

Researches on the accumulation and transfer of heavy metals in the soil in tomatoes - *Solanum lycopersicum*

Mihaela Nițu¹, Augustina Pruteanu^{1,*}, Despina Maria Bordean^{1,2)}, Carmen Popescu^{4,5)}, Gyorgy Deak⁶⁾, Mădălina Boboc⁶⁾ and Gabriel Mustățea³⁾

¹ INMA National Institute of Research - Development for Machines and Installations designed to Agriculture and Food Industry, Bucharest

² USAMVBT Banat's University of Agricultural Sciences and Veterinary Medicine "King Mihai I of Romania", Timisoara

³ IBA National Institute of Research and Development for Food Bioresources, Bucharest

⁴ S.C. HOFIGAL Export Import S.A.

⁵ Faculty of Medicine, Pharmacy and Medical Dentistry, "Vasile Goldiș" Western University, Arad

⁶ INCDPM National Institute for Research and Development in Environmental Protection, Bucharest

Abstract. Heavy metals in contaminated soils have benefited from a considerable attention due to the possible risks for the human body.

The current study has investigated the accumulation and transfer coefficient for three heavy metals (Cu, Pb, Zn) found in the contaminated soil with three concentrations (c1=1.5%, c2=3.0%, c3=4.5%, c4=6.0%), obtained by mixing the three metals, in the tomato fruit. The highest accumulation in the tomato fruits was recorded for zinc, then copper and the smallest for lead, for all four concentrations used. The transfer coefficient decreases as the concentration of heavy metals increases, so that for high heavy metals concentrations, the values of the transfer coefficient are very low, and for small heavy metals concentrations in the soil, the values for the transfer coefficient are higher.

The assessment of accumulation and transfer of heavy metals in the fruits of tomatoes grown in the contaminated soil has concluded that all concentrations of the copper, lead and zinc mix have shown a low risk for human consumption.

Key words: Heavy metals, tomato, contamination, pollution

1 Introduction

Environmental pollution has become one of the most debated issues of contemporary times. One of the current problems of mankind is the accumulation of heavy metals in agricultural soils. The harmful metals in the soil can come from the base rock, from solid or liquid waste landfills, agricultural inputs and industrial and urban emissions. This accumulation of heavy metals determines the contamination of agricultural soils, having consequences on food quality and safety [1, 2].

* Corresponding author: pruteanu_augustina@yahoo.com

Fruits and vegetables are an important component of food, with input of carbohydrates, proteins, vitamins, minerals and fibers indispensable to human health [3].

Also, being are the most exposed to environmental pollution due to airborne load, they represent the major source of toxic metal intake by human beings. They accumulate heavy metals in their edible and inedible parts and can cause various dysfunctions to humans [4].

Good functioning of the human body is also due to the presence of heavy metals in a small amount, but a large amount of heavy metals present in the body can lead to the appearance of certain diseases. Some metals present in fruits and vegetables are biochemically and psychologically important for health but, without exceeding the recommended concentrations, when they can cause metabolic disturbances [5, 6].

In this respect, information on heavy metal concentrations in fruits and vegetables, as well as their nutritional input are essential for assessing the health risk for beings [7].

In paper [8] was shown that almost half of the average intake of Pb, Cd and Hg through ingestion of food is owed to plant category (vegetables, fruit and cereals). Therefore, vegetarians, through the high consumption of fruits and vegetables, which can be contaminated with metals, are most exposed to exceeding the tolerable daily intake.

Also, in paper [9], was analyzed and evaluated both concentrations of heavy metals in the soil and the fruit of tomato. Plants were grown in places with soils contaminated with metals, and the results showed that there was a large transfer of soil metals into the plants. All sites studied had Fe, Cr in small amount and Pb, Zn, Cu in larger quantity.

In paper [10], the authors analysed the toxic heavy metals from irrigation water, soil and vegetative parts of tomato plants. In irrigation water and in soil were found elements such as Cu, Pb, Cr, Fe, Mn, Na, K, Ca and Mg, and Zn. The results of analysis have indicated that toxic metals Fe, Pb, Co, Cr, Mn, Zn and Cu are accumulated in the roots of tomato plants. The most toxic metal, Pb, was found in the roots and in the stalks of tomatoes. Fe was accumulate in all vegetative parts of the tomato plant and in tomato fruit, were found of Zn, Mn, Cr, Pb and Cu. Also, tomato (*Solanum lycopersicum*) seeds were planted and grown in pots in greenhouse under optimum conditions.

