Investigation of Cadmium Content in Rice in Heilongjiang Province and Health Risk Assessment

Dong-mei Cao*[1,a,b,c], Chang Zhang[1a], Dong-jie Zhang*[,a,b]

[a]College of Food Science, HeiLongjiang Bayi Agricultural University, 163319 Daqing, People's Republic of China

[b]Key Laboratory of Agro-Products Processing and Quality Safety of Heilongjiang province

[c]National Coarse Cereals Engineering Research Center

1 These authors contributed equally to this work.

* Corresponding author

E-mail: caodong3018@sina.com, Tel. 13836962229;

E-mail: byndzdj@126.com, Tel.: +8604596819006

Abstract

We investigated the cadmium content in soils and rice in Cha Hayang, Wuchang, Fangzheng, Xiangshui, and Jiansanjiang areas of Heilongjiang Province, and characterized the effect of rice intake on human health. The samples were analyzed by ICP-MS, and the cadmium transfer in soil-rice system was modeled by the Nemero comprehensive pollution index method. The health risk assessment model was used to study the status of cadmium pollution in rice and its health risk assessment for adults and children. The results showed that the average contents of cadmium in rice were 0.003 (Cha Hayang), 0.016 (Wuchang), 0.006 (Fangzheng), 0.006 (Xiangshui), and 0.005 (Jiansanjiang) mg kg-1. The prediction model developed in this study, including the total heavy metals and pH value of the soil, effectively described the transfer of cadmium in the soil-rice system of Wuchang, Chahayang and Xiangshui paddy fields (with R2 between 0.256 and 0.468). The pollution index of the study area was less than 1. The comprehensive pollution index was 0.037<1, sugesting no pollution, and the comprehensive pollution index was between 0.059 and 0.158. The health risk index of carcinogenic heavy metal cadmium to adults and children in Cyang and JianSanjiang areas was lower than that recommended by USEPA (1 × 10-4), suggesting no risk of cancer. However, the mean values in Wuchang, Fang Zheng and Xiangshui were higher than the maximum acceptable risk recommended by USEPA, suggesting a risk of cancer.

Key words：soil; rice; cadmium; modeling; pollution characteristics; health risk;

Introduction

As a country with a large population, agriculture in China is of primary importance. Most people in the country use rice as their staple food [7]. With the development of industrialization, the pollution of soil with heavy metals, especially cadmium, is particularly prominent. Scholars have done a lot of research on the potential risks of heavy metals to human health. However, this research concentrated mostly on mining areas [8,9], sewage irrigation [10,11] and waste treatment plants [12,13], with the research subjects focusing on dust reduction [14,15], corn [16,17] , vegetables [18,19], drinking water [20,21], rice [22,23], etc. These studies have carried out in-depth research on the accumulation characteristics, physicochemical properties, occurrence forms and physiological and biochemical effects of contamination by heavy metals, laying a foundation for further research on accumulation of heavy metals in crops and their impact on human health. However, most of these studies were the pot experiments conducted under controlled conditions; there are only few studies on the accumulation characteristics of heavy metals in rice grown in the natural environment[24].

In this paper, we study the content of cadmium in soil and rice as well as a risk of harm to human health. We chose Heilong Jiang province as the big grain-producing area to collect soil and rice for detection of cadmium pollution situation. We selected five areas to assess cadmium intake by the population via eating rice . We also conducted risk assessment regarding potential health effects. By analyzing the pollution situation, we can emphasize sustainable development that pays attention not only to the gross national product, but also to environmental protection and human health.

Foreword

Cadmium was discovered together with zinc. It is a heavy metal with many industrial uses. In nature, cadmium exists in the form of various compounds. Cadmium is not an essential element for humans. It has strong toxicity, non-biodegradability and durability. It is absorbed by crops from soil and accumulated in plant tissues, which reduces the quality of agricultural products and may cause harm to the human body through the food chain [1]. Excessive intake of cadmium has toxic effects on liver, kidney, bones and other organs, and is especially harmful to children's health.

