Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

CADMIUM ACCUMULATION IN SOME LEAFY VEGETABLES FROM PRIVATE GARDENS IN COPȘA MICĂ

Nicoleta Olimpia VRÎNCEANU, Dumitru Marian MOTELICĂ, Mihaela COSTEA, Bogdan OPREA, Georgiana PLOPEANU, Vera CARABULEA, Veronica TĂNASE, Mihaela PREDA

National Research and Development Institute for Soil Science, Agrochemistry and Environment, 61 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: veronica.tanase@icpa.ro

Abstract

Many previous studies have reported high levels of cadmium content in soils and vegetation from area affected by historical contamination in Copșa Mică area. Furthermore, cadmium can be slowly and consistently transferred from contaminated soils into food crops increasing Cd exposure to human beings in the long-term through the food chain. Regarding individual gardens from contaminated area, humans can be exposed via ingestion/inhalation of soil particles and consumption of contaminated vegetables. Therefore, this study attempts to quantify quality and safety of some leafy vegetables grown in individual gardens from contaminated area, Copșa Mică. The cadmium contents in leafy vegetables were positively correlated to total contents of cadmium in soil. Additionally, models were developed to predict the accumulation of Cd in different leafy vegetables (parsley, celery and lettuce) based on cadmium content in soils. The results of this study are important to estimate the Cd accumulation in vegetables from individual gardens, while also improving the safety of foodstuff produced in contaminated areas.

***Key words**: cadmium, accumulation, vegetables, Copsa Mica.*

INTRODUCTION

Vegetables constitute an important part of the human diet and in recent years, their consumption is increasing gradually, particularly due to the increased awareness on the food value of vegetable. Sometimes, they contain toxic elements over a wide range of concentrations (Bidar et al., 2020).

Heavy metals are one of the important types of contaminants that can be found on the surface and in the tissue of fresh vegetables. In order to protect public health, it is essential to keep contaminants at levels which are toxicologically acceptable, so Commission Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs.

Among heavy metals, Cd is highly toxic to plants and animals even at very low concentrations due to its non-essentiality in living organisms (Rizwan et al., 2016). Due to highly mobility in soil, cadmium can be slowly and consistently transferred from contaminated soils into food crops increasing Cd exposure to human beings in the long-term through the food chain (Liu et al., 2018). The high dose exposure to cadmium (Cd) by ingestion can cause severe stomach disease. Long-term exposure to low doses causes kidney disease, which damages the renal tubules and impedes the absorption of calcium (Ca), leading to brittle bones that are less resistant to breakage (Huang et al., 2021).

Therefore, the European Food Safety Authority adopted an opinion on cadmium in food and, in view of the toxic effects of cadmium the Authority established a tolerable weekly intake for cadmium of 2.5 μg/kg body weight. It also concluded that subgroups such as vegetarians, children, smokers and people living in highly contaminated areas may exceed the tolerable weekly intake by about 2-fold. As measure to achieve this target, the values limits for cadmium in some foodstuff were reduced according with Commission Regulation (EU) 2021/1323.

According with previous studies, a large number of national environmental agencies recommend investigating the environmental factors related to the plant Cd uptake (Swartjes et al., 2013; Augustsson et al., 2015) and despite of this recommendation there are few studies focused on this subject. Cadmium is one of the main contaminants that posed a risk to the health of the population in the area affected by pollution from most important factory for processing non-ferrous ores - Copșa Mică, Romania.

Local community can cease to cultivate of highly contaminated fields to avoid the harmful effects of cadmium on human health but there are still a lot of individual gardens where owners continue to use them for vegetables production. Since many communities rely on home gardens for dietary vegetable consumption, soil metal contamination is a concern for residents in close proximity to industrial emissions (Ferri et al., 2015; Kim et al., 2015; Bidar et al., 2020).

