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Evaluation of lead and nickel in wheat (*Triticum aestivum* L.) using sugarcane biochar

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ABSTRACT

Today, heavy metal contamination in soil due to toxicity, stability, high shelf life in soil, and elemental accumulation in foods is considered biologically and ecologically hazardous. This study aimed to investigate the distribution of lead and nickel in wheat using sugarcane biochar. The experimental design was factorial with a completely randomized design in triplicate, and the factors included sugarcane biochar at four levels of zero (control), 2, 4, and 6% of soil weight and soil type (contaminated and non-contaminated with lead and nickel). Lead (500 mg/kg) and nickel (250 mg/kg) were added to each pot based on the threshold and critical levels of contaminated agricultural soil. The maximum lead in roots (1,771.8 mg/kg), stems (119.73 mg/kg), and grains (32.36 mg/kg) and maximum nickel in roots (562.5 mg/kg), stems (39.54 mg/kg), and grains (9.4 mg/kg) were measured in the contaminated soil. The maximum reduction of lead and nickel in the plants was measured using 6% biochar, and the reduction rate of lead in roots, stems, and grains with 6% biochar was 22.2, 75.7, and 83.3%. The reduction rate of nickel in roots, stems, and grains was 16.9, 81, and 62.8% compared to the biochar absence, respectively. In the contaminated soils, 6% biochar was effective in reducing the lead below the standard level in foods, especially in the grains, while the grain nickel was slightly higher than the food standards, and further investigations should increase food safety.

Keywords: Biochar, Lead, Nickel, Contaminated soil, Sugarcane, Wheat

Introduction

Heavy metals are among the most hazardous environmental pollutants.[1] Unlike organic matters, heavy metals are non-biodegradable and accumulate in the environment, thereby reducing the capacity of soil to preserve these elements and causing heavy stabilized metals to enter soil solutions and their bioavailability to increase.[2] When the concentration of heavy metals in soil exceeds the maximum, it may be hazardous to the human health through the consumption of the food products that are grown in such environments.[3] Heavy metals could enter the soil through urban wastewater, insecticides, fertilizers, drainage, and metal smelting industries.[4]

Nickel is a heavy metal, and its low concentrations are essential to the human body, while its high concentrations are associated with human health risks.[5] The amount of nickel in nature is extremely low,[6] and some foods naturally contain some nickel.[5] Evidence suggests that nickel could accumulate in the tissues of some plants, especially vegetables.[7] Therefore, the consumers of the vegetables that are cultivated in contaminated soils with nickel tend to have higher amounts of nickel in their body.[8] Some of the adverse effects of high nickel consumption include lung cancer, nasal cancer, laryngeal and prostate cancer,

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decreased reproductivity, asthma, chronic bronchitis, and skin itching.[9]

Lead is an important heavy and toxic element, which enters the body through water, food, and breathing and becomes stable as a biotoxin with body biomolecules such as proteins and enzymes. As a result, their structure is altered, and their biological interactions become difficult. Lead contamination hinders hemoglobin synthesis and renal, reproductive, joint, and cardiovascular function, while also causing acute and chronic damage to the central nervous system and lateral nervous system.[10] According to the literature, heavy metals such as lead are not completely stabilized by soil, and large amounts of the mobile form of this element are absorbed through plant roots.[1]

Biochar is a carbon material obtained by heating plant debris and waste in an environment containing limited or no oxygen. The unique properties of biochars have rendered them a viable option for soil use; these properties mainly depend on the applied source and production conditions of the biochar. The addition of biochar to soil improves the soil structure and soil properties, such as water retention capacity, amount of organic matter, aeration conditions, cation exchange capacity, aggregate formation, soil bioavailability (microbial activity, diversity, pH), microbial chemistry, enzymatic activity, and microbial population. Meanwhile, the leaching of nitrogen and phosphorus from soil reduces in the presence of biochar, thereby improving soil fertility.[11-13] Biochar has a porous structure, electrical charge surface, and functional groups. These properties largely influence the transfer, deformation, and accessibility of heavy metals in soil. The mechanisms of the absorption of heavy elements by biochars include electrostatic interactions, ion exchange, chemical deposition, and complex with functional groups on the biochar surface. In other words, the frequency of biochar functional groups, electrostatic interaction, ion exchange, and strong surface complexes with heavy metals stabilizes metals such as lead and nickel and increases their non-absorbable concentration in soil, thereby reducing their bioaccumulation and concentration in plant shoots.[14-16]

Lyu *et al.* have reported that biochar has positive, significant effects on the uptake and reduction of nickel in soil and could improve the physical and chemical properties of soil.[17] In addition, Ahmad *et al.* and Mohan *et al.* have stated that biochar have a remarkable ability to absorb heavy elements.[18, 19] Doumer *et al.* investigated the effects of the biochar of sugarcane, eucalyptus, castor, and green coconut shell on the uptake of cadmium, copper, lead, and zinc, reporting that all the biochar types could reduce heavy metals by up to 95%.[20] On the same note, Biria *et al.* reported that the application of sugarcane biochar could reduce the concentrations of cadmium and lead in the roots and shoots of maize.[21]

Given the importance of wheat in human nutrition,[22] the sources of sugarcane biochar that are produced by sugarcane cultivation in various regions in the world, and their role in sustainable agriculture and adsorption of pollutants (especially heavy metals),[23] the present study aimed to investigate the effects of sugarcane biochar on the uptake of lead and nickel by the wheat grown in contaminated soils.

