



Bioconcentrations and health risk assessment of heavy metals in crops in the Naoli River Basin agricultural area, Sanjiang Plain, China

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Abstract

Ingesting crop grains contaminated with heavy metals is the most urgent problem related to food security and human health. Additionally, an overall analysis of heavy metal concentrations in different crop organs has guiding significance for ensuring food safety production. In this study, the concentrations of Cr, Ni, Cu, Zn, As, Cd, Hg, and Pb in soil, corn and soybean were determined in an agricultural area to assess the health risks associated with the ingestion of crop grains. Results showed the soil heavy metals were at a moderate pollution level, with an average pollution load index (PLI) of 1.07. For heavy metals Cr, Ni, Cu, Zn, As, and Cd, the concentrations and bioconcentration factors in soybean grain were significantly higher than those in corn grain. For Hg and Pb, corn and soybean grains exhibited no difference in their concentrations and bioconcentration ability. Moreover, heavy metal concentrations in corn and soybean grains were at a very low polluted level and low polluted level, and the Nemerow comprehensive pollution index (*P*) values were 0.96 and 1.09, respectively. The hazard index (HI) values for children caused by corn and soybean ingestion were all greater than 1, the target carcinogenic risk (TCR) values of Ni in corn and soybean for both children and adults were $> 1 \times 10^{-4}$, indicating the ingestion of heavy metals in crop grains posed a potential non-carcinogenic risk to children and a potential carcinogenic risk to both children and adults.

Keywords Corn · Soybean · Heavy metal · Concentration · Health risk assessment

Introduction

Crops provide food for human beings, which is the material basis for human survival. As an important basic resource in agricultural production, soil not only provides nutrients for crop growth but also allows various pollutants to enter the crops, endangering human health (Song et al. 2020a). Recent rapid developments in industry and agriculture have led to increasingly serious heavy metal pollution in soil (Sharma et al. 2009). Different from organic pollutants, soil heavy metals are difficult to be degraded by microorganisms. However, microorganisms can change the mobility and bioavailability of heavy metals through influence plant uptake,

absorption and enrichment, dissolution and precipitation, and oxidation and reduction (Wu et al. 2006; Bahadur et al. 2016; Song et al. 2020b). Heavy metals present in soil can enter crops through the soil–crop system and become distributed in different crop organs, including the root, stem, leaf, and grain (Clemens and Ma 2016). Therefore, ingestion of crop grain is a significant pathway by which heavy metals enter the human body (Khan et al. 2008; Roy and McDonald 2015). Corn and soybean are important components of the human diet, and if they are contaminated with heavy metals may pose a significant threat to human health (Filippini et al. 2019; Ferrante et al. 2019; Abdi et al. 2020). Previous research has shown that every year around the world, over 420 thousand people die and 60 million people fall ill after eating food contaminated with heavy metals (Zheng et al. 2020). As such, there is a growing demand for assessment of the health risks caused by the ingestion of food crops contaminated with heavy metals.

The human health risk from heavy metals can be assessed using non-carcinogenic and carcinogenic risk assessment methods. The target hazard quotient (THQ), hazard index (HI) are typically indicators used to assess the

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non-carcinogenic risk, whereas the target carcinogenic risk (TCR) is typically used to assess the carcinogenic risk (Jiang et al. 2020). These methods are widely used in many fields, especially in relation to heavy metal-related health risks in vegetables, fruits, groundwater and soil (Roy and McDonald 2015; Shaheen et al. 2016; Song et al. 2017, 2018a). However, due to the limited available data on heavy metal concentrations in crops or other factors, several previous studies have only considered the health risks associated with a few heavy metals or only assessed the non-carcinogenic risks (Bian et al. 2016; Luo et al. 2020), have led to inadequate assessment of the actual risk of heavy metal exposure from food. Additionally, crop species and organs vary greatly in their capacity to absorb and accumulate heavy metals (Clemens and Ma 2016), an overall analysis of heavy metal concentrations in different crop organs, including the root, stem, leaf, and grain has guiding significance for ensuring food safety production.

The Sanjiang Plain is an important grain-producing area in China. In recent years, the soil quality in the region has declined dramatically owing to the substantial use of fertilizers and pesticides (Song et al. 2018a). This may affect the quality of crops and has serious implications for human health. Therefore, considering a typical agricultural area in Naoli River Basin of Sanjiang Plain as the study area, this study evaluated the heavy metal pollution status in soil and analyzed the distribution characteristics of heavy metal in different organs of corn and soybean. The potential health risks of consuming corn and soybean were also assessed. The results are of great significance in better understanding the status of corn and soybean to accumulate heavy metals from the soil and the health risks associated with the heavy metals in these crops within the study area. Moreover, the findings provide a scientific basis for adjusting and optimizing the agricultural planting structure and ensuring the quality of agricultural products and the safety and health of humans.

Materials and methods

Study area

The study area is located in Naoli River Basin in Sanjiang Plain, where the main crops are corn and soybean. It has a continental monsoon climate with semi-humid and semi-arid conditions, an average annual temperature of 3.6 °C, and average annual precipitation of 505 mm. This area contains abundant fertile black soil, where the soil type is silty loam soil (clay (<0.002 mm, 10.29%), silt (0.002–0.02 mm, 67.29%), sand (0.02–2 mm, 22.42%)), and the organic carbon concentration is relatively high (average concentration is 5.52%), which has natural advantages for agriculture development. However,

with the rapid development of agriculture and extensive use of chemical fertilizers and pesticides in recent years, soil quality has declined substantially (Song et al. 2018a), which may affect the quality of crops and has serious implications for human health.

