ARSENIC UPTAKE AND TRANSLOCATION IN SOYBEAN PLANTS IN NEUTRAL SOIL ENVIRONMENT

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Abstract

Arsenic is a highly toxic metalloid that is classified as a non-threshold class-1 carcinogen. The enhance of knowledge about the plant cultivars that avoid the transport of As in its edible plant parts is of great importance. The goal of this study was to investigate the ability of soybean to take up arsenic from contaminated soil and translocate it in to the plant parts in order to make an assessment of its potential risk for human and animal health. The experiment was performed in a controlled environment in pots. Two types of naturally polluted soils with pH 6.9 and different other chemical and mechanical properties were collected from the Zletovo mining area. Soil and plant samples were digested and analyzed by ICP-MS. The geoaccumultion index reveals moderately to high contamination of investigated soils with As. The assessment of bioaccumulation in plant tissues was determined by calculating the bioaccumulation (BAF) and the biotranslocation factor (BTF). The results showed that soybean possesses low ability to take up As from soil and act as an excluder, accumulating it mostly in the roots followed by the leaves and shoots. Arsenic content in the pod and seed was found to be under the limit of detection (<0.1 mg/kg) in all cultivars indicating that soybean grown in As polluted soils does not possess risk for human and animal health and that the chemical and mechanical composition of the soil does not have influence on its bioaccumulation when it comes to the neutral type of soil.

Key words: heavy metal, bioaccumulation, biotranslocation, soil properties, excluder.

Introduction

Arsenic is a highly toxic metalloid that is classified as a non-threshold class-1 carcinogen. Millions of people worldwide suffer from As toxicity due to the intake of As-contaminated drinking water and food. Arsenics ingestion can lead to serious diseases, including cancers. Currently, millions of people, worldwide are at risk for exposure to contaminated food and drinking water, so the enhance of knowledge about the plant cultivars that avoid the transport of As in its edible plant parts is of great importance. It is also known that As limits the uptake of some essential elements like iron (Fe) and zinc (Zn), by plants. Arsenics is primarily taken up by terricolous plants via the root system although some submerged plants can absorb As from water via their leaves. Three main forms of As in soil are available to plants, namely arsenate [As(V)], arsenite [As(III)] and methylated As [monomethylarsinic acid (MMA) and dimethylarsinic acid (DMA)]. These forms of As exist simultaneously in the soil. Microorganisms in the soil transform As species from As(V) to As(III) and further to MMA and DMA. Plant roots selectively take up specific As species via distinct pathways and transporters. The ability to take up and tolerate metals varies between and within species as well as between metals. Three types of plant-soil relationship are proposed by Baker (1981): accumulators, indicators and excluders. Excluders are plant species adapt to extreme soil metal environments and avoid the uptake of heavy metals in the above-ground plant parts. Excluders are of great interest for soil utilization because its consumption shouldn't cause risk to human and animal health. The natural phenomenon of heavy metal tolerance has enhanced the interest of plant species around the world. Soybean (*Glycine max* L. Merrill) is a well-known legume species which is able to establish an association with plant growth-promoting rhizobacteria under different conditions including stress. It is an annual crop from the family *Leguminosae*. It is fast-growing, high in biomass agriculture crop successful in climates with hot summers, with optimum growing conditions in mean temperatures of 20 to 30 °C. It can grow in a wide range of soils, with optimum growth in moist alluvial soils with good organic content. Cultivars generally reach a height of around 1 m and take 80 – 150 days from sowing to harvesting. The major uses of soybean globally are as livestock feed, and in a large variety of processed food for human consumption. The study deals with the ability of soybean to up take As from polluted soil and make an assessment of its translocation in the seeds.

Materials and methods

Inductively coupled plasma with mass spectrometry, ICP-MS (model 7500cx, Agilent Technologies, USA) was applied for determination of elements content in plant and soil samples.