Data from previous studies indicates that vegetables could be classified according with their ability to accumulate heavy metals in edible parts, as follows: leafy/stem vegetables > root vegetables > tubercles > fruiting vegetables/fruits. Besides the vegetable species and cultivars, the cadmium uptake is also governed by the physico-chemical parameters of soils. The total cadmium content in soils is considered as a good predictor parameter on cadmium accumulation in vegetables.

Main leafy vegetables identified in studied area were lettuce, celery and parsley. A better understanding of the influences of Cd accumulation in leafy vegetables is critical to produce vegetables with low amounts of Cd.

Therefore, this study attempts to quantify quality of some leafy vegetables grown in individual gardens from contaminated area, Copșa Mică.

The study will provide a theoretical reference for a safe production of leafy vegetables in contaminated areas.

MATERIALS AND METHODS

The present study was carried out during 2019-2021 in one of the critical areas in terms of heavy metal contamination, Copșa Mică.

The studied area includes seven localities: Avente Sever, Agârbiciu, Soala, Micăsasa, Târnava, Copșa Mica and Bazna. This area presents the highest risk of interception of heavy metals through locally produced local food, due to the large abundance of agro-systems in the structure of local socio-ecological systems.

During this study were collected 55 soil samples, 55 parsley (*Petroselium crispum*), 45 celery (*Apium graveolens*) and 20 lettuce (*Latuca sativa*) samples from individual gardens located in contaminated area. Each soil sample was a mixture of 6 sub-samples that were collected from the surface soil (0-20cm). The corresponding leafy vegetables was a mixture of shoots and leaves from mature plants from each garden.

The soil samples were air-dried at room temperature and then crushed and sieved through 2 and 0.2 mm meshes, before storage and analysis.

The withered and decay tissues were removed from the leafy vegetables samples and then the edible parts were washed twice in tap water before being cut and frozen.

Soil pH was measured using the potentiometric method (1:2.5 w/v, soil: water). The soil organic carbon content (SOC) was determined on 0.2mm grounded soil samples using dichromate oxidation followed by titration with ferrous ammonium sulphate (Walkley and Black, 1934).

The available phosphorus and potassium in soil were extracted with ammonium acetate lactate (AL extractable) at pH 3.75 (Romanian Standard STAS 7184/19-82 based on the Egner-Riehm-Domingo method, Egner et al., 1960) and analysed by flame photometry (for potassium content) and UV/Vis spectrometry (for phosphorus content).

The pseudo-total concentration of Cd was determined only in the soil samples by atomic absorption spectrometry, after extraction by the aqua regia - microwave digestion method. Microwave digestion was performed using 10 mL of aqua regia (7.5 mL HCl and 2.5 mL HNO_3) at 140°C for 30 min, method developed according to SR ISO 11466:1999. A certified soil reference material (ERM–CC141) was used to ensure the accuracy of the analytical data. The average recovery value of Cd in the reference soil was 85%.

The vegetable samples were digested with nitric acid in a microwave digestion system. The metal content was measured using atomic absorption spectrometry (Flame GBC 932AA or Graphite furnace GBC SavanatAAZ).

Means of data were compared by least significant difference tests at $p < 0.05$. Linear regression analyses were performed using the statistical package STATISTICA CSS (Complete Statistical System by StatSoft, Tulsa, OK, USA).

RESULTS AND DISCUSSIONS

A summary of main soil chemical characteristics and metals contents are presented in Table 1. Soil pH ranged from slightly acid (pH 6.34) to slightly alkaline (pH 8.26) with mean pH value was 7.47.

Soil organic carbon (SOC) ranged from 1.47 to 3.92% with average value 2.44%, nitrogen content in soil ranged from 0.16 to 0.60% with average value 0.27%, levels of available phosphorus (P_{AL}) ranged from 67 mg kg^{-1} to 744 mg kg^{-1} with average value 379 mg kg^{-1} and K_{AL} contents ranged between 262 mg kg^{-1} and 1360 mg kg^{-1} with average content 615 mg kg^{-1}. Also, the average contents for Cd, Cu, Pb and Zn exceeds the alert thresholds for sensitive use of land (according with Order 756/1997). These soils have a great variability in their chemical parameters as well as the large range of multiple contaminations.

