SOIL-TO-PLANT BIO-ACCUMULATION FACTOR AS INDICATOR OF TRACE METAL IMPLEMENTATION INTO THE FOOD CHAIN

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Abstract: The content and behaviour of metals in agricultural soils are very important for food safety. The results presented in this paper are part of a great research that includes monitoring of the parameters in the soil and plant at the site of the largest power plant in Serbia. Part of the study presented in this paper investigates soil contamination with Cd and Zn and their translocation to edible parts of spelt (*Triticum spelta* L.) with calculation of bio-accumulation factor (BAF). Spelt is well adapted to marginal lands and present healthy attractive crop which better absorb nutrients from soil comparing to common wheat. Oppositely to common wheat its grains have high protein content but a low Cd content. The DTPA-extractable BAF values of Zn for almost every crop were higher than those for Cd, indicating that Zn is more easily translocated into the plant from soil than Cd. BAF indicates possibility of toxic metal implementation into the food chain. Comparing to previous research, studied spelt showed a high translocation of Zn and Cd from the soil to the edible part of plant, even though the concentration of Zn and Cd in soil were below the threshold limit for agricultural soils.

Key words: soil contamination, cadmium, zinc, food safety, bio-accumulation factor

1. INTRODUCTION

Toxic metals are natural constituents of every compartment of the environment. They take part in bio-geochemical reactions and they are transported between compartments by natural processes. Typical concentrations in the soil solution of uncontaminated soils are in the order of micrograms per litre (Kabata-Pendias, 2004). As such, they generally pose no risk to agricultural production. Nevertheless, recent researches have shown that soils in different parts of the world, particularly in urban and industrial regions, contain enormously high concentrations of toxic metals (Cui et al., 2004; Duong & Lee, 2011; Wei & Yang, 2010; Bošković-Rakočević et al., 2014).

Persistence of pollutants in soils is considerably higher than in other parts of the biosphere and toxic metals soil contamination is practically permanent (Kabata-Pendias, 2011). A number of metals (Fe, Mn, Cu, Zn and Co) are required in small amounts for normal growth and development of plants, but in high concentrations they are toxic to plants. However, many metals as Pb, Cd, Ni, and Cr, are not necessary for the nutrition of plants and they are considered as toxic metals (Alloway, 1995).

The content and behaviour of metals (both essential and toxic) in agricultural soils are of great importance for quality of safe food production (Surdyk et al., 2010).

Even at low doses cadmium is toxic to humans, animals, and plants (Wagner, 1993). Cd presented in the soil is easily absorbed by roots and translocated to the edible plant parts - because of their wide consumption, cereal products are major sources of Cd exposure in humans and animals (Ryan et al., 1982). The European Commission has recommended that Cd levels in food need to be reduced (European Union, 2014). Therefore, developing strategies to decrease Cd concentrations in crops is a public health priority.

Zinc contamination of soils is relatively common. Anthropogenic Zn sources are related to several industrial processes and agricultural practices. There is still a disagreement whether Zn

uptake is an active or a passive process. It is most probably that both processes may occur, depending on both soils and plants. However, there are many suggestions that Zn uptake is mostly metabolically controlled. In general, Zn is the most easily adsorbed and transported metal within plants, compared with other trace metals (Kabata-Pendias, 2011).

Spelt (*Triticum spelta* L.) is one of several species and numerous varieties of wheat, with a long history of cultivation (since 5000 BC). In the middle of the twentieth century it was replaced with more productive genotype of other varieties of wheat, but its cultivation started in highland of north Europe and later continued in other part of Europe, in Serbia as well (Glamočlija et al., 2012). It is slightly different than common wheat. It is suitable for low-input agriculture, well adapted to marginal lands, has a strong response to weeds and present healthy attractive crop (D'Antuono & Pavoni, 1993; Stallknecht et al., 1996; Suchowilska et al., 2012). It develops stronger root system, and therefore this type of wheat better absorb nutrients from soil and can be grown on less fertile soils (Moudrý & Dvořáček, 1999; Bojňanská & Frančáková, 2002).

Compared with most cereals, wheat has been demonstrated to have among the highest Cd content in its grains. The high protein content cultivars are usually also those with high Cd concentration in the grains. This is not the case in *Triticum spelta,* in which the grains have a high protein content but a low Cd content (Prasad, 2008).