Sampling and chemical analyses

The sampling method was based on the national standard (MLRPRC 2016). In this study, 11 corn samples and 12 soybean samples were collected from the study area in September 2018 at the maturation stage of the crop. During sampling, the soil was removed from the collected crop samples by washing with distilled water, and samples were, then, dried with filter paper. For each crop sample, four organs (i.e., root, stem, leaf, and grain) were separated using a stainless-steel knife and, then, packed in cloth bags for subsequent analysis. Soil samples (0–20 cm) were also collected from the same locations as crop samples.

The soil samples were dried naturally in the laboratory and sifted with a 2-mm sieve to remove residue. Crop samples were dried at 38 °C till constant weight, then, ground into a fine powder. 0.5 g of each soil sample was digested with 5 mL of HNO₃ and HClO₄ (4:1, v:v), and 0.1 g of each crop sample was digested with 1 mL HNO₃ at room temperature for 15 h followed by digestion at 110 °C for 3 h, and the digestion continued for 30 min after adding 0.2 mL H₂O₂. The total concentrations of Cr, Ni, Cu, Zn, Cd, and Pb were determined via inductively coupled plasma mass spectrometry (ICP-MS, Nexion350D), and As and Hg levels were determined via atomic fluorescence spectrometry (AFS, PF6-2). Quality assurance and quality control (QA/QC) procedures were conducted using certified soil, corn and soybean component analysis reference materials GBW07403 (GSS-3), GBW10012 (GSB-3) and GBW10013 (GSB-4) from the Center of National Standard Reference Material of China. The relative standard deviation (RSD) was less than 5% and the recovery percentages were 90–110%, which indicates that the heavy metal detection was relatively accurate and reliable.

Pollution assessment of heavy metals in soil

The pollution load index (PLI) method can be used to evaluate the comprehensive soil pollution status in a certain area. The PLI is calculated as follows (Islam et al. 2019):

$$CF_i = \frac{G_i}{B_i}, \quad (1)$$

$$PLI_i = \sqrt[n]{CF_1 \times CF_2 \times \dots \times CF_n}, \quad (2)$$

where n is the number of heavy metal elements ($n=8$ in this study); G_i and B_i represent the concentrations (mg/kg) of

heavy metal i in the soil and background, respectively; CF_i is the contamination factor of heavy metal i , which can be separated into four levels (Islam et al. 2020): $CF_i < 1$, $1 \leq CF_i < 3$, $3 \leq CF_i < 6$, and $CF_i \geq 6$, corresponding to low, moderate, considerable, and very high degrees, respectively. The PLI can similarly be separated into four levels (Ding et al. 2019): $PLI < 1$, $1 \leq PLI < 2$, $2 \leq PLI < 3$, and $PLI \geq 3$, corresponding to no, moderate, high, and very high pollution, respectively.

Pollution assessment of heavy metals in crop grains

The single factor pollution index method is commonly used in heavy metal assessments (Luo et al. 2020). The method is a widely used method that boasts a simple calculation and a clear target. However, this method can only assess a single heavy metal element, which makes its use difficult in assessing the comprehensive pollution status of heavy metals. Based on the single factor pollution index method, the Nemerow pollution index method comprehensively considers the pollution index of heavy metals and involves a more rigorous evaluation. Therefore, the Nemerow pollution index method was used to evaluate the heavy metal pollution level of crop grains as follows (Jiang et al. 2019):

$$P_i = \frac{C_i}{S_i}, \quad (3)$$

$$P = \sqrt{\frac{[\text{Max}(P_i)]^2 + [\text{Ave}(P_i)]^2}{2}}, \quad (4)$$

where P_i is the single factor pollution index; C_i is the measured concentration of heavy metal i in the crop grain; S_i is the limit of heavy metal i in the crop grain according to the national standards for food safety (MHPRC 1991; MHPRC 1994; MHPRC 2005) and relevant standards suggested by Fu et al. (1999). The limit values of Cr, Ni, Cu, Zn, As, Cd, Hg, and Pb concentrations are 1.0, 0.4, 10, 50, 0.2, 0.1, 0.01, and 0.2 mg/kg for corn, respectively, and 1.0, 3.0, 20, 100, 0.1, 0.2, 0.02, and 0.2 mg/kg for soybean, respectively. P is the comprehensive pollution index; $\text{Max}(P_i)$ is the maximum pollution index of each heavy metal in crop grain; $\text{Ave}(P_i)$ is the average value of the single pollution index. P can be differentiated into five levels (Fang et al. 2019): $P \leq 0.7$, $0.7 < P \leq 1.0$, $1.0 < P \leq 2.0$, $2.0 < P \leq 3.0$, and $P > 3.0$, corresponded to unpolluted, very low polluted, low polluted, moderately polluted, and strongly polluted, respectively.

Bioconcentration factor

The bioconcentration factor (BCF) can be used to evaluate the ability of crops to accumulate heavy metals from

soil (Ghosh and Singh 2005), and is defined as the ratio of the heavy metal concentration in the crop to that in the soil; the higher the BCF the stronger the crop's ability to accumulate heavy metals. The BCF is calculated as follows (Song et al. 2018b):

$$\text{BCF} = \frac{Z_i}{G_i}, \quad (5)$$

where Z_i and G_i represent the concentration of heavy metal i in the crop and soil (mg/kg), respectively.

Health risk assessment

Heavy metals can harm human health through chronic accumulation in the human body via food intake. According to the different mechanisms by which heavy metal elements harm human health, they can be divided into non-carcinogens and carcinogens. In this study, the health risk assessment model recommended by the United States Environmental Protection Agency (USEPA) was used to calculate the health risks caused by these two types of heavy metals in crops.

