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Uptake effects of toxic heavy metals from growth soils into jujube and persimmon of China

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Abstract

Compared with other agricultural plants, information about uptake effects of toxic heavy metals from growth soils into persimmon and jujube are scarce. In this study, the single and comprehensive uptake effects of five toxic heavy metals (Pb, As, Cd, Cr, and Hg) between the two fruits and their growth soils were investigated. The results showed that the average concentrations of heavy metals in the two fruits were found to be 30 (Pb), 6.6 (As), 2.3 (Cd), 38 (Cr), and 0.33 (Hg) μg/kg, respectively. The average concentrations of heavy metals in their growth soils were 26.31 (Pb), 9.63 (As), 0.12 (Cd), 57.6 (Cr), and 0.049 (Hg) mg/kg, respectively. An uptake effect was observed for the two fruits. The values of Nemerow pollution index (NPI) in the two fruits and their growth soils were 0.10 and 0.55, respectively. The average bioconcentration factor (BCF) values of Pb, As, Cd, Cr, and Hg in the two fruits were 0.0012, 0.00075, 0.021, 0.00077, and 0.012, respectively. Based on the residue levels of toxic heavy metals in the growth soils and soil parameters, the prediction models for NPI and BCF were established, with the adjusted regression coefficients of 0.65 (NPI) and 0.81 (BCF). The contribution rates of different soil parameters to NPI were 21.7% (OC), 16.1% (Pb), 17.1% (Cr), 19.8% (Cd), and 25.4% (As), respectively. The contribution rates of different soil parameters to BCF were 10.2% (OC), 9.4% (Cr), and 80.4% (Cd), respectively.

Introduction

Fruits play an important role in human diet and they are an important source of many dietary nutrients. Populations that consume fruits, however, can be exposed to high levels of heavy metals when they are contaminated or produced from polluted areas. Heavy metals belong to a group of inorganic pollutants that have gained attention from the public and researchers due to their persistence in the environment, bioaccumulation and toxicity to plants and animals, and adverse effects on human health (via the food chain) (Han et al. 2018). Average Cd content (0.08 mg/kg) in apples from northern Pakistan was approximately 1.6 times of the limit (0.05 mg/kg) set by the World Health Organization (WHO) (Khan et al. 2013). The contamination of Pb in pear (0.32 mg/kg) collected from Kohistan region in Pakistan was observed above the FAO/WHO safe limit (0.3 mg/kg) (Nawab et al. 2016). Chronic consumption of excess concentrations of heavy metals through food could disrupt various biochemical processes and result in malfunction of organs, chronic syndromes (Giri and Singh 2017), and bone disorders (Ganeshan et al. 2012). Therefore, it is vital to control the pollution level of heavy metals in fruits to protect human health.

Soil is one of the important sources for heavy metals in plants. When heavy metal was accumulated in agricultural soils, it aggravated soil contamination and led to elevated heavy metal uptake by crops (Zhu et al. 2014). Scientific community has paid more attention to study the uptake effect of heavy metals by plants. There were some reports that focused on the uptake of heavy metals by crops (Wang et al. 2017; Ye et al. 2014), vegetables (Chang et al. 2014; Li et al.

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2016), and fruits (Cheng et al. 2015). Pollution index (PI) was adopted to compare the contamination levels of heavy metals in plants and their soils, which could also be used to reflect the uptake effect between plant and soil (Chen et al. 2014). Besides PI, bioconcentration factor (BCF) was usually applied for the demonstration of uptake effect. BCF value has commonly been used for demonstrating the various capacities of plants to accumulate heavy metals from soils (Chang et al. 2014; Li et al. 2016; Wang et al. 2017). Wheat grains showed significantly uptake effect for three heavy metals (Cd, Cu, and Zn), with the BCFs of 0.25, 0.11, and 0.054, respectively (Wang et al. 2017). The previous works showed that the plant type was a key factor for their uptake ability of Cd. The BCFs of Cd (0.019–0.346) in leaf and root vegetables (celery, lettuce, endive, carrot, potato, and radish) were higher than those in fruit vegetables (0.004–0.012 from green been, tomato, and cucumber) (Li et al. 2016). The uptake effect could be applied for the establishment of mathematical models that would be used to predict the concentrations of various heavy metals in plant (based on the concentration of corresponding heavy metal in soil). A plateau model (Wang et al. 2006), linear model (Wang et al. 2006), and Freundlich-type model (Dai et al. 2016) had been established for heavy metals (Cd, Pb, Cu, and Zn) in edible parts of various vegetables and wheat grains. Besides the concentrations of heavy metals in soil, some soil properties, including soil pH, organic carbon (OC), and cation exchange capacity (CEC) were suggested to be taken into consideration for the models (Gan et al. 2017). However, the developed models were used to predict the uptake effect of single heavy metal in various vegetables and cereals (Ding et al. 2013; Gan et al. 2017; LombnÆS and Singh 2004; Wang et al. 2006). Additionally, most prediction models were used to estimate the uptake effect for Pb or Cd in various vegetables (radish, lettuce, carrot, et al) (Ding et al. 2013). Thus, prediction models about uptake effect in fruits, especially in tree fruits, are scarce. To the best of our knowledge, prediction models for the comprehensive uptake effects of multiple heavy metals in plants (including tree fruits) have not been previously reported.

