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Potential antagonist Zn effect on faba bean (*Faba vulgaris* m.) contaminated by Pb and Cd

Antagonistyczny wpływ Zn na bób (*Faba vulgaris* m.) zanieczyszczony Pb i Cd

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Słowa kluczowe: *bób, ołów, kadm, cynk, plon, gleba*

Abstract
The pollution of soil by heavy metals is considered to be a big problem in the world today. Currently, attention is being paid to the content of individual heavy metals in the soil-plant-food system. In our work, mainly the effect of bivalent cations of lead, cadmium and zinc and its uptake by faba bean (*Faba vulgaris* M.) was surveyed. The results obtained suggest that the incorporation of Pb (200 mg•kg^{-1} soil) and Cd (10 mg•kg^{-1}) had a negative effect on the quantitative and qualitative parameters of faba bean. The incorporation of Pb in the faba bean crop is statistically significantly decreased by 24.86%, and the reduction of Cd represented 29.91% compared to the control. In the case of common application of zinc, cadmium and lead in soil (variants C, E), there was a slight increase in crop yield compared to the individual incorporation of heavy metals (variants B, D); in the case of Pb, the increase was 13.14%, and in case of Cd 27.77%. A common application of heavy metals with zinc had a positive influence on quality parameters of the faba bean. We have seen a decrease in Cd to 0.15 ± 0,018 mg•kg^{-1} (a statistically significant decrease) and decrease in Pb to 0.61 ± 0.17 mg•kg^{-1} (without significant differences).

Streszczenie
Zanieczyszczenie gleb metalami ciężkimi stanowi jeden z ważniejszych problemów na świecie. Obecnie, uwaga kierowana jest nie tylko na zawartość poszczególnych metali ciężkich w systemie gleba–roślina–żywność. W naszej pracy badaliśmy wpływ i pobór dwuwartościowych kationów ołowiu, kadmu i cynku przez bób (*Faba vulgaris* M.).
Uzyskane wyniki sugerują, że pobranie Pb (200 mg • kg^{-1} gleby) i Cd (10 mg • kg^{-1}) miało negatywny wpływ na parametry ilościowe i jakościowe bobu. W przypadku pobrania ołowiu, plon bobu zmniejszył się statystycznie istotnie o 24.86% a redukcja Cd stanowiła 29.91% w porównaniu z próbką kontrolną. W przypadku łącznej dostawy Zn, Cd i Pb do gleby (warianty C, E), obserwowano nieznaczne podwyższenie plonu w porównaniu z dostawą poszczególnych metali ciężkich (warianty B, D). W przypadku Pb wzrost plonu wyniósł 13.14% a w przypadku Cd – 27.77%. Łączna dostawa metali ciężkich z cynkiem miała pozytywny wpływ na jakość parametrów bobu. Zaobserwowano obniżenie zawartości Cd do 0.15 ± 0,018 mg • kg^{-1} (wartość statystycznie istotna) oraz obniżenie zawartości Pb do 0.61 ± 0.17 mg • kg^{-1} (bez istotnych różnic).

1. INTRODUCTION

Faba bean (*Faba vulgaris* M.) is one of the most important crops in most parts of the world including Africa, Asia and Latin America. Major producers of the Faba bean are China, Ethiopia, France and Egypt. The nutritional value of a faba bean is high [Gnanasambandan et al. 2012] and in some areas it is considered to be superior to peas or other grain legumes [Crépon et al., 2010]. Faba bean (*Faba vulgaris* M.) seeds are rich in protein and starch [Chaieb et al. 2011]. Of the legumes, the faba beans in fresh condition contain most fiber. In bean seeds, the content of lysine and limiting amino acids as methionine and threonine is very favorable. Bean seeds contain a factor that aggravates the retention of Zn and Fe [Gálik et al. 2011]. Faba beans are also grown for green manure and can significantly enhance yields of cereals or other crops [Wani et al. 1994]. Local environmental conditions have influence on the quantitative and qualitative parameters of faba beans [Al-Barri, Shtaya 2013].
Heavy metals occur in the soil in various concentrations and forms. Heavy metals affect plants as a stress factor. Cadmium, lead and arsenic, in particular, are the most dangerous toxic elements. Cadmium (Cd) is a toxic heavy metal which causes oxidative stress in plants and has a high level of toxicity for plants, animals and humans [Bahmani et al. 2012].
Lead (Pb) is a major environmental pollutant of worldwide concern [Kadhim 2011]. The toxic effects of Pb rest mainly in its ability to react with functional groups such as sulfhydryl, carboxyl and amine, leading to decrease or loss of activity of many enzymes that are important for cell functions [Salte et al. 1995]. Some methods were suggested for elimination of negative effects of toxic elements in soils. The values of pH, cation exchangeable capacity and the content of $CaCO_3$ in soil belong to the most important parameters that affect heavy metals in soil. The uptake of heavy metals by plants can be affected by interaction with other elements. Cd and Zn are elements having similar geochemical and environmental properties; their chemical similarity can lead to interaction between Cd and Zn during plant uptake, transport from roots to the aerial parts, or accumulation in edible parts [Das et al. 1997]. It is generally