Non-carcinogenic risk

Non-carcinogenic risks caused by the ingestion of heavy metals from crops can be assessed based on the target hazard quotient (THQ), which is calculated as follows:

$$\text{THQ} = \frac{C \times \text{DI} \times \text{EF} \times \text{ED}_{\text{total}}}{\text{RfD} \times \text{BW} \times \text{ATn}}, \quad (6)$$

where C is the average concentration of the heavy metal (mg/kg) in crop grains; DI is the daily intake of grains (corn: 0.100 kg/day and 0.150 kg/day for children and adults, respectively; soybean: 0.037 kg/day and 0.076 kg/day for children and adults, respectively) (Luo et al. 2020; Zhou et al. 2020); EF is the exposure frequency, which is taken as 365 days/year (Vatanpour et al. 2020); ED_{total} is the exposure duration (children: 10 years; adults: 30 years) (Zang et al. 2017; Liu et al. 2020); RfD is the reference dose (Cr: 1.5; Ni: 0.02; Cu: 0.04; Zn: 0.3; As: 0.0003; Cd: 0.001; Hg: 0.3; Pb: 0.004) (Wei et al. 2020); BW is the average body weight (children: 16 kg; adults: 70 kg) (Zang et al. 2017); and ATn is the average exposure time for non-carcinogenic heavy metals, which is equal to $\text{ED}_{\text{total}} \times 365$ days/year.

The overall non-carcinogenic risk from all heavy metals was estimated using the hazard index (HI) obtained by summing the THQ of each heavy metal (assuming additive effects) (Islam et al. 2019). HI can be calculated as follows:

$$HI = \sum_{i=1}^n THQ_i, \quad (7)$$

where n is the number of heavy metal elements ($n=8$ in this study); THQ or HI values < 1 , are assumed to be safe, whereas values > 1 indicate a potential non-carcinogenic risk (Zheng et al. 2020).

Carcinogenic risk

Carcinogenic risks caused by the ingestion of heavy metals from crops can be assessed based on the target carcinogenic risk (TCR), which is calculated as follows:

$$TCR = \frac{C \times DI \times EF \times ED_{total} \times SF}{BW \times ATc}, \quad (8)$$

where C , DI , EF , ED_{total} and BW are the same as previously defined for non-carcinogenic risk; ATc is the average exposure time for carcinogenic heavy metals (70×365 days) (Liu et al. 2020); and SF is the cancer slope factor (Cr: 0.50; Ni: 1.70; As: 1.50; Cd: 0.0085; Pb: 15.00) (Wei et al. 2020). TCR values ranging from 1×10^{-6} to 1×10^{-4} are deemed to indicate an acceptable or tolerable risk, values $< 1 \times 10^{-6}$ indicate no risk, and values $> 1 \times 10^{-4}$ indicate a high risk (Wei et al. 2020).

Data analysis

Data analysis was conducted using Origin 8.0, SPSS 16.0, and Microsoft Excel (2010). Statistical analysis was used to study the heavy metal concentrations in soil and crops, and the bioconcentration factor of heavy metals in crop grains. Differences in the bioconcentration factor of heavy metals in corn and soybean grains were analyzed using the analysis of variance (ANOVA).

Results and discussion

Concentrations and pollution levels of soil heavy metals

Soil heavy metal concentrations varied markedly and are shown in Table 1. The highest average concentration was that of Cr, followed by Zn, Ni, Cu, Pb, As, Cd, and Hg in descending order. The average Cr, Ni, Cu, Cd, and Pb concentrations in the soil exceeded the soil element background values of the study area (CEMC 1990) in varying degrees. Several previous studies found that overuse of chemical fertilizers and pesticides can often lead to Cr, Ni, Cu, Cd, and Pb accumulation in soil (Chen et al. 2008; Chen et al. 2008; Jayasumana et al. 2015; Song et al. 2018a). For Zn, As,

Table 1 Statistical values of soil heavy metal concentrations and related background values

Heavy metal	Min	Max	SD	Average	Background value
Cr	47.10	93.90	11.20	78.85	58.60
Ni	20.45	36.70	4.42	29.18	22.80
Cu	22.50	28.90	1.58	26.18	20.00
Zn	48.40	89.65	10.91	67.24	70.70
As	1.11	11.80	3.07	6.26	7.30
Cd	0.07	0.23	0.04	0.11	0.09
Hg	23.90	93.00	13.85	36.64	37.00
Pb	18.25	30.60	3.13	24.83	24.20

Units are mg/kg for all heavy metals except Hg ($\mu\text{g}/\text{kg}$)

and Hg, although the average heavy metal concentrations were lower than the background values, 38.10%, 38.10%, and 23.81% of the soil samples, respectively, did exceed the background values.

The contamination factor of heavy metal (CF) was adopted to identify heavy metal pollution level in the soil. The average CF values of the heavy metals decreased as follows: Cr (1.34) > Cu (1.31) > Ni (1.28) > Cd (1.20) > Pb (1.03) > Hg (0.99) > Zn (0.95) > As (0.86), which indicates that the Cr, Cu, Ni, Cd, and Pb in the soil were at moderate pollution degree. The PLI was also used to evaluate the pollution level of soil heavy metals. The PLI values in the study area were in the range of 0.79–1.27 (average: 1.07), and the values for 76.19% of the soil samples were > 1 , which indicates that the soil heavy metals in the study area were generally at moderate pollution level.

Distribution characteristics of heavy metals in corn and soybean

The uptake and accumulation of heavy metals in crops are controlled by the crop type, the crop organ, the type of heavy metal, the concentration and fraction of heavy metal, and other factors. Therefore, the differences in the heavy metal concentrations in different organs are observed. As shown in Fig. 1, the average Cr, Ni, Cu, and Hg concentrations in different corn organs decreased as follows: leaf > root > stem > grain. For other different heavy metals, the order was as follows: leaf > grain > stem > root for Zn; root > stem > leaf > grain for As; leaf > stem > root > grain for Cd; and root > leaf > stem > grain for Pb. Thus, As and Pb predominantly accumulated in the root, whereas Cr, Ni, Cu, Zn, Cd, and Hg predominantly accumulated in the leaf, which indicates that these heavy metals were not retained in the root but transferred to aerial parts, as also reported by Zhang et al. (2010). This may be because the aboveground biomass of corn is much larger than that of the root, and the

