Bull. Environ. Contam. Toxicol. (1993) 50:709–716

Environmental Contamination and Toxicology

Cadmium Uptake and Distribution in Three Cultivars of *Lactuca* sp.

A. Garate, I. Ramos, M. Manzanares, and J. J. Lucena

Department of Agricultural Chemistry, Autónoma University of Madrid, 28049 Madrid, Spain

Even at relatively low concentrations Cadmium (Cd) is considered to be a toxic element for all living beings. Although it can be present in different plant tissues, the metal is phytotoxic. Use of industrial wastes and sludges as agricultural amendments has surely increased the amount of Cd that is available to plants. Consequently Cd uptake and accumulation in plants and its possible effects on human health have received attention in recent years. The process of Cadmium uptake by plant roots can be either active or passive, in function of the metal concentration in the nutrient solution (Cataldo *et al.*, 1983). These authors found that the process was mainly passive at Cd concentrations below 0.5 μM but active at those above 0.5 μM. Both xylem and phloem can translocate Cd in the form of complexes which can be synthesized by the reaction of the metal with small organic molecules in the roots and can be transported to the shoot (Cabot *et al.*, 1988; Poschenrieder *et al.*, 1983).

Plant species vary in their capacity for Cd accumulation. In this sense lettuces, endives and similar horticultural plants are considered Cd accumulative since they have a relatively high potential for Cd uptake and translocation (FAO, 1983). Nevertheless heavy metal accumulation in plants differs greatly not only among species but also among organs or tissues in the same plant. As a general rule, metal content is normally higher in roots than shoots. According to Davies (1980), this pattern is observed in grasses, where 65 to 90% of the total Cd of the plant is located in the roots. However, in lettuce, only 50% of the total Cd content is found in the roots. K-Pendias and Pendias (1984) observed a higher Cd concentration in leaves than in roots of spinach and lettuce grown in a medium without added contamination.

Send reprint requests to A. Gárate at the above address

In a previous paper (Cala *et al.*, 1988) we found Cd levels in leaves from endives and lettuce plants grown in truck gardens near Madrid that were higher (4 mg Cd/Kg DM) than those recommended by the FAO (1 mg Cd/Kg DM). This paper studies Cd uptake under hydroponic conditions in lettuce and two varieties of endives as well as the level of Cd accumulation in different plant tissues and organs.

MATERIALS AND METHODS

Lettuce (*Lactuca sativa*, cv. Winter yellow), giant endive (*Lactuca serriola*, cv. Hortelano) and curly endive (*Lactuca serriola*, cv. Pancalieri) seeds were germinated and grown in a mixed substrate of peat and acid-washed quartz sand for 75 days. Plants were irrigated with a complete 50% diluted nutrient solution (NS) which was prepared according to Hewitt and Smith (1975), at a final pH of 5.5.

75-day old plants were transferred to 0.7 L plastic pots (4 plants/pot). Polystyrene solid plates with holes were physical support for plants; roots were submerged in aerated nutrient solution.

Experiments were conducted in a greenhouse with controlled temperature and humidity (13-28 °C and 80-50% RH). The treated nutrient solutions were renewed weekly.

Plants of similar size were transferred to 3 L plastic pots (2 plants/pot) with an aerated system. Treatments included: 0, 0.1 and 1.0 mg Cd L^{-1} from a solution of 1000 mg Cd L^{-1} as $3CdSO_4 \cdot 8H_2O$ (Merck), with three replicates per treatment. Roots, old and young leaves were sampled at the beginning of treatment and after 15 and 35 days of exposure to the Cd solutions. Samples were dried at 80 °C, and after a controlled acid digestion in a nitric-sulphuric-perchloric (5:1:2) medium (Cala *et al*, 1988), were taken to 25 ml with distilled water for Cd determination in a Perkin Elmer Atomic Absorption spectrophotometer using an air-acetylene flame.

RESULTS AND DISCUSSION

Average values for dry matter content of the different plant parts decreased with the treatments over time, but the differences were not significant in most cases (Table 1). In general, Cd addition did not significantly reduce the yield of the tested cultivars although a slight decrease was observed in giant endive.

Table 1. Dry weight of different parts of the *Lactuca* species treated with Cd (g·plant^{-1}).