There are three main ways in which cadmium enters human body: breathing, skin contact and dietary intake. Compared with the respiratory and skin contact pathways, dietary intake is the main route for heavy metal intake due to factors such as large amount of food intake, complex diet, and potentially high cadmium levels in some food [2-4]. Long-term consumption of contaminated grains can cause chronic poisoning by heavy metals [5,6]. In recent years, with the increase in public health risk awareness, research on the status of heavy metal pollution in crops and its health risks has been intensive.

Research method

Overview of the study area

Heilongjiang Province is located in the rice-growing area with the northernmost latitude. It has large temperature difference between day and night, fertile soil, excellent water quality and low pollution. It is conducive to the development of rice production. Heilongjiang rice production is now entering a new era of high quality, high efficiency and professionalism. Due to stable production, excellent rice quality and high commodity rate, Heilongjiang rice has become an important high-quality glutinous rice production base in China, and its products are shipped to all parts of the country. In 2015, rice planting area in Heilongjiang Province accounted for 17.0% of the country's rice planting area, and represented 69.25% of the rice planting area in the three northeastern provinces. Rice production in Heilongjiang accounts for 16.3% of the national rice production, and 67.6% of the rice production in the three northeastern provinces, playing an important role in the rice market.

Sample source

The rice and corresponding soil samples used in this study were from the rice producing areas in Heilongjiang province, including 22 from Chahayang（123°56′E-124°20′E, 48°05′N-48°30′N） region, 22 from Wuchang（126°33′E-128°14′E, 44°04′N-45°26′N） region, 22 from Fangzheng（128°13′E-129°33′E, 45°32′N-46°09′N） region, 22 from Xiangshui（128°07′E-130°00′E, 44°27′N-48°30′N） region, and 22 from Jiansanjiang（132°31′E-134°22′E, 46°45′N-48°28′N） region.

Sample testing

The determination of the content of Cd in rice samples was carried out according to the method specified in Chinese National Standard GB 5009.286-2016 "Determination of Multi-Elements in Foods".

Risk assessment of heavy metal pollution in rice grains

The limit of Cd in rice grains was based on the limits of 8 elements including lead, chromium, cadmium, mercury, selenium, arsenic, copper and zinc in grain (including cereals, beans and potatoes) and products (NY861-2004). The single factor pollution index method and the Nemero comprehensive pollution index method were used to evaluate the heavy metal content in crops [25].

Single factor pollution index:

$$P_{\mathrm{Cd}} = \frac{C_{\mathrm{Cd}}}{S_{\mathrm{Cd}}} \qquad (1)$$

In the formula, Pcd is the comprehensive pollution index of heavy metals in crop grains; Ccd is the average value of single metal pollution index of heavy metals, and Scd is the maximum value of one-way pollution index of heavy metal Cd.

Nemero Integrated Pollution Index:

$$P = \sqrt{\frac{\overline{P}_{\mathrm{Cd}}^{2} + P_{\mathrm{Cdmax}}^{2}}{2}} \qquad (2)$$

In the formula, P is the comprehensive pollution index of heavy metals in crop grains; $\overline{P}$ is the average value of single metal pollution index of heavy metals, and P_{Cdmax} is the maximum value of one-way pollution index of heavy metal Cd.

Rice health risk assessment

In order to evaluate the health risks of rice in the diet of adults and children in the study area, the US Environmental Protection Agency (USEPA) recommended health risk assessment model was used [26]. The model used in this study was the carcinogenic risk model.

Average daily intake of pollutants through crops (ADD):

$$ADD = \frac{C_{\mathrm{Cd}} \times I \times EF \times ED}{BW \times AT} \qquad (3)$$

Where ADD is the average daily intake of pollutants in crops [mg·(kg·d)-1]; C_{Cd}

is the content of heavy metal Cd in crops (mg·kg-1); I is the daily human body intake of crops (kg·d-1); EF is the frequency of exposure (d·a-1); ED is the exposure time (a); BW is the recipient body weight (kg); AT is the life expectancy (d). The names and values of various parameters are shown in Table 1.

Carcinogenic risk assessment

$$RI = ADD \times SF \tag{4}$$

In the formula, RI is the carcinogenic risk of human exposure to heavy metal Cd; SF is the carcinogenic strength coefficient [(kg·d)·mg-1]. When $RI < 1\times10^{-6}$, the risk is not obvious; when $1\times10^{-6} < RI < 1\times10^{-4}$, the risk is in the acceptable range; when $RI > 1\times10^{-4}$, it means there is a significant health risk.

