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Differences of cadmium absorption and accumulation in selected vegetable crops

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Abstract: A pot experiment and a sandy culture experiment grown with three vegetable crops of Chinese cabbage (*B. chinensis* L., cv. Zao-Shu 5), winter greens (*B. var. rosularis* Tsen et Lee, cv. Shang-Hai-Qing) and celery (*A. graveolens* L. var. *dulce* DC., cv. Qing-Qin) were conducted, respectively. The initial soil and four incubated soils with different extractable Cd (0.15, 0.89, 1.38, 1.84 and 2.30 mg Cd/kg soil) were used for the pot experiment. Five treatments were designed (0, 0.0625, 0.125, 0.250 and 0.500 mg Cd/L) in nutrient solution in the sandy culture experiment. Each treatment in pot and sandy culture experiments was trireplicated. The objectives of the study were to examine Cd accumulation in edible parts of selected vegetable crops, its correlation with Cd concentrations in vegetable garden soil or in nutrient solution, and evaluate the criteria of Cd pollution in vegetable garden soil and in nutrient solution based on the hygienic limit of Cd in vegetables. Cadmium concentrations in edible parts of the three selected vegetable crops were as follows: 0.01—0.15 mg/kg fresh weight for Chinese cabbage, 0.02—0.17 mg/kg fresh weight for winter greens, and 0.02—0.24 mg/kg fresh weight for celery in the pot experiment, and 0.1—0.4 mg/kg fresh weight for Chinese cabbage, 0.1—1.4 mg/kg fresh weight for winter greens, and 0.05—0.5 mg/kg fresh weight for celery in the pot experiment(except no-Cd treatment). The order of the three test vegetable crops for cadmium accumulation in the edible parts was celery > winter greens > Chinese cabbage in both the pot experiment and the sandy culture experiment. Cadmium accumulation in edible parts or roots of the vegetable crops increased with increasing of cadmium concentration in the medium(soil or nutrient solution). And cadmium concentrations in edible parts of the test vegetable crops were significantly linearly related to the Cd levels in the growth media (soil and nutrient solution). Based on the regression equations established and the limit of cadmium concentration in vegetable products, the thresholds of Cd concentration in the growth medium evaluated was as follows: 0.5 mg/kg soil of extractable Cd for soil and 0.02 mg/L for nutrient solution. The high capacity for cadmium accumulation in the edible parts of different vegetable crops together with the absence of visual symptoms implies a potential danger for humans.

Keywords: cadmium; Chinese cabbage(*B. chinensis* L., cv. Zao-Shu 5); winter greens (*B. var. rosularis* Tsen et Lee, cv. Shang-Hai-Qing); celery (*A. graveolens* L. var. *dulce* DC., cv. Qing-Qin)

Introduction

Cadmium is principally dispersed in natural and agricultural environments through various agricultural, mining and industrial activities as well as resulting from the exhaust gases of automobiles (Das, 1997). This trace metal is the pollutant and potential toxin that has unknown function in any biological organism, and is one of the most dangerous heavy metals for the environment due to its high mobility and low toxic concentration in organisms. Cadmium in soils is readily taken up by plants and is not phytotoxic at concentration in crops that can significantly increase human exposure(Adriano, 1986). Excessive exposure to Cd has been associated with various illnesses in humans, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis(Wagner, 1993). For example, elevated levels of Cd in the diet and drinking water were concluded to be causative factors in the 1964 occurrence of Itai Itai disease (severe osteoporosis/osteomalacia and renal tubular dysfunction) in the Toyoma Prefecture in Japan(Hallenbeck, 1984). Cadmium absorption, accumulation and distribution in food crops such as rice, wheat, barley, maize and potato, oil seed crops such as sunflower and flaxseed crops, and forage crops had been well studied (Devkota, 2000; Jeng, 1995; Zhou, 1994; Grant, 1996; Oliver, 1995; Yang, 1999; Ramachandran, 1998; McLaughlin, 1994; Maier, 1996; Moraghan, 1993; Grant, 1997; Simon, 1998; Singh, 1994). However, Ryan *et al*. (Ryan, 1982) estimated that vegetable foods contribute ≥70% of Cd intake in

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humans. Up to now, cadmium accumulation in vegetable crops, especially in foliar vegetable crops is still not informed.