Given the above, focus in this paper was to determine the concentration of Zn and Cd in soil and in *Triticum spelta* L. grown around the location of ash deposits of thermo-power plant Nikola Tesla B in Obrenovac, Serbia, and to identify potential soil contamination. Moreover, toxic metal content was determined to calculate the soil-to-plant transfer as the major pathway of human exposure to soil contamination.

2. EXPERIMENTAL PROCEDURES

2.1 Description of the study area

This study is developing at the location of ash deposits of thermo-power plant Nikola Tesla B in Obrenovac, at 44°37'58" N and 20°2'34" E. Thermal power plant complex "Nikola Tesla", A and B, is the largest power plant site in Serbia. The termal power station part B (TENT B) is located on the left bank of the river Sava, 17 km upstream from Obrenovac. It covers area of 1 080 000 m^2 with 600 ha of ash waste area. During regular working conditions, daily lignite coal consumption at TENT B is approximately 9×10^7 kg·day^{-1}, and the total amount of obtained ash, containing smaller particles of filter ash and larger particles of bottom ash, is approximately $1,7 \times 10^7$ kg·day^{-1}. After lignite combustion, the obtained ash is transported to an ash dump using water from the Sava River (Pergal et al., 2014).

Plants are simultaneously and continuously affected by the unfavourable physical and chemical characteristics of the ash, together with the adverse microclimatic conditions and the intensive and continuous deposition of toxic substances causes disturbances in the physiological processes of plants, visible damage symptoms, the decay of individuals, and even the disappearance of certain species from those sites exposed to pollution (Pavlovic et al., 2007). Trace element distribution study in topsoils in the vicinity of thermal power plants Nikola Tesla A and B (Dragović et al., 2013) has indicated anthropogenic impact and contribution of emissions to pollution.

For the purpose of this experiment we cultivated parts of degraded land in the potentially polluted zone in the distance of 2, 3 and 4 kilometres from location of ash deposits of thermo-power plant, in further text marked as I, II and III, respectively.

2.2. Sample collection and treatment

Soil sampling was done in accordance with the standard ISO 10381-2 (ISO, 2002). Soil samples were taken from a 0–30 cm depth representing both the plough layer and the root zone. Five increments of a 1 kg soil sample were taken using diagonal pattern in a 50 m diameter area, and a composite sample was formed. The shoots of the plants were harvested from the spots at which the soil samples were taken.

2.3. Soil and plant analysis

In the laboratory, soil samples were dried and passed through a 2 mm sieve and after digested with concentrated HNO$_3$ and H$_2$O$_2$ for extraction of total forms of trace elements. The available Zn and Cd contents of soils were determined by extraction in the DTPA (a mixture of 0.005 mol dm^{-3} DTPA, 0.01 mol dm^{-3} CaCl$_2$, 0.1 mol dm^{-3} triethanolamine (TEA) with the pH adjusted to 7.3 and with a 1 mol dm^{-3} HCl solution). The vegetation samples were air dried and milled into powder. For the analyses of plant material, one gram of sample was digested with mix of HNO$_3$ and H$_2$O$_2$ (8 ml of mixture at ratio HNO$_3$: H$_2$O$_2$ = 7 : 1 was added per 1 g of plant material).

The content of metals in all the extracts were

determined by inductively coupled plasma atomic emission spectrometry, iCAP 6500 Duo (Thermoscientific, Cambridge, UK). For the verification of the results, the reference soil sample was determined for all metals ERM-CC135a Contaminated Brickworks Soils.

2.4. Bio-accumulation factor (BAF)

The BAF, also referred to as 'bio-accumulation factor', an index of the ability of a vegetable to accumulate a particular metal as a function of its concentration in the soil, was calculated from the following equation (Abdu et al., 2011):

$$BAF = \frac{Cplant}{Csoil} \qquad (1)$$

where Cplant and Csoil are the Zn and Cd concentrations in edible portions of vegetables and in soils, respectively, on a dry weight basis. To calculate the bioaccumulation factor of the plant available trace metal concentration, BAF was also calculated as a ratio of plant concentration of trace metal (Zn, Cd) and the respective DTPA-extractable concentrations in the soil.