Results and analysis

Contents of cadmium in soil and rice in Heilongjiang region

The cadmium content in 110 soil samples collected is shown in Table 2-4, between 0.061~0.225mg/kg, the average value was 0.122 mg/kg, and the coefficient of variation was 0.280% <11%. Within the range of the coefficient of variation allowed, and according to the Chinese national standard GB 15618-2018 (soil environmental quality - agricultural land risk control standards), the cadmium content in the soil in the five regions did not exceed the acceptable range. Hence, the risk of cadmium pollution in agricultural land in the study area was low. The content of cadmium in the soil was in the order: Chahayang> Xiangshui> Wuchang> Fangzheng> Jiansanjiang.

The content of cadmium in brown rice and polished rice in 110 rice samples collected was between 0.0003-0.0610 mg/kg and 3.96×10-6 to 0.056, with the average values of 0.007 mg/kg and 0.004 mg/kg, respectively. The coefficients of variation were 1.470% (brown rice) and 2.009% (polished rice), both within the range allowed by GBT27404-2008 "Laboratory Quality Control Specification Food Physical and Chemical Testing".In addition, according to GB 2762-2017 "Food Safety National Standards for Contaminants in Foods" the standard content of cadmium is below 0.2 mg/kg. None of the 110 samples of rice samples determined in this experiment exceeded this limit. The content of cadmium in brown rice ranged in the order: Chahayang> Xiangshui> Fangzheng> Jiansanjiang> Wuchang. The order of cadmium content in polished rice was consistent with that in brown rice.

The average value of cadmium in soil in this study was 0.122 mg/kg, which does not exceed the limit specified in the China's soil environmental quality standard. It is higher than the content of cadmium in soil of Heilongjiang area (0.096mg/kg) reported in 2012[31]. The content of cadmium in the soil of Wuchang area was 0.124, which was lower than the cadmium content in the soil of Harbin area reported by Wang (2011) [32]. The cadmium content was much higher in Chahayang than the other four regions, but the cadmium content in the soil was not much different in the five regions.

Studies have shown that the absorption and accumulation of heavy metals in rice is greatly affected by genetic background, cultivar type and heavy metal interaction [33] (Lin 2018). The varieties with high Se accumulation showed a tendency to inhibit the accumulation of heavy metal Cd [34] (Li 2003). In addition, some studies found that the cadmium content in rice was decreased by the optimal zinc content in soil [35] (Zhang 2015).

The single rice variety (rice flower) and soil background in Wuchang area are the main factors leading to the difference between Wuchang and other regions. The cadmium content in rice in the two areas of Jianshuanjiang is also different by the cadmium content in paddy soil. In the process of absorption and accumulation of heavy metals, rice is not only affected by heavy metal content in soil, but also affected by other factors. Such as rice varieties, soil microbial content, precipitation, air quality and so on.

Analysis of the significance of differences between different regions

The variance analysis of five areas of polished rice, brown rice and soil was carried out by SPSS statistics 12.0. The results are shown in the figure below.

It can be seen from Fig. 1 (a) that the content of cadmium in soils in Wuchang, Chahayang and Jiansanjiang was significantly different. In addition, there was a significant difference in the content of cadmium in soils in Chahayang and Fangzheng areas and also in soils in Fangzheng and Xiangshui areas and between Xiangshui and Jiansanjiang. The differences between Wuchang and Fangzheng and between Chahayang and Xiangshui were not significant.

It can be seen from Fig. 1 (b) that the content of cadmium in brown rice was significantly different between Wuchang and Chahayang, Fangzheng, Xiangshui, and Jiansanjiang as well as between Chahayang and Fangzheng, Xiangshui and Jiansanjiang. There was no significant difference between Xiangshui and Jiansanjiang in the content of cadmium in brown rice.

It can be seen from Fig. 1 (c).There were significant differences in the content of cadmium in polished rice between Chahayang and Wuchang, Fangzheng, Xiangshui, and Jiansanjiang. The differences in cadmium content in polished rice between Wuchang and Fangzheng, Xiangshui and Jiansanjiang were not significant.