As Cd accumulated in vegetable crops or edible parts of vegetable crops is principally from vegetable garden soil and partially from irrigation water in general. In this paper, a pot experiment and a sandy culture experiment with different Cd doses were conducted for comparing Cd accumulation among selected vegetable crops. The correlative relationships between Cd concentration in edible parts of selected vegetable crops and Cd contents in vegetable garden soil or in nutrient solution were also discussed. And then, the criteria of Cd pollution in vegetable garden soil and in nutrient solution based on the hygienic limit of Cd in food were evaluated.

1 Materials and methods

1.1 Soil pre-incubation

Before the pot experiment, the topsoil(0—20 cm) of a vegetable garden soil, collected from the suburb of Hangzhou City, Zhejiang Province of China, as the initial soil was incubated with different doses of Cd added as $CdSO_4$ under the appropriate soil moisture content (about 70% of the maximum water holding capacity of the soil) for 12 weeks. The transformation of added Cd in the same soil became equilibrated after 8-weeks incubation under similar condition (Long, 1999, data unpublished). Martinez and Motto (Martinez, 2000) reported that the transformation of heavy metals added as single solutions in mineral soils could get balance after 40-days incubation. After 12 weeks incubation, the soils were air-dried, and the extractable Cd (extracted by 0.005 mol/L DTPA) contents in the soils were determined by atomic absorption spectrophotometer (AAS). Thus, the initial soil and incubated soils with different extractable Cd contents (0.15 mg/kg soil in the initial soil, 0.89, 1.38, 1.84, 2.30 mg/kg soil in the incubated soils) were prepared for the pot experiment.

1.2 Preparation of seedlings of test vegetable crops

Seeds of three vegetable crops as Chinese cabbage (*B. chinensis* L., cv. Zao-Shu 5), winter greens (*B. var. rosularis* Tsen et Lee, cv. Shang-Hai-Qing) and celery (*A. graveolens* L. var. *dulce* DC., cv. Qing-Qin) were germinated on wetted filter paper for two days in the dark (25℃). The germinated seeds were sowed on quartz sand with Cd-free nutrient solution for preparing seedlings. The processes of preparing seedling for the pot experiment and the sandy culture experiment were the same.

1.3 Pot experiment

A pot experiment was performed on the prepared soils grown with selected vegetable crops of Chinese cabbage (*B. chinensis* L., cv. Zao-Shu 5), winter greens (*B. var. rosularis* Tsen et Lee, cv. Shang-Hai-Qing) and celery (*A. graveolens* L. var. *dulce* DC., cv. Qing-Qin), respectively. The initial soil used in this experiment had the following characteristics: pH(H_2O) 7.15, organic C 37.8 g/kg soil, CEC 139.0 me/kg soil, total N 2.6 g/kg soil, total P 0.90 g/kg soil, hydrolyzable N 107.8 mg/kg soil, available P 47.6 mg/kg soil, exchangeable K 140.0 mg/kg soil and extractable Cd 0.15 mg/kg soil.

The initial soil and four incubated soils with different extractable Cd were used as the treatments. One thousand gram of the prepared soils was placed in each plastic pot. The doses of N (in urea), P (in calcium dihydrophosphate) and K (in potassium chlorite) supplied were equal for all treatments in the pot experiment: 0.466 N, 0.147 P_2O_5 and 0.157 K_2O g/kg soil. The treatments were trireplicated and randomly arranged. Seedlings of equal length were selected and transplanted into each plastic pot. During the experimental period, deionized water was added to compensate for evapotranspiration when it was needed. Plants were harvested after 7 weeks of growth for Chinese cabbage, 5 weeks of growth for winter greens and 10 weeks of growth for celery. Before separated into shoots (leaf blades and petioles-edible portion for celery) and roots, plants were washed with deionized water.