China is a leading producer of jujubes (*Diospyros spp.*) and persimmons (*Ziziphus spp.*) in the world and export many dry fruits and jams to other countries every year. Jujubes and persimmons are important common fruits in human diet, especially in Asian countries. The two fruits contain substantial amounts of nutrients such as glutamic acid, vitamins, and antioxidant compounds (Nie et al. 2016) and even could be used as medicine to treat some diseases (Abdoulazize 2016). Compared with other agricultural plants, however, information regarding the levels of heavy metals in jujubes and persimmons are scarce. The residues of heavy metals in persimmons were only reported on samples collected from northern Pakistan (Khan et al. 2013; Nawab et al. 2016). The ratios of pesticides exceeded the maximum residue limits (MRLs) set

by China detected in two fruits were 25.0% (jujube) and 4.5% (persimmon) in our previous works (samples were collected from three primary producing areas of China) (Liu et al. 2016). The objectives of this study are (1) to investigate the uptake effects of heavy metals between the two fruits and their growth soil; (2) to establish the appropriate predicted models for the comprehensive uptake effects for heavy metals in the two fruits; and (3) to ascertain the key influencing factors on the uptake effects of heavy metals in fruits. Besides, the results from this study are beneficial to site planning, risk prediction, pollution prevention, and control in order to protect the environment and people's health.

Materials and methods

Materials

Ultrapure water was obtained by a Milli-Q-Plus water purification system (Millipore, Bedford, MA, USA). Jujube and persimmon samples were digested by nitric acid (trace metal grade, 69%, Fisher, Ottawa, Canada) and hydrogen peroxide (Guaranteed reagent, 30%, Guanghua Sci-Tech, Tianjin, China). Other solvents of analytical reagent were purchased from Shanghai Guo Yao Chemical Reagents (Shanghai, China).

Sample collection

One hundred twenty-four samples (62 fruits samples and the corresponding soil sample) were carried out at harvest date in 2013, 2014, and 2015 from seven main producing areas of China (Hebei, Shaanxi, Shandong, Shanxi, Xinjiang, and Zhejiang). A detailed description of the sampling methods could be seen in our previous work (Liu et al. 2016). All samples were prepared and kept frozen (− 20 °C) until analysis.

Sample analysis

Sample of fried and powdered fruit bodies was digested with HNO_3–H_2O_2 in polytetrafluoroethylene (PTFE) tube. Next, the PTFE tube was digested in a microwave system of type MARS 5 (CEM, Matthews, NC, USA). The total concentrations of five heavy metals in fruit samples were determined by inductively coupled plasma mass spectrometry (ICP-MS). The ICP-MS parameters are given in Table S1. In addition, in order to reduce the matrix effects, Rh, Ge, and Bi (100 μg/L) were used as the internal standards. The details for the microwave digestion process could be seen in our previous work (Han et al. 2018).

The soil samples were digested using HNO_3–HCl–HF and aqua regia described by (Han et al. 2018). Soil property

measurements could be given by our previous work (Liu et al. 2014). The concentrations of Pb, Cd, Cr, As, and Hg were analyzed by an atomic absorption spectrometer (AAS) and a hydrogenide generation-atomic fluorescence spectrometer (HG-AFS, AFS-9130), respectively. The AAS and HG-AFS parameters are given in Table S2 and Table S3.

Quality assurance

For precision and accuracy, blank and standard reference materials (GBW10021 for fruits, GBW07309 for soils) were used. The results are shown in Table S4. Each sample was analyzed in triplicate. In addition, acceptable relative standard deviation among replicates was lower than 10%.

Pollution index

Single-factor pollution index (SFPI) was applied to assess the pollution level of a single heavy metal in each sample, The SFPI was calculated as

$$SFPI = \frac{Ci}{Bi} \tag{1}$$

where Ci is the concentration of heavy metal in fruit or soil, Bi is the concentration of heavy metal in background, which was adopted from the food or environment standards of China (Table S5). SFPI classes, according to GB/18407.2-2001 and GB15618-1995, are as follows: ≤ 1, nonpollution; 1–2, minor pollution; 2–3, light pollution; 3–5, medium pollution; > 5, heavy pollution.

Similarly, Nemerow pollution index (NPI) is given as

$$NPI = \sqrt{\frac{SFPI^2 max + SFPI^2 avg}{2}} \tag{2}$$

where $SFPImax$ is the highest SFPI in all heavy metals, and $SFPIavg$ is the average SFPI in the system. NPI classes, according to Chen et al. (2014), that are < 0.7 fall within a safety domain.

Bioconcentration factor

The bioconcentration factor was computed by Wang et al. (2017). The BCF was given as

$$BCF = \frac{C_{plant}}{C_{soil}} \tag{3}$$

where C_{plant} and C_{soil} represent the total heavy metal concentration in fruits (mg/kg) and soils (mg/kg), respectively.

Similarly, the comprehensive bioconcentration factor is given as

$$BCF.T = \frac{\sum BCF_{each\ heavy\ metal}}{5} \tag{4}$$

where $BCF_{each\ heavy\ metal}$ includes BCF_{Pb}, BCF_{As}, BCF_{Cd}, BCF_{Cr}, and BCF_{Hg}.

Statistical analysis

The social sciences (SPSS) version 18.0 (SPSS, Chicago, IL, USA) was used for all statistical analyses. Analysis of variance (ANOVA) was applied for assessing statistical differences in heavy metal concentrations of samples. Differences were considered significant at $p < 0.05$. Also, multiple linear regression analysis was employed to examine the relationships between various parameters and establish different mathematical models to predict NPI and BCF. The multiple linear regression analysis was carried out by the "leaps" package within the "R" statistical platform. The relative influence of different parameters on heavy metals bioaccumulation ability can be quantitatively evaluated by the "gbm" package within the "R" statistical platform.