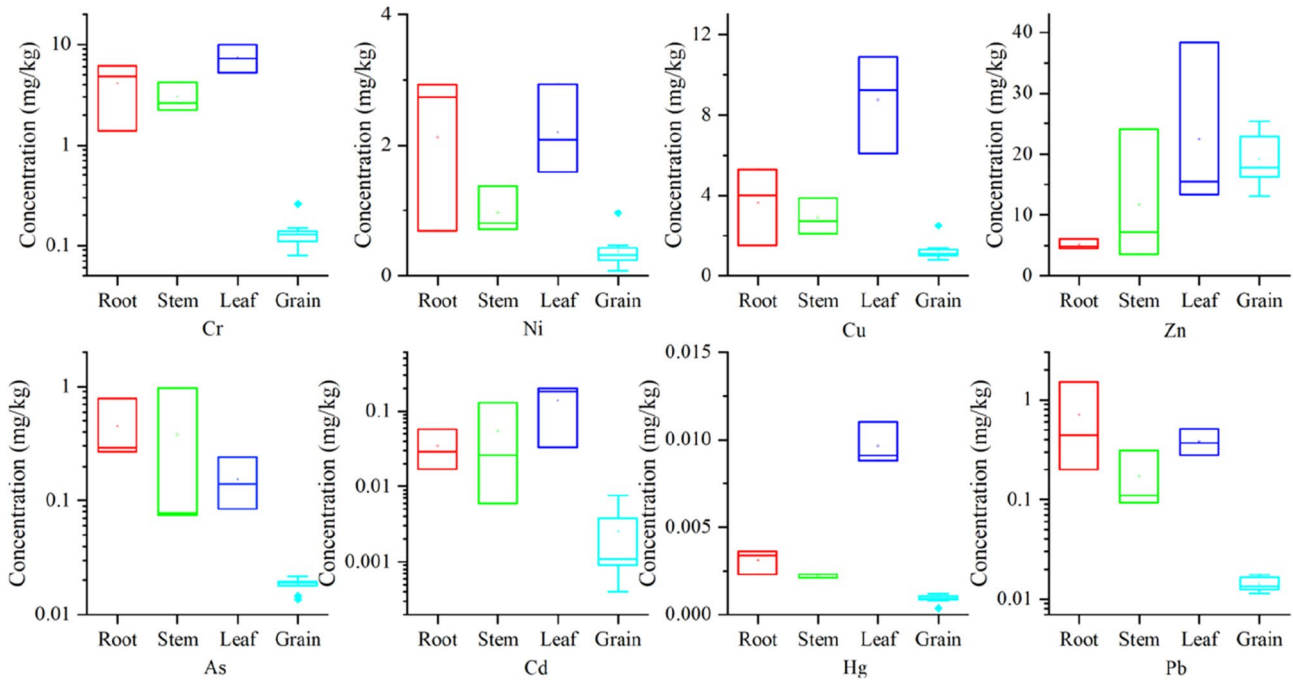


Fig. 1 Concentrations of heavy metals in different corn organs

vascular tissue and mechanical tissue of the aboveground part are better developed, with a strong ability to absorb and accumulate heavy metals, thereby leading to their accumulation in the leaf.

As shown in Fig. 2, the average Cr and As concentrations in different soybean organs decreased in the following order: root > leaf > stem > grain; the order was grain > root > leaf > stem for Ni; grain > leaf > root > stem for

