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Abstract: Comparative research has been carried out to determine the quantities and accumulation of lead (Pb), zinc (Zn), and cadmium (Cd) in the vegetative and reproductive organs of crops of the Solanaceae family (tomato, pepper, and aubergine) as well as to identify the possibilities of growing them on soils contaminated by heavy metals. The analyses were carried out by inductively coupled plasma–atomic emission spectrometry after dry ashing. Heavy metals have an impact on the development and productivity of the crops of the Solanaceae family. The high anthropogenic contamination impedes the normal development and fruit-bearing ability of the pepper and aubergine plants, and in the case of tomatoes, it led to an increased assimilation of heavy metals without reducing the yield and the quality of the production of tomatoes. Crops from the Solanaceae family, tomato, pepper, and aubergine plants, could be cultivated on soils having low and medium levels of contamination of heavy metals, because they do not show a tendency to accumulating Pb, Zn, and Cd in their fruits, which could still be used for consumption.

Keywords: Bioaccumulation, distribution, heavy metals, polluted soils, vegetable crops

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INTRODUCTION

Vegetables form an important part of healthy diets, and it is recommended that people consume considerable quantities of them (Cobb et al. 2000). However, there might be a risk to people's health if the vegetables are contaminated by heavy metals. Research studies have shown that most vegetables offered at the markets in Karachi, Pakistan, contain cadmium (Cd) in proportions of more than $0.05\,mg\,kg^{-1}$ (Parveen, Khuhro, and Rafiq 2003). Similar results have been obtained also by El-Sharnouby and Hoda (2003), who found that the contents of lead (Pb) and Cd in lettuce, tomatoes, peppers, cucumbers, and carrots, offered for consumption in Alexandria, Egypt, exceed the maximum permissible concentrations (MPC) recommended by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) (WHO 1973, 1978). According to the authors, washing the vegetables with water could reduce the contents of Pb and Cd up to 80% and 53%, respectively.

It is known that the ability of vegetable crops to assimilate heavy metals varies. The soil conditions and the type of plants affect the level of their absorption into the vegetable crops. The main soil factors having an impact on the mobility of these elements and the total content in the soil are the cation exchange capacity (CEC), pH of the soil solution, mechanical composition of the soil, humus content, and the interaction (competition) among them (Alloway 1995). According to Kádár (1995), the local characteristics such as type of soil, agricultural technology used, and climate are also of importance.

Many authors find a species-specific and variety-specific reaction in the assimilation and distribution of heavy metals. Based on those results, the authors have concluded that some species react sensitively to the changes in the content of cadmium (Cd) in the soil while others are not affected. For example, the increase of Cd content in soil the might cause both an intensive moving of Cd from the roots to the ground parts of the plants, as well as Cd retention in the roots. Particularly interesting is the fact that those species-specific differences are observed only in Cd, but they do not refer to the movement of zinc (Zn) and copper (Cu) (Becher, Worner, and Schubert 1997).

The type of contamination that is most often observed in vegetable crops is combined contamination by heavy metals: assimilation of the accumulated heavy metals (i) into the soil through the root system of the plants and (ii) through aerosols from the atmosphere on the surface of the leaves. The assimilation of these elements by plants depends mostly on their total contents in the soil and by the distribution along the soil profile, as well as the depth of penetration into the root systems of plants. In the case of a lack of aerosol contamination, a very small part of Pb assimilated by the roots moves to the stems (Yu, Wu, and Wang 1995). Most of Pb is retained by roots of vegetable crops, as only a small part moves to the stems and the least content is observed in the blossoms and seeds. However, this dependence does not relate to the leafy vegetables or to the vegetables with fluffy leaves, which assimilate Pb in an aerosol way. In this case, the content of Pb would depend on the aerosol contamination, as the greatest content of Pb is found in the fruit shells, stems, and leaves. Under the conditions of aerosol contamination, Cd could be assimilated both through the roots of the plants and through the plants' leaves and move into the plant, which is of significant importance in the case of growing the crops in regions characterized by aerosol contamination. According to Castaldy (2004), Pb and Cd enter tomato plants mainly through the roots (more than 95% for Pb and 85% for Cd); the assimilation of Pb through the leaves is insignificant (less than 5%) and for Cd is within 10–18%.

This shows the strong impact of heavy metals over the development of plants. Better understanding and the eventual control of this impact call for clarification of a number of issues related to enterance and the deposition of localized heavy metals in each agricultural crop.

In the present work, we aimed to carry out a comparative research study to determine quantities of Pb, Cu, Zn, and Cd in the vegetative and reproductive organs of crops of Solanaceae family (tomatoes, peppers, aubergines) as well as to identify the possibilities of growing the plants on soils contaminated by heavy metals.

MATERIALS AND METHODS

Soils

Soils used in this experiment were sampled from the area contaminated by the Non-Ferrous-Metal Works (KCM SA) near Plovdiv, Bulgaria. Soils were collected from the surface (0–20 cm deep) of fields located at different distances (0.1 and 15.0 km) from the NFMW. The investigated soils were characterized by alkaline reaction, moderate calcium carbonate content, loamy texture, and moderate content of organic matter (Table 1). The soil samples were air dried, homogenized in an agitate mortar, and sieved. A fraction with particle size < 1 mm was taken for analysis.

Plants

The research was carried out during the period 2003–2005. Vegetable crops of the Solanaceae family (tomatoes, *Lycopersicon esculentum*;

Table 1. Soil properties for soil sampled from the Non-Ferrous-Metal Works (NFMW) near Plovdiv

Classification	Distance from NFMW (km)	Depth (cm)	pH (H_2O)	Humus (%)	$CaCO_3$ (%)	Clay (%)
Calcaric	0.1	0–20	7.41	2.20	3.85	37.60
Alluvial soil		20–40	7.36	1.50	4.39	26.30
Calcaric	15.0	0–20	7.47	1.54	8.70	12.71
Alluvial soil		20–40	7.62	1.01	8.94	13.82

peppers, *Capsicum annuum*; and aubergines, *Solanum melongena*), grown in an industrially polluted region, were included in the research. The experimental plots were situated at different distances (0.1 and 15 km) from the source of pollution, the NFMW near Plovdiv. The field tests were set in blocks with four replications. The size of the test parcel was 25 m^2. The crops were grown after a wheat forecrop. Tomato cultivar 'Miljana,' pepper cultivar 'Sivrija 600,' and aubergine cultivar 'Patladjan 12' were utilized.

Tomatoes, peppers, and aubergines were planted in April in the following scheme: 80 cm × 30 cm for tomatoes, 60 cm × 15 cm for the peppers, and 100 cm × 60 cm for the aubergines. The plants were grown in accordance with standard technology. Ten plants from each replication were used in the analysis.

On reaching commercial ripeness, the vegetable crops of Solanaceae family were gathered and the contents of Pb, Zn, and Cd in their different parts (roots, stems, leaves, and fruits) were determined.

Heavy-Metal Analysis

Soils

Total contents of heavy metals in soils were determined after decomposing the soils by heating them in a sand bath heater for 3 h with 21 mL of concentrated hydrochloric acid (HCI) + 7 mL of concentrated nitric acid (HNO_3). After cooling, the soil was transferred into a 50-mL flask, and water was added to the mark (ISO 1995).

For extraction of the heavy metals, we used the following extractant: 0.005 M diethylentriaminepentaacetic acid (DTPA) + 0.1 M triethanolamine (TEA), pH 7.3 (ISO 2001). Soil samples were shaken for 2 h at 20 °C. After shaking, the soil–solution system was centrifuged and filtered. The ratio of soil to liquid was 1:2.

Plants

A 1-g sample was weighed into a quartz crucible and put into a furnace (T = 400 °C) until ashing had occurred. After cooling to room temperature, 1 mL HNO_3 (1:1) was added, evaporated in a sand bath, and put again into the furnace (T = 400 °C). The procedures were repeated until the ash was white. It was finally dissolved in 2 mL 20% HCl, transferred to a graduated 10-mL flask, and brought to volume with twice-distilled water.

Heavy-Metal Determination

To determine the heavy-metal content in the samples, inductively coupled emission spectrometry (Jobin Yvon Emission, JY 38 S, France) was used. The working wavelengths were as follows: Zn, 213.9 nm; Pb, 220.4 nm; and Cd, 214.4 nm. The detection limits were for Pb, 0.1 mg/L; Zn, 0.1 mg/L; and Cd, 0.02 mg/L. The calibration was performed using five aqueous standard solutions in 2% v/v HNO_3. A commercial multielement standard solution (Merck) with a concentration of 100 mg/L was used as a stock solution. The calibration standard solutions have the following concentrations: 0, 0.2, 0.5, 2.0, and 5.0 mg/L. The acidity of the standard and sample solutions was the same.

RESULTS AND DISCUSSION

Soils

The results given in Table 2 showed that with increasing distances from NFMW and with increasing the depth of the horizon, the total contents of heavy metals in the soil decreased. In the soil samples taken from the region situated 0.1 km from NFMW, the Pb values exceeded the

Table 2. Contents of Pb, Zn, and Cd (mg/kg) in soils sampled from NFMW (0.1 and 15.0 km)

Distance from NFMW (km)	Depth (cm)	Pb		Zn		Cd	
		Total	DTPA	Total	DTPA	Total	DTPA
0.1	0–20	913.5	194.3	1903.8	297.0	26.2	9.2
	20–40	724.8	167.7	1467.9	261.0	20.0	6.5
15.0	0–20	24.6	2.1	33.9	2.4	2.7	0.67
	20–40	22.7	1.9	31.9	2.2	2.5	0.60
	MPC[a]	80		340		2.5	

[a]MPC, maximum permissible concentration (approved for Bulgaria).

maximum permissible concentrations (80 mg/kg); 913.5 mg/kg in the 0 to 20-cm layer and 724.8 mg/kg in the 20 to 40-cm layer. In the region situated 15 km away, the contents of Pb decreased about 20 times, and there was almost no difference between the two horizons. Analogous results were obtained for Cd and Zn. In the immediate region of NFMW, the concentrations were 1903.8 mg/kg Zn and 26.2 mg/kg Cd, which exceeded the maximum permissible concentrations, whereas in the more distant region, concentrations were recorded as 33.9 mg/kg and 2.7 mg/kg Cd. With increasing depth of the soil horizon, the contents decreased more intensively (up to 1467.9 mg/kg Zn and 20.0 mg/kg Cd) than the more distant region, where the differences between the two horizons were not important.

Table 2 shows the results for the mobile forms of Pb, Zn, and Cd in the tested soils. The results for the mobile forms of the metals, established with DTPA, show that the mobile forms of Cd in the polluted soils constitute the biggest part of heavy-metal total content and varied from 32.5 to 35.1%, followed by Pb with 21.3 to 23.1% and Zn with 15.6 to 17.8%. In the nonpolluted soils, again the mobile forms of Cd constitute the biggest part of heavy-metal total content and reach up to 24.8%, followed by Zn with 10% and Pb with 8.5%.

Vegetable Crops

In Tables 3, 4, and 5, the contents of heavy metals in the studied vegetable crops are presented. Considerable differences in the distribution of the metals in the separate parts of the plants were ascertained. In all three elements, the greatest concentration was accumulated in the roots, and the quantity was reduced with the distance from the source of pollution, in conformity with results of other authors (Wahbi, Wided, and Ghorbel

Table 3. Content of Pb (mg/kg) in crops of Solanaceae family

Crop	Distance from NFMW (km)	Roots	Stems	Leaves	Fruits
Tomato	0.1	24.8	22.0	17.9	0.34
	15.0	1.6	1.6	2.7	nd[a]
Pepper	0.1	35.8	8.9	31.3	—
	15.0	0.6	0.6	1.5	0.25
Aubergine	0.1	6.6	5.0	26.5	—
	15.0	1.2	0.62	5.3	0.11
MPC[b]					0.5

[a]nd, not detected.

[b]MPC, maximum permissible concentration (approved for Bulgaria).

Table 4. Content of Zn (mg/kg) in crops of Solanaceae family

Crop	Distance from NFMW (km)	Roots	Stems	Leaves	Fruits
Tomato	0.1	88.3	76.1	32.5	2.9
	15.0	46.7	56.6	21.3	0.9
Pepper	0.1	101.6	21.7	55.2	—
	15.0	3.8	3.5	33.8	1.7
Aubergine	0.1	71.0	104.8	40.8	—
	15.0	48.4	71.7	35.9	1.6
MPC[a]					10

[a]MPC, maximum permissible concentration (approved for Bulgaria).

Table 5. Content of Cd (mg/kg) in crops of Solanaceae family

Crop	Distance from NFMW (km)	Roots	Stems	Leaves	Fruits
Tomato	0.1	2.5	1.7	2.4	0.13
	15.0	0.19	0.12	0.32	0.006
Pepper	0.1	3.8	1.9	1.5	—
	15.0	0.09	0.07	0.36	0.01
Aubergine	0.1	2.0	2.2	1.9	—
	15.0	0.14	0.19	0.23	0.02
MPC[a]					0.03

[a]MPC, maximum permissible concentration (approved for Bulgaria).

2002; Cintra et al. 2004). This was explained by the fact that on penetration in the plasma, inactivation and precipitation of considerable quantities of heavy metals take place, probably as a result of the formation of compounds with organic substances that decrease their mobility.

The greatest values were registered at the roots of the peppers, where Pb reached 35.8 mg/kg, Zn was 101.6 mg/kg, and Cd was 3.8 mg/kg. Lesser values were registered at the roots of the tomatoes, 24.8 mg/kg Pb, 88.3 mg/kg Zn, and 2.5 mg/kg Cd, and the least accumulation was at the roots of the aubergine: 6.6 mg/kg Pb, 71.0 mg/kg Zn, and 0.14 mg/kg Cd.

These results could be explained with the anatomic and biological peculiarities of the plants. The greater part of the heavy metals is fixed and accumulated in the roots of pepper, because the most of the root mass is located on the surface soil horizon. The lesser values, reported for tomatoes and aubergine, correlate with the deeper penetrating root system, reaching up to 50–60 cm.

The content of heavy metals in the roots of plants grown in the uncontaminated area is considerably smaller, varying from 0.6 mg/kg in pepper up to 1.6 mg/kg in tomatoes for Pb, from 3.8 mg/kg up to 46.7 mg/kg for Zn, and from 0.09 mg/kg up to 0.19 mg/kg for Cd. In this case, the results could be explained by the size and form of the root system. The smallest contents of Pb, Zn, and Cd have been found in peppers, which have root systems that are weaker and smaller in volume. The larger contents of those elements in tomatoes and aubergine were related to the well-developed root system, covering considerably larger quantities of soil.

The results obtained were in accordance with the results of Kloke (1979), which showed that most of the heavy metals were accumulated in the roots of tomatoes. The Cd content in the roots of tomatoes surpasses the Cd content in the fruits by 30 to 100 times. This could be explained by the processes of oxalate chelation and phytochelatine immobilization (Castaldy 2004).

The movement and accumulation of heavy metals in the vegetative organs of the studied crops differ both in terms of the crops and in terms of the concrete elements. The content of Pb in the stems of the plants grown in a contaminated area is significantly less than in the root system, which shows that movement along the conductive system is limited, especially in peppers. The contents of Zn and Cd in the stems of aubergine are more than in the root system, whereas in tomatoes and pepper the opposite tendency has been observed.

We should also mention that the absolute value of the accumulated metals in the stems varies widely and depends on the type of crop and the observed element. For example, the greatest levels of Zn and Cd contents were registered in the stems of aubergine plants, 104.8 mg/kg and 2.2 mg/kg, respectively, and the greatest level of Pb in tomatoes (22.0 mg/kg). The results could not be explained by the anatomical structure of the stems of the studied crops. The tomatoes and aubergine are characterized by a stem covered by pappus, while the stem of the pepper is smooth and ligneous. This shows that also in this case the dominant factor is the form and size of the root system, and the main part of the assimilated elements enters through the root system and not in an aerosol way. With the increase of the distance from the NFMW, a clear decrease in the content of heavy metals in the stems of the investigated crops was observed. The content of Pb varied from 0.60 mg/kg in peppers up to 1.60 mg/kg in tomatoes, Zn varied from 3.5 mg/kg in peppers to 71.7 mg/kg in aubergines, and Cd varied from 0.07 mg/kg in peppers up to 0.19 mg/kg in aubergines. These results are in accordance with the results of Kloke (1979) and Cintra et al. (2004), according to whom a considerable part of the heavy metals are accumulated in the stems of tomatoes.

The content of heavy metals in the leaves of the investigated crops grown in a contaminated area is less than in the root system. An exception is observed only in the case of Pb content in aubergines. In this case, again, the accumulation of metals in the leaves varies widely and depends on the type of the crop and the element observed. For example, the greatest levels of Pb and Zn contents were registered in the leaves of pepper plants, 31.3 mg/kg and 55.2 mg/kg, respectively, and the greatest level of Cd in tomatoes (2.4 mg/kg). Considerably lower levels were observed in the aubergine leaves: 26.5 mg/kg Pb, 40.8 mg/kg Zn, and 1.9 mg/kg Cd. These results cannot be related to the volume and form of the leaf mass. With an increase of distance from the NFMW, a clear decrease in the content of heavy metals in the leaves of the investigated crops was observed. The content of Pb varied from 1.5 mg/kg in peppers up to 5.3 mg/kg in aubergines, Zn varied from 21.3 mg/kg in tomatoes to 35.9 mg/kg in aubergines, and Cd varied from 0.23 mg/kg in aubergines up to 0.36 mg/kg in peppers. The contents of Pb, Zn, and Cd in the leaves of pepper, grown in an uncontaminated area, were considerably larger than the contents in the roots and stems. This tendency is not observed in the plants grown in a contaminated area. Obviously, under normal conditions, this crop has the tendency to accumulate selectively heavy metals in the leaf mass. A similar but less obvious tendency was observed in tomatoes and aubergines, regarding Pb and Cd, whereas regarding Zn the tendency is reverse.

The results have shown that it was difficult to give a definite answer regarding the accumulation tendencies of heavy metals in the vegetative and reproductive organs of the investigated crops. Obviously, these tendencies depend on the level of contamination of soils, as in some cases they could be completely opposite for plants grown in uncontaminated and highly contaminated areas. A good illustration of this conclusion was the distribution of Pb, Zn, and Cd in the organs of pepper plants grown under different conditions, as well as the distribution of Pb and Cd in tomatoes and Cd in aubergines. Another conclusion drawn was that the dominant factor in these extreme cases was the ability of roots and the conductive system to retain or transport the heavy metals that have been transferred into the plant. This also explains the fact that in the aubergines grown in a contaminated area, the contents of Pb, Zn, and Cd were less than or commensurable with the contents in the stems and leaves, whereas in the case of the other two crops the dependencies were more complex. This was also the reason for the discrepancies in parts of the results of Stefanov et al. (1995) and Hassan, Mandeel, and Nabi (2003), according to whom the major part of the heavy metals accumulates in the leaves of tomatoes and peppers. The content of heavy metals in the fruits is considerably less than in the roots, stems, and leaves. The results we have obtained agree with the results obtained by Secer et al. (2002), Badawy and El-Motaium (2003), Singh et al. (2004), and Cintra et al. (2004), according to whom the contents of Pb, Zn, Cu, Cd, iron (Fe), and chromium (Cr) were lowest in the fruits of tomatoes and pepper.

Tomatoes accumulate Pb and Cd to a lesser extent because they have well-constructed plant barriers, which prevents heavy metals from reaching the generative organs (Kloke 1979). The mechanisms of accumulation and tolerance of plants toward metals are related to intracellular and extracellular processes of chelation, precipitation, localization, and movement along the conductive tissues. These processes have not been yet fully clarified for most of the crops, including tomatoes (Maywald and Weigel 1997).

The content of Pb in tomatoes grown at a distance of 0.1 km from NFMW reaches up to 0.34 mg/kg, Zn reaches up to 2.90 mg/kg, and Cd reaches up to 0.13 mg/kg. The results demonstrated that in the fruits of tomatoes grown at a distance of 0.1 km from NFMW, the contents of Pb and Zn were under the MPC, whereas the content of Cd exceeded the maximum permissible concentrations of 0.03 mg/kg. It should be noted that pepper and aubergine plants grown at a distance of 0.1 km of NFMW did not bear fruits. The plants developed normally up to the phase of efflorescence and after that aborted the blossoms. With the increase of the distance away from NFMW, a clear tendency toward decreasing the content of heavy metals in the fruits of tomatoes was observed, where the content of Zn decreased up to 0.9 mg/kg, Cd decreased up to 0.006 mg/kg, and the content of Pb was less than the limits of detection of the apparatus. The greatest values were registered in the fruits of pepper plants grown at a distance of 15 km from NFMW, where Pb reached up to 0.25 mg/kg, Zn reached up to 1.70 mg/kg, and Cd reached up to 0.01 mg/kg. Lesser values were registered in the aubergine fruits: 0.11 mg/kg Pb, 1.60 mg/kg Zn, and 0.02 mg/kg Cd. Analogous results were obtained by Nordberg (1974) and Wolnik et al. (1985), in which the content of Cd in the fruits of the tomato plants grown on uncontaminated soils reached up to 0.02 mg/kg, the content of Zn reached up to 1.4 mg/kg (Wolnik et al. 1985), and Pb was less than the limits of detection up to 0.002 mg/kg (Montford et al. 1980; Wolnik et al. 1985). Heavy metals in the fruits most probably accumulated through the conductive system, and the accumulation was dependent mostly on the type of crop.

To confirm the conclusion drawn, an additional experiment with tomatoes, peppers, and aubergines planted at distances of 1.0 and 3.0 km from the source of contamination was conducted. Tables 6 and 7 present the results regarding Pb, Zn, and Cd contents in soils and investigated crops.

The results show that with lesser contents of heavy metals in the soil (421.3 mg/kg Pb, 670.1 mg/kg Zn, and 6.6 mg/kg Cd), the pepper and aubergine plants developed normally and did bear fruits; the content of Pb in the fruits varied from 0.12 mg/kg in tomatoes up to 0.22 mg/kg in peppers, Zn varied from 2.1 mg/kg up to 4.2 mg/kg, and Cd varied from

Table 6. Contents of Pb, Zn, and Cd (mg/kg) in soils sampled from the NFMW (1.0 and 3.0 km)

Distance from NFMW (km)	Depth (cm)	Pb		Zn		Cd	
		Total	DTPA	Total	DTPA	Total	DTPA
1.0	0–20	421.3	88.8	670.1	79.9	6.6	2.7
3.0	0–20	114.6	26.2	354.3	47.1	2.32	0.8
	MPC[a]	80		340		2.5	

[a]MPC, maximum permissible concentration (approved for Bulgaria).

Table 7. Contents of Pb, Zn, and Cd (mg/kg) in fruits of tomatoes, peppers, and aubergines grown in fields located at different distances (1.0 and 3.0 km) from the NFMW

Crop	Distance from NFMC (km)	Pb	Zn	Cd
Tomato	1.0	0.12	2.1	0.013
	3.0	0.07	1.6	0.002
Pepper	1.0	0.22	4.2	0.041
	3.0	0.11	3.3	0.004
Aubergine	1.0	0.15	3.0	0.032
	3.0	0.09	1.9	0.003
MPC[a]		0.5	10	0.05

[a]MPC, maximum permissible concentration (approved for Bulgaria).

0.013 mg/kg up to 0.041 mg/kg. The results clearly show that when growing tomato, pepper, and aubergine plants on low- and medium-contaminated soils, the content of heavy metals in the fruits was less than the MPC. Similar results were obtained by Ozores-Hampton, Stansly, and Obreza (2005), according to whom no heavy metals accumulate in the fruits of pepper plants (Cd, Cu, Pb, and Zn) when they were being grown on uncontaminated and low-contaminated soils. Loboda and Chuprikova (1999) and Bletsos, Gantidis, and Tsialtas (2001) found that the content of heavy metals in the fruits of pepper and aubergine plants was low and did not exceed the MPC.

The results show that tomato, pepper, and aubergine plants could be successfully grown on soils that have low to medium levels of contamination by heavy metals. The content of heavy metals in the fruits, in fact, does not depend on the aerosol contamination and on the content of those metals in the soil. A proof of that is the fact that the content of heavy metals in the fruits of the plants grown in uncontaminated soil is commensurable with that in plants grown in low- and medium-contaminated soils. Also, the fact that heavy metals do not affect the development of tomato, pepper, and aubergine plants when they were grown on medium-contaminated soils, as well as the quality and quantity of the obtained production, supports this conclusion. Similar results have been obtained by Kowalczyk, Borkowska-Burnecka, and Cieslak (2003), according to which the quality of the tomatoes does not depend on the content of Cd, Cr, Cu, Fe, manganese (Mn), nickel (Ni), Pb, and Zn in the soil.

According to Bojinova et al. (1994), tomatoes belong to the highly tolerant crops, which might be grown under conditions of high heavy-metal contamination and do not show a tendency of accumulating pollutants in the production. When those plants are grown on soils, which are highly contaminated by Pb and Cd, the content of the valuable secondary metabolites in their fruits (licopene, carotenoides, and phenols) does not decrease (Balba, Shibiny, and El-Khatib 1991). According to Tinker (1981), the good reserve of Ca in tomatoes makes them more resistant to the toxic effect of Pb, because the calcium compounds chelate Pb to biologically inactive compounds and impede its inclusion into the biochemical cycle of the plant. Similar results were also achieved by Zenk (1996) and Cobet (2000), which showed that tomatoes had a considerable resistance to Pb and Cd contamination of the soil. This induced tolerance is implemented through the following protective mechanisms, synthesis of metaltioneins (phytochelatines), and immobilization of Pb and Cd in the roots of the plant.

The distribution of the heavy metals in the organs of the plants that were grown in heavily polluted areas have selective character, which is specific for the different elements and crops, as follows: tomatoes (Pb and Zn) and pepper (Cd): roots > stems > leaves > fruits; tomatoes (Cd) and pepper (Pb and Zn): roots > leaves > stems > fruits; aubergine (Pb and Zn): leaves > roots > stems > fruits, and Cd: stems > roots > leaves > fruits.

The results show that there were significant differences in the assimilation of the heavy metals by the crops, which generally follow the order Zn > Pb > Cd. This order corresponds to the total contents of the elements in the soil: Zn > Pb > Cd, as well as to the amount of the quantity of their assimilated forms. This confirms the results obtained by Shraddha et al. (2004), which showed that in the tomato plants, the order of phytoaccessibility of the heavy metals is Zn > Cu > Ni > Cd > Pb and the mobility of these metals in the soil follows the order Cd > Zn > Cu > Ni > Pb.

There is a clearly defined species-specific feature in the accumulation of heavy metals in the vegetative and reproductive organs of different crops. Crops from the Solanaceae family could be divided into two groups according to their ability to accumulate and tolerate heavy metals: (i) medium tolerant (pepper, aubergine) and (ii) highly tolerant (tomatoes). Heavy metals have an impact on the development and productivity of the crops of the Solancae family. The high anthropogenic contamination impedes the normal development and fruit bearing of the pepper and aubergine plants, and in the case of tomatoes, it leads to an increased assimilation of heavy metals without reducing the yield and the quality of the production of tomatoes. The accumulation of Cd in the fruits of tomato plants, grown on highly contaminated soils, was in quantities considerably exceeding the MPC. This calls for a very careful approach in growing them under such conditions. Crops from the Solanaceae family, tomato, pepper, and aubergine plants, could be cultivated on soils having low and medium levels of contamination by heavy metals, because they do not show a tendency to accumulate Pb, Zn, and Cd in their fruits and could be used for consumption. However, periodic control of the production is necessary.

CONCLUSIONS

Based on the obtained results for the contents of heavy metals in the studied crops from family Solanaceae, the following conclusions can be made:

1. The phytoaccessibility of the heavy metals in all of the three crops follows the mobility of the elements in the soil: Cd > Zn > Pb.
2. There was a clearly defined species-specific feature in the accumulation of heavy metals into the vegetative and reproductive organs of different crops. Crops from Solanaceae family could be divided into two groups according to their ability to accumulate and tolerate heavy metals: (i) medium tolerant (pepper, aubergine) and (ii) highly tolerant (tomatoes).
3. The distribution of the heavy metals in the organs of the plants grown in the heavily polluted area have selective characteristics specific for the different elements and crops: tomatoes (Pb and Zn) and pepper (Cd): roots > stems > leaves > fruits; tomatoes (Cd) and pepper (Pb and Zn): roots > leaves > stems > fruits; aubergine (Pb and Zn): leaves > roots > stems > fruits, and Cd: stems > roots > leaves > fruits.
4. The distribution of heavy metals in the vegetative and reproductive organs of plants depends, to a great extent, on the species-specific difference, the element, and the level of contamination of soil, as in the extreme cases the tendencies could be completely opposite.
5. The crops from the Solanaceae family (tomatoes, pepper, and eggplant) could be grown on soils that are lightly to medium polluted with Pb, Zn, and Cd, as they do not accumulate these elements. On heavily polluted soils (Pb 913.5 mg/kg, Zn 1903.8 mg/kg, Cd 26.2 mg/kg), however, the growth of tomatoes should not be allowed, as the accumulation of Cd in the fruits exceeds the MPC.

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