Results and discussion

Heavy metal concentrations in jujubes and persimmons and their growth soils

According to the US Environmental Protection Agency (EPA) and the US Agency for Toxic Substances and Disease Registry (ATSDR) in 2007,the toxicity order for four heavy metals in environment was As > Pb > Hg > Cd (Han et al. 2018). The concentrations of five heavy metals in jujubes and persimmons and their growth soils collected from different main regions of China during 2013–2015 are shown in Fig. 1. The average concentrations of heavy metals in jujube samples were found to be 33.0 (Pb), 7.3 (As), 3.2 (Cd), 36.0 (Cr), and 0.35 (Hg) μg/kg, respectively. Compared with jujubes, the overall heavy metal concentrations in persimmon samples were found in the same descending order of Cr > Pb > As > Cd > Hg. Except for Cr, all heavy metal concentrations in persimmon samples were lower than those in jujube samples. The Pb and Cd concentrations in jujube samples from our work were approximately equal to those found in jujubes (24.6 μg/kg, 2.9 μg/kg) collected from four provinces of China (Nie et al. 2016). However, there was still reported that the Pb and Cd levels were up to 11.2 μg/kg and 34 μg/kg in jujube samples collected from Zhejiang province of China (Zhu et al. 2014). Additionally, the heavy metal (Pb, Cd, and Cr)
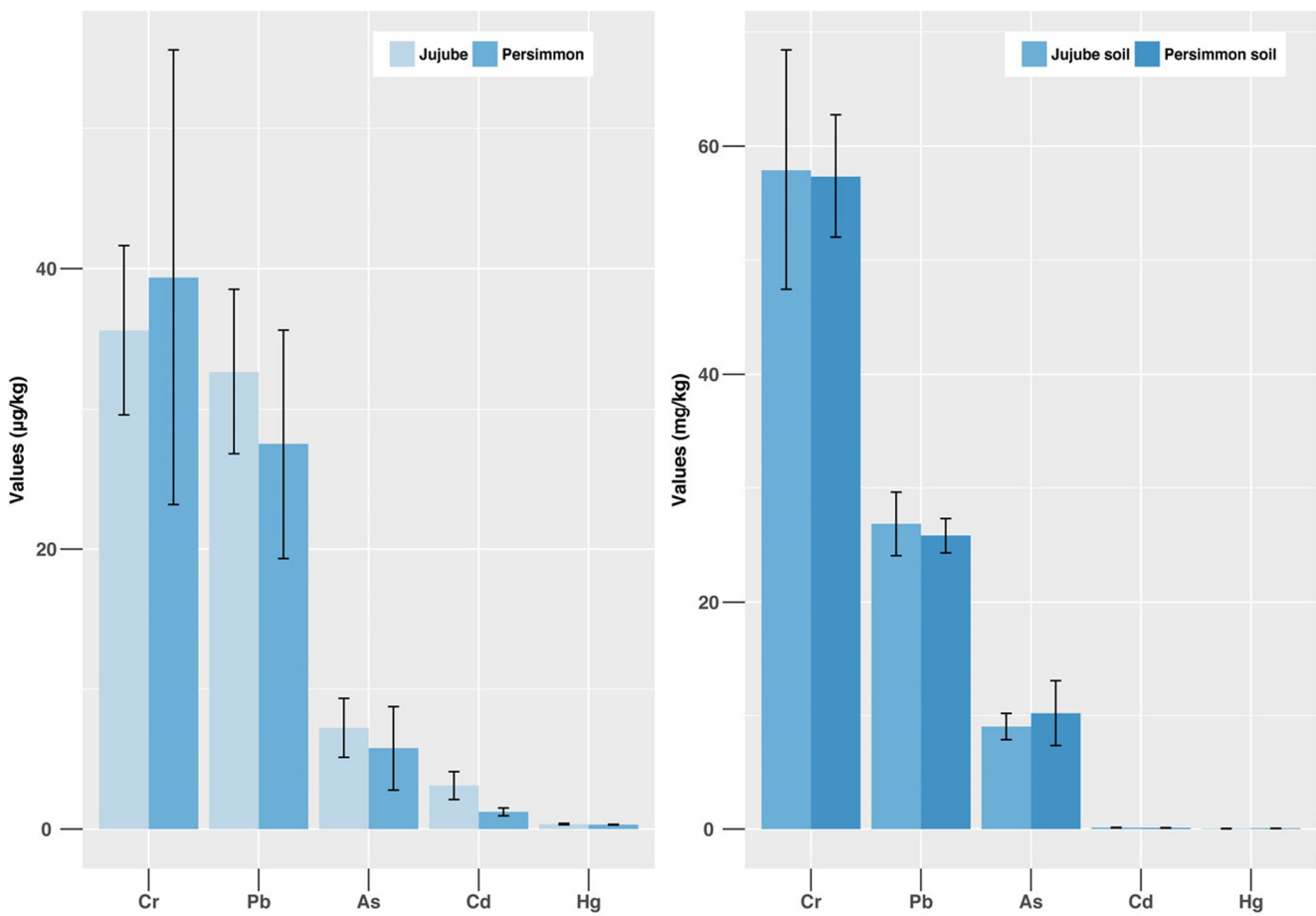
Fig. 1 The concentrations of heavy metals in two fruits (jujube and persimmon) and growth soils

concentrations in our jujube samples were close to previous studies (Nie et al. 2016), while the As concentration (7.3 μg/kg) was much lower than those found in previous studies (52 μg/kg) (Zhu et al. 2014). Though there was no research that reported the Hg level in jujube samples, our results indicated that the Hg level was 0.35 μg/kg, which was a bit lower than those found in tree fruit (navel orange (1 μg/kg)) (Cheng et al. 2015). Conversely, the Pb, Cd, and Cr levels in our persimmon samples were all lower than persimmons collected in Pakistan (Khan et al. 2013; Nawab et al. 2016). According to the MRLs of heavy metal in China, the concentrations of five metals in two fruits (jujube and persimmon) did not exceed the limits.