accepted that Zn status in soils and plants plays an important role in Cd accumulation in crop plants [Sarwar et al. 2010].
The main objective of the present study was to determine the influence of selected heavy metals (Pb, Cd) added to the soil singly or in combination with zinc on quantitative and qualitative parameters of Faba beans (*Faba vulgaris* M).

2. MATERIAL AND METHODS

The tested crop was the faba bean (*Faba vulgaris* M.) variety – Merlin. Experiment was carried out as a trial experiment; variants of observation A, B, C, D, and E are shown in Table 1.
Six kilograms of soil was weighed into plastic bowl-shaped pots with average dimensions of 20 cm and height of 25 cm with foraminated bottom. Basic nutrients were added in the form of NPK fertilizer. Heavy metals were added in the form of solutions:

– lead in the form of Pb $(NO_3)_2$,
– cadmium in the form of $CdCl_2 \cdot ½H_2O$,
– zinc in the form of $ZnSO_4 \cdot 7H_2O$

Basic nutrients were added in the form of aqueous solution. After the emergence, the plants were thinned to eight per pot. The experiment was conducted in four replications.

Table 1. Characteristic of pot trial variants

Variants	Characteristic	Repetition
A	NPK – control	1–4
B	NPK + 200 mg Pb•kg^{-1} soil	5–8
C	NPK + 200 mg Pb + 80 mg Zn•kg^{-1} soil	9–2
D	NPK + 10 mg Cd•kg^{-1} soil	13–16
E	NPK + 10 mg Cd + 80 mg Zn•kg^{-1} soil	17–20

The weights of yield of the faba bean after adding of heavy metals to the soil and its qualitative grain composition from the standpoint of risky elements were evaluated. Content of risky elements was assessed after mineralization by the dry way method (AAS: atomic absorption spectrophotometry on apparatus Varian AA 240 FS).
Results obtained were statistically evaluated in SAS 9.1 (SAS Institute Inc.). For determination of significant differences among mean values in particular groups, the Student t-test was used.