2.5. Statistics

The differences in soil and plant characteristics within treatments were conducted by one-way ANOVA using SPSS 18.0 software (SPSS, 2009). The LSD test was used to assess the differences within the means of different treatments.

3. RESULTS

Total concentration of Zn and Cd in soil samples from the site of thermal power plant Nikola Tesla B are presented in the table 1. As known, Zn is essential plant micronutrient which turn into contaminant if its concentration exceeds maximum permissible concentration (Official Gazette of the Republic of Serbia, 25/2010 and 28/2011).

Concentration of Zn and Cd in the soil of the experimental sites are below maximum permissible concentration (Table 2). Average concentration of Zn in soil varied from 61,622 to 65,522 mg kg^{-1}, while in *Triticum spelta* L. it ranged from 12,395 to 28,717 mg kg^{-1} on a dry weight basis.

Zn concentration in the edible parts of *Triticum spelta* L. ranged from 30.100 to 39.242 mg kg^{-1}. Average concentration of Cd in soil ranged from 0.223 to 0.237 mg kg^{-1}, while in *Triticum spelta* L. it ranged from 0.043 to 0.062 mg kg^{-1}. Edible parts of *Triticum spelta* L. contained Cd in range from 0.025 to 0.127 mg kg^{-1}.

Table 1. Average concentration of Zn and Cd (mg kg^{-1}) on the site of thermal power plant Nikola Tesla B

Location		Zn		Cd	
		Total	DTPA	Total	DTPA
Control	(n=3)	63,772±8,208[a]	7,588±0,504[a]	0.227±0,003[a]	0,030±0,000[a]
I	(n=3)	65,522±9,326[a]	5,305±1,038[a]	0.237±0,008[a]	0,020±0,000[a]
II	(n=3)	61,622±9,501[a]	9,306±1,757[a]	0.223±0,020[a]	0,020±0,006[a]
III	(n=3)	64,655±9,404[a]	8,236±2,595[a]	0.225±0,018[a]	0,023±0,006[a]
Value indicate average concentration ± standard deviation; values in column followed by the same letter are not statistically different at P>0.05.					

Table 2. Reference values for Zn and Cd in soil (mg kg^{-1})

Reference values for soil	Zn	Cd
(Kabata-Pendias & Pendias, 2001)[a]	300	3
Official Gazette of the Republic of Serbia 23/94[b]	300	5
[a] Maximum permissible concentration for agricultural soils in some European countries		
[b] Rulebook on allowable quantities of hazardous and harmful substances in soil and irrigation water and methods for their testing		

Table 3. Average concentration of Zn and Cd (mg kg^{-1}) in *Triticum spelta* L.

Location		Zn		Cd	
		shoot	grain	shoot	grain
Control	(n=3)	25.488±3.642[b]	30.100±12.037[a]	0.047±0.021	0.025±0.005[b]
I	(n=3)	16.665±4.631[ab]	39.242±2.372[a]	0.062±0.008	0.127±0.083[a]
II	(n=3)	12.395±2.154[a]	31.648±2.608[a]	0.043±0.008	0.095±0.035[ab]
III	(n=3)	28.717±18.100[b]	35.290±7.868[a]	0.060±0.035	0.060±0.010[ab]
Value indicate average concentration ± standard deviation; values in column followed by the same letter are not statistically different at P>0.05; standard for Cd and Zn in wheat are 0.2 and 60 mg kg^{-1}, respectively (WHO/FAO, 2007).					

Table 4. Bio-accumulation factor /BAF/ of Zn and Cd from soil to grain of *Triticum spelta* L. based on total and DTPA-extractable value

Location		Zn BAF		Cd BAF	
		total	DTPA	Total	DTPA
Control	(n=3)	0.548±0.236[a]	4.969±1.614[a]	0.110±0.023[b]	0.833±0.167[b]
I	(n=3)	0.610±0.122[a]	7.623±1.735[a]	0.528±0.334[a]	6.333±4.141[a]
II	(n=3)	0.520±0.070[a]	3.505±0.858[a]	0.434±0.185[ab]	4.444±2.275[ab]
III	(n=3)	0.564±0.196[a]	4.728±2.116[a]	0.268±0.052[ab]	2.722±0.948[ab]
Value indicate average concentration ± standard deviation; values in column followed by the same letter are not statistically different at P>0.05					

The Codex Alimentarius Commision (2005) proposed a maximum level of 0.2 mg kg^{-1} Cd for wheat as an international criterion to protect human health. Threshold level of Zn concentration set by Food and Agriculture Organization of the United Nation (WHO/FAO, 2007) is 60 mg kg^{-1}.