Soil plays a vital role for heavy metals in plants (Wang et al. 2017). There are several reports regarding heavy metal contamination in agricultural soils (Ding et al. 2014; Mazurek et al. 2017). However, information about heavy metal contaminations in persimmon and jujube soils is unspecified. According to Fig. 1, the overall heavy metal concentrations in jujube and persimmon soils were found in the same descending order of Cr > Pb > As > Cd > Hg. However, except for As and Hg, the levels of other heavy metals (Pb, Cr, and Cd) in jujube soil samples

were a bit higher than those of persimmon soil samples. Among the five heavy metals, the mean concentration of Cr was highest in soil samples, which was also reported in other agricultural fields. The concentration of Cr (320 mg/kg) was notably higher than those of Cd (2.55 mg/kg) and Pb (27.83 mg/kg) in fruits, vegetables, and cereal soil (Nawab et al. 2016). The four heavy metal levels (Pb, As, Cd, and Cr) in two fruit soil samples were a bit lower than those in corn grain soils and navel orange pulp soils (Cheng et al. 2015; Wang et al. 2017). In addition, the Hg levels in two fruit soil samples were lower than those in navel orange pulp soils (Cheng et al. 2015). Thus, the ratios of heavy metals detected in the two fruit soils exceeded their MRLs were 2.7% (jujube soil) and 3.8% (persimmon soil).

Assessment of heavy metal pollution in jujubes and persimmons and their growth soils

Due to the difference in toxicity thresholds of various heavy metals and the background of the soil parent material, the concentrations of heavy metals in food and growth soil cannot fully reflect the pollution level. Researchers used single-factor

pollution index (Chen et al. 2005) to directly compare the degree of heavy metal pollution and further used Nemerow pollution index to reflect the degree of comprehensive pollution (Chen et al. 2014; Mazurek et al. 2017). The SFPIs of different heavy metals in jujubes and persimmons and their growth soils are shown in Table 1. The mean SFPI values of five heavy metals in jujube samples were all very small, ranged from 0.012 to 0.13. The values of mean SFPI for the five heavy metals in the two fruits were 0.125 (Pb), 0.109 (As), 0.03 (Cd), 0.062 (Cr), and 0.0125 (Hg). It is noteworthy that the max SFPI values for some heavy metals in the two fruits were relatively high, especially the max SFPI value of As in persimmon samples even up to 0.9. Nonetheless, the SFPI values as a whole were lower than 1, which suggested that the pollution level of heavy metals in jujube and persimmon samples was nonpollution (following the class criteria). Besides, the NPI values in jujube and persimmon samples were 0.1068 and 0.0965, respectively. According to the pollution class for NPI introduced by Chen et al. (2014), the results from our work fall within a safety domain (NPI < 0.7).

Compared with the fruits, the SFPI values in soils were significantly ($p < 0.05$) higher than the former. The average SFPI values for five heavy metals in two soil samples were 0.635 (Pb), 0.55 (As), 0.415 (Cd), 0.535 (Cr), and 0.135 (Hg). In addition, according to the class criteria, about 93.2% of the two soil samples were under nonpollution (SFPI < 1), and about 6.5% of the soil samples were under minor pollution (1 < SFPI ≤ 2). Notably, about 3.8% of persimmon soil samples were under medium contamination (3 < SFPI ≤ 5). The NPI values in two fruit soil samples were 0.5371 (jujube) and 0.5660 (persimmon), which also showed that all of the soil samples fall within a safety domain (NPI < 0.7) for the above-mentioned metals. Thus, the pollution level of heavy metals in all of the fruits and most of the soil samples were nonpollution and under low pollution, respectively.

BCF values of heavy metals in jujube and persimmon

The bioconcentration factor is used to compare the ability of plants to take up pollutants. Our previous works have shown that some pesticides could accumulate in nut (Han et al. 2017), jujube, and persimmon samples (Liu et al. 2016) by the uptake effect from soil. Apart from organic pollutants (pesticides), inorganic pollutants (heavy metals) could also accumulate in plants by the uptake effect from soil (Dai et al. 2016; Ding et al. 2018). Figure 2 shows the BCF values for heavy metals in jujube and persimmon samples. The average BCF values of Pb, As, and Cr in jujube samples were 0.0013, 0.00089, and 0.00080, respectively. Interestingly, the BCF values of Cd and Hg in jujube samples were notably higher than the above three heavy metals, with 0.027 and 0.016, respectively. The BCF value of Cd in jujube samples was approximately 21-fold that of Pb and 30-fold that of As and Cr. However, compared with the BCF values from jujube samples, the average BCF values of five heavy metals in persimmon samples were lower than the former. The average BCF values for the five heavy metals from persimmon samples were 0.0011 (Pb), 0.0006 (As), 0.0146 (Cd), 0.00073 (Cr), and 0.0070 (Hg). Obviously, the BCF value of Cd in persimmon samples was approximately 13-fold that of Pb and 20-fold that of As and Cd. It is worth noting that the ability of tree fruits (jujube and persimmon) to take up Cd is higher than other heavy metals. In our previous work, the BCF value of Cd (0.038) in tree nut (walnut) was higher than those of other four heavy metals (Han et al. 2018). The similar performance was also observed in other reports. The BCF values of Cd (0.064–0.17) in fruits (walnut, pear, persimmon, fig, date-plum, and white mullberry) were higher than those of Cr (0.005–0.024) and Pb (0.002–0.011) (Nawab et al. 2016). The BCF value of Cd in edible part of vegetables was higher than other heavy metals (Chang et al. 2014). The performance might be attributed to the competition between Cd^{2+} and Ca^{2+}. Cd^{2+} replaced Ca^{2+} easily than other heavy