Paper [11] analyses the ability of cereals and vegetables to absorb potentially toxic heavy metals from the sludge treatment – soil system. It was found that cereals and vegetables accumulate less Cd in the leaves compared to the strains, and tomatoes, accumulate more Mn, even than barley or beans. Also, a high iron content was observed in the soil, the other elements being within normal limits. The highest transfer factor values were determined for iron, copper and lead having low values.

In paper [6], an investigation was conducted to determine the toxic concentration of heavy metals in wastewater, irrigated soil, their cumulation in vegetables and the potential risks for human illness. The researches showed that the concentration of Cr in residual waters, Cd, Zn in soil and plants was found well above the tolerable doses. The Health Risk Index (HRI) was found to be > 1 for Pb in okra (*Abelmoschus esculentus*), while the remainder of the heavy metals (Cr, Cd, Ni and Zn) were marked with less than 1 indicating the relative absence of ingestion risk for the vegetables. The study suggested that even low concentrations of heavy metals in wastewater pose risks to human health through accumulation over a longer period of time.

In Romania, the authors of paper [12] studied the concentration of six heavy metals (Zn, Cu, Pb, Ni, Cd and Cr) in a few vegetables (potato, onion, garlic, carrot, parsley, and beans) grown in the gardens of inhabitants of the Ferneziu neighbourhood in the Baia Mare mining area (NW Romania) to characterize the transfer of heavy metals from the soil into vegetables.

Concentrations of heavy metals varied among the investigated vegetables (potato, onion, garlic, carrot, parsley, salad, tomato and beans) grown in the gardens of the inhabitants due to their different absorption capacity. The total fraction of heavy metals in the soil followed the

Zn> Pb> Cu> Ni> Cr> Cd sequence, the results showing that Cd, Zn and Ni had the highest transfer factor.

The transfer of heavy metals from contaminated soil to plants is the main route of human exposure to metal contamination. This work investigated the accumulation and the transfer coefficient of three heavy metals (Cu, Pb, Zn) with four concentrations (c1 = 1.5%, c2 = 3.0%, c3 = 4.5%, c4 = 6.0%) obtained by mixing the three metals, from the contaminated soil in the tomato fruit.

2 Material and method

In the paper, the tomato fruit was studied to identify the levels of heavy metals absorbed during plant growth after planting them in agricultural soils contaminated with mixtures of heavy metals (copper, zinc and lead) at different concentrations.

Six kg of soil was mixed with 60 ml of copper, zinc and lead solution in equal proportions for each concentration: 1.5%, 3.0%, 4.5% and 6.0%. To obtain the mixtures of solutions with Cu, Pb, Zn for each of the concentrations of 1.5, 3.0, 4.5 and 6.0% individually prepared, equal parts were taken from each solution, element and concentration, and mixed until homogeneous, thus resulting the mixture. For each concentration of the mixture of Cu, Zn, Pb, the contaminated soil was divided into three pots (3 repetitions) in which a seedling of tomato was planted. Heavy metal loading was performed only by initial loading without supplementing until harvest.

The reference samples consisted in planting three tomato seedlings in three different pots, adding uncontaminated soil (fertile soil). During experimental research, the plants were watered weekly to maintain soil moisture and implicitly plant growth.

2.1 Soil samples

Basic properties of the farmland soil under study were: pH 6.0; total nitrogen 1.9 %, total phosphorus 0.5%, total potassium 0.9%, electrical conductivity 1.2, particle elements of over 20 mm maximum 5%, moisture 14.7% [13].

2.2 Plant material

For this study, tomato (*Solanum lycopersicum*) was chosen as research material (Figure 1) because it is a nutrient-rich fruit.

Tomato, scientifically called *Solanum lycopersicum*, is a plant of the Solanaceae family, genetically close to the line of pepper, potato, eggplant and physalis alkekengi. It is a perennial plant, cultivated at almost all latitudes, often grown in temperate climates as an annual plant, often reaching 1 to 3 m in height, with a grassy stem, growing like any creeping plant, on the stems of other plants, on sticks or fences. The leaves of the plant are 10-25 cm long, pen-composite in shape, both the stem and the small branches, respectively the leaves being covered with animal hair-like excrescences. Flowers are small, about 1-2 cm. Tomato has an acidic pH of 5.5. From a botanical point of view, tomato is a fruit [14].



Fig. 1. Tomato (*Solanum lycopersicum*).

2.3 Determination of heavy metals in the contaminated soil

The farmland soil is contaminated with mixture of heavy metals (Pb, Cu, Zn) in this study, with four concentrations.

The method by which the heavy metals (Cu, Zn, Pb) from soil samples (uncontaminated, contaminated with mixtures solutions of 1.5 %, 3.0 %, 4.5 % and 6.0 % concentration) was represented by x-ray fluorescence analysis.