In summary, the differences in cadmium content in soil, brown rice and polished rice in the study area were not consistent. The rice varieties have an effect on the absorption and accumulation of cadmium by rice, and some agricultural factors such as pesticides, fertilization and irrigation may also greatly affect absorption of cadmium by rice. Some studies have shown that natural conditions such as precipitation and CO2 concentration [36] also have an impact on absorption and accumulation of cadmium in rice.

Soil-rice system migration model of Cd element

The absorption and accumulation of heavy metals in rice is not only affected by the total metal content in the soil, but also by the physical, chemical and biological properties of the soil. Many researchers have studied the factors affecting the absorption of metal elements in rice, including soil pH [37,38], organic matter [39,40], redox potential [41], salinity [42], and phosphorus content [43]. Soil pH is an important factor in controlling heavy metal absorption [44,45]. Table 5 shows the physical and chemical properties of soils in the study area.

The present paper studied the factors affecting absorption of cadmium in the “soil-rice system” and proposed the best fitting model for predicting the content of cadmium in rice. A multivariate regression model of arsenic content in rice was established by using soil pH and organic matter. The multiple regression equation was shown in Table 6. There was a significant negative correlation between the content of cadmium in rice and the concentration of cadmium in soil ($P<0.05$). The content of cadmium in Chahayang rice was positively correlated with soil pH ($P<0.05$), and it was significantly related to soil cadmium concentration The negative correlation ($P<0.05$); the content of cadmium in Xiangshui rice was significantly positively correlated with the concentration of cadmium in soil ($P<0.05$). The partial coefficient between cadmium content and soil pH in Jiansanjiang rice was not significant. Therefore, the best prediction model for the Jiansanjiang area was based on the concentration of cadmium in soil.

The content of cadmium in rice in Chahayang, Wuchang and Xiangshui areas could be predicted well by the concentration of cadmium in soil. The pH value of soil could predict the content of arsenic in rice in Chahayang area. However, in the established regression model, the content of cadmium in rice in Fangzheng and Jiansanjiang areas was not significantly correlated with soil cadmium content, pH and organic matter. Therefore, the prediction models of these two regions have yet to be worked out. Dudka [46] et al. (1996) reported that the relationship between heavy metals in rice and soil could be described by three models: linear (constant distribution model), plateau model (saturated) and Langmuir model. The metal adsorption also followed a linear model in the range of low metal concentrations in the soil.

In the present study, soil samples collected from paddy fields contained relatively low levels of cadmium. By fitting and comparing the three models, it was found that the linear model was the best fitting model. Therefore, the linear model is used for fitting.

The R2 value of the fitted model was between 0.256 and 0.468 (Table 5). The D-W index was close to 2, the autocorrelation of the independent variables was not obvious, and the model design was good . Dudka etal.[46] reported R2 values of 0.94 and 0.92 for the correlation between, respectively, Cd and Zn contents in barley grains and Cd and Zn contents in soil. McBride [47] found similar correlation coefficients. In the present study, the correlation coefficient was lower than the correlation coefficients (<0.9) of the previous studies. These above-mentioned studies were carried out in pots or small experimental field; so, the soil properties changed little, if at all, during the modeling process. Hence, the model established under these conditions had a higher degree of fit. In the present study, the rice and soil samples were collected under natural field conditions. Paddy soils are a complex system. In addition to the variability in total metal content and pH value of soil, other soil properties may also affect the availability of heavy metals, potentially weakening the model fit between metal accumulation by rice and the soil metal content and pH.

Evaluation of cadmium pollution in rice grains and health risk assessment of intake

According to formulae (1) and (2), the results of heavy metal pollution assessment in the study area were obtained (Tables7-8). The single factor pollution index evaluation was less than 1 (Table 7), indicating that the five areas of the study were not polluted by Cd (the proportion of pollution-free soil in each region was 100%). The comprehensive rice pollution index in the study area was 0.153 (Table 8), which was non-polluting; the comprehensive pollution index of each region was in the order Chahayang>

Fangzheng> Xiangshui> Jiansanjiang> Wuchang.