3. RESULTS AND DISCUSSION

Heavy metals such as Pb and Cd rank among substantial environmental pollutants that are very phytotoxic in environment. Higher amount of heavy metals in soil could be manifested by increased accumulation in plants, animals and also in human body.
In the present study, the results of pot trial experiments obtained during the observation of ability of bivalent cation Zn to reduce the contents of Pb and Cd in bean and simultaneously to eliminate its adverse effects on crop yields have been explained. The effects of heavy metals (Pb, Cd) in the soil as well as the relationships between Pb and Zn and between Cd and Zn were evaluated. The mass yield of bean and the content of Pb and Cd in bean seeds in mg/kg dry mass were measured.
The results of pot experiments showed the ability of bivalent cation Zn to decrease the Pb and Cd intake by faba beans and simultaneously to eliminate its negative influence of the faba beans yield.
The yield of faba beans after treatment with heavy metals (Pb, Cd) in soil, in single doses as well as in combination with zinc cation, is shown in Figure 1.
The results obtained suggest that the addition of Pb to the soil (variant B, 200 mg) had a negative influence on the crop yield and on qualitative parameters. An applied amount of Pb in the soil significantly (P value = 9E^{-04}) reduced the grain yield by 24.86% against control. Joint application of Pb and Zn (variant C) resulted in significant crop yield reduction (P value = 1.8E^{-03}), by 14.98% as compared with the control; however, in comparison with variant B (application 200 mg of Pb) an increase of 13.14% occurred which can be evaluated positively (P value = 0.04).
In case of further application of heavy metal Cd (variant D), joint application with Zn showed positive influence of this divalent cation. Our results showed that the dose of 10 mg Cd per kg soil (variant D) lowered the average yield (statistically significant, P value = 4E^{-04}) of faba beans by 29.91% when compared to variant A (control variant). The joint combination of Zn and Cd (variant E) caused only slight decline in yield of grain of faba beans when compared to the control variant, but in comparison with variant D a significant increase (P value = 3.6E^{-03}) in yield by 27.77% was noted, which can be positively evaluated.
Many works [Georgieva et al. 1996, Lin, Arts 2012] have mentioned about interaction between Cd and Zn, especially with regard to their chemical relation. Generally, it is suggested that the interaction between Cd and Zn is based on the principle of competitive inhibition, when cadmium and zinc compete with similar active centers of carriers [Cibuľka 1991]. Similar results were published by Moustakas et al. [2011].
An important criterion for assessing the phytotoxicity of heavy metals besides quantity is the qualitative assessment of the growing crop. While application of Cd had increased its content in faba beans (2.41 ± 0.13 mg Cd•kg^{-1}), the application of Cd and Zn ions significantly decreased (P value = 1E^{-04}) the content of Cd in bean (0.15 ± 0.018 mg Cd•kg^{-1}, Figure 2).
Similar results were achieved by combining the treatments of zinc and lead. Pb application alone enhanced this heavy metal content in faba beans by 0.76 ± 0.14. After joint application with Zn, the Pb content in the bean declined, however without significant differences (P>0.05, Figure 3).
Many works [Adiloglu 2002; Adiloglu et al. 2005; Angelova, Ivanov 2006] deal with interactions among heavy metals, especially the interactions between Cd and Zn. The mechanism of action and the final explanation of these relationships are not unified. According to Poongothai et al. [1997], the addition of Zn to the environment lowered the cadmium content in plants. According to Sharma et al.

Table 2. Agrochemical characteristic of soil substrate

Soil reaction pH		Cox	Hum.	Content of nutrients (mg•kg^{-1})				
H_2O	KCl	%	%	N	P	K	Ca	Mg
5.98	4.63	1.527	2.633	2979.0	19.86	215.5	1459.5	265.0

Table 3. Content of potentially available heavy metals (mg•kg^{-1}) in tested soil (in solution of HNO_3, c = 2 mol•dm^{-3})

Cu	Fe	Zn	Mn	Cr	Pb	Cd	Ni	Co
9.54	1645.0	51.5	398.5	2.34	13.18	0.37	7.30	4.54

[1999] and Lombi et al. [2000], the mechanisms of cadmium and zinc intake by plants are dependent on each other, and thus the equal uptake of both under conditions of high accumulation in soil is predicted.

Zinc is an essential trace element for the normal, healthy growth and reproduction of some plants, and in higher concentrations is phytotoxic. Zinc concentrations in plant above 300 mg•kg^{-1} are considered toxic [Marschner 1995].

4. CONCLUSION

Soil contamination with heavy metals becomes a worldwide problem, leading to reduction of plant growth and productivity. Few methods concerning minimizing or eliminating entry of foreign substances, especially heavy metals into food chain, are known. Individual effects of both Cd^{2+} and Pb^{2+} ions together in relation to synergic or antagonistic effect of cations of zinc on yield and qualitative parameters of faba bean (*Faba vulgaris* M) were evaluated in this work. Results obtained showed that the addition of zinc, in dose 80 mg•kg^{-1} (variant C, E), was positively manifested on high yield and qualitative parameters of the faba bean.

Our obtained results cannot be uniformly associated with the effect of bivalent zinc cations, because reaction of plants on the presence of zinc is individual and is affected by various factors such as soil reaction, total content of heavy metals in soil as well as climate conditions.

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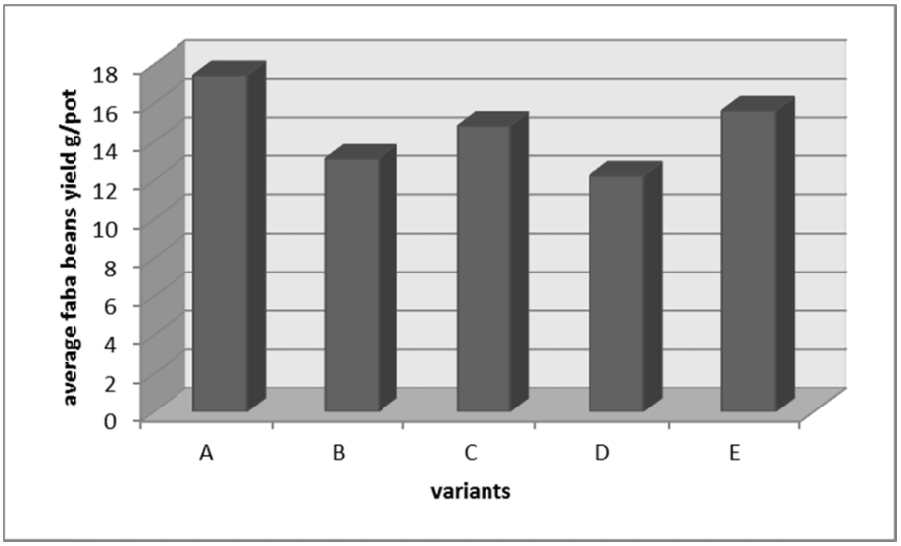

Figure 1. Faba beans yield after application of Pb, Cd and Zn cations

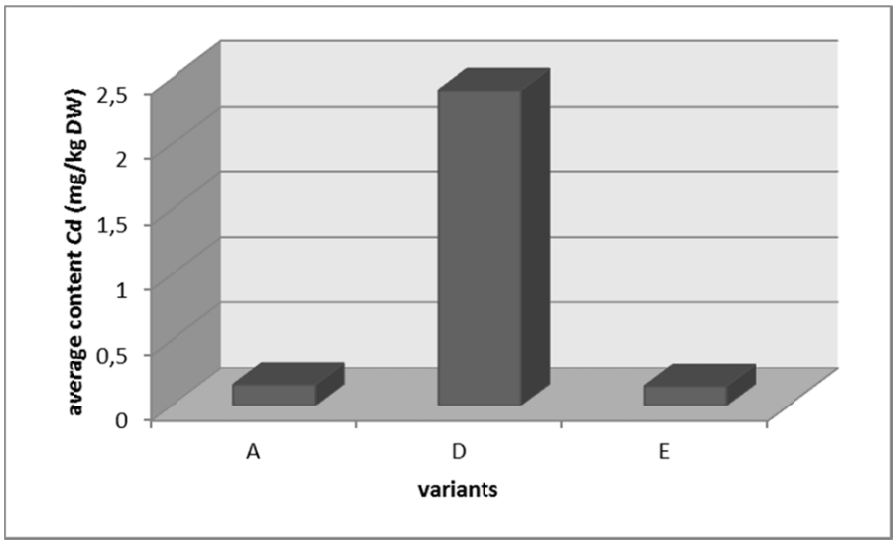

Figure 2. Content of Cd (mg•kg^{-1} DW) in faba bean

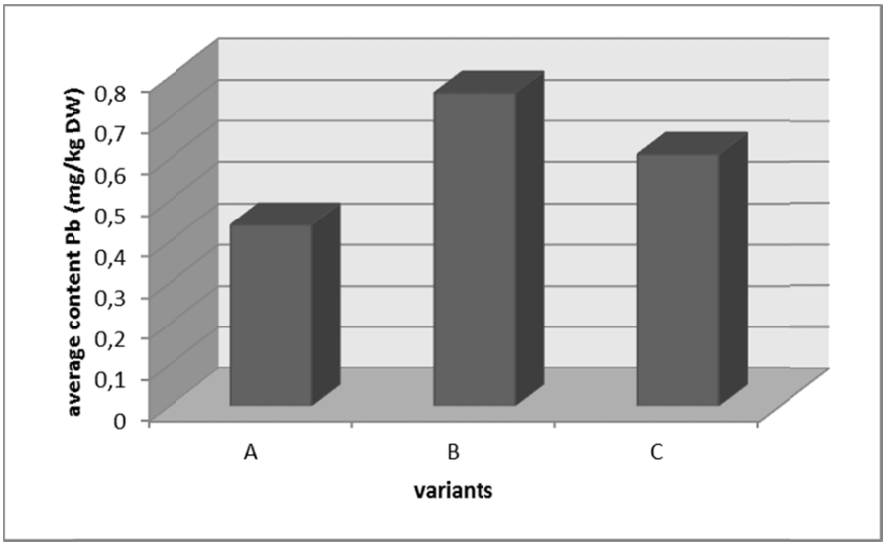

Figure 3. Content of Pb (mg • kg^{-1} DW) in faba bean

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