Cd in NS mg·L^{-1}	LETTUCE		GIANT ENDIVE		CURLY ENDIVE	
	15 d	35 d	15 d	35 d	15 d	35 d
Roots						
0.0	2.00	2.30	1.83	4.40a	3.30	8.65
0.1	1.53	3.00	1.20	3.16b	2.80	9.33
1.0	1.86	2.70	1.53	2.06b	3.86	8.80
Old leaves						
0.0	3.96	5.06	4.86	8.53ab	6.63a	11.25
0.1	3.56	4.70	3.76	9.16a	4.36b	11.96
1.0	3.53	4.23	3.86	6.56b	6.33a	8.00
Young leaves						
0.0	3.40	7.90	4.10	6.73	3.46	10.00
0.1	3.96	5.73	2.76	4.56	2.66	10.40
1.0	2.70	6.50	2.76	4.26	3.50	10.00

Cd concentrations in the three organs sampled for each cultivar are shown in Table 2. Root, young leaf and adult leaf Cd concentration are statistically higher in the plants treated with 1.0 mg Cd·L^{-1} DM with respect to those treated with 0.1 mg Cd·L^{-1} and these are higher than the levels found in the

Table 2. Cd concentration (mg·Kg^{-1}) in different parts of the plants.

Cd in NS mg·L^{-1}	LETTUCE		GIANT ENDIVE		CURLY ENDIVE	
	15 d	35 d	15 d	35 d	15 d	35 d
Roots						
0.1	182	115	86	54	89	53
1.0	1336	740	910	902	693	727
Old leaves						
0.1	35	57	22	31	12	24
1.0	71	137	81	142	58	100
Young leaves						
0.1	21	27	26	20	14	14
1.0	45	83	68	86	55	54
Whole plant						
0.1	54	64	34	31	34	29
1.0	353	232	232	245	236	289

controls (Table 2). The Cd levels in the controls fall within the detection limits of the analytical technique used here.

With the 0.1 mg $Cd \cdot L^{-1}$ treatment, the Cd concentration in the roots of the three different species decreased by some 40% between the first sampling time (15 days) and the second (35 days). However when the NS Cd content was 1.0 mg $Cd \cdot L^{-1}$, only the lettuce root decreased its Cd concentration by 40% between the two sampling times; Cd concentration in the roots of the two endive cultivars did not vary between the two sampling times (Table 2).

The concentration of Cd increased by 50-100% in old leaves in all three varieties and in both Cd treated NS between the 15th and 35th day of treatment. This tendency was not constant in young leaves, particularly in young curly endive leaves which showed the same Cd concentration at both sampling times in both NS.

Among other objectives, this paper aims to compare the Cd absorption rates of the three species studied. The average daily Cd absorption rate per plant for either time period, 0-15 or 15-35 days, was calculated and is shown in table 3. A relative decrease in Cd uptake is observed in lettuce and giant endive during the course of the experiment or with the increased Cd concentration in the nutrient solution. If Cd uptake is considered in respect to the Cd available in the NS (dividing data on table 3 by 0.1 or 1.0 depending on the NS Cd level), lower values are obtained at 1.0 mg $Cd \cdot L^{-1}$ than at 0.1 $mg \cdot L^{-1}$ Cd in the external medium; values are also lower after 35 days than after 15 days. This decline in the relative amount of Cd uptake suggests that a saturation mechanism may be involved in the Cd absorption and is in agreement with the results of Fujimoto and Uchida (1979), who

Table 3. Mean daily Cd uptake per plant ($mg \cdot plant^{-1} \cdot day^{-1}$) by each species in the two treated nutrient solutions during the two growth periods.

Days after treatment	Species	Cd ($mg \cdot L^{-1}$ NS) 0.1	1.0
0-15	Lettuce	0.032	0.190
	Giant Endive	0.017	0.126
	Curly Endive	0.022	0.215
15-35	Lettuce	0.014	0.013
	Giant Endive	0.014	0.063
	Curly Endive	0.029	0.225

observed a decrease in Cd uptake by rice plants when the Cd concentration in the nutrient solution was higher than 0.15 mg $Cd{\cdot}L^{-1}$. A growth dilution effect could also contribute to the relative reduction in plant Cd uptake.