Due to the different geographical locations, and the differences in economic development level and industrial structure distribution, there are expected differences in the content of Cd in rice in different regions. The areas studied in this paper represent the geographically-protected rice products in Heilongjiang Province. The results reported in this paper did not exceed the values specified in the health risk index, and 100% of rice in the five regions was non-contaminated. This is despite extensive economic development in the five regions studied in recent years, including the construction of farm towns, usage of pesticides and fertilizers, agricultural irrigation, and automobile exhaust gases, representing the main sources of heavy metals.

According to the results of heavy metal carcinogenic risk assessment (Table 9), the average intake (ADD) of Cd in adults and children was lower than the reference exposure dose (RfD). Hence, the individual health risk index was less than 1, indicating the amounts of daily intake of cadmium would not be considered a health risk to humans. The order of rice intake influencing the health risks to adults and children was Chahayang> Fangzheng> Xiangshui> Jiansanjiang> Wuchang. Comparing the results of individual pollution assessment of rice in the study area, the evaluation results of Wuchang, Jiansanjiang and Chahayang were completely consistent. The pollution index of Wuchang was the smallest of all areas, indicating Wuchang was not affected by Cd.

The average Cd carcinogenic risk index of adults in different regions of each region was Wuchang 0.34×10-4, Chahayang 5.61×10-4, Fangzheng 1.08×10-4, Xiangshui 1.26×10-4, Jiansanjiang 0.56×10-4; the average health risk index of children was Wuchang 0.52×10-4, Chahayang 8.69×10-4, Fangzheng 1.67×10-4, Xiangshui 1.95×10-4,Jiansanjiang 0.87×10-4. The risk index values of Chahayang, Fangzheng and Xiangshui were higher than the USEPA recommendation. The maximum acceptable level was 1×10-4,and there is a risk of cancer; The risk index values of both Wuchang and Jiansanjiang were lower than the maximum acceptable level recommended by USEPA (1×10-4). The health risk of Fangzheng and Xiangshui was on the edge of the acceptable risk range for humans, and the risk of cancer was low.

There was a certain deviation between the Cd carcinogenic risk index values and the evaluation results of rice single factor pollution in the study area. In the single factor pollution assessment, the pollution index of the Fangzheng area was higher than that of Xiangshui, and the opposite was true in the cancer risk assessment, which is mainly related to the original level of heavy metals. Cadmium is a harmful element upon accumulation. It has obvious toxic effects on human nervous and reproductive systems, and is a heavy metal element with a high carcinogenic risk.

Discussion

According to the "National Soil Pollution Status Survey Bulletin" published by the Ministry of Environmental Protection of China and the Ministry of Land and Resources of China, out of the total soil area surveyed in the country (6.3 million km2) 16.1% (1.08 million km2) had pollution exceeding the acceptable standards. On May 28, 2016, the “Soil Pollution Prevention and Control Action Plan” issued by the State Council of China clearly requires the provision of soil environmental management for agricultural land based on soil pollution prevention, investigation and monitoring, classification management, supervision and management, etc., to prevent pollution, control agricultural use, and guarantee the quality and safety of agricultural products.

This paper theoretically evaluated the heavy metal content in the geographically-protected products of the five major rice-producing areas in Heilongjiang Province, and analyzed the health risks brought about by eating local rice, which has practical significance. According to the research results (Table 4), the average content of cadmium in rice in the study area was in the order of Chahayang> Xiangshui> Fangzheng> Jiansanjiang> Wuchang. The content of cadmium in rice in Chahayang area was the highest in the study area. The average cadmium content did not exceed the national food hygiene standard limit, and was much lower than the cadmium content in rice in Hunan Province [35] and Taihu Lake, Jiangsu Province [34]. Given that the rice produced in the study area is China National Geographic Protection Mark rice, the production area is located in the Songnen Plain and Sanjiang Plain in Northeast China, and is little affected by human activities (urban, mining and metallurgical activities). Therefore, the cadmium in rice in the study area was within the non-pollution standard (with the compliance rate of 100%). However, the difference between the content of cadmium across China and in the study area was not consistent. This is because the rice varieties planted in the study area were different, and the pesticides applied, irrigation water quality and rainfall were also inconsistent. The extent to which rice absorbs and accumulates cadmium from the soil would be expected to differ among various regions, influencing the modeling of soil-rice systems in different regions. The modeling results were shown in Table 6. There were significant differences in the cadmium content in rice and soil in Wuchang, Chahayang and Xiangshui areas. The cadmium content in rice in Fangzheng and Jiansanjiang areas was greatly affected by other factors, and the model fit was low. The better-fitting model remains to be determined.

