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Cadmium Accumulation in the Edible Parts of Different Cultivars of Radish, *Raphanus sativus* L., and Carrot, *Daucus carota* var. sativa, Grown in a Cd-contaminated Soil

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Abstract Cadmium accumulation among 12 cultivars of radish (*Raphanus sativus*) and 10 cultivars of carrot (*Daucus carota* var. sativa) was studied in a Cd-contaminated soil. The Cd concentration in the edible parts of radish and carrot ranged from 0.04 to 0.14 and 0.14 to 0.19 mg kg^{-1} fresh weight, respectively. All the tested carrot cultivars and 33% of the tested radish cultivars exceeded the Chinese allowable limit for Cd. The study showed a greater scope for selecting radish cultivars than for carrot to avoid the excess of the Cd limit when grown on lightly contaminated soils.

Keywords Bioconcentration factor · Cadmium · Carrot · Radish

Cadmium is a nonessential heavy metal to plants, but it is taken up by crops rather readily, and then accumulated in the edible parts. The main source of exposure to cadmium for non-smoking humans is via intake of foodstuffs. It is therefore necessary to decrease Cd accumulation in plants, especially in the edible parts of crops. Numerous studies have been made in soil remediation such as adjusting soil chemical conditions, excavation and chemical soil washing to reduce cadmium transfer from soil to plant. However, it is difficult for these technologies to be carried out because of their high cost, damage of soil structure and undesirable consequences. Recently phytoremediation are drawing much more attention internationally in environmental cleanup (Brown et al. 1994; Chaney et al. 2005). But due to some disadvantages of rare hyperaccumulators discovered so far such as slow growth, particular area distribution and being only effective for certain metals, it is not suitable to remediate large areas of farmland with light or moderate metal-contamination through phytoextraction. Another strategy of phytoremediation of metal-contaminated soil is phytostabilization which aims to minimize metal mobility and to reduce the uptake of toxic metals by plants. So selecting low heavy metal accumulating cultivars may provide alternatives to reducing heavy metal intake in human diets. Much work has been done on the accumulation of Cd by plants due to its relatively high transfer factor from soil to plant. Differences between plant species and between varieties of the same species in the accumulation of Cd are also recognized. Cd accumulation in many crops varies significantly among species and cultivars (Alexander et al. 2006). Many researches have also shown that there are variations in Cd accumulation among cultivars or genotypes in cereals such as wheat (Stolt et al. 2006), rice (Liu et al. 2005), and potato (Dunbar et al. 2003). In leafy vegetables Cd accumulates in the leaves, whereas in cereals, accumulation is greatest in the roots and declines towards the top of the plant (Cutler and Rains 1974). However rootstalk vegetables, whose taproot is not only a sink organ but also a functional organ surrounded with soil, may have a particular pathway of cadmium uptake different from the crops mentioned above. However, less information is available on varietal differences in metal accumulation within rootstalk vegetables, especially radish and carrot. McLaughlin et al. (1994) compared the uptake of Cd by 14 commonly grown potato cultivars. Significant differences were found between the cultivars with an average range of concentrations of 30–50 μg Cd kg^{-1} (fresh weight).

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In most cases, genotypic differences between plant species as well as between varieties were examined in culture solution or in the metal-spiked soil. It is important to determine the extent of accumulation of metal between cultivars from contaminated soil. The selected crops with lower Cd accumulation in the edible part can be planted on contaminated soils to avoid excessive metal accumulation. Selecting and planting low-Cd cultivars therefore become quite economical and feasible. In this paper, several cultivars of radish and carrot were selected and grown in a Cd-contaminated soil. The principal purpose of this study was to select low Cd-accumulation cultivars and to evaluate the possibility of cultivar selection. Bioconcentration factor and taproot-to-shoot transfer coefficient were also assessed to compare their differences between radish and carrot.

Materials and Methods

The soil used in the experiment was collected from Zhangshi county, Shenyang city, Liaoning province, northeastern China. The soil is contaminated with Cd due to the long-term irrigation of metal-contaminated water. Physical and chemical characteristics of the polluted soil are as follows: pH 6.8, organic matter 2.89%, total N 0.14%, available P 23.9 mg kg^{-1}, available K 129.4 mg kg^{-1}, total Cd 3.6 mg kg^{-1}, DTPA-extractable Cd 2.6 mg kg^{-1}. Twelve cultivars of radish (*Raphanus sativus* L.) and ten cultivars of carrot (*Daucus carota* var. sativa) were selected and presented in Table 1.