Materials and Methods

This study was conducted at the Agricultural Research Station of Ahvaz University in Ahvaz, Iran with the latitude of 48 degrees, 65 minutes east, latitude of 31 degrees, 27 minutes north, and altitude of 17 meters. In this experiment, soil samples were collected from the depth of 0-30 cm. The physical and chemical properties of the soil samples are presented in Table 1.

The study was conducted as a factorial experiment with a completely randomized design in triplicate. The studied factors included various amounts of sugarcane biochar in four levels of zero (control), 2, 4, and 6% of the soil weight and soil contamination in two levels of non-contaminated and contaminated. The soil samples were collected from the experimental field. To contaminate the soil, lead (500 mg/kg) and nickel (250 mg/kg) were added to each pot based on the threshold and critical levels contaminated of agricultural soil, and the pots were preserved for two weeks of incubation.[24]

Table 1. Physical and chemical characteristics of soil

Soil texture	Clay (%)	Silt (%)	Sand (%)	K (mg/kg)	P (mg/kg)	N (%)	OC (%)	Ni (mg/kg)	Pb (mg/kg)	pH	EC (dS/m)
Clay	49	35	16	181	5.2	0.05	0.48	38.5	22.16	7.8	4.6

In the experiments, sugarcane bagasse was used for biochar production. To prepare the sugarcane biochar, initial heat was applied for two hours in a metal enclosure, which was placed in a handmade furnace under free oxygen conditions for three hours at the temperature of 550 °C. Following that, the contents were filtered by a two-millimeter sieve.[25] In this experiment, we used PVC plastic pots (height: 60 cm, diameter: 20 cm) with the weight of 10 kg of soil. In each pot, 10 seeds were planted, and after germination, the seedlings were thinned to five plants per pot. The lead and nickel concentrations in the roots, stems, and grains were measured via atomic absorption (Shimadzu AA 6300) at the final harvest.

The collected data were analyzed in the SAS software using Duncan's multiple range tests at the alpha level of 5% to compare the significant differences between the means.

Results and Discussion

Lead concentration

The screening of the lead concentration of the roots, stems, and grains showed that the effects of soil type, biochar, and the interaction between the biochar and soil were significant (Table 2). The results of the mean comparison also indicated that the maximum lead concentration in the roots (1771.8 mg/kg), stems (119.73 mg/kg), and grains (32.36 mg/kg) were observed without the biochar, and the concentration of lead significantly decreased with the increased biochar application (Table 3).

Table 2. Analysis variance for concentrations of Ni and Pb in different parts of wheat

S.O.V	df	Lead			Nickel		
		Root	Stem	Grain	Root	Stem	Grain
Soil type	1	13498305**	25830**	562.02**	1242218**	3432.52**	101.106**
Biochar	3	50299**	2016.8**	171.40**	4121**	181.15*	3.939^{ns}
Soil type * Biochar	3	54365**	2678.2**	230.57**	4940**	410.29**	19.089**
Error	16	4538	14.9	8.49	80	40.97	2.297
Cv (%)	-	9.34	7.97	1.77	3.01	8.39	3.84

ns, *, ** were not significant and significant at the P value of 0.05 and 0.01 probability level, respectively

Table 3. Mean comparisons for concentrations of Ni and Pb in different parts of wheat

Treatments		Means					
		Lead (mg/kg)			Nickel (mg/kg)		
Soil type	Biochar	Root	Stem	Grain	Root	Stem	Grain
Contaminated	Zero	1771.8^{a}	119.7^{a}	32.3^{a}	562.5^{a}	39.5^{a}	9.4^{a}
	2	1588.1^{b}	92.8^{b}	13.8^{b}	530.6^{b}	32.5^{a}	4.7^{b}
	4	1390.7^{c}	60.0^{c}	12.1^{b}	482.0^{c}	27.1^{a}	4.7^{b}
	6	1377.9^{c}	29.1^{d}	5.4^{cde}	467.5^{cd}	7.5^{b}	3.5^{bc}
Non-contaminated	Zero	31.4^{d}	5.4^{fg}	5.4^{cde}	11.4^{g}	0.9^{c}	0.01^{d}
	2	24.4^{d}	7.2^{f}	5.4^{cde}	12.1^{g}	1.7^{c}	2.1^{c}
	4	26.5^{d}	12.1^{ef}	6.3^{cd}	47.4^{f}	1.1^{c}	1.9^{c}
	6	46.5^{d}	14.5^{e}	7.9^{c}	81.4^{e}	1.2^{c}	1.9^{c}

Means with different letters are significantly different at P=0.05 probability level, using Duncan's Multiple Range Test.

The lead concentration with 6% biochar in the roots, stems, and grains was estimated at 1377.9, 29.1, and 5.4 mg/kg, which decreased by 22.2, 75.7, and 83.3% by using 6% biochar compared to the absence of the biochar, respectively. Lead accumulation in the roots relative to the grains is considered important since it prevents the transmission of this element to the food chain, which may increase the associated contamination. Similar results have been proposed by Liu *et al.* in the case of rice.[26] Furthermore, some researchers have attributed the increased concentration of lead in roots compared to shoots to the free intercellular space and their reduced mobility toward the shoots.[27] Furthermore, the phytochelatins that are produced in root cells have been reported to partly precipitate the heavy metals in the roots.[21]

According to the National Institute of Standards and Industrial Research, the maximum concentration of lead in wheat grains without adverse effects on humans is 0.15 mg/kg.[28] Therefore, it seems that in the contaminated soils in the present study, the application of the 6% biochar was effective in reducing the contamination to less than the standards levels, especially in the grains. In a study in this regard, Biria *et al.* attributed the reduction of lead concentration to functional groups and the high specific surface of sugarcane biochar.[21] The researchers also stated that the biochar had potent electrostatic interactions, ion exchange, and surface complexation for heavy metal uptake, which stabilized and increased the unabsorbed soil concentration and ultimately reduced the concentration of the element in the plant. In addition, Khanmohammadi *et al.* have reported the reduction of lead with the use of biochar in maize compared to the non-consumption of biochar.[29]

Nickel concentration

In the present study, the results of the analysis of variance showed that the effects of soil type and interaction between the soil type and biochar were significant on the nickel concentration of the roots, stems, and grains. Moreover, the effects of the biochar on the nickel concentration of the stems and roots were significant, while they were insignificant for the grains (Table 2). On the other hand, the results of the mean comparisons indicated that the maximum concentration of nickel in the roots (562.5 mg/kg), stems (39.54 mg/kg), and grains (9.4 mg/kg) were observed without the use of the biochar (Table 3). According to the studies by Ker and Charest and Page and Feller, nickel uptake significantly increased with its increased soil concentration.[3, 30] However, nickel translocation to the shoots was observed to be significantly lower than that the roots. Other findings have demonstrated that nickel in the plants moves smoothly, and its mobility depends on the plant species, the physical and chemical properties of soil, and soil pathogens.[28, 29]

In the contaminated soil in the current research, the nickel concentration with 6% biochar was estimated at 467.5, 7.5 and 3.5 mg/kg in the roots, stems and grains, respectively. In addition, the reduction rate of nickel in the roots, stems, and grains with 6% biochar was 16.9, 81, and 62.8% compared to the non-application of the biochar, respectively. According to the literature, biochars affect the adsorption, deformation, and availability of heavy metals due to their high specific surface, porous structure, and presence of oxygenated functional groups (e.g., carbonyl, carboxyl, and hydroxyl).[15, 31] Other researchers have attributed the mechanism of heavy metal uptake to electrostatic interactions, ion exchange, chemical deposition, and complexation with functional groups on the biochar surface.[16]

In the present study, the comparison of the nickel concentration in the wheat samples with world standard of food (1.63 mg/kg)[32] showed that the biochar could reduce the nickel concentration (especially in the wheat grains), and the element could also be stored at the minimum levels of consumption risk by entering the food chain. However, the reduction of the nickel concentration in the wheat grains was more significant than the standard value and should be below the standard level. Therefore, it seems that more biochar should be used to reduce nickel to below the standard level, which requires further investigation.

Conclusion

According to the results, the wheat roots had a remarkable ability to absorb lead and nickel from the soil. Meanwhile, the accumulation of lead and nickel in the roots was significantly higher than the other parts of the plant, while the accumulated concentration of these heavy metals in the grains was lower than the other parts of the plant. Furthermore, the application of the sugarcane biochar in the contaminated soil could effectively control and decrease the uptake of lead and nickel in the plant. In this experiment, the maximum reduction of the heavy metals was observed with 6% biochar application. The reduction rate of lead was below the standard level in different parts of the plant, especially in the grains, while the reduction rate of nickel was higher than the standard level, especially in the grains. This could be due to the differences in the stabilizing power of biochars and absorption and transfer of lead and nickel from the roots to the shoots. In conclusion, it is recommended that further investigations be conducted in this regard in order to increase food safety.

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