Table 1. Soybean varieties used in the study

Soybean variety	Origin	Mature group	Vegetation period
Balkan	Serbia	0	100 days
Ilindenka	Macedonia	I	120 days
Pavlikeni	Macedonia	II	150 days

Field settings

The experiment was performed in pots with dimensions that allow undisturbed development of the plant. Soil samples were collected from the soil top layer (25 cm depth) near the „Zletovo" mining area with Pb-Zn mineralization, located in the Kratovo-Zletovo volcanic region of the Vardar zone.

Soil and plant sampling and sample preparation

The total and bioavailable content of investigated elements in soil were determined before sawing of soybean seeds according to the protocols of ISO 14869-1 and Tessier et al. (1979), respectively. Soil properties like pH as well as the clay content, were determined using standard procedures. The content of heavy metals in soybean plants was determined at the end of the vegetation period of the investigated mature group according to the adopted protocol from Wolnik et al.

Soil metal contamination assessment

The level of soil pollution was evaluated using the geoaccumulation index according to Müller (1969):

$Igeo = \log_2 [Cn/(1.5 \times Bn)]$

Assessment of bioaccumulation in plant tissues

The degree of which bioaccumulation occurs can be expressed as a bioaccumulation factor $BAF = C_{plant} / C_{soil}$

Biological Transfer Factor ($BTF = C_{plant\ part} / C_{root}$) refers to the ability of the plant to accumulate chemical element or compound from the soil through the roots and transfer it in its areal parts.

Table 2. Chemical and mechanical composition of investigated soil samples Z1 and Z5.

	pH	CEC cm/mol	EC mS/cm	OM %	K2O mg/100 g	P_2O_5 mg/100 g	Clay %
Z1	6.9	9.0	0.41	1.47	13.7	12.0	10.2
Z3	6.9	0.3	0.22	0.92	4.9	3.4	0.09

Results and discussion

Metal content in the soil

Investigated soils are neutral with low organic content. Soil sample Z1 showed high content of clay while the content in Z3 was very low. The total content of As in soil was higher than the background level (Bn) of the Vardar zone. Available content was very low in both soils which means that the soil properties are not favorable and make it harder its accumulation in plants. According to the geoaccumlation index, investigated soils showed moderately to high contamination (Table 3) with As. Other elements like Cd, Pb, and Zn also showed high to extremely high contamination.

As content in soybean varieties

Investigated soybean varieties showed low accumulation of As. This heavy metal was mostly accumulated in roots (mass fraction 54.72 - 83.51) (Figure 1 and Figure 2), followed by the leaves and shoots. The tendency was present in plants grown in both soil samples with low and high clay content. The content in pods and seeds was negligible and under the limit of detection (Table 4). It was noticed that the content of As was higher in plants grown in Z3 soil with low clay content which is strongly accepted because of its ability to retained heavy metals in the soil.

Assesment of bioaccumulation in soybean

The BAF of As calculated for investigated soybean varieties in two soil samples showed values greater than 1 (Table 5), but still not so high as in plants considered as hyperaccumulators. BTF values for shoots, leaves, pods, and seeds were lower than 1, suggesting that investigated varieties act as an excluders of As when grown in neutral soils no matter if the clay content is higher or low.

Figure 1. Mass fraction of As in investigated soybean varieties grown in Z1 soil sample

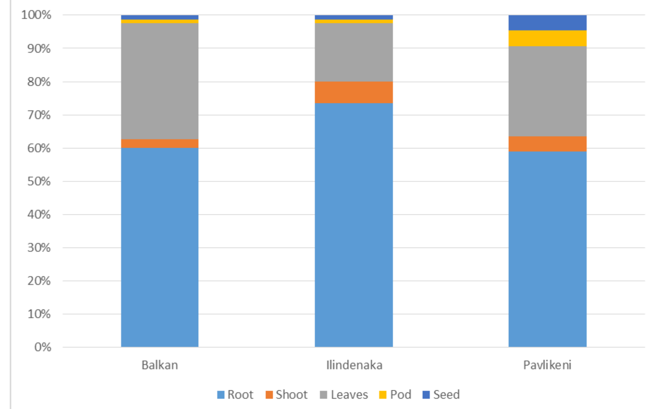

Figure 2. Mass fraction of As in investigated soybean varieties grown in Z3 soil sample