1.4 Sandy culture experiment

The sandy culture experiment grown with vegetable crops included five treatments with 0, 0.065, 0.125, 0.250, 0.500 mg Cd/L in the basic nutrient solution. The basic nutrient solution contained the following nutrients(μmol/L): 6000 KNO_3, 3500 $Ca(NO_3)_2 \cdot 4H_2O$, 1330 KH_2PO_4, 2000 $MgSO_4 \cdot 7H_2O$, 480 NaCl, 10.0 H_3BO_3, 0.50 $MnSO_4 \cdot H_2O$, 0.50 $ZnSO_4 \cdot 7H_2O$, 0.20 $CuSO_4 \cdot 5H_2O$, 0.01 $(NH_4)_6Mo_7O_{24}$ and 200 Fe-EDTA. Cadmium was added to the nutrient solutions as cadmium sulfate.

Selected seedlings of equal length were transplanted into quartz sand with nutrient solutions in plastic containers. Nutrient solutions were renewed weekly. The plants were lifted with quartz sand and adhering nutrient solution was rinsed off with deionized water before the plants were transferred into the fresh nutrient solution. Plants were harvested after 3 weeks of growth for Chinese cabbage and winter greens, and 5 weeks of growth for celery, and then washed with deionized water before being separated into shoots (leaf blades and petioles-edible portion for celery) and roots.

1.5 Chemical analysis

The important characteristics of the soils were measured with conventional methods (Committee of Agrochem., Soil Sci. Soc. of China, 1983). Plant tissues were oven-dried at 70℃ to constant weight and ground in a stainless steel mill. Dry matter contents of plants were calculated based on the weight difference before and after oven-drying at 70℃. Dry plant material was placed in porcelain crucibles and mineralized by oven-drying digestion methods. Digested samples were dissolved, filtered and brought to 25-ml with 1:1 HCl. The extractable Cd in soils was extracted by 0.005 mol/L DTPA. Cadmium in extracting solution of soils and digesting solution of plant materials was measured by atomic absorption spectrophotometer(Committee of Agrochem., Soil Sci. Soc. of China, 1983). Then, plant Cd content expressed in fresh weight basis was calculated based on the plant Cd content expressed in dry weight basis and dry mater content of plant.

1.6 Data analysis

The significance of differences between the means of the treatments was evaluated by one-way analysis of variance followed by Duncan multiple range test at the significance levels of 1% and 5%. Linear regression analysis was performed to establish linear relations between Cd concentrations in plant tissues and extractable Cd contents in soils or Cd concentrations in nutrient solutions.

2 Results and discussion

2.1 Growth responses of selected vegetable crops to Cd addition

Neither nutrient deficiency nor toxicity symptoms were visible on the test crops in both the pot and sandy culture experiments. Biomass production of root and shoot for Chinese cabbage and winter greens, as well as root, petiole and leaf blade for celery, expressed as fresh weight, were not significantly different among the treatments(Table 1). This result indicated that Cd concentrations of the treatments established in this study were likely to be below phytotoxic levels for the tested vegetable crops. Bingham(Bingham, 1979) observed that the most sensitive soil-grown plants tested in his study(spinach and soybean) required 4 to 5 mg Cd/kg soil to produce a 25% yield decrement. Garate *et al*. (Garate, 1993) reported that there was no significant yield reductions for three lettuce varieties exposed to Cd concentrations up to 1 mg/L in nutrient solution. Therefore, vegetable crops with the general tolerance to cadmium grown in Cd-polluted media have potential to contribute substantial Cd to the human diet.