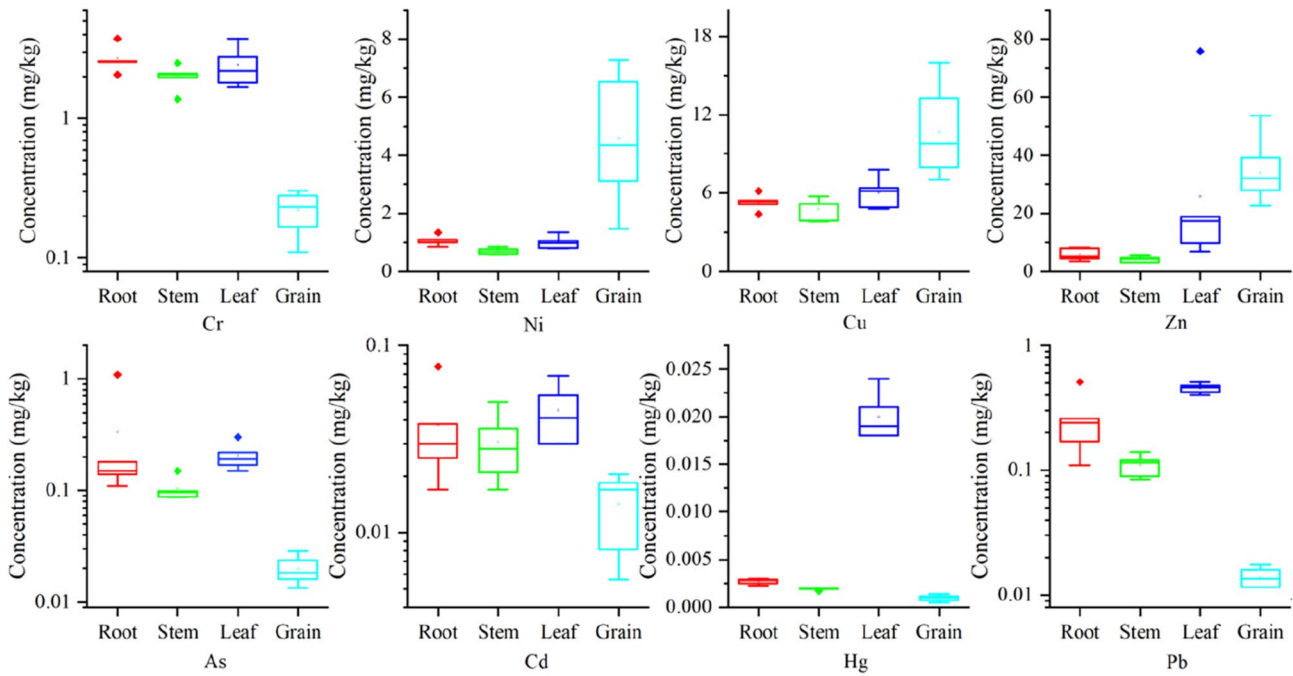


Fig. 2 Concentrations of heavy metals in different soybean organs

Cu and Zn; and leaf > root > stem > grain for Cd, Hg, and Pb. Thus, Cr and As predominantly accumulated in the root; Ni, Cu, and Zn predominantly accumulated in the grain; and Cd, Hg, and Pb predominantly accumulated in the leaf. These findings are consistent with the results of Bian, (2009).

Bioconcentrations and pollution assessment of heavy metals in crop grains

The concentrations of different heavy metals in the crop grains are shown in Table 2. The concentration of Zn was highest in both corn and soybean, followed by Cu, which was much higher than that of other heavy metals. The concentrations of Cr, Ni, Cu, Zn, As, and Cd were higher in soybean than in corn, whereas the concentrations of Hg and Pb were similar in the two crops. According to the bioconcentration factors of different heavy metals in crop grains (Table 3), the values for heavy metals in corn and soybean grains decreased in the order Zn > Cu > Cd > Hg > Ni > As > Cr > Pb and Zn > Cu > Ni > Cd > Hg > As > Cr > Pb, respectively. However, the ability of soybean grains to accumulate heavy metals (except Hg and Pb) from the soil was significantly higher than that of corn grains. This may be because soybean has more proteins than corn, and proteins play an important role in the absorption, transport and storage of heavy metals in plant organs, which can promote the transport of heavy metals in plants (Prasad and Kazimierz 2002; Luo and Shen 2003). For Hg and Pb, corn and soybean grains exhibited no difference in their bioconcentration ability.

Based on the limit values of heavy metals for corn and soybean grains, we obtained the single factor pollution index of heavy metals in crop grains (Fig. 3). Except for that of

Ni in soybean grains, the single pollution index of all heavy metals is less than 1 for both crops. The single pollution index for heavy metals in corn grains and soybean grains decreased in the following order: Ni > Zn > Cr > Cu > As > Hg > Pb > Cd and Ni > Cu > Zn > Cr > As > Cd > Pb > Hg, respectively, indicating serious Ni pollution in both crop grains. The Nemerow pollution index (*P*) indicated that the pollution index of heavy metals in corn grains was 0.96, which was at the very low polluted level. Conversely, the pollution index of heavy metals in soybean grains was 1.09, which corresponded to a low polluted level. Therefore, it is necessary to assess the health risks of heavy metals in crop grains.

Health risk assessment of heavy metals in crop grains

The THQ and HI values of the non-carcinogenic risk to children and adults caused by corn and soybean ingestion are shown in Tables 4 and 5. Zn and As exhibited the highest THQ value in corn, followed by Cu, Ni, Pb, Cd, Cr, and Hg in descending order. Conversely, Cu and Ni exhibited the highest THQ value in soybean, followed by Zn, As, Cd, Pb, Cr, and Hg in descending order. The THQ values of all heavy metals were < 1 in corn and soybean grains for both children and adults. However, the HI values for children were greater than 1, which indicated that children were at higher risk of non-carcinogenesis than adults, and heavy metal ingestion via crops had potential non-carcinogenic risks for children. Furthermore, Zn exhibited the highest contribution to the HI value in corn grains (accounting for 35.448%), followed by As (accounting for 33.473%), with

Table 2 Statistical values of heavy metal concentrations (mg/kg) in crop grains

Crop	Item	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
Corn	Min	0.075	0.081	0.825	13.150	0.0135	0.0004	0.0004	0.0115
	Max	0.255	0.955	2.545	25.400	0.0215	0.0076	0.0012	0.0175
	SD	0.053	0.250	0.516	4.146	0.003	0.003	0.0002	0.002
	Average	0.129	0.371	1.261	19.239	0.0182	0.0025	0.0009	0.0142
Soybean	Min	0.110	1.460	7.015	22.450	0.0135	0.0056	0.0005	0.0115
	Max	0.305	7.295	16.000	53.650	0.0285	0.0205	0.0014	0.0175
	SD	0.068	2.011	2.962	8.573	0.005	0.006	0.0003	0.002
	Average	0.220	4.579	10.626	33.867	0.0197	0.0142	0.0009	0.0139

Table 3 Bioconcentration factor of heavy metals in crop grains

Crop	Bioconcentration factor (BCF)							
	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
Corn	0.0016 ^a	0.0126 ^a	0.0487 ^a	0.2620 ^a	0.0029 ^a	0.0328 ^a	0.0234 ^a	0.0005 ^a
Soybean	0.0029 ^b	0.1625 ^b	0.4035 ^b	0.5492 ^b	0.0061 ^b	0.1353 ^b	0.0293 ^a	0.0006 ^a

Numbers shown are average values. Values followed by different letters in the same column are significantly different at the 0.05 level