The soil was air-dried and passed a 5-mm sieve. Ten seeds were sown into pots containing 8 kg soil mixed with 0.36 g N kg^{-1}, 0.12 g P kg^{-1}, 0.76 g K kg^{-1} as urea, KH_2PO_4 and K_2SO_4 respectively. The amount of Cd in soil was 28.8 mg per pot. All nutrients were mixed thoroughly with soil before sowing, and the plant seeding and growth were carried out in a greenhouse from late August to early November, which is the appropriate growth season of radish and carrot. The pots were randomly arranged with three replicates for each cultivar. Following emergence the number of seedlings was thinned to one or three per pot for radish and carrot, respectively. During the experimental period, tap water was added to compensate for evaporation and transpiration. Radish and carrot grown in the pot for three months were harvested. At harvest, plants were removed carefully from soil and separated into shoots and taproots, firstly washed with tap water to remove any attached particles, then rinsed with deionized water three times thoroughly. Fresh weight was recorded and then sample was squashed in an electric blender, and kept in clean polyethylene bags for Cd analysis. Subsamples were dried at 105°C for 30 min and 70°C for 48 h to determine the water content of plants.

Table 1 Cultivars of radish and carrot used in the experiment

Series no.	Cultivars of radish	Series no.	Cultivars of carrot
R1	Sijidagen	C1	Juhong no 1
R2	Changbai 20-day	C2	Xinhong
R3	Dongyangbaichun	C3	Italy 5-inch
R4	Xiangyabai	C4	Kaqi
R5	Dagen 20-day	C5	Xinheitian 5-inch
R6	Yubeidagen	C6	Texuan 7-inch
R7	Chunbaiyu	C7	Gaoguan 5-inch
R8	Hanyudagen	C8	Touxinhong
R9	Chunbaodagen	C9	Jinsun 5-inch
R10	Baiyudagen	C10	Japan 5-inch
R11	Huaye		
R12	Chaojimeinong		

Subsamples of fresh vegetables were digested by HNO_3 and $HClO_4$ (4:1). Soil samples were air-dried and ground (<0.149 mm), and digested by HNO_3–HCl–$HClO_4$–HF set by State Environmental Protection Administration of China (SEPAC 1997). The Cd concentrations in soil and vegetables were determined by an atomic absorption spectrophotometer with graphite furnace atomization with limit of detection of 0.5 μg/L (GFAAS, Hitachi Z-8000). Blanks and standard reference materials (Tomato Leaves NIST 1572 and Soil ESS-4 GSBZ50014-88) were included for quality assurance. And the recovery ratios were from 89% to 116% throughout the analysis procedures. The Cd concentrations in radish and carrot were expressed on a fresh weight basis or dry weight basis. Bioconcentration factors (BCF) were calculated as the ratio between the Cd concentration in the edible part (taproot) and that in the soil. Taproot-to-shoot transfer coefficients (TC) indicating the mobility of Cd from root to shoot were also computed as the ratio between the Cd concentration in shoot and taproot.

All data were analyzed with SAS. The differences among means of cultivars were tested using the least significant difference test.

Results and Discussion

Significant differences in the Cd concentration were found among radish cultivars, showing 1.4-fold and 3.5-fold variations for shoot and taproot respectively (Fig. 1). Cd concentration in the edible part of radish varied from 0.04 to 0.14 mg kg^{-1} with one third of the cultivars exceeding the Chinese maximum allowable limit of 0.1 mg kg^{-1} FW set by Ministry of Health of the People's Republic of China and Standardization Administration of China (MHPRC and SAC 2005). Radish cv. R12 had the lowest concentration