Table 1 Single-factor pollution index (SFPI) of different heavy metals in fruits and their growth soils

| Sample type	SFPI	Pb	As	Cd	Cr	Hg
Fruit (jujube and persimmon)	Mean	0.13, 0.12	0.12, 0.098	0.04, 0.020	0.06, 0.064	0.012, 0.013
	Max	0.34, 0.47	0.56, 0.9	0.3, 0.084	0.15, 0.47	0.064, 0.04
	SFPI ≤ 1 (%)	100, 100	100, 100	100, 100	100, 100	100, 100
	1 < SFPI ≤ 2	0, 0	0, 0	0, 0	0, 0	0, 0
	2 < SFPI ≤ 3	0, 0	0, 0	0, 0	0, 0	0, 0
	3 < SFPI ≤ 5	0, 0	0, 0	0, 0	0, 0	0, 0
Soil (jujube soil and persimmon soil)	Mean	0.62, 0.65	0.52, 0.58	0.42, 0.41	0.55, 0.52	0.10, 0.17
	Max	1.63, 1.00	1.01, 3.13	1.59, 1.39	1.68, 1.10	1.45, 0.66
	SFPI ≤ 1 (%)	91.7, 96.2	97.2, 96.2	88.9, 94,4	88.9, 96.2	97.2.100
	1 < SFPI ≤ 2	8.3, 3.8	2.8, 0	11.1, 5.6	11.1, 3.8	2.8, 0
	2 < SFPI ≤ 3	0, 0	0, 0	0, 0	0, 0	0, 0
	3 < SFPI ≤ 5	0, 0	0, 3.8	0, 0	0, 0	0, 0
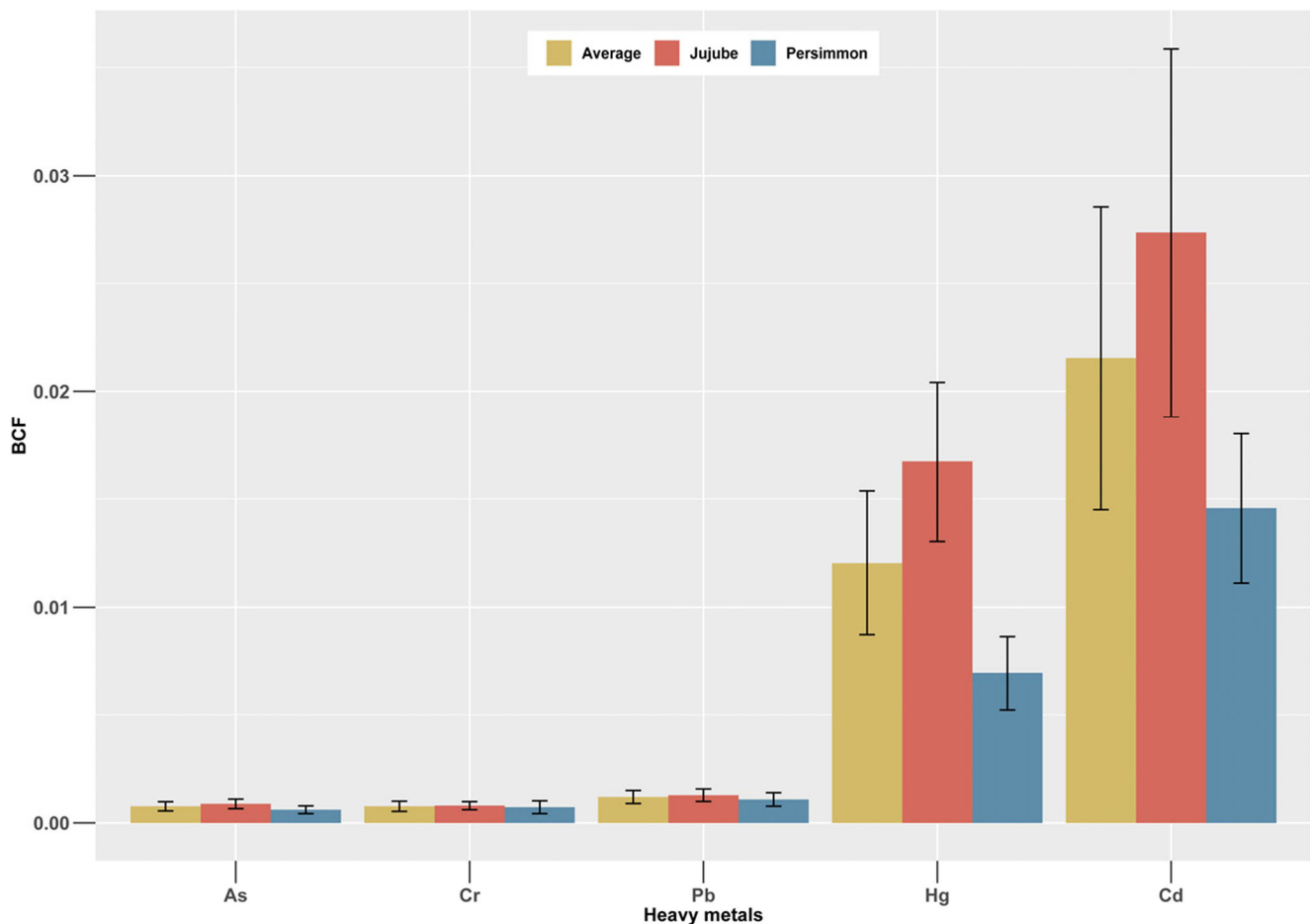
Fig. 2 The BCF values between jujube, persimmon, and their soils. BCF, bioconcentration factor