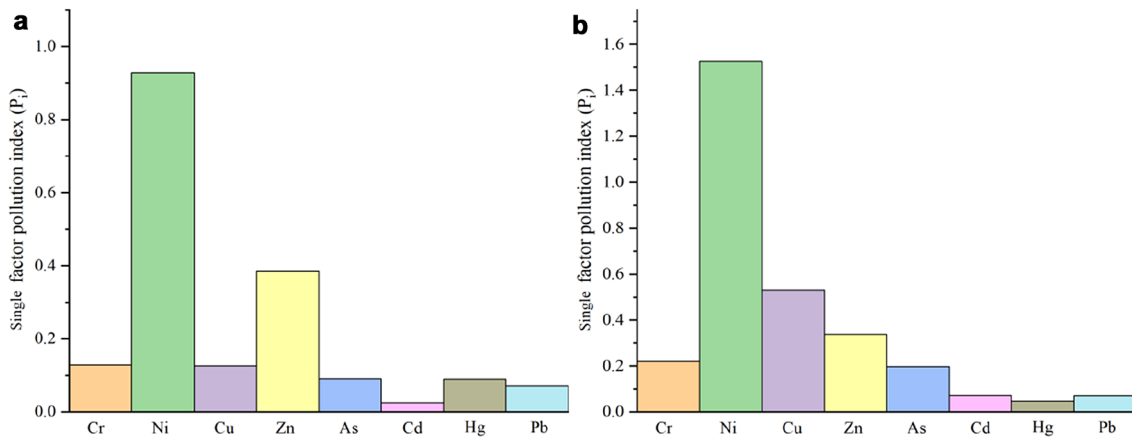


Fig. 3 Single-factor pollution index of heavy metals in crop grains (a corn; b soybean)

Table 4 THQ and HI values for non-carcinogenic risk due to corn ingestion and contribution of each heavy metal to HI

Heavy metal	Target hazard quotient (THQ)		Contribution of each heavy metal to HI (%)
	Children	Adults	
Cr	5.37×10^{-4}	1.84×10^{-4}	0.048
Ni	1.16×10^{-1}	3.98×10^{-2}	10.260
Cu	1.97×10^{-1}	6.75×10^{-2}	17.420
Zn	4.01×10^{-1}	1.37×10^{-1}	35.448
As	3.78×10^{-1}	1.30×10^{-1}	33.473
Cd	$1.57 \times 10^{-2} \times 10^{-2}$	$5.40 \times 10^{-3} \times 10^{-2}$	1.393
Hg	1.87×10^{-5}	6.42×10^{-6}	0.002
Pb	2.21×10^{-2}	7.59×10^{-3}	1.958
HI	1.13	3.88×10^{-1}	100.000

Table 5 THQ and HI values for non-carcinogenic risk due to soybean ingestion and contribution of each heavy metal to HI

Heavy metal	Target hazard quotient (THQ)		Contribution of each heavy metal to HI (%)
	Children	Adults	
Cr	3.40×10^{-4}	1.60×10^{-4}	0.021
Ni	5.29×10^{-1}	2.49×10^{-1}	33.132
Cu	6.14×10^{-1}	2.88×10^{-1}	38.445
Zn	2.61×10^{-1}	1.23×10^{-1}	16.337
As	1.52×10^{-1}	7.13×10^{-2}	9.507
Cd	3.28×10^{-2}	1.54×10^{-2}	2.055
Hg	7.27×10^{-6}	3.41×10^{-6}	0.000
Pb	8.02×10^{-3}	3.77×10^{-3}	0.502
HI	1.60	7.50×10^{-1}	100.00

the lowest contributions from Cu, Ni, Pb, Cd, Cr, and Hg for both children and adults. For soybean grains, Cu exhibited the highest contribution to the HI value (accounting for 38.445%), followed by Ni (accounting for 33.132%), with the lowest contributions from Zn, As, Cd, Pb, Cr, and Hg

for both children and adults. In summary, the heavy metals in corn and soybean grains posed a non-carcinogenic risk to children, and the non-carcinogenic risk of soybean ingestion was higher than that of corn.

The TCR carcinogenic risk to children and adults caused by corn and soybean ingestion was also calculated. As shown in Table 6 and Table 7, the TCR values were higher for adults than for children. For corn, Ni had the highest TCR value, followed by Cr, Cd, As, and Pb. For soybean, Ni also exhibited the highest TCR value, followed by Cd, Cr, As, and Pb. The TCR values of Ni in corn and soybean grains for both children and adults were $> 1 \times 10^{-4}$, indicating that the intake of heavy metals in crop grains posed a potential carcinogenic risk to humans, including lung and nasal cancer (Arita et al. 2012). The contributions of heavy metals to the total TCR (sum of TCR) also exhibited marked differences. Ni exhibited the highest contribution to the total TCR value in both crops (accounting for 82.959% and 95.663%, respectively). In summary, heavy metals in corn and soybean grain posed a carcinogenic risk to humans, and the carcinogenic risk of soybean ingestion was higher than that of corn.

Table 6 TCR values for carcinogenic risk due to corn ingestion and contribution of each heavy metal to total TCR

Heavy metal	Target carcinogenic risk (TCR)		Contribution of each heavy metal to total TCR (%)
	Children	Adults	
Cr	5.76×10^{-5}	5.92×10^{-5}	8.475
Ni	5.63×10^{-4}	5.80×10^{-4}	82.959
As	2.43×10^{-5}	2.50×10^{-5}	3.582
Cd	3.37×10^{-5}	3.47×10^{-5}	4.968
Pb	1.08×10^{-7}	1.11×10^{-7}	0.016

Table 7 TCR values for carcinogenic risk due to soybean ingestion and contribution of each heavy metal to total TCR

Heavy metal	Target carcinogenic risk (TCR)		Contribution of each heavy metal to total TCR (%)
	Children	Adults	
Cr	3.64×10^{-5}	5.13×10^{-5}	1.354
Ni	2.57×10^{-3}	3.62×10^{-3}	95.663
As	9.77×10^{-6}	1.38×10^{-5}	0.363
Cd	7.04×10^{-5}	9.91×10^{-5}	2.618
Pb	3.90×10^{-8}	5.49×10^{-8}	0.001

Conclusions

The main conclusions drawn from the present study are given below.

1. The soil heavy metals in the study area were at a moderate pollution level. For corn, Cr, Ni, Cu, Zn, Cd, and Hg predominantly accumulated in the leaf, whereas As and Pb predominantly accumulated in the root. For soybean, Cr and As predominantly accumulated in the root; Ni, Cu, and Zn predominantly accumulated in the grain; and Cd, Hg, and Pb predominantly accumulated in the leaf.
2. The concentrations and bioconcentration factors of heavy metals Cr, Ni, Cu, Zn, As, and Cd in soybean grains were significantly higher than those in corn grains. Heavy metal concentrations in corn and soybean grains were at the very low polluted level and low polluted level, respectively. In addition, serious Ni contamination was observed in both crop grains.
3. Zn and As, Cu and Ni were the major contributors to the non-carcinogenic risk for corn and soybean, respectively. The ingestion of heavy metals in crop grains posed a potential non-carcinogenic risk to children. Ni was the major contributor to the carcinogenic risk for corn and soybean. The ingestion of heavy metals in crop grains posed a potential carcinogenic risk to humans.

4. To reduce the concentrations of heavy metals in crops, as well as the health risk to humans, chemical fertilizers and pesticides must be used appropriately. Moreover, by adopting passivation technology and using a series of reactions such as adsorption, complexation, and oxidation/reduction, et al., the soil heavy metal mobility and bioavailability can be decreased. For non-grain organs of crop, phytomining technology can be used to extract heavy metals from these parts and recover heavy metals with economic value to avoid secondary pollution.
5. Heavy metals enter the human body through crop grains ingestion, but not all are bioavailable. The health risk based on the total concentrations of the heavy metals would be overestimated, and an accurate health risk assessment should be based on bioaccessible heavy metals. In addition, crop grains ingestion is only one exposure pathway to humans. Exposure to heavy metals through vegetables and drinking water also poses significant health risks to humans. In the future, the health risks caused by multiple exposure pathways to heavy metals should be considered.

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Availability of data and material The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

References

- Abdi L, Aghaee EM, Nazmara S, Alipour MR, Fakhri Y, Khaneghah AM (2020) Potentially toxic elements (PTEs) in corn (*Zea mays*) and soybean (*Glycine max*) samples collected from Tehran, Iran: a health risk assessment study. *Int J Environ Anal Chem.* <https://doi.org/10.1080/03067319.2020.1786548>

- Arita A, Niu JP, Qu QS, Zhao NJ, Ruan Y, Nadas A, Chervona Y, Wu F, Sun H, Hayes RB, Costa M (2012) Global levels of histone modifications in peripheral blood mononuclear cells of subjects with exposure to nickel. *Environ Health Perspect* 120(2):198–203
- Bahadur A, Afzal A, Ahmad R, Nasir F, Khan A, Suthar V, Jan G, Batool A, Zia MA, Mahmood-ul-Hassan M (2016) Influence of metal-resistant rhizobacteria on the growth of *Helianthus annuus* L. in Cr(VI)-contaminated soil. *Water Air Soil Poll* 227(12):467
- Bian W, E Y, Hu ZB, Zhang XL (2009) Distribution of heavy metals in cropland soils amended with sewage sludge and in the uptake by soybean. *J Northeast Agric Univ* 40(8):37–43 (in Chinese)
- Bian B, Lin C, Lv L (2016) Health risk assessment of heavy metals in soil-plant system amended with biogas slurry in Taihu basin, China. *Environ Sci Pollut Res* 23(17):16955–16964
- CEMC, China Environmental Monitoring Centre (1990) Chinese soil element background values. China Environmental Science Press, Beijing (in Chinese)
- Chen T, Liu XM, Zhu MZ, Zhao KL, Wu JJ, Xu JM, Huang PM (2008) Identification of trace element sources and associated risk assessment in vegetable soils of the urban-rural transitional area of Hangzhou, China. *Environ Pollut* 151(1):67–78
- Clemens S, Ma JF (2016) Toxic heavy metal and metalloid accumulation in crop plants and foods. *Annu Rev Plant Biol* 67:489–512
- Conte F, Copat C, Longo S, Conti GO, Grasso A, Arena G, Brundo MV, Ferrante M (2015) First data on trace elements in *Haliotis tuberculata* (Linnaeus, 1758) from southern Italy: safety issues. *Food Chem Toxicol* 81:143–150
- Ding XG, Ye SY, Laws EA, Mozdzer TJ, Yuan HM, Zhao GM, Yang SX, He L, Wang J (2019) The concentration distribution and pollution assessment of heavy metals in surface sediments of the Bohai Bay, China. *Mar Pollut Bull* 149:110497
- Fang AA, Dong JH, Zhang R (2019) Simulation of heavy metals migration in soil-wheat system of mining area. *Int J Environ Res Public Health* 16(14):2550
- Ferrante M, Napoli S, Grasso A, Zuccarello P, Cristaldi A, Copat C (2019) Systematic review of arsenic in fresh seafood from the Mediterranean Sea and European Atlantic coasts: a health risk assessment. *Food Chem Toxicol* 126:322–331
- Filippini T, Malagoli C, Wise LA, Malavolti M, Pellacani G, Vinceti M (2019) Dietary cadmium intake and risk of cutaneous melanoma: an Italian population-based case-control study. *J Trace Elem Med Biol* 56:100–106
- Fu YG, Hu X, Yu SX (1999) Study on the tolerance limit of nickel in foods. *Acta Academiae Medicinae Zhejiang* 37:9–11 (in Chinese)
- Ghosh M, Singh SP (2005) A comparative study of cadmium phytoextraction by accumulator and weed species. *Environ Pollut* 133(2):365–371
- Islam MA, Akber MA, Rahman MB, Rahman MA, Haque MA, Islam MA (2019) Trace elements in rice grain and agricultural soils: assessment of health risk of inhabitants near a former secondary lead smelter in Khulna, Bangladesh. *Environ Geochem Health* 41(6):2521–2532
- Islam MS, Ahmed MK, Al-Mamun MH, Eaton DW (2020) Human and ecological risks of metals in soils under different land-use types in an urban environment of Bangladesh. *Pedosphere* 30(2):201–213
- Jayasumana C, Fonseka S, Fernando A, Jayalath K, Amarasinghe M, Siribaddana S, Gunatilake S, Paranagama P (2015) Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. Springerplus 4:90
- Jiang L, Yi X, Xu B, Wang W, Lai KR (2019) Soil treatment and crop rotation for in situ remediation of heavy metal-contaminated agricultural soil in gold mining areas. *Hum Ecol Risk Assess* 25(1–2):374–392
- Jiang YL, Ma JH, Ruan XL, Chen X (2020) Compound health risk assessment of cumulative heavy metal exposure: a case study of a village near a battery factory in Henan Province, China. *Environ Sci Proc Imp* 22(6):1408–1422
- Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environ Pollut* 152(3):686–692
- Liu YM, Liu DY, Zhang W, Chen XX, Zhao QY, Chen XP, Zou CQ (2020) Health risk assessment of heavy metals (Zn, Cu, Cd, Pb, As and Cr) in wheat grain receiving repeated Zn fertilizers. *Environ Pollut* 257:113581
- Luo CL, Shen ZG (2003) The mechanisms of heavy metal uptake and accumulation in plants. *Chin Bull Bot* 20(1):59–66 (in Chinese)
- Luo X, Ren BZ, Hursthouse AS, Jiang F, Deng RJ (2020) Potentially toxic elements (PTEs) in crops, soil, and water near Xiangtan manganese mine, China: potential risk to health in the foodchain. *Environ Geochem Health* 42(7):1965–1976
- MHPRC, Ministry of Health of the People's Republic of China (1991) Tolerance limit of zinc in foods (GB 13106–1991). China Standard Press, Beijing (in Chinese)
- MHPRC, Ministry of Health of the People's Republic of China (1994) Tolerance limit of copper in foods (GB 15199–1994). China Standard Press, Beijing (in Chinese)
- MHPRC, Ministry of Health of the People's Republic of China (2005) Maximum levels of contaminants in foods (GB 2762–2005). China Standard Press, Beijing (in Chinese)
- MLRPRC, Ministry of Land and Resources of the PRC (2016) Specification of Land quality geochemical assessment (DZ/T 0295–2016). China Standard Press, Beijing (in Chinese)
- Prasad M, Kazimierz S (2002) Physiology and biochemistry of metal toxicity and tolerance in plants. Springer, Amsterdam
- Roy M, McDonald LM (2015) Metal uptake in plants and health risk assessments in metal-contaminated smelter soils. *Land Degrad Dev* 26(8):785–792
- Shaheen N, Irfan NM, Khan IN, Islam S, Islam MS, Ahmed MK (2016) Presence of heavy metals in fruits and vegetables: health risk implications in Bangladesh. *Chemosphere* 152:431–438
- Sharma RK, Agrawal M, Marshall FM (2009) Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. *Food Chem Toxicol* 47(3):583–591
- Song TJ, Chen YX, Du SH, Yang FT (2017) Hydrogeochemical evolution and risk assessment of human health in a riverbank filtration site, northeastern China. *Hum Ecol Risk Assess* 23(4):705–726
- Song TJ, Su XS, He J, Liang YK, Zhou T (2018a) Source apportionment and health risk assessment of heavy metals in agricultural soils in Xinglonggang, Northeastern China. *Hum Ecol Risk Assess* 24(2):509–521
- Song TJ, Su XS, He J, Liang YK, Zhou T, Liu C (2018b) Selenium (Se) uptake and dynamic changes of Se content in soil-plant systems. *Environ Sci Pollut Res* 25(34):34343–34350
- Song TJ, Cui G, Su XS, He J, Tong SZ, Liu Y (2020a) The origin of soil selenium in a typical agricultural area in Hamatong River Basin, Sanjiang Plain, China. *Catena* 185:104355
- Song TJ, Liu C, Cui G, Tong SZ (2020b) Research on the migration and transformation behaviors of soil selenium in the flood irrigation process. *Arch Agron Soil Sci*. <https://doi.org/10.1080/03650340.2020.1795643>
- Vatanpour N, Feizy J, Talouki HH, Es'haghi Z, Scesi L, Malvandi AM (2020) The high levels of heavy metal accumulation in cultivated rice from the Tajan river basin: health and ecological risk assessment. *Chemosphere* 245:125639
- Wei RP, Wang X, Tang WL, Yang YC, Gao Y, Zhong H, Yang LY (2020) Bioaccumulations and potential human health risks assessment of heavy metals in ppk-expressing transgenic rice. *Sci Total Environ* 710:136496

- Wu SC, Luo YM, Cheung KC, Wong MH (2006) Influence of bacteria on Pb and Zn speciation, mobility and bioavailability in soil: a laboratory study. *Environ Pollut* 144(3):765–773
- Zang F, Wang SL, Nan ZR, Ma JM, Zhang Q, Chen YZ, Li YP (2017) Accumulation, spatio-temporal distribution, and risk assessment of heavy metals in the soil-corn system around a polymetallic mining area from the Loess Plateau, northwest China. *Geoderma* 305:188–196
- Zhang DG, Liu J, Quan SZ, Tian T (2010) Research on the character of distribution of the pollution of heavy metal in the maize around the stannary in Yunnan. *J Anhui Agric Sci* 24:13312–13314 ((in Chinese))
- Zheng SN, Wang Q, Yuan YZ, Sun WM (2020) Human health risk assessment of heavy metals in soil and food crops in the Pearl River Delta urban agglomeration of China. *Food Chem* 316:126213
- Zhou Y, Wan JZ, Li Q, Huang JB, Zhang ST, Long T, Deng SP (2020) Heavy metal contamination and health risk assessment of corn grains from a Pb–Zn mining area. *Environ Sci* 1:1–16 ((in Chinese))

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