Table 1. Summary of soil properties and metals contents in soil

		Range of variation	Geometric mean	Median	Arithmetic mean
pH		6.34 - 8.26	7.46	7.58	7.47
Cd	mg/kg	0.10 - 35.81	2.77	4,92	6.03
Pb	mg/kg	19 - 952	117	133	171
Zn	mg/kg	124 - 1811	366	358	454
Cu	mg/kg	25 - 132	63	62	67
Mn	mg/kg	219 - 910	569	621	592
Organic C	%	1.47 - 3.92	2.37	2.35	2.44
Total N	%	0.16 - 0.60	0.26	0.26	0.27
Available P (PAL)	mg/kg	67 - 744	335	348	379
Available K (KAL)	mg/kg	262 - 1360	559	580	615

The high anthropization level and the diversity of cultivation practices have effects on the chemical parameters of soils collected from private gardens included in this study.

The different cultivation practices such as liming, organic fertilization or irrigation could explain the heterogeneity of the pH values (Scheromm, 2015).

The intense application of fertilizer increases the contents of nitrogen (N), phosphorus (P), and potassium (K) in garden soils. Similar results were reported by other studies regarding urban kitchen gardens (Burghardt et al., 2018; Joimel et al., 2016).

Total Cd in soils ranged from 0.10 to 35.8 mg kg^{-1} covering a range that has been classified as background levels to highly polluted soil.

The soil physico-chemical properties as pH, soil texture and depth of contamination, soil OM, salinity, potential redox, and nutrient status are known to be important factors that control the metals uptake in vegetables (Bidar et al., 2020).

The influence of these parameters on metals accumulation in vegetables can be assessed by using predictive approaches.

The soil-plant transfer model is the most used model for predict metal in vegetables. Bidar et al. (2020) considered that in this type of model, metal concentrations in plant tissues ($[M]_{plant}$) are often linked to total and extractable metal concentrations in soil ($[M]_{soil}$) by regression analysis using Freundlich-type equation (linear or log transformed data: $[M]_{plant} = 10^a\ [M]^b_{soil}$ or $\log [M]_{plant} = a + b \log[M]_{soil}$).

Therefore, in our study, the total cadmium content was used as variable to develop the stochastic models for estimating the cadmium content of leafy vegetables. The selection of this parameter was also based on the fact that it is the only indicator for which reference values are found in the regulations for assessing the degree of pollution (Order 756/1997).

According to log-log diagram (Figure 1), the parsley (leaf) plant accumulated high amounts of cadmium. The values of cadmium contents in parsley were correlated with total cadmium content in soil by means of a power regression equation.

For cadmium, the value of linear correlation coefficient (r = 0.373**), corresponding to linear form of the regression equation was significantly ($p<0.05$) indicating a good correlation between the cadmium content in parsley plant and the cadmium content in soil.

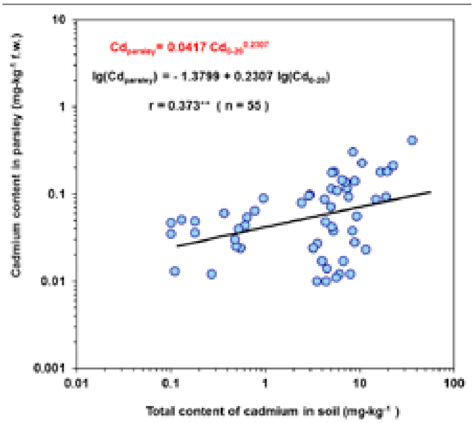

Figure 1. Log-log diagram for power regression curve that estimates the stochastic dependency between total cadmium content in soil and cadmium content in parsley (leaves)

According with EU Regulation 2021/1323, the maximum allowable value for cadmium for leafy vegetables is 0.10 mg kg^{-1}, except aromatic herbs. For aromatic herbs the maximum allowable limits is 0.20 mg kg^{-1} Cd reported to fresh material.

The cadmium content values in parsley plants collected during this study ranged between 0.010 mg kg^{-1} and 0.415 mg kg^{-1}. The high cadmium accumulation capacity of aromatic herbs, like parsley, was observed by other authors (Mihali et al., 2012; Säumel et al., 2012) in studies carried out in another contaminated areas.

In order to assess the quality of celery plants cultivated in individual gardens from studied area, 45 samples were collected. The cadmium content values in celery collected during this study ranged between 0.072 mg kg^{-1} and 3.424 mg kg^{-1}.

The Figure 2 presents the dependency of cadmium in edible parts of celery (leaf) on total cadmium content in soil.

The value of linear correlation coefficient (r = 0.724***), corresponding to linear form of the regression equation was highly significant indicating a very strong correlation between the cadmium content in celery plant and the cadmium content in soil.

Our results are in agreement with those of Xiao et al. (2018), who reported that total Cd in soil can be used to estimate soil-crop Cd transfer in celery plant.

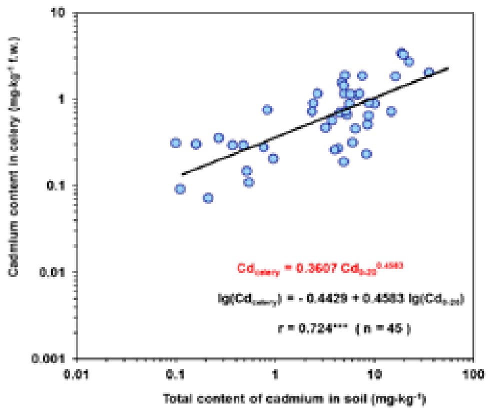

Figure 2. Log-log diagram for power regression curve that estimates the stochastic dependency between total cadmium content in soil and cadmium content in celery (leaves)

Celery potential to accumulate Cd was previously reported by Piekut et al. (2018) the authors observed a serious Cd contamination of agricultural soil and vegetables grown on that soil, where even 77% of analysed celery samples exceeded permissible level for Cd, while the same was recorded for only 14% of parsley samples. Based on plant growth associated with Cd accumulation, celery was considered as a hyper-tolerant species (Arsenov et al., 2021).

Lettuce is one of the most widely cultivated and consumed leafy vegetables worldwide (Bidar et al., 2020). According with these authors, lettuce has high capacity of accumulating cadmium.

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

In our study, the values of cadmium content in lettuce ranged between 0.015 mg kg^{-1} and 1.820 mg kg^{-1}. The dependency of cadmium content in lettuce on total cadmium content in soil is presented in Figure 3.

The value of linear correlation coefficient (r = 0.754***), corresponding to linear form of the regression equation was highly significant indicating a very strong correlation between the cadmium content in lettuce leaves and the cadmium content in soil.

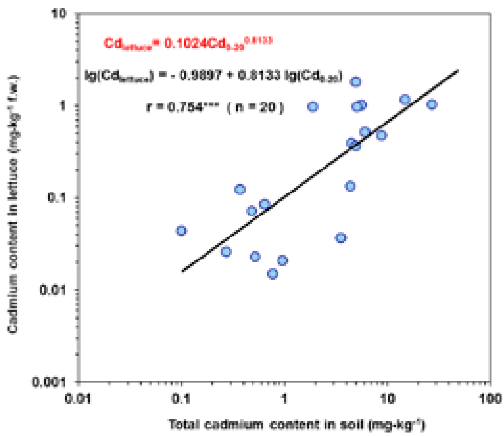

Figure 3. Log-log diagram for power regression curve that estimates the stochastic dependency between total cadmium content in soil and cadmium content in lettuce (leaves)

Similar results were reported by Tokalioğlu et al. (2006) in a study carried out in Turkish urban gardens.

The investigations relied on a large-scale field survey and the results indicated that all vegetables included in this study have high capacities to accumulate cadmium in edible parts. There were many vegetables collected from studied area whose cadmium concentrations exceeded the threshold values (0.10 mg kg^{-1}). Considering this, leafy vegetables ability to accumulate cadmium can be a problem when it comes to edible parts, since that can lead to misinterpretation that vegetables are healthy for human consumptions. Taking all that into account, metals transferring in soil-plant system, associate with food safety, became a major public concern all around the world (Sun & Zhang, 2020).

CONCLUSIONS

Gardening, which is a wide spread activity in studied area, could contribute to human exposure through the consumption of home-grown vegetables. Also, the consumption of self-produced vegetables is of great concern because these products are not subject to control of the metal concentrations unlike commercial foodstuff production, which is constrained to regulatory threshold values established by EC.

Besides the vegetable species, the cadmium uptake by vegetables is also governed by the physico-chemical parameters of soils. The total cadmium content of individual gardens soils is considered as a good predictor parameter on cadmium concentration in celery and lettuce leaves.

Using the regression equations developed during this study, cadmium accumulation in parsley, celery and lettuce were quantitatively predicted by the measurement of total cadmium content in soil.

The results of our study can be used in all contaminated areas where individual gardens exist, to ensure a comprehensive understanding of where potential hazards exist and how to reduce the risk on human health.

ACKNOWLEDGEMENTS

This work was supported by two grants of the Romanian Ministry of Research, Innovation and Digitization, project number PN 34.05.01 entitled: "Modeling the bioaccumulation of heavy metals in vegetables - a method used as scientific tool for development of a Good Practices Guide for growing vegetables in households in areas affected by industrial pollution" and project number 44 PFE /2021, Program 1 – Development of national research-development system, Subprogramme 1.2 – Institutional performance – RDI Excellence Financing Projects.

REFERENCES

Arsenov, D., Župunski, M., Pajević, S., Borišev, M., Nikolić, N., & Mimica-Dukić, N. (2021). Health assessment of medicinal herbs, celery and parsley related to cadmium soil pollution-potentially toxic elements (PTEs) accumulation, tolerance capacity and antioxidative response. *Environmental Geochemistry and Health, 43(8),* pp. 2927–2943. https://doi.org/10.1007/s10653-020-00805-x

Augustsson, A.L.M., Uddh-Söderberg, T.E., Hogmalm, K.J., Filipsson, M.E.M. (2015). Metal uptake by homegrown vegetables - the relative importance in human health risk assessments at contaminated sites. *Environmental Resources, 138*, pp. 181–190.

Bidar, G., Pelfrêne, A., Schwartz, C., Waterlot, C., Sahmer, K., Marot, F. & Douay, F. (2020). Urban kitchen gardens: Effect of the soil contamination and parameters on the trace element accumulation in vegetables – A review. *Science of the Total Environment, 738, 139569*

Burghardt,W., Heintz, D. & Hocke, N. (2018). Soil fertility characteristics and organic carbon stock in soils of vegetable gardens comparedwith surrounding arable land at the center of the urban and industrial area of Ruhr, Germany. *Eurasian Soil Science, 51 (9)*, pp. 1067–1079.

Ferri, R., Hashim, D., Smith, D. R., Guazzetti, S., Donna, F., Ferretti, E., Curatolo, M., Moneta, C., Beone, GM. & Lucchini, R. G. (2015). Metal contamination of home garden soils and cultivated vegetables in the province of Brescia, Italy: Implications for human exposure. *Science of The Total Environment, 518–519*, pp. 507–517

Huang, W-L., Chang, W.H., Cheng, S.F., Li, H.Y., & Chen, H.L. (2021), Potential Risk of Consuming Vegetables Planted in Soil with Copper and Cadmium and the Influence on Vegetable Antioxidant Activity. *Applied Sciences, 11, no. 9: 3761*. https://doi.org/10.3390/app11093761

Joimel, S., Cortet, J., Jolivet, C.C., Saby, N.P.A., Chenot, E.D., Branchu, P., Consalès, J.N., Lefort, C., Morel, J.L. & Schwartz, C. (2016). Physico-chemical characteristics of topsoil for contrasted forest, agricultural, urban and industrial land uses in France. *Science of the Total Environment, 545–546*, 40–47.

Kim, H.K., Jang, T.I., Kim, S.M. & Park, S.W. (2015). Impact of domestic wastewater irrigation on heavy metal contamination in soil and vegetables. *Environmental Earth Sciences, 73 (5)*, pp. 2377–238

Liu, C., Chang, C., Fei, Y., Li, F., Wang, Q., Zhai, G &Lei, J. (2018). Cadmium accumulation in edible flowering cabbages in the Pearl River Delta, China: Critical soil factor and enrichment models, *Environmental Pollution, 233*, pp. 880–888.

Mihali, C., Michnea, A., Oprea, G., Gogoaşa, I., Pop, C., Senilă, M. &Grigor, L. (2012). Trace element transfer from soil to vegetables around the lead smelter in Baia Mare, NW Romania. *Journal of Food, Agriculture and Environment*. 10 (1), pp. 828–834.

Piekut, A., Baranowska, R., Marchwińska-Wyrwał, E., Ćwieląg-Drabek, M., Hajok, I., Dziubanek, G., & Grochowska-Niedworok, E. (2018). Is the soil quality monitoring an effective tool in consumers' protection of agricultural crops from cadmium soil contamination?—A case of the Silesia region (Poland). *Environmental Monitoring and Assessment, 190*, 25.

Rizwan, M., Ali, S., Abbas, T., Zia-ur-Rehman, M., Hannan, F., Keller, C., Al-Wabel, M.I., & Ok, Y.S. (2016). Cadmium minimization in wheat: a critical review. *Ecotoxicol. Environ. Saf., 130*, pp. 43–53.

Säumel, I., Kotsyuk, I., Hölscher, M., Lenkereit, C.,Weber, F.& Kowarik, I. (2012). How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable crops from plantings within inner city neighbourhoods in Berlin, Germany. *Environmental Pollution, 165,* pp. 124–132.

Scheromm, P. (2015). Motivations and practices of gardeners in urban collective gardens: the case of Montpellier, *Urban Forestry & Urban Greening, 14*, pp. 735–742.

Sun, X., & ZhangJ, L. L. (2020). Spatial assessment models to evaluate human health risk associated to soil potentially toxic elements. Environmental Pollution. https://doi.org/10.1016/j.envpol.2020.115699.

Swartjes, F.A., Versluijs, K.W.& Otte, P.F. (2013). A tiered approach for the human health risk assessment for consumption of vegetables from with cadmium contaminated land in urban areas. *Environmental Resources, 126*, pp. 223–231.

Tokalioğlu, S., Kartal, S. & Gültekin, A. (2006). Investigation of heavy-metal uptake by vegetables growing in contaminated soils using the modified BCR sequential extraction method. International *Journal of Environmental Analytical Chemistry*, 86 (6), pp. 417–430.

Xiao, W., Ye, X., Zhang, Q., Che, D., Hu, J. & Gao, N. (2018). Evaluation of cadmium transfer from soil to leafy vegetables: Influencing factors, transfer models and indication of soil threshold contents, *Ecotoxicology and Environmental Safety,* 164, pp. 355–362.

***COMMISSION REGULATION (EU) 2021/1323 of 10 August 2021 amending Regulation (EC) No 1881/2006 as regards maximum levels of cadmium in certain foodstuffs