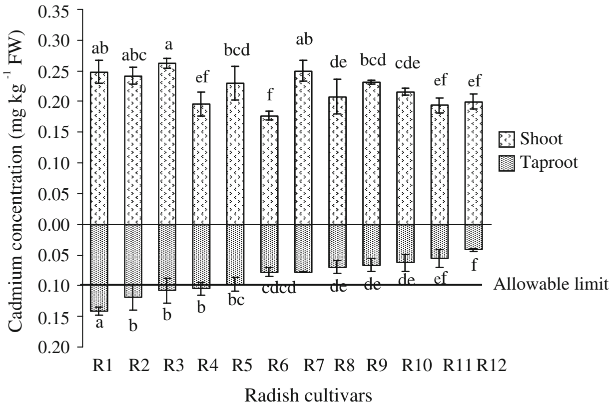

Fig. 1 Variation among 12 radish cultivars in Cd concentration of shoot and taproot based on fresh weight (mg kg^{-1} FW) grown for three months in the pots. Significant differences in Cd concentration among cultivars are indicated by different letters ($p < 0.05$); vertical bars represent ±SD of three replicates

of Cd in taproot. In addition, significant differences in Cd concentration among carrot cultivars were also observed (Fig. 2). The Cd concentration in carrot taproot ranged from 0.14 to 0.19 mg kg^{-1}, representing only 1.4-fold variation. The Cd concentration in all of the tested cultivars of carrot exceeded the Chinese allowable limit for rootstalk vegetables. The concentration of Cd in carrot shoot varied within a narrow range, from 0.22 to 0.25 mg kg^{-1}.

Although the order of Cd concentration based on dry weight among cultivars was not as same as that based on fresh weight, radish cv. R12 and carrot cv. C10 had the lowest Cd concentration in taproot based either on fresh weight or on dry weight (Table 2). Significant differences could also be found among radish and carrot cultivars in Cd

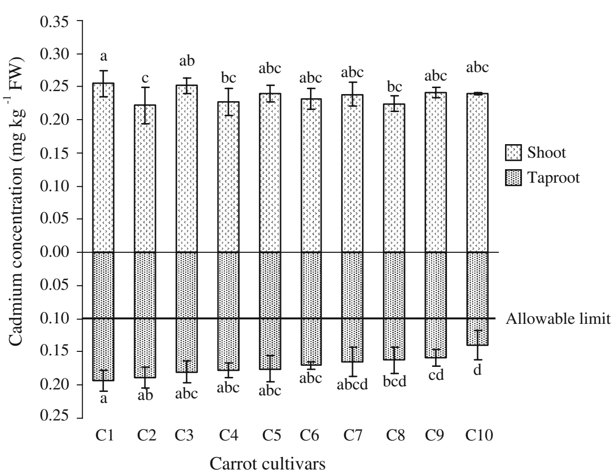

Fig. 2 Variation among 10 carrot cultivars in Cd concentration of shoot and taproot based on fresh weight (mg kg^{-1} FW) grown for three months in the pots. Significant differences in Cd concentration among cultivars are indicated by different letters ($p < 0.05$); vertical bars represent ±SD of three replicates

concentration based on dry weight. On the dry weigh basis, Cd concentration varied from 0.60 to 1.64 mg kg^{-1} (2.7-fold) in radish, and from 1.06 to 1.46 mg kg^{-1} (1.4-fold) in carrot. Small variations were also found in the shoot Cd concentration based on dry weight, but only 1.8-fold and 1.3-fold variations for radish and carrot cultivars respectively (Table 2).

Compared with carrot, all of radish cultivars had lower Cd concentration in the edible parts based on fresh weight (Figs. 1 and 2). However, on the dry weight basis, carrot and radish had similar concentrations of Cd in the edible part (Table 2), indicating that the high water content in radish taproots is the main reason for the low Cd concentrations on the fresh weight basis. In contrast, the Cd concentration in shoot of radish was higher than that of carrot based on dry weight.

BCF value of Cd in the edible part, which is an index for evaluating the transfer potential of Cd from soil to the edible part, represents the potential risk to human health. The BCF values on the basis of dry weight were 0.17–0.46 and 0.29–0.41 for radish and carrot cultivars respectively (Fig. 3). The highest BCF value was found in radish cultivar R1 and lowest in R12. BCF values of carrot cultivars based on fresh weight were higher than that of radish cultivars, whereas the BCF mean values based on the dry weight were almost the same for radish and carrot. There were no apparent differences between radish and carrot in BCF mean values (in DW), suggesting that radish and carrot had the similar accumulating ability for Cd in the edible part. However, if BCF value on the basis of fresh weight is taken as an index, carrot cultivars would appear to accumulate more Cd in the edible part than radish cultivars.