The average daily intake (ADD) of cadmium in adults and children in the study area was lower than the reference exposure dose (RfD). The cancer risk index in Wuchang and Jiansanjiang was within the maximum acceptable risk level recommended by USEPA. The carcinogenic risk index of both Fangzheng and Xiangshui was close to the maximum acceptable risk level recommended by USEPA, with the cancer risk still being low. However, the carcinogenic risk index in Chahayang was much higher than the maximum acceptable level recommended by USEPA, suggesting a high risk of causing cancer, which was similar to the results of cancer risk assessment in Zhejiang Province [34] and Zhejiang area [48]. According to the research results (Tables 5-7), the cadmium pollution existed in the Chahayang area, and the corresponding carcinogenic risk exceeded the acceptable level for humans, which should be paid attention to by the relevant departments.

Due to the international nature of the experimental parameters and the regional nature of the study area, as well as the differences in human quality status under different living conditions, the results of this study have certain limitations and one-sidedness.In addition, since the impact of rice varieties is not considered in the research process, in the subsequent research, the migration in the “soil-plant-human body” system should be established on the basis of comprehensive consideration of various current impact factors. Experimental studies on transformation, and bioavailability, with a view to providing data references for soil conservation and food security in agricultural land.

Conclusion

（1）The average content of cadmium in brown rice in the study area was (in mg·kg-1) 0.003 (Wuchang), 0.016 (Chahayang), 0.006 (Fangzheng), 0.006 (Xiangshui), and 0.005 (Jiansanjiang). The cadmium content in brown rice in the five regions did not exceed the cadmium content specified in the National Food Hygiene Standard of China. The difference in cadmium content between brown rice, polished rice and soil was inconsistent. The prediction models developed in this study, including the total cadmium content and pH of the soils, could significantly describe the transfer of cadmium in the soil-rice system of Chahayang, Wuchang and Xiangtian paddy fields, with R2 values ranging from 0.256 to 0.468.

（2）The pollution index of the entire study area was less than 1.The comprehensive pollution index was 0.037<1, which belongs to the non-polluting category. The comprehensive pollution index of each region was in the order of Chahayang> Fangzheng> Xiangshui> Jiansanjiang> Wuchang, and ranged between 0.059 and 0.158. The average daily intake of cancer-causing cadmium (ADD) for adults and children was lower than the reference dose (RfD). The average risk of carcinogenic heavy metal Cd for adults and children's in Chahayang, Fangzheng and Xiangshui was higher than the maximum acceptable risk level of 1×10-4 recommended by USEPA, suggesting a real cancer risk. The average values of Wuchang and Jiansanjiang were lower than the maximum acceptable risk level of 1×10-4 recommended by USEPA, suggesting there was no risk of causing cancer.

Abbreviation Description

ICP-MS——Inductively Coupled Plasma Mass Spectrometry

USEPA——nited States Environmental Protection Agency

SD——Standard deviation

Cd——Cadmium

Declarations

Ethical Approval and Consent to participate

Not applicable

Consent for publication

All authors agree to publish this paper

Competing interests

Not applicable

Funding

This work was funded by Heilongjiang Province Applied Technology Research and Development Project (GA14B104) and Heilongjiang Bayi Agricultural University Support Program for San Heng San Zong”（TDJH201906）.

Availability of data and materials

It is hereby declared that the source of this experimental material is reliable and the measurement data is accurate.

Authors' contributions

Dongmei Cao contributed to the conception of the study;

Chang Zhang contributed significantly to analysis and manuscript preparation;

Chang Zhang performed the data analyses and wrote the manuscript;

Dongjie Zhang and Dongmei Cao helped perform the analysis and complete the manuscript with constructive discussions.

Acknowledgments

This work was funded by Heilongjiang Province Applied Technology Research and Development Project (GA14B104) and Heilongjiang Bayi Agricultural University Support Program for San Heng San Zong”（TDJH201906）. The authors would like to thank teachers and classmates for their valuable help with these experiments.