The concentration of Zn and Cd in *Triticum spelta* L. (Table 3), both shoot and grain, didn't exceeded threshold limit for edible vegetables set by WHO/FAO

In order to assess the transfer of trace metals from soil to plant, the transfer factor (BAF) values of Cd and Zn were calculated. Bio-accumulation factor (BAF) values are represented in table 4. The BAF values based on both the total and extractable metal contents were higher for Zn than for Cd. For Zn BAF$_{total}$ values ranged from 0.520 to 0.610, that values for Cd ranged from 0.110 to 0.528. For Zn BAF$_{DTPA}$ values ranged from 3.505 to 7.623 and for Cd it ranged from 0.110 to 0.528.

4. DISCUSSION OF RESULTS

Assessment of toxic metals concentration around the largest coal fired power plant in Serbia, Nikola Tesla, found that Cd and Zn in soil are in range from 0,03 to 1,05 mg kg^{-1} and from 24,6 to 207,5 mg kg^{-1} respectively (Ćujić et al., 2016). Our results are consisted with this study. On the other hand concentration of Cd in our study are lower than those reported in the same area (Dragović et al., 2013). Toxic metals concentration in soil around power plant Nikola Tesla are very variable, showing influence of power plant as a potential source of pollution. A reason for lower values of toxic metals in our study is also a sampling depth (0-30 cm) and cultivation measures that have been applied during spelt growing season.

Toxic metal concentrations in soil are typically quantified and regulated on the basis of total metal content, however, it has been argued by several authors that for toxic metals it is better to calculate BAF with DTPA-extractable concentrations rather than with total concentration of metals in soil

(McBride et al., 2003; Hu et al., 2013).

The concentrations of cadmium and zinc are below the maximum permissible concentration determined by the European Union for agricultural land (Tóth et al., 2016). However, if anthropogenic impact continues quantity of these metals may reach potentially toxic levels.

The DTPA-extractable BAF values of Zn for almoust every crop were higher than those for Cd, indicating that Zn is more easily translocated into the plant from soil than Cd. Several studies reported higher BAF values for Cd than for Zn (Wang et al., 2012; Jolly et al., 2013), but another studies showed that metal BAF values can vary in the order of Zn > Pb > Cd (Andráš et al., 2016; Ogunkunle et al., 2015).

Abdu et al., (2011) showed that DTPA-extractable BAF values of Zn for four of their studied crops were significantly higher than those of Cd, they concluded that translocation of Zn and Cd from soil to plant is not a function of soil metal concentration, considering rather that this is in a function of specific physiological mechanisms. Adamo et al., (2014) also confirmed that accumulation of the metal by plants is not greatly affected by soil contamination. Plant genotype is the most important factor that affect toxic metal uptake by plants (Bhargava et al., 2012).

High correlation between trace metal content in soil and in plant is determined by the species of plants, type of soil and physicochemical properties of toxic metal (Conesa et al., 2011).

Kubo et al., 2016 suggested that common wheat (*Triticum aestivum* L.) possesses various mechanisms to avoid the translocation of Cd in grains. Other study showed that the concentration of Cd in the roots of common wheat were about 5, 14 and 8 times higher than those in the shoots, shells and grains, respectively (Wang et al., 2011). Our results indicate that spelt wheat has high level of Cd in its grains.

5. CONCLUSION

The overall high BAF observed in this study indicate the importance of the soil–plant–human

pathway for toxic metal transfer into the food chain. Even though the concentration of Zn and Cd reported in this study were below the threshold limit for agricultural soils the studied wheat showed a high translocation of Zn and Cd from the soil to the edible part of plant, which has important consequences for the contamination of the food chain.

Given the above, long-term, uncontroled emissions of trace elements can cause high level of their concentrations in edible part of plants causing health risks to consumers, and also high concentrations lead to conversion of essential elements to toxic.

Acknowledgments

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