The highest Cd concentration at treatment 0.1 mg $Cd{\cdot}L^{-1}$ was found in lettuce leaves (42 $mg{\cdot}Kg^{-1}$ DM) after 35 days of treatment (Table 4). When the Cd concentration in the nutrient medium was 1.0 mg $Cd{\cdot}L^{-1}$ the Cd level in leaves at the same sampling time was around 110 mg $Cd{\cdot}Kg^{-1}$ DM in both lettuce and giant endive. The Cd level in curly endive leaves after 35 days in 1.0 mg $Cd{\cdot}L^{-1}$ NS was 77 mg $Cd{\cdot}Kg^{-1}$ DM, approximately 50% less Cd than in the most accumulative cultivar.

Table 4. Concentration of Cd ($mg{\cdot}Kg^{-1}$ DM) in leaves of lettuce, giant endive and curly endive after 15 and 35 days of treatment.

Days after treatment	Species	Cd ($mg{\cdot}L^{-1}$ NS) 0.1	1.0
15	Lettuce	27 ± 3	52 ± 21
	Giant Endive	24 ± 3	74 ± 16
	Curly Endive	13 ± 1	56 ± 2
35	Lettuce	42 ± 8	110 ± 18
	Giant Endive	25 ± 5	114 ± 19
	Curly Endive	37 ± 4	77 ± 7

No visual symptoms were observed in the treated vegetables although remarkable Cd concentrations (as shown in Table 4) were found in plant tissues. The high potential for Cd accumulation in the leaves of the different *Lactuca* plants together with the absence of visual symptoms point to a potential danger for humans and animals.

Barceló *et al* (1986) observed that Cd treatments caused a decrease in the growth of beans and an important decrease in the water content of treated plants. In our case the water content of plant tissues remains fairly constant between treatments at each sampling time: $91 \pm 2\%$.

Differences in plant species or cultural conditions such as Cd concentration supply and the physical support of the plants could partially explain the different observations made as to growth and water content.

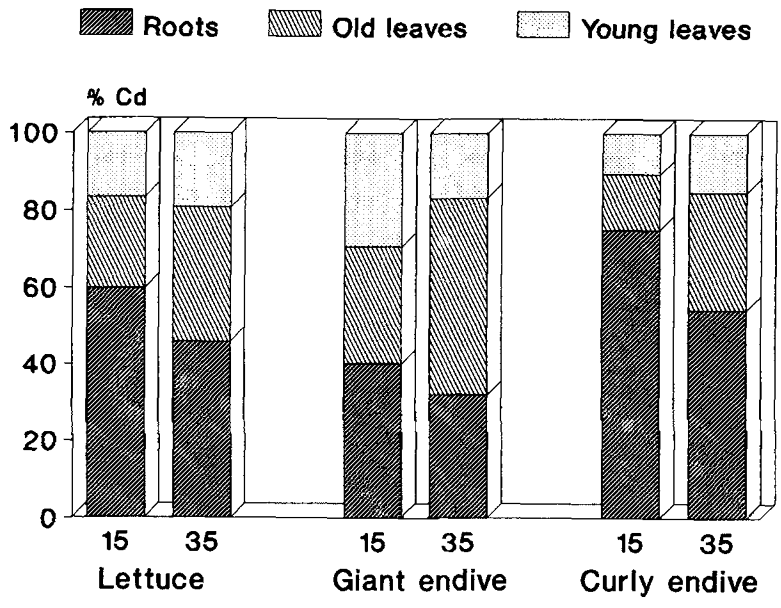

Figure 1. Percentage of Cd in each organ with respect to the total Cd in the plant for lettuce, giant endive and curly endive with 0.1 mg Cd·L^{-1} NS.

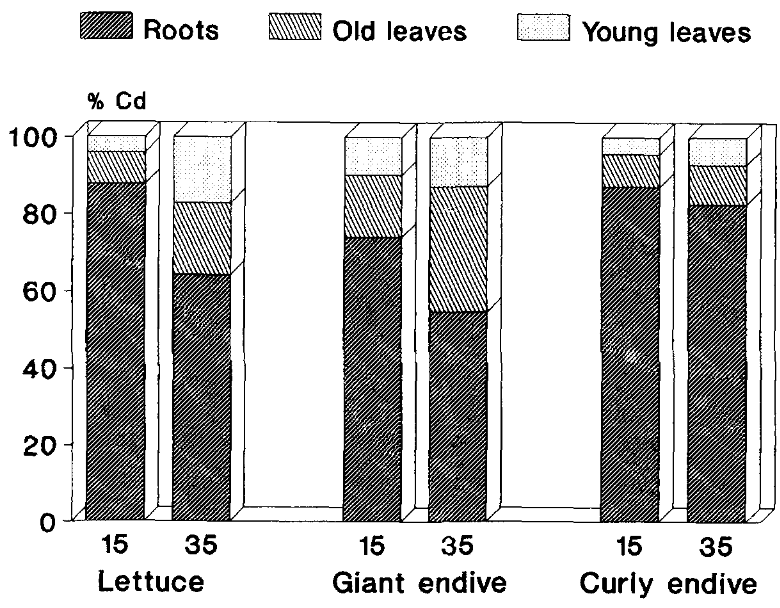

Figure 2. Percentage of Cd in each organ with respect to the total Cd in the plant for lettuce, giant endive and curly endive with 1.0 mg Cd·L^{-1} NS.

To study the distribution of the total absorbed Cd, the percentage of the Cd found in each of the plant organs was calculated with respect to the total Cd in the plant. The heavy metal accumulates in curly endive and lettuce roots after 15 days in the 0.1 mg $Cd \cdot L^{-1}$ NS (Fig. 1). Some 30% of the total available Cd is moved to the leaves. Giant endive presented a more uniform distribution of Cd among the three organs. After 35 days in the 0.1 mg $Cd \cdot L^{-1}$ NS some translocation of Cd from root to leaves is observed in all three species (Fig. 1). In giant endive most of the Cd accumulates in the old leaves.

No significative differences were detected in curly endive between sampling times in the 1.0 mg $Cd \cdot L^{-1}$ NS (Fig.2). However, after 15 days in the NS, most of the plant cadmium in lettuce and giant endive is located in the roots but by the second sampling time, a significant fraction of the Cd is located in the leaves.

In summary, Cd concentration among plant organs in lettuce and the two endives treated with Cd followed the sequence root> old leaves> young leaves. The process of Cd uptake is more efficient at the first sampling time and with the low Cd treatment for lettuce and giant endive but not curly endive. Although all three are cadmium accumulative species, the Cd concentration in the edible part of lettuce and giant endive is some 1.5 times that in curly endive.

REFERENCES

Barceló J, Poschenrieder Ch, Andreu I, Gunse B (1986) Cadmium- induced decrease of water stress resistance in bush bean plants (Phaseolus vulgaris L cv. Contender). I. Effects of Cd on water potential, relative water content and cell wall elasticity. J Plant Physiol 125: 17-25.

Cabot C, Poschenrieder Ch, Barceló J (1988) Efecto del cadmio sobre la fructificación en judía, en Nutrición mineral y su repercusión en la producción, calidad y fisiología de la postrecolección. Actas II Simposio Nacional sobre la Nutrición de las Plantas. Granada.

Cala V, Sanchidrian J, Gárate A (1988) Absorción de Cd por plantas hortícolas regadas con aguas contaminadas. III Congreso Nacional de la S.E.C.H: 261-266

Cataldo DA, Garland TR, Wildung RE (1983) Cadmium uptake kinetics in intact soybean plants. Plant Physiol 73: 844-848.

Davies BE (1980) Applied soil trace elements. J. Willey & Sons, New York., pp. 482.

FAO-EUROPEAN TRACE ELEMENTS NETWORK (1983) Influence of sludge and wastes products on trace elements inputs and environmental effects. Denmark.

Fujimoto T, Uchida Y (1979) Cadmium absorption by rice plants. I. Mode of the absorption. Soil Sci Plant Nutr 25:407-415.

Hewitt EJ, Smith TA (1975) Plant Mineral Nutrition. The English Universities Press. London.

K-Pendias A, Pendias H, (1984) Trace elements in soils and plants. CRC Press, Inc. pp. 315.

Poschenrieder Ch, Cabot C, Barceló J (1983) Influencia de altas concentraciones de cadmio sobre el crecimiento, desarrollo y contenido de pigmentos fotosintéticos de *Phaseolus vulgaris*. Anal Edaf Agrobiol 42(1-2):315-327.

Received June 30, 1992; accepted December 2, 1992.