Authors' information

Dongmei Cao：Title: Professor Research Interest: Food Quality and Safety Professor E-mail: caodong3018@sina.com, Tel. 13836962229;

Chang Zhang：Postgraduate Research Interest: Food Quality and Safety E-mail: 17645486275@163.com, Tel. 17645486275;

Ddongjie ZhangE-mail: Title: Professor Research Interest: Food Quality and Safety byndzdj@126.com, Tel.: +8604596819006

References

[1] Lu-Ping Z , Jun-Hao Q , Shu-Yu D , etal. Accumulation of heavy metals copper, zinc, and cadmium in cassava varieties and the associated human health risk[J]. Journal of Agro-Environment Science, 2017.

[2] Fariss M W . Cadmium toxicity: unique cytoprotective properties of alpha tocopheryl succinate in hepatocytes[J]. Toxicology, 1991, 69(1):63-77.

[3] Yu H , Wang J , Fang W , et al. Cadmium accumulation in different rice cultivars and screening for pollution-safe cultivars of rice[J]. Science of the Total Environment, 2006, 370(2-3):302-309.

[4] Rehman M Z U , Khalid H , Akmal F , etal. Effect of limestone, lignite and biochar applied alone and combined on cadmium uptake in wheat and rice under rotation in an effluent irrigated field[J]. Environmental Pollution, 2017, 227:560.

[5] Zhibo Z . Effects of soil pH on growth and grain cadmium content in rice[J]. Journal of Agro-Environment Science, 2017.

[6] Huang G , Li X , Ding C , etal. Underlying mechanisms and effects of hydrated lime and selenium application on cadmium uptake by rice (Oryza sativa L.) seedlings[J].Environmental Science and Pollution Research, 2017, 24(23):1-10.

[7] Wei B , Yang L . A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China[J]. Microchemical Journal, 2010, 94(2):99-107.

[8] Yanming W U , Gaoming L V , Hang Z , etal. Contamination status of Pb and Cd and health risk assessment on vegetables in a mining area in southern Hunan[J]. Acta Ecologica Sinica, 2014, 34(8):2146-2154.

[9] Yadav I , Devi N , Syed J , etal. Assessment of exposure to heavy metals and health risks among residents near Tonglushan mine in Hubei, China[J]. 2015.

[10] Wang Z , Yu X , Geng M , etal. Accumulation of heavy metal in scalp hair of people exposed in Beijing sewage discharge channel sewage irrigation area in Tianjin, China[J]. Environmental Science & Pollution Research International, 2017, 24(4):1-8.

[11] Zeng X , Wang Z , Wang J , etal. Health risk assessment of heavy metals via dietary intake of wheat grown in Tianjin sewage irrigation area[J]. Ecotoxicology, 2015, 24(10):2115-2124.

[12] Xie H T , Zhang C Z , Xu F , etal. Distribution and assessment of mercury in the ambient soil of a municipal solid waste incinerator[J]. Huan jing ke xue= Huanjing kexue / [bian ji, Zhongguo ke xue yuan huan jing ke xue wei yuan hui "Huan jing ke xue" bian ji wei yuan hui.], 2014, 35(4):1523-1530.

[13] Li N , Kang Y , Pan W , etal. Concentration and transportation of heavy metals in vegetables and risk assessment of human exposure to bioaccessible heavy metals in soil near a waste-incinerator site, South China[J]. Science of The Total Environment, 2015, 521-522:144-151.

[14] Yinan C , Jianhua M A . Assessment of pollution and health risks of heavy metals in surface dusts from driving schools in a city of Henan,China[J]. Acta Scientiae Circumstantiae, 2016, 36(8):3017-3026.

[15] Mehr M R , Keshavarzi B , Moore F , etal. Contamination level and human health hazard assessment of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in street dust deposited in Mahshahr, Southwest of Iran[J]. Human and Ecological Risk Assessment, 2016, 22(8):1726-1748.

[16] Xiao-Feng J I , Na Z , Yang W , etal. Accumulation of Mercury in Soil-maize System of Non-ferrous Metals Smelting Area and Its Related Risk Assessment[J]. