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Lead concentration and allocation in vegetable crops grown in a soil contaminated by battery residues

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ABSTRACT

Lead (Pb) is a very stable metal in soil and is highly toxic to humans and animals. Exposure to Pb occurs via inhalation of particles from industry and soil, as well as household dust, water, and contaminated food. A greenhouse experiment was carried out to evaluate Pb contents and allocation in vegetable crops grown in a soil contaminated by battery recycling wastes. Eight plant species were studied: tomato, sweet pepper, beet, carrot, cabbage, green collards, eggplant, and okra. The experiment was set up in blocks at random with four replicates. The results showed that carrot, green collards, beet, and okra were the most Pb tolerant species, while the others were very Pb-sensitive, since they did not complete their cycle. The decreasing order for Pb accumulation in the vegetables crops was: carrot > okra > tomato > eggplant > sweet pepper > green collards > cabbage > beet. Taking into account the Pb allocation in plants, the order was: root > stems > leaves > edible parts. Although carrot translocated the lowest Pb amount into the edible part, such level exceeded the legal limit.

Keywords: Battery recycling, soil pollution, soil contamination, heavy metals.

RESUMO

Teores e alocação de chumbo em hortaliças cultivadas em solo contaminado por resíduos de baterias

O chumbo (Pb) é um elemento extremamente estável no solo e altamente tóxico para seres humanos e animais. A contaminação com chumbo geralmente ocorre pela exposição decorrente da inalação de partículas oriundas de indústrias ou do solo, ou ainda, pela ingestão de poeira doméstica, água e alimentos de origem animal e vegetal contaminados. O presente trabalho objetivou avaliar os teores e a alocação de Pb em hortaliças cultivadas em solo contaminado com resíduos de reciclagem de baterias. O experimento foi conduzido em casa-de-vegetação com delineamento experimental em blocos casualizados, com quatro repetições. Os tratamentos corresponderam a oito hortaliças: tomate, pimentão, beterraba, cenoura, repolho, couve manteiga, berinjela e quiabo. Os resultados mostraram que as espécies mais tolerantes ao Pb foram cenoura, couve-manteiga, beterraba e quiabo. As demais hortaliças foram consideradas muito sensíveis aos teores de Pb no solo, não completando inclusive seu ciclo biológico. A ordem decrescente de teores de Pb nas espécies foi: cenoura > quiabo > tomate > berinjela > pimentão > couve-manteiga > repolho > beterraba. A alocação do Pb na planta, seguiu a ordem geral: raiz > caule > folha > parte comestível. Embora a cenoura tenha transferido baixo teor de Pb para a parte comestível, o valor encontrado foi superior ao limite de tolerância máximo estabelecido na legislação.

Palavras-chave: Reciclagem de baterias, contaminação de solo, poluição do solo, metais pesados.

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Heavy metals occur naturally in soils, and some of these, such as copper (Cu), zinc (Zn), and cobalt (Co), play an important role in the nutrition of plants and animals, while others, such as cadmium (Cd), lead (Pb), and arsenic (As), have deleterious effects on various components of the biosphere. Normally, these elements are present in the soil at concentrations or forms that do not pose a risk to the environment (Silva *et al.*, 2007), but their levels can be altered by different anthropogenic routes.

Lead is an element that is extremely stable in soil and highly toxic to humans and animals (Reeder & Shapiro, 2003). The metal is classified as the second most dangerous on the priority list of the U.S. Environmental Protection Agency (ATSDR, 2008). This metal has evoked heightened concern due to its toxicity and high quantity in the environment, caused by its generalized utilization in various products (Segura-Muñoz *et al.*, 2006). The exposure to this element can occur by inhalation of particulate material emitted by industrial processes or by re-suspension after deposition in the soil, or even, through the ingestion of household dust, water, and foods of animal and plant origin produced in locations close to pollutant sources (Okada *et al.*, 2004).

Lead levels found in foods are greater in industrialized regions, especially those where the metal and its components are widely utilized. The preoccupation with lead effects on human health and the environment have led many countries to adopt laws restricting or prohibiting its utilization (Meyer *et al.*, 1999). However, developing countries are not in the vanguard of controlling lead use (Olivero-Verbel *et al.*, 2007). In view of the global scenario of lead utilization, it is estimated that the manufacture of batteries is responsible for about 70% of the lead consumed worldwide. The large worldwide growth in the automobile industry in the last decades (Paoliello & Chasin, 2001), as well as the expansion of the market for batteries, makes the use and recycling of batteries one of the principal forms of lead contamination in soils.

Lead can occur naturally in plants as a result of the processes of taking up the lead normally found in the soil. Lead forms and contents in vegetables vary greatly with the species and depend principally on the environmental conditions, because contaminated soils can induce lead accumulation by crops (Nan *et al.*, 2002). Lead accumulation by vegetable crops grown in soils with abnormally elevated levels of the metal poses a risk to human health. Therefore, the capacity of these plants to accumulate lead and its presence in edible parts should be evaluated.

Thus, the aim of the present work was to determine lead contents and allocation in vegetables cultivated in soil contaminated with residues from the recycling of batteries.

MATERIAL AND METHODS

The soil used in the study was a haplic podzol with sandy texture, collected out of an area naturally contaminated with lead (Pb), belonging to a company that recycles batteries. The soil was collected at the surface layer (0-20 cm), and was air-dried, broken up, homogenized, and sifted through a 2-mm mesh screen. Subsamples of the soil were separated for chemical and physical characterization (EMBRAPA, 1997, 1999). The results were: pH in H_2O= 3.89; P= 2.30 mg dm^{-3}; Na^{+}= 0.28 cmol$_c$ dm^{-3}; K^{+}= 0.05 cmol$_c$ dm^{-3}; Ca^{+2}+ Mg^{+2}= 5.50 cmol$_c$ dm^{-3}; Ca^{+2}= 0.90 cmol$_c$ dm^{-3}; Al^{+3}= 0.50 cmol$_c$ dm^{-3}; H+Al= 3.30 cmol$_c$ dm^{-3}; C.O.= 8.54 g kg^{-1}; organic matter= 14.73 g kg^{-1}; Pb= 413 mg kg^{-1}; sand= 943 g kg^{-1}; silt= 27 g kg^{-1}; and clay= 30 g kg^{-1}.

To determine the total Pb level, 10 ml of extracting solution (HCl:HNO_3, in a proportion of 3:1) were added to 1 g of soil, and the mixture was allowed to stand in a beaker covered with a watch glass for 16 h, at room temperature. After this period, the samples were heated for 2 h (80ºC), cooled, brought to 50 mL in a volumetric flask, and filtered (Pereira *et al.*, 2007). After filtering, the extracts were transferred to PET-type flasks, labeled, and kept at 4ºC in a refrigerator until read in an atomic absorption spectrophotometer.

The soil was incubated for 20 days with calcium carbonate and magnesium dioxide (3:1), to raise the pH to 6.5. Eight vegetable crops were studied: tomato (*Lycopersicum esculentum*), cultivar Rio Fuego; sweet pepper (*Capsicum annuum*), hybrid All Big; beet (*Beta vulgaris*), cultivar Itapuã 202; carrot (*Daucus carota*), cultivar Brasília; green collards (*Brassica oleracea* var. *acephala*), cultivar Georgia; cabbage (*Brassica oleracea* var. *capitata*), cultivar Coração-de-boi; eggplant (*Solanum melongena*), cultivar Embu; and okra (*Abelmoschus esculentus*), hybrid Dardo. Seedlings were produced in a greenhouse, in polystyrene foam trays, utilizing Vermicompost as substrate.

To set up the experiments, 5.5 kg of soil were transferred to a plastic pot and fertilized prior to sowing in accordance with Nascimento *et al.* (2006). Each pot corresponded to one experimental unit (plot). Twenty days after sowing, seedlings were transplanted to pots, and 15 days after, pots were thinned, leaving three plants per pot. During the study, the soil was kept at 80% of the maximum water retention, assessed by daily weighing and irrigation to replace the water lost by evapotranspiration. The experiments were carried out in a greenhouse, from January to April 2008, in blocks at random. Treatments corresponded to the eight vegetable crops, with four replications.

The plants were collected, separating roots, stems, leaves, and fruits. Plant parts were thoroughly washed with tap water and then with distilled water. The parts collected were placed in paper bags and set in an oven at 65-70ºC. The dry samples were weighed and then ground in a Wiley type mill. After, samples were submitted to nitroperchloric digestion (EMBRAPA, 1999) for assessing Pb levels in the extracts by atomic absorption spectrophotometry. Pb bioaccumulation rate in the plant, which represents the percentage of the element present in the dry biomass in relation to total content in the soil (Vyslouzilova *et al.* 2003), was calculated according the formula:

$$BR = \frac{Pb_{plant}}{Pb_{soil}} x\,100\ (\%)$$

Where

Pb_{plant} = concentration of Pb in the dry biomass collected (mg kg^{-1}); B_{plant} = total dry biomass collected (g); Pb_{soil} = concentration of total Pb in the soil (mg kg^{-1}); w_{soil} = total amount of soil in pot (g).

The translocation index (TI), in percentage, was calculated as the ratio between the amount of Pb accumulated in the aboveground part and the total amount in the whole plant (Abichequer & Bohnen, 1998). Data regarding Pb contents in the various parts of the crops studied were submitted to analysis of variance and the means were compared by the Scott & Knott test at 5% probability.

RESULTS AND DISCUSSION

The highest Pb concentration in roots was found in carrots, while green collards and cabbage showed the lowest level of Pb allocated in the root system (Table 1). Based on these results, carrots represent the crop with least biological restriction in absorbing Pb from the soil. The difference in the Pb concentration in roots among the plants analyzed was due to intrinsic characteristics of the crops. Similar results were observed by Al-Lahham *et al.* (2007), where two cultivars of tomato and their parts differed with respect to the capacity to accumulate heavy metals. This emphasizes the need for studies that indicate the differences in the preferential allocation of this metal in different crops and plant parts.

In examining the Pb contents in the various plant parts, it is evident that the highest Pb concentration is found in the roots in all the crops studied. Carrots

Table 1. Lead concentration in vegetable crops grown in Pb-contaminated soil (Concentração de chumbo nas hortaliças cultivadas em solo contaminado com Pb). Recife, UFRPE, 2009.

Crop	Pb Concentration (mg kg^{-1})			
	Root	Stem	Leaf	Edible part
Carrot	2.162.1 Aa	NA	25.4 Cb	54.6 Bb
Beet	NA	NA	40.3 Bb	108.3 Aa
Tomato	405.5 Ac	40.3 Bb	9.9 Cc	*
Sweet pepper	281.0 Ad	27.6 Bb	7.7 Cc	*
Green Collards	175.8 Ae	10.3 Bc	3.2Bc	3.2 Bc
Cabbage	152.5 Ae	23.3Bb	7.9Cc	*
Okra	757.2 Ab	133.5Ba	75.7Ca	5.2 Dc
Eggplant	389.4 Ac	37.9Bb	7.1Cc	*
CV (%)	11.95			

Means followed by the same capital letter in the row and small letter in the column do not differ significantly from each other, Scott & Knott test, $P < 0.05$. (Médias seguidas de mesma letra maiúscula nas colunas e minúscula nas linhas não diferem significativamente entre si, teste de Scott & Knott, $P < 0,05$).
NA = not applicable (não se aplica); * species that did not complete production cycle (espécies que não completaram o ciclo reprodutivo).

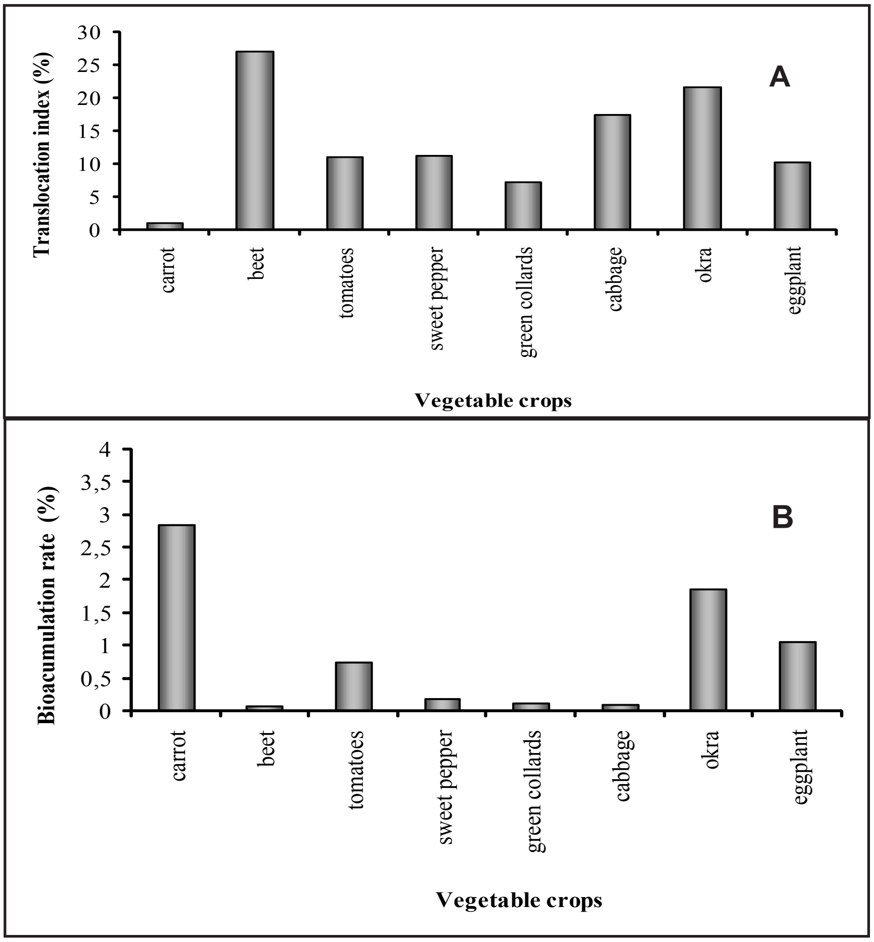

Figure 1. Translocation index (A) and bioaccumulation rate (B) of lead in vegetable crops grown in a contaminated soil. (Índice de translocação (A) e fator de bioacumulação (B) de chumbo em hortaliças cultivadas em solo contaminado). Recife, UFRPE, 2009.

accumulated the highest percentage (96.5%), followed by green collards (91.3%), eggplant (89.6), tomato (88.9%), sweet pepper (88.8%), cabbage (83.0%), and okra (77.9%). This finding corroborates the characteristic of Pb in accumulating preferentially in the roots. This metal moves in the root through the apoplast, crossing the cortex, and accumulating close to the endodermis, which acts as a partial barrier in Pb translocation to the aboveground part. This may be one of the reasons for the greater accumulation of this metal in the roots in relation to the aboveground part (Verma & Dubey, 2003). The high Pb concentration in roots can also be related to the immobilization of this element by insoluble organic polymers present in the root tissue (Kahle, 1993).

There was no significant difference between the crops studied regarding the Pb content in stems, except for okra and green collards which showed, respectively, the highest and lowest concentration. This result demonstrates that green collards is the crop that, proportionally, restricts more the allocation of Pb in the stem, which accumulated only 5.4% of the total absorbed by the plant.

The analysis of Pb contents in leaves showed that okra had the highest concentration, followed by carrot and beet, while tomato, pepper, green collards, cabbage, and eggplant concentrated the lowest Pb amounts. In comparing the Pb concentration in green collards leaves with the tolerable level of 0.3 mg kg^{-1} (Codex Alimentarius, 2008), it was found that the consumption of these leaves would pose a potential risk to human health.

On studying the edible parts of the vegetables, it is seen that beet has the highest level of Pb, followed by carrot, while green collards and okra accumulated the lowest Pb amounts (Table 1). All these Pb contents in the edible parts are above the tolerance limits established by the Codex Alimentarius (2008): carrot, beet, and okra, 0.1 mg kg^{-1}; and green collards, 0.3 mg kg^{-1}. Similar results were obtained by Okada *et al.* (2004) who showed that the Pb level in the soil caused an increase in Pb contents in the edible parts of tuber vegetables. It is worth noting that (1) the accumulation of Pb in the edible parts of plants represents a real risk to consumers, and (2) the analysis of the edible parts is definitely the most important to be carried out when human foods is taken into account.

Among the crops evaluated, carrot showed the highest bioaccumulation rate (2.85%). In carrots, little of the Pb absorbed was transferred to the aboveground part of the plant, thereby the remaining accumulated in the roots, as demonstrated by the low translocation index (1.15%) (Figure 1). On the other hand, among the crops studied, beet showed the lowest bioaccumulation rate (0.07%) and highest translocation index (27.02%), being the crop that least restricts Pb to the root. Sweet pepper, green collards, and cabbage showed a behavior that was similar among the three, with a low bioaccumulation rate when compared to tomato, okra, and eggplant.

In general, for all the crops studied, there was a very low bioaccumulation rate of the Pb present in the soil, due not only to the toxicity of this metal to the plants, but also to its inherent low solubility in the soil (Manecki *et al.*, 2006). However, the highest translocation index observed for some crops should be analyzed with caution due to the possibility of contamination of these vegetables.

Carrot, okra, beet, and green collards, even taking up Pb from the contaminated soil, completed the cycle without showing visible symptoms of phytotoxicity. It should be noted that the residue deposition in the soil, particularly discharges from the automobile battery industry, can result in metal bioaccumulation in the plant before any phytotoxicity symptom becomes visible (CETESB, 2008). This represents a concern, since vegetables with considerable Pb contents can be inadvertently consumed.

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