2.2 Effects of Cd treatments on Cd concentration and accumulation in vegetable crops

Cadmium concentration in the different vegetative parts of three vegetable crops from the pot experiment and the sandy culture experiment are presented in Table 2 and Table 3, respectively. In the pot experiment, cadmium concentrations were 0.02—1.10, 0.02—0.43, and 0.10—0.65 mg/kg fresh weight for the roots of Chinese cabbage, winter greens, and celery, respectively, and 0.01—0.15, 0.02—0.17, and 0.02—0.24 mg/kg fresh weight for the shoots of Chinese cabbage and winter greens, and the petiole (edible part) of celery in order. And in the sandy culture experiment, cadmium concentration were 0.3—1.6, 0.5—10, and 1—13 mg/kg fresh weight for the roots of Chinese cabbage, winter greens, and celery in order, and 0.1—0.4, 0.1—1.4, and 0.05—0.5 mg/kg fresh weight for the shoots of Chinese cabbage and winter greens, and the petiole (edible part) of celery with the Cd treatment (except no-Cd treatment), respectively. The order of the three test vegetable crops for cadmium accumulation in the edible parts was celery > winter greens > Chinese cabbage in both the pot experiment and the sandy culture experiment. The differences on cadmium accumulation among other plant species (Hatch, 1988; Kim, 1988), other vegetable crops(McKenna, 1993), even culture varieties or inbred lines of the same crop(Florijn, 1992;1993) were commonly reported. And the gradient of Cd accumulation was root > shoot for Chinese cabbage and winter greens or root > petiole and leaf blade for celery. This evaluation was based on a common observation in similar experiments with cucumber(Moreno-Caselles, 2000), and other food crops(Kim, 1988).

Table 1 Biomass production of vegetable crops

Extractable Cd concentration of soil, mg/kg	Biomass production expressed as fresh weight (gram per pot) Pot experiment						
	Chinese cabbage		Winter greens		Celery		
	Root	Shoot	Root	Shoot	Root	Petiole	Blade
0.15	3.0a	62.7a	3.0a	64.7a	23.6a	32.6a	32.4a
0.89	3.1a	69.1a	2.7a	60.0a	23.7a	32.9a	33.6a
1.38	3.0a	61.3a	2.5a	63.3a	22.5a	33.5a	32.0a
1.84	3.1a	64.7a	2.8a	65.1a	22.7a	33.2a	32.2a
2.30	3.2a	69.8a	2.7a	62.8a	22.9a	32.6a	32.2a
F-anova	ns	ns	ns	ns	ns	ns	ns
	Sandy culture experiment						
Cd level, mg/L	Chinese cabbage		Winter greens		Celery		
	Root	Shoot	Root	Shoot	Root	Petiole	Blade
0.000	19.2a	370.7a	11.1a	145.9a	21.8a	46.6a	42.2a
0.065	19.2a	371.6a	10.5a	146.5a	22.4a	46.6a	42.2a
0.125	19.0a	353.8a	10.8a	143.2a	21.9a	46.4a	42.6a
0.250	19.1a	337.4a	10.8a	148.0a	21.6a	46.2a	41.8a
0.500	19.7a	385.1a	11.3a	144.6a	21.9a	46.0a	42.1a
F-anova	ns	ns	ns	ns	ns	ns	ns

Note: ns = non-significant

Table 2 Cadmium concentration in different parts of vegetable crops under pot experiment condition (expressed in fresh weight basis)

Extractable Cd concentration of soil, mg/kg	Plant Cd contents, mg/kg fresh wt.						
	Chinese cabbage		Winter greens		Celery		
	Root	Shoot	Root	Shoot	Root	Petiole	Blade
0.15	0.017e	0.010e	0.023e	0.022e	0.096e	0.020e	0.020e
0.89	0.158d	0.049d	0.095d	0.038d	0.265d	0.085d	0.040d
1.38	0.332c	0.076c	0.151c	0.103c	0.385c	0.113c	0.072c
1.84	0.455b	0.086b	0.235b	0.119b	0.439b	0.204b	0.082b
2.30	1.095a	0.151a	0.428a	0.166a	0.653a	0.241a	0.253a
F-anova	* *	* *	* *	* *	* *	* *	* *

Note: * * Represents significant differences between values at $p = 0.01$, by Anova Test. Values followed by the same letter in vertical direction are non-significantly different by Duncan's Multiple Range Test ($p = 0.01$).

