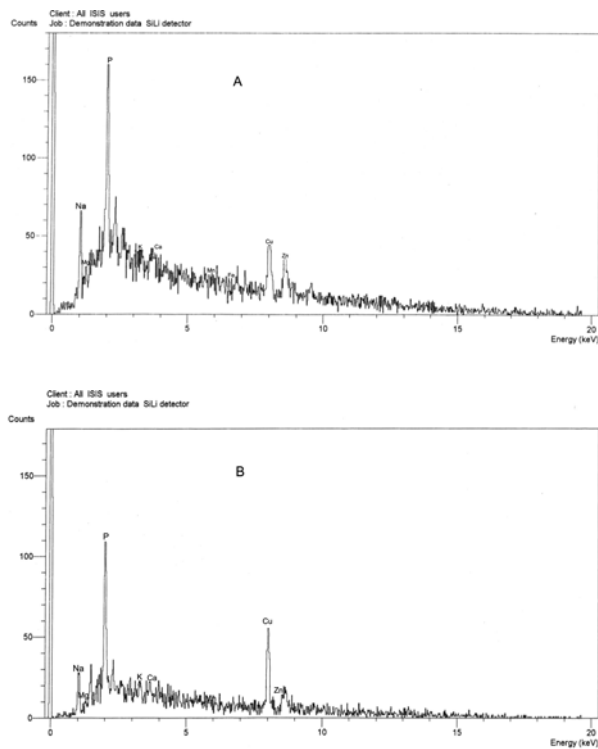
The concentrations of Na, Mg, P, K, Ca, Mn, Fe and Zn were bounded to the chloroplastic membrane, as determined by X-ray microanalysis (Fig. 4). In the presence of Cd²⁺, the decrease of intensities of the peaks belonging to these metals was significant especially with highest Cd concentration (250 mg L⁻¹). The electron dense particles from the plastids of the 250 mg L⁻¹ Cd²⁺ treated sample contained Fe, Mn and Ca in trace amount compared with control. High amounts of Cu were measured in addition to P (Fig. 4).

DISCUSSION

Growing cucumber seedlings for 10 d on nutrient solution supplied with Cd²⁺ resulted in a marked inhibition of root but a slight decrease in shoots growth. Based on root length, cucumber was tolerant to 100 mg L⁻¹ Cd²⁺, with a tolerance index (TI) 95% but not to 250 mg L⁻¹ (TI = 46%). This suggested that cucumber could tolerate a moderate level of Cd²⁺ (≤ 150 mg L⁻¹) although it was more sensitive to the higher concentrations of Cd²⁺. In particular, 250 mg L⁻¹ appeared to be the most phytotoxic. Also, results from the present study showed that cucumber was tolerant to 100 mg L⁻¹ Cd²⁺, with a total accumulation of 8.3 μg g⁻¹ DW day⁻¹, whilst Cd²⁺ concentrations above 200 mg L⁻¹ increased the total accumulation rate to greater than 29 μg g⁻¹ DW day⁻¹. This was in agreement with other studies using various plant species (Sharma *et al.*, 2004). Moreover, a depressive effect of metal on roots was greater than shoots. This showed sensitivity in the organs of absorption and those of photosynthesis (Pinto *et al.*, 2004).

Generally subjecting cucumber to various Cd²⁺ concentrations simultaneously led to an increase of shoot/root ratios in comparison with control plants (Table II). This could be explained either by a greater decrease in root

Fig. 4. The X-ray microanalysis spectra of electron dense precipitates in leaves plastids of *Cucumis sativus* (control–A; 250 mg L⁻¹ Cd²⁺–B) after exposition to Cd²⁺ over 10 days. The peaks belonging to individual elements in cucumber chloroplast membrane are denoted by symbol