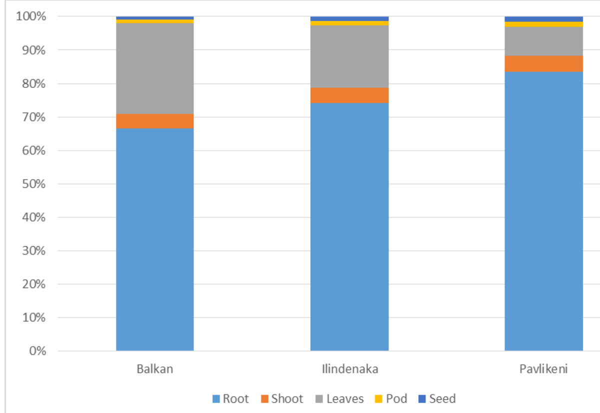

Table 3. Total and available content (values are given in mg kg^{-1}), background levels (Bn) and geoaccumulation index (I_{geo}) of analyzed elements in the soil samples.

	Total content		Available content		Bn	I_{geo}	
	Location		Location			Location	
	Z1	Z3	Z1	Z3		Z1	Z3
As	39	25	0.26	0.19	9.2	1.50	0.86
Cd	2.3	1.32	1.1	0.84	0.3	2.35	1.55
Cu	44	27	2.7	2.21	24	0.29	-0.41
Fe	42146	37280	291	412	29%	-0.04	-0.22
Mn	3191	2320	690	430	810	1.40	0.93
Pb	437	306	83.5	89.5	31	3.23	2.77
Zn	608	369	104.7	81.57	71	2.51	1.79

Conclusion

Bioaccumulation of As in soybean was investigated in this study. The results indicate that soybean act as an excluder when grown in heavily polluted soil with As. The accumulation mostly occurs in roots while the accumulation in seed and pods was under 0.1 mg/L, suggesting that investigated soybean varieties Balkan, Ilindenka and Pavlikeni can be grown in As polluted soils posing no risk for human health since the accumulation of As in the seed is negligible. This should be accepted with caution because they can accumulate Cd and Pb in the seed in amount greater than the national and the international MPL of 0.2 mg/kg (Mihajlov et al. 2019).

It was also noticed that the clay content in the soil have some influence in the As up take but still does not affect the content it in the seed.

Table 4. The content of As in investigated soybean varieties grown in Z1 and Z3 soil samples

	Balkan	Ilindenka	Pavlikeni
		Z1	
Roots	2.44.	2.95	0.63
Shoots	0.11	0.26	<0.1
Leaves	0.13	0.61	0.37
Pods	<0.1	<0.1	<0.1
Seeds	<0.1	<0.1	<0.1
		Z3	
Roots	3.47	2.78	2.78
Shoots	0.23	0.17	0.16
Leaves	1.42	0.70	0.29
Pods	<0.1	<0.1	<0.1
Seeds	<0.1	<0.1	<0.1

Table 5. BAF and BTF values of As for investigated soybean varieties

	Z1			Z3		
	Balkan	Ilindenka	Pavlikeni	Balkan	Ilindenka	Pavlikeni
BAF	10.69	15.06	4.40	27.47	19.77	17.52
		BTF			**BTF**	
Shoots	0.04	0.09	0.08	0.07	0.06	0.06
leaves	0.05	0.21	0.59	0.41	0.25	0.10
Pods	0.02	0.02	0.08	0.01	0.02	0.02
Seeds	0.02	0.02	0.08	0.01	0.02	0.02

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