Root-to-shoot transfer coefficient (TC) can be used to evaluate the transfer potential of a metal from root to shoot. In order to assess the potential transfer of Cd from taproot to shoot, TC values based on dry weight and fresh weight were calculated. The results indicated that there were large differences of TCs among radish and carrot cultivars (Fig. 3). In most cases, higher TC values were found in radish cultivars, and the mean TC values were also higher in radish than that in carrot. Based on the fresh weight, the TC values were in the range of 1.75 to 4.84 and 1.18 to 1.74 for radish and carrot respectively. TC values varied by 2.8-fold among the radish cultivars tested. Similar results were also found on the basis of dry weight.

In addition, on the basis of fresh weight, radish cv. R12 which contained the minimum Cd concentration in taproot had the highest TC, whereas radish cv. R1 had the highest concentration of Cd in the taproot and the lowest TC.

The study showed that significant differences in Cd content (fresh weigh) among cultivars existed both in radish and carrot with a 3.5-fold and 1.4-fold variation

Table 2 Cd concentration in shoot and taproot based on dry weight (mg kg^{-1} DW)

Radish	Shoot	Taproot	Carrot	Shoot	Taproot
R1	1.68 ± 0.06 cd	1.55 ± 0.22 ab	C1	0.86 ± 0.07 abcde	1.39 ± 0.22 ab
R2	1.40 ± 0.03 efg	1.64 ± 0.36 a	C2	0.76 ± 0.10 de	1.27 ± 0.04 abc
R3	2.17 ± 0.15 a	1.25 ± 0.23 bc	C3	0.74 ± 0.13 e	1.06 ± 0.14 c
R4	1.18 ± 0.12 g	1.07 ± 0.13 cde	C4	0.95 ± 0.07 ab	1.46 ± 0.10 a
R5	1.69 ± 0.11 cd	1.59 ± 0.37 a	C5	0.77 ± 0.07 de	1.14 ± 0.27 bc
R6	1.32 ± 0.08 fg	0.77 ± 0.06 ef	C6	0.93 ± 0.07 abc	1.26 ± 0.10 abc
R7	2.01 ± 0.08 ab	1.18 ± 0.05 cd	C7	0.92 ± 0.06 abcd	1.29 ± 0.15 abc
R8	1.27 ± 0.20 fg	0.81 ± 0.09 ef	C8	0.79 ± 0.08 bcde	1.20 ± 0.11 abc
R9	1.89 ± 0.17 bc	1.05 ± 0.16 cde	C9	0.79 ± 0.02 cde	1.09 ± 0.06 bc
R10	1.50 ± 0.07 def	0.86 ± 0.13 def	C10	0.96 ± 0.18 a	1.06 ± 0.37 c
R11	2.05 ± 0.39 ab	0.76 ± 0.13 ef			
R12	1.63 ± 0.14 cde	0.60 ± 0.02 f			
Mean	1.65	1.09	Mean	0.85	1.22

Significant differences in Cd concentration among cultivars are indicated by different letters ($p < 0.05$); values represent the means ± SD of three replicates