growth than shoots (Fig. 1). The change in color of roots was probably due to an increase in the production of phenolic compounds (Liu *et al.*, 2003). In similar studies, *P. australis* showed a 50% depression in root elongation when grown at a supply of Cd²⁺ ranging from 2.85 to 3.20 mm (Ye, 1995). Otherwise, in the present study, 250 mg L⁻¹ Cd²⁺ decreased root length of cucumber by 42% compared to control plants (Fig. 1). According to Sharma *et al.* (1999), the effects of Cd²⁺ on root growth of *S. vulgaris* were response-additive at high metal treatments. Cucumber can be considered as tolerant to relatively excessive concentrations of Cd²⁺, as shown by TI values and also because the P and K composition was not significantly affected. Cu²⁺ concentration tended to decrease in the root and increased significantly in shoot, suggesting an alteration of copper translocation to the shoot due to Cd treatment. Sharma *et al.* (1999) also found an increasing concentrations of Cu²⁺ in shoot of *S. vulgaris*, when the Cd²⁺ concentration in the nutrient solution was increased up to 0.5 mm. Interactions between plant Cd²⁺ uptake and other micronutrients (Cu, Mn, Fe) were noted in solution culture (Table I). In the present study, no detectable accumulation of Cd²⁺ was obtained in the shoot of cucumber, for the treatment of 100 mg L⁻¹ Cd²⁺, whilst the concentration in

roots increased compared with the other treatments. This may be explained by the interaction of excess Cd²⁺ with the uptake of other nutrients present in the media (McLaughlin & Henderson, 1999). This hypothesis is consistent with the results obtained by Cataldo *et al.* (1983). Nevertheless, pronounced interactions between nutrients and Cd²⁺ with respect to Cd²⁺ uptake and translocation have been demonstrated in many plant species (McLaughlin & Henderson, 1999). With respect to metal bioaccumulation, cucumber accumulated higher amounts of metal in root than shoot. This was in agreement with other studies using various wetland plant species (Zhu *et al.*, 1999; Stoltz & Greger, 2002).

There was a significant increase ($p \leq 0.05$) in Cd²⁺ concentrations in both root and shoot especially at higher concentrations of Cd²⁺ (Fig. 3b). A greater accumulation of metals in roots relative to shoots is generally reported in semi-resistant plants including sorghum (Pettersson, 1976) in sensitive plants such as bean (Obata & Umabayashi, 1997) and in resistant plants such as Cucumber (Pettersson *et al.*, 1976). In agreement with other work, the reduced transport of Cd²⁺ from root to shoot may be due to metal immobilization in cell walls (Gussarson *et al.*, 1996), or a result of Cd²⁺ binding with phytochelatins in the root (Salt *et al.*, 1995).

To evaluate the phytoextraction ability of any plant species, whole plant biomass, the metal concentration in the growth media and the metal concentration in plant tissue must be considered. A good metal accumulator has: (i) a total tissue concentration of the metal higher than 0.5% of total DW and (ii) a BCF above 1000 (Zayed *et al.*, 1998). Based on these criteria for a low Cd treatment (200 mg L⁻¹), cucumber can be considered as a good accumulator with respect to roots with a BCF of 1209 (Fig. 3b) and Cd²⁺ concentration was about 3.2% of root DW. According to our results, it appeared that the Cd²⁺ treatments have a strong effect on shoot and root length of cucumber. Based on root elongation, we conclude that exposure to 200 mg L⁻¹ Cd²⁺ significantly decreased growth of cucumber plants. Therefore, cucumber can be considered as a Cd-tolerant plant up to 200 mg L⁻¹ Cd²⁺ in the nutrient solution.

A differential tolerance was also observed in the ability of cucumber to maintain tissue nutrient concentrations. Cd²⁺ had no effect on macronutrient (P & K) concentrations, in root except with highest concentration of Cd²⁺ (250 mg L⁻¹). However, the treatments of cucumber seedlings with 250 mg L⁻¹ Cd²⁺ significantly decreased Fe, Mn, K and Zn in the root tissue (Fig. 4). In other plant species very high Cd²⁺ concentrations (1 mM) induced an important decline in tissue nutrient levels of *Triticum aestivum* especially those of Mg, Ca and K (Ouzounidou *et al.*, 1997). It is possible that the composition of membranes of *Cucumis sativus* varies seasonally. The metal binding could be influenced by this as well as by the pH of the medium. The root bioconcentration factor (BCF = 1209) of cucumber was just higher than the threshold value of 1000

for a 'good' accumulator, as defined by Zayed *et al.* (1998), which makes this species potentially interesting for treatment of wastewater.

Several studies demonstrated accumulation of heavy metals in higher plants often as phytochelatin complexes (Cobbett, 2003). According to our results, it appears that the Cd²⁺ treatments had a strong effect on root and shoot growth of cucumber. It can be concluded that higher concentration of Cd²⁺ significantly decreased growth of cucumber seedlings. Therefore, cucumber can be considered as a Cd-tolerant plant at up to 150 mg L⁻¹ Cd²⁺ in the nutrient solution.

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