Table 3 Cadmium concentration in different parts of vegetable crops under sandy culture experiment condition (expressed in fresh weight basis; nd: under detection limit)

Cd level, mg/L	Plant Cd contents, mg/kg fresh wt.						
	Chinese cabbage		Winter greens		Celery		
	Root	Shoot	Root	Shoot	Root	Petiole	Blade
0.000	nd	nd	nd	nd	nd	nd	nd
0.065	0.268d	0.096d	0.482d	0.085d	0.895d	0.050d	0.354d
0.125	0.901c	0.139c	1.169c	0.224c	1.233c	0.081c	0.399c
0.250	1.169b	0.294b	1.540b	0.453b	6.209b	0.125b	0.682b
0.500	1.626a	0.409a	9.666a	1.419a	13.148a	0.512a	1.264a
F-anova	* *	* *	* *	* *	* *	* *	* *

* * Represents significant differences between values at $p = 0.01$, by Anova Test. Values followed by the same letter in vertical direction are non-significantly different by Duncan's Multiple Range Test ($p = 0.01$).

From Table 2 and Table 3, it could be also observed that cadmium accumulation in the different parts of the vegetable crops increased with the increasing of cadmium concentration in the growth medium (the soil in the pot experiment or the nutrient solution in the sandy culture experiment). The results of statistical analysis indicated that cadmium concentration in edible part of vegetable crop was positively correlative to extractable Cd content in soil in pot experiment or Cd concentration in nutrient solution. The linear equations illustrating the correlative relationships and their regression coefficients were presented in Table 4. In many cases, a linear relationship between Cd in plant material versus Cd in growth medium was reported (Filip, 1998; Kabata-Pendias, 1984). As the regression coefficients were significant at the level of 1%, the regression equation could be used to estimate the criteria of cadmium concentration in the growth media (soil and nutrient solution) with the limit of cadmium concentration in vegetable product (0.05 mg/kg fresh weight, GBN 238 – 84 in China). The calculated results (Table 4) indicated that the criteria for extractable Cd content in soil are 0.869, 0.730, and 0.489 mg/kg soil for Chinese cabbage, winter greens, and celery in order, and these for Cd concentration in nutrient solution are 0.055, 0.019 and 0.055 mg/L for Chinese cabbage, winter greens, and celery in order, understanding that the threshold for extractable Cd content in soil is 0.5 mg/kg soil and that for Cd concentration in nutrient solution is 0.02 mg/L. Since it was well established that plant species or varieties vary in their capacity for cadmium accumulation, the critical value of Cd concentration in the growth medium for other agronomic or vegetable crops with higher capacity for cadmium accumulation may be lower than that evaluated in this study.

Table 4 Correlative relationships between Cd concentration in edible part of vegetable crop (Cp) and extractable Cd content in soil (Cs) or Cd concentration in nutrient solution (Cns) and the evaluated criteria of Cd pollution in growth media

Crops	Pot experiment			
	Correlative equation	Correlative coefficient	Significance	The criteria of Cd concentration, mg/kg soil
Chinese cabbage	Cp = 0.0575Cs	0.965 ($n = 5$)	* *	0.869
Winter greens	Cp = 0.0685Cs	0.969 ($n = 5$)	* *	0.730
Celery	Cp = 0.1022Cs	0.983 ($n = 5$)	* *	0.489
Crops	**Sandy culture experiment**			
	Correlative equation	Correlative coefficient	Significance	The criteria of Cd concentration, mg/kg soil
Chinese cabbage	Cp = 0.9072Cns	0.974 ($n = 5$)	* *	0.055
Winter greens	Cp = 2.5757Cns	0.983 ($n = 5$)	* *	0.019
Celery	Cp = 0.9049Cns	0.964 ($n = 5$)	* *	0.055

Note: ** Represents that the correlative relationship is significant at the level of 1%.

3 Conclusions

Cadmium did not affect the growth of Chinese cabbage, winter greens and celery at the level up to 0.5 mg/L in nutrient solution under the sandy culture condition, as well as at the level up to 2.3 mg/kg soil as extractable Cd of soil in the pot experiment. Cadmium concentrations in the edible parts of the test vegetable crops were linearly responded to the Cd levels in the growth media (soil and nutrient solution). Based on the regression equations established in this study and the limit of cadmium concentration in vegetable products, the threshold of Cd concentration for the growth medium was evaluated as follows: 0.5 mg/kg soil of extractable Cd for soil and 0.02 mg/L for nutrient solution. The high capacity for cadmium accumulation in the edible parts of the different vegetable crops together with the absence of visual symptoms points to a potential danger for humans.

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