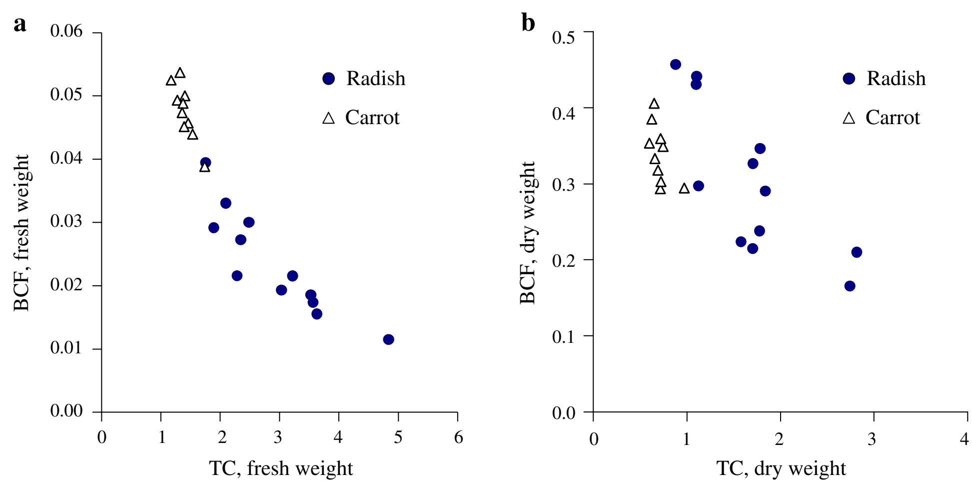

Fig. 3 Bioconcentration factors (BCF values) and transfer coefficients (TCs) of Cd based on fresh weight (**a**) and dry weight (**b**)

respectively (Figs. 1 and 2). Wider variations in Cd concentration on the basis of fresh weight were found among radish cultivars compared with that of carrot. In general, carrot appears to be relatively high accumulators of Cd in the edible part and thus it could be argued that this species should not be grown on Cd-contaminated soils. On the other hand, radish tends to accumulate less Cd than carrot but the significant differences among cultivars indicate that cultivars from R6 to R12 are more suitable to grow on Cd-contaminated soils in respect of minimizing Cd intake via this vegetable. The wide range in Cd concentration among radish cultivars shows that there is a considerable potential for producing radish low in Cd, whereas the narrow range shows less possibility for carrot.

Some studies have indicated that the ability of cadmium accumulation in plant should be attributed to the specific genes (Pandey and Sharma 2002). Moreover, many researchers have shown variations in cadmium accumulation and distribution among different cultivars or genotypes of a given plant species (Dunbar et al. 2003; Stolt et al. 2006). Significant differences in Cd concentration in the edible part were also found among cultivars of radish and carrot in this experiment. However, Jansson and Öborn (2000) found there were no significant differences between varieties with respect to Cd concentration in carrots. Though significant differences were found among carrot cultivars in our study, the range of Cd concentration on the basis of fresh weight and dry weight was small (Fig. 2 and Table 2). Furthermore carrot also exhibited relatively high accumulation concentration in the edible part and should probably be avoided planting on Cd-contaminated soils.

The BCF values have been used by many researchers to evaluate the transfer potential of a metal from soil to plant, which varies greatly with the plant species (Samsoe-

Petersen et al. 2002). The plants with lower BCF values can be planted on contaminated soils to avoid excessive metal accumulation, while those with higher BCF will increase the transfer of metal into food chain. In this experiment BCF values calculated by taproot varied greatly for radish cultivars, whereas carrot cultivars had a low range of BCF values. Higher BCF values were found in carrot. BCF values were below 1 in this study, which is in agreement with the results obtained by Dudka (Dudka et al. 1994).

The plant Cd level and the way in which Cd is distributed within the plant differ between species as well as between varieties (Alexander et al. 2006). Transfer coefficient (TC) is used to measure the mobility of metal from root to shoot. The process of phytoextraction generally requires high translocation from root to shoot, whereas phytostabilization tends to restrict root-shoot transfer. But for rootstalk crops, higher TC is required and therefore less metal is accumulated in the edible part, i.e. root. Comparing the TC values of radish and carrot, radish had a higher translocation of Cd from root to shoot (Fig. 3). Among radish cultivars, cv. R7–R12 had high TC values. Rootstalk crops exhibiting high TC values are more suitable for planting in contaminated soil. The difference of TC values between radish and carrot may be attributed to the difference in the morphology of xylem and phloem of taproot. Cd absorbed into radish taproot can be easily transferred to shoot through xylem to reduce Cd amount in taproot, but not easy to carrot for its thinner xylem. Further investigation is merited.

In conclusion, these results indicated the existence of substantial genotypic or cultivar variation in the uptake and accumulation of Cd and carrot was more likely to exceed the Cd limit than radish. It would be worthwhile extending this type of screening study to a wider range of cultivars of other vegetables. It is important to reduce Cd amount in vegetables and any reduction in Cd intake via food should be considered positive with regard to health. High TC indicates a good mobility of Cd in plant from taproot to shoot, and then more Cd can easily move up from taproot to shoot to decrease Cd concentration in taproot accordingly.

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