An x-ray fluorescence (XRF) spectrometer was used, measuring the peak line emission was obtained a value, which represented the concentration of the analyte. The concentration of the sample to be analysed was correlated with the net measured value [13].

2.4 Determination of heavy metals in tomatoes (fruit)

The plant samples were dried (60° C, 72 h), grinded and then were digested with nitric acid (65 %) in a microwave digestion system as follow:

-weigh 300 mg of the sample into the digestion vessel and add 7.5 ml of nitric acid.

-heat in the microwave oven with the following program.

- First step: T 150° C, power (%) – 50, time - 5 min.
- Second step: T 190° C, power (%) – 70, time 5 min.

The metal content was measured using a flame atomic absorption spectrometry (FAAS, GBC 932AA or GFAAS, GBC Savant AAZ) [15].

2.5 Transfer Coefficients of system Soil-Plant

The transfer factor is an important parameter for soil and plant. Transfer coefficient values show both the biological availability of plants to absorb more or less heavy metal and the amount of metal retained by the soil. Low transfer coefficients indicate that the metals are sown in soil colloids, and high transfer coefficients show the presence of large metals in a particular plant species and indicate that the plant can be successfully used in soil remediation [9].

Due to the fact that plants have the capacity to accumulate metals in the soil, the ratio between metal concentration in the plant and in the soil was measured. Using equation (1) [16], the transfer coefficient (tf) was determined.

$$tf = \frac{\text{heavy metal concentration in plant}}{\text{heavy metal concentration in soil}} \quad (1)$$

The value of a transfer factor of 0.1 indicates that the plant excludes metal from its tissues, while the value of a transfer coefficient of 0.2 indicates the pollution plant through human activities [17], and therefore environmental monitoring is necessary [18].

3 Results and discussions

In fig. 2, 3 and 4 are shown the average values of the results of the three repetitions on the content of metals (Cu, Pb, Zn) from soil samples (mg / kg) contaminated with mixed solutions of different concentrations (1.5%, 3.0%, 4.5%, 6.0%).

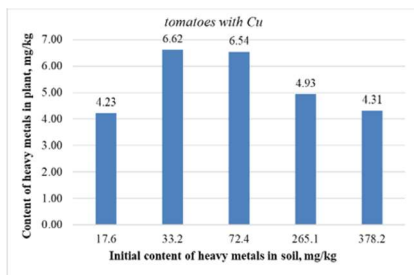


Fig. 2. Concentrations of heavy metals (Cu) in soil and in plant.

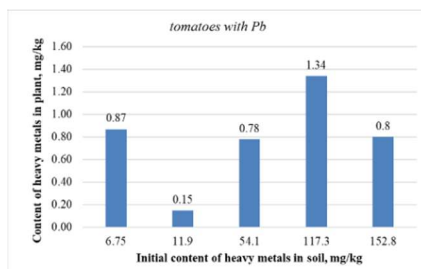


Fig. 3. Concentrations of heavy metals (Pb) in soil and in plant.

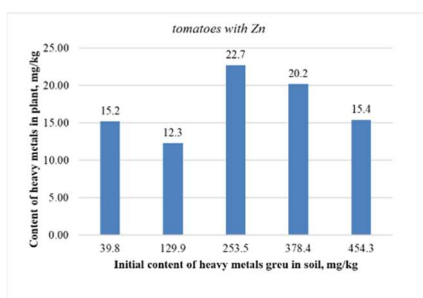


Fig. 4. Concentrations of heavy metals (Zn) in soil and in plant.

Analysing figures 2, 3 and 4 with the content of heavy metals in the soil and their transfer into plants (fruit), the following are observed:

- in case of Cu, the content drops in the fruit as the soil content increases;
- in the case of Pb, the content is progressively increased in fruit for the first three concentrations of 1.5% (11.9 mg / kg), 3% (54.1 mg / kg) and 4.5% (117.3 mg / kg). At the maximum concentration of 6% (152.8 mg / kg) in soil, the Pb content decreases in fruit;
- for Zn, the 3% concentration in soil (253.5 mg / kg) is maximal in fruit (22.7 mg / kg). For the other Zn concentrations in the soil, the quantity found in the fruit is lower;
- for uncontaminated soil (control sample), it is found that there are quantities present in the fruit for each of the three metals. It was therefore found that at the highest concentration (6%), for each of the three metals, their content in the tomato fruit tends to have values approximately equal to those in the fruit grown in the uncontaminated soil.