metals due to their same ionic radius and valence (Kim et al. 2002). Compared with other heavy metals (through passive methods), Cd could further enter plant issues by active transport (through Ca channels) (Chang et al. 2014). However, some opposite results were also reported in corn collected from typical black's region, in which the BCF values of Cd were the same as (Wang et al. 2017) or lower than those of Hg (0.057) (Wang et al. 2017). The results indicated that Cd contamination in tree fruits should be paid more attention. Fortunately, the average BCF values of Cd from our study (0.021) and from previous studies of navel orange (0.002) (Cheng et al. 2015), mango (0.025) (Bi et al. 2010) in tree fruits were much lower than those in edible part of vegetables (0.521) (Chang et al. 2014), rice grains (0.23) (Ye et al. 2014), and wheat grains (0.25) (Wang et al. 2017). Especially, the BCF values of As in the edible part of vegetables and grains were 10-fold those of Cd in tree fruits, while the BCF values of Pb in tree fruits were approximately equal to those of Hg in edible part of vegetables (Chang et al. 2014; Li et al. 2016). These comparisons showed that the ability of tree fruits to take up soil metals was lower than the edible part of vegetables and grains. In addition, jujube was more susceptible to heavy metal accumulation than persimmon.

The prediction model for uptake effect of single heavy metal and its validation

Due to most of previously reported prediction models for uptake effect of single heavy metal that were referred to Cd in different plants (Cheng et al. 2015; Gan et al. 2017; Ye et al. 2014), the prediction model for Cd uptake effect in the two fruits was also established in our study (Table 2). The adjusted regression coefficient in our prediction model for Cd ($R^2 = 0.90$, $p < 0.01$) was greater than previously reported models for Cd in fruits ($R^2 = 0.342$) (Cheng et al. 2015), cereals ($R^2 = 0.76$) (Ye et al. 2014), and vegetables ($R^2 = 0.75$) (Gan et al. 2017; Wang et al. 2006). The detailed information is given in the "supplementary material" (Table S6). Compared with the stepwise linear regression used in the previous models, all-subset regression was used in the present model establishment, which might result in the optimal introduced parameters into our model and a better fitting effect. In addition, the contents of Cd and OC in soil were introduced into our model. Although some of the previous models were also established by Cd in soil (Wang et al. 2006), the soil OC was not included (Cheng et al. 2015), or the data was not transformed (Gan et al. 2017). Therefore, these parameters (soil pH and CEC) should

Table 2 The application of the predicted model for Cd uptake effect

	Plant species	Measured LogBCF$_{Cd}$	Predicted LogBCF$_{Cd}$	Predicted deviation (%)	Reference
Tree fruit	Date-plum	−0.74	−0.83	11	(Nawab et al. 2016)
	Persimmon	−0.96	−0.82	14	(Nawab et al. 2016)
Tree nut	Walnut[a]	−1.66	−2.03	22	(Han et al. 2018)
	Walnut[b]	−1.66	−2.13	28	(Han et al. 2018)
	Walnut	−0.90	−0.85	5.4	(Nawab et al. 2016)
Vegetables	Water spinach	−1.25	−1.60	35	(Wang et al. 2006)
	Pumpkin	−1.21	−0.76	38	(Nawab et al. 2016)
	Towel gourd	−1.8	−1.69	6.8	(Wang et al. 2006)
Grains	Wheat	−0.60	−0.89	48	(Nawab et al. 2016)
	Rice	−0.82	−0.96	17	(He et al. 2010)
Predicted model	Log (BCF$_{Cd}$) = −0.68 + 1.01Log(Cd) − 0.57Log(OC)				

[a] Walnut samples come from Hebei; [b] walnut samples come from Sichuan

BCF bioconcentration factor, *OC* organic carbon

$$Predicted\ deviation = 100 \left| \frac{measured\ LogBCFCd - predicted\ LogBCFCd}{measured\ LogBCFCd} \right|.$$

be considered in the further prediction model establishment. To better understand the model application accuracy, the model validation was conducted with previous literature data on BCF of Cd in plants (tree fruits, tree nut, vegetables, and grains) (Table 2). According to Table 2, the predicted deviation in tree plants (tree fruits and tree nuts) ranged from 5.4 to 28.0%, which meant that the prediction model was able to accurately predict the BCF in tree plants. Interestingly, we found that the model even could predict the BCF of Cd in some vegetables and grains, with most of the predicted deviation below 40.0%. The results showed that the established model for Cd uptake effect had a broad application for various plants.

The prediction model for uptake effect of comprehensive heavy metals

Compared with the prediction model for uptake effect of single heavy metal, the prediction model for uptake effect of comprehensive heavy metals might help with further understanding the effect and to control the contamination. In addition, there is yet none of any prediction model for NPI from single or multiple heavy metals. In our work, different prediction models for NPI and BCF were established. Furthermore, soil parameters were taken into our predicted models, because soil parameters had been demonstrated to be important factors for uptake effects and introduced into models in previous studies (Ding et al. 2013; Gan et al. 2017). At the first, our data without transformation was used to establish models, but no significant correlation ($R^2 < 0.3$, $p > 0.01$) was found. Fortunately, after our data with log transformation, some appropriate predicted models were established which were based

on all-subset regression. The predicted models for NPI and BCF are presented in Table 3. The adjusted regression coefficients of prediction models for NPIs of jujube, persimmon, and total (two fruits as a whole) were greater than 0.56 ($p < 0.01$). According to Table 3, OC and total As content in soil were introduced into all prediction models for NPIs of jujube, persimmon, and total (two fruits as a whole). Total Pb and Cd contents in soil were taken into prediction models for NPIs of jujube and total (two fruits as a whole), while soil pH and total Hg content in soil were only introduced into prediction models for NPIs of persimmon. In addition, total Cr content in soil was taken into prediction models for NPIs of persimmon and total (two fruits as a whole). The results suggested that there were at least four soil parameters which were taken into prediction models for NPIs. By comparison, prediction models for BCFs take into less soil parameters but the adjusted regression coefficients were higher ($R^2 > 0.8$, $p < 0.0001$). OC and total Cd content in soil were introduced into all prediction models for BCFs of jujube, persimmon, and total (two fruits as a whole). Total Cr content in soil was taken into prediction models for BCFs of jujube and total (two fruits as a whole), while total Hg content in soil was only introduced into prediction models for BCFs of persimmon. In our study, soil OC was taken into account in prediction models for BCFs. Previous studies had shown that the addition of soil OC in prediction models was better for the result (Ding et al. 2013; Ye et al. 2014). After soil OC was introduced into the regression models of BCF for Cd uptake in grains, the adjusted regression coefficient was significantly improved from 0.52 to 0.63. Interestingly, Dai et al. found that soil pH was the best predictor of BCF for As uptake from soil to wheat plants, with the adjusted regression coefficient 0.847 (Dai et al. 2016).

Table 3 The prediction models for NPIs and BCFs

All-subsets regression	Object	Regression model	R^2	p
	NPI.J	Log (NPI) = -2.01 − 0.17 Log (Pb) + 0.23 Log (As) + 0.18 Log (Cd) + 0.24 Log (OC)	0.66	< 0.001
	NPI.P	Log (NPI) = -8.85 + 0.21 Log (As) + 0.28 Log (Cr) − 0.13 Log (Hg) + 0.48 Log (OC) +1.82 Log (pH)	0.56	< 0.01
	NPI.T	Log (NPI) = -2.58 − 0.15 Log (Pb) + 0.08 Log (As) + 0.17 Log (Cd) + 0.18 Log (Cr) + 0.30 Log (OC)	0.65	< 0.001
	BCF.J	Log (BCF) = -1.34 + 0.50 Log (Cd) + 0.06 Log (Cr) − 0.57 Log (OC)	0.86	< 0.001
	BCF.P	Log (BCF) = -1.10 + 0.40 Log (Cd) + 0.12 Log (Hg) −0.71 Log (OC)	0.84	< 0.001
	BCF.T	Log (BCF)= -1.83 + 0.46 Log (Cd) + 0.08 Log (Cr) − 0.56 Log (OC)	0.81	< 0.001

NPI.J, Nemerow pollution index of jujube; NPI.P, Nemerow pollution index of persimmon; NPI.T, Nemerow pollution index of total (two fruits as a whole); BCF.J, the sum of five heavy metals' bioconcentration factors of jujube; BCF.P, the sum of five heavy metals' bioconcentration factors of persimmon; BCF.T, the sum of five heavy metals' bioconcentration factors of total (two fruits as a whole)

However, soil pH was not introduced into BCF prediction models in our study. A possible explanation for this phenomenon is that plant types might influence the results. Further research is needed to be done.

The contribution rate of soil parameters to the comprehensive uptake effect

Soil parameters (total heavy metal content in soil, soil pH, and soil OC) are commonly reported to influence the uptake effect in plants (herbaceous and tree fruits) (Ran et al. 2016). Research in uptake effect is a benefit for uptake effect regulation, protection of food safety, and soil pollution control. Thus, it is very important to quantitatively ascertain the contribution rate of soil parameters. At present, although some studies have established the predicted models of uptake effect for BCF (mentioned above), few studies have quantitatively dealt with the contribution of soil parameters to BCF (Gan et al. 2017; Ye et al. 2014). However, the contribution rates of soil parameters for the comprehensive uptake effects of heavy

metals in plants were not reported in previous studies. Figure 3 shows the contribution rates of different soil parameters to NPIs and BCFs in the two fruits. According to Fig. 3, the contribution rates of different soil parameters to NPI of jujube were 25.0% (OC), 21.8% (Pb), 17.5% (Cd), and 35.7% (As), respectively. By comparison, the concentrations of Pb and Cd did not influence NPI of persimmon while soil Cr and soil Hg played an important role to NPI. Although soil pH had a notable effect on NPI of persimmon, it could be negligible to NPI of jujube. In addition, soil As, soil Cr, soil Cd, soil Pb, and soil OM to NPI of total (two fruits as a whole) were very important. Compared with NPIs, soil Cd was the most crucial factor to BCFs for the comprehensive uptake effect, with the contribution rate of 80.4%. Furthermore, the contribution rate of total Hg content in soil to BCF was about 3.9% in persimmon and the contribution rate of total Cr content in soil to BCF was 14.0% in jujube. Taken together, these results suggested that total Cd content in soil was the most crucial factor for uptake effect of heavy metals; and soil OC was an important cofactor for uptake effect. In addition, soil OC had a
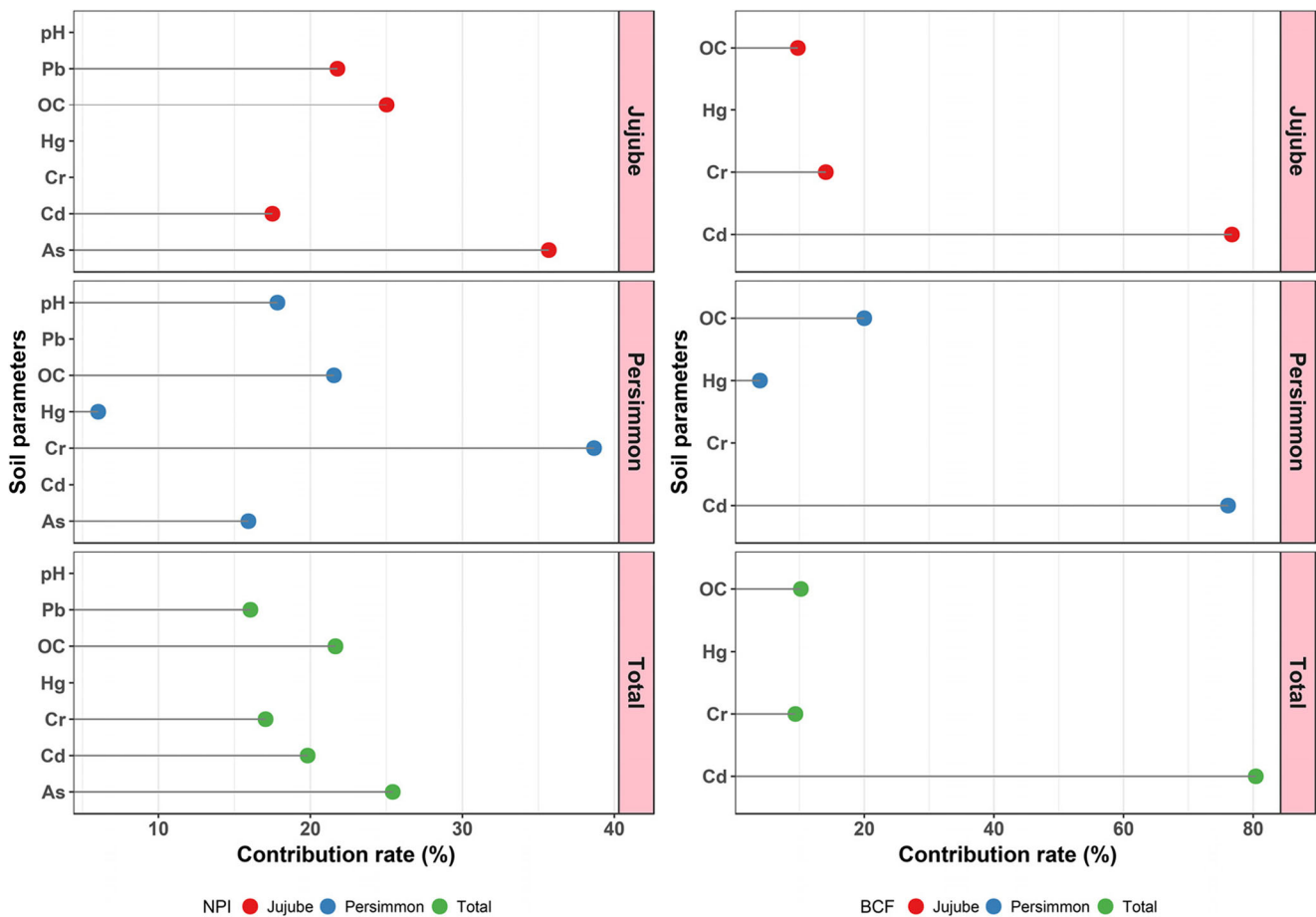
Fig. 3 Contribution rate (%) of different soil parameters to NPI and BCF for heavy metal uptake effect in the two fruits. Left, NPI; right, BCF. NPI, Nemerow pollution index. BCF, the sum of five heavy metals' bioconcentration factors

significant negative effect on correlation with the transfer factor of Cd in navel orange samples (Cheng et al. 2015) and Cd bioavailability in paddy soils (Ding et al. 2013; Ye et al. 2014). A possible explanation for the phenomenon is that soil OC could give rise to the soil's ability to retain cationic metals (Cheng et al. 2015). On the other hand, the average contribution rate of OC to BCF for Cd uptake in grains was 16.0% (Ye et al. 2014), which was a little higher than the average contribution rate of OC (10.2%) to BCF for comprehensive uptake effects of heavy metals in our study. Besides soil OC, soil pH is often termed the master soil variable and generally has a significant negative correlation with the mobility and bioavailability of heavy metals (Cheng et al. 2015; Ding et al. 2013). The average contribution rates of soil pH to BCF for Cd uptake in rice grains and uptake in some vegetables were 52.0% (Ye et al. 2014) and 68.1% (Gan et al. 2017). In this study, however, soil pH was not important to influence the uptake heavy metals by jujube and persimmon from soil. The comparison suggested that soil pH played an important role in uptake heavy metals by the edible part of grains from soil,

but soil pH may not influence the uptake effect in tree fruits. The reason for this phenomenon is still necessary to investigate further.

Conclusion

In this study, the comprehensive uptake effects of five toxic heavy metals (Pb, As, Cd, Cr, and Hg) between two fruits (jujube and persimmon) and their growth soils were investigated. The results showed that the pollution level of heavy metals in all of fruits and most of soil samples was nonpollution and under low pollution, respectively. The ability of tree fruits to take up soil metals was lower than the edible part of vegetables and grains. In addition, jujube was more susceptible to heavy metal accumulation than persimmon. The appropriate predicted models for the comprehensive uptake effects for heavy metals in the two fruits were established. Besides, prediction models for BCFs take into less soil parameters but the adjusted regression coefficients

were higher ($R^2 > 0.8$, $p < 0.01$) than prediction models for NPIs. Total Cd content in soil was the most crucial factor to BCF for heavy metal uptake effect; and soil OC was an important cofactor for uptake effect.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

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