Using the numerical data from the experiments and represented graphically in figures 2, 3, 4, the interpolation of the metal mixture data into the tomato fruit was performed.

$$Cp = (C_{Cup}, C_{Pbp}, C_{Znp}) \quad (2)$$

$$Cp = (C_{Cup}(C_{Cus}, C_{Pbs}, C_{Zns}), C_{Pbp}(C_{Cus}, C_{Pbs}, C_{Zns}), C_{Znp}(C_{Cus}, C_{Pbs}, C_{Zns})) \quad (3)$$

where, C_p - Cu, Zn, Pb mixture content on the plant; C_{Cup} - Cu content in the plant; C_{Pbp} - Pb content in the plant; C_{Znp} - Zn content in the plant; C_{Cus} - Cu in the soil; C_{Pbs} - Pb content in the soil; C_{Zns} - Zn in the soil.

The linear regression corresponding to this data set will take the form:

$$C_{Cup} = \alpha_{Cup} + \beta_{Cup}C_{Cus} + \gamma_{Cup}C_{Pbs} + \theta_{Cup}C_{Zns} \quad (4)$$

$$C_{Pbp} = \alpha_{Pbp} + \beta_{Pbp}C_{Cus} + \gamma_{Pbp}C_{Pbs} + \theta_{Pbp}C_{Zns} \quad (5)$$

$$C_{Znp} = \alpha_{Znp} + \beta_{Znp}C_{Cus} + \gamma_{Znp}C_{Pbs} + \theta_{Znp}C_{Zns} \quad (6)$$

Table 1 - Coefficients of the interpolation data for tomato fruits

Function Coefficients					
α_{Cup}	3.57	α_{Pbp}	1.097	α_{Znp}	16.094
β_{Cup}	$3.632 \cdot 10^{-3}$	β_{Pbp}	-0.012	β_{Znp}	-0.166
γ_{Cup}	-0.098	γ_{Pbp}	0.058	γ_{Znp}	0.514
θ_{Cup}	0.032	θ_{Pbp}	$-9.766 \cdot 10^{-3}$	θ_{Znp}	-0.035

where, α , β , γ , θ - function coefficients for Cu, Pb and Zn in the plant.

Due to the fact that the data in figures 2, 3 and 4 does not have linear distributions, many of the values taken from outside the interpolation points have negative values.

The results regarding the transfer factor (tf) of the metals in the soil in the tomato fruit are graphically represented in figures 5, 6 and 7.

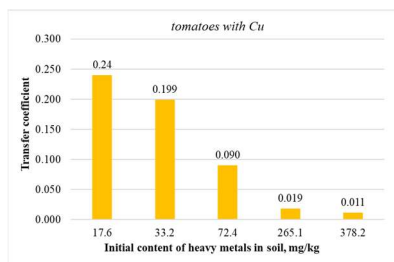


Fig. 5. The transfer coefficient of Cu in tomato fruit.

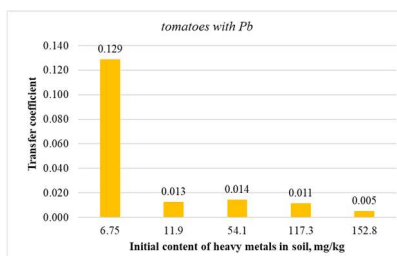


Fig. 6. The transfer coefficient of Pb in tomato fruit.

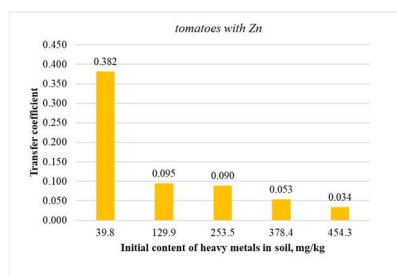


Fig. 7. The transfer coefficient of Zn in tomato fruit.

From figures 5, 6 and 7 it is observed that heavy metals found in tomato fruits grown in contaminated soil at different concentrations show a decrease in the heavy metal transfer coefficient from the soil to the plant along with an increase of the initial heavy metal concentrations in the soil.

Therefore, for tomatoes, the bioaccumulation is even weaker as the initial heavy metal concentration in the soil is higher.

4 Conclusions

As a result of the experimental results obtained after soil contamination with heavy metals and their absorption by the plants, the following conclusions were drawn:

- the most absorbed metal was zinc, regardless the concentration, then copper and the least lead;
- the transfer factor is biggest for Cu, followed by Zn and has a fairly low value for Pb;
- a tendency of increase of the final heavy metal content was noticed in the tomato fruit and a decrease of the transfer coefficient of heavy metal in the fruit at the end of the vegetation period;
- because vegetables are known to intake and accumulate traces of heavy metals from the contaminated soil, the detection in tomato leaves was not surprising.

Results obtained for *Solanum lycopersicum* show that the experiments and statistical models can provide the basis for the construction of dynamic mathematical models that can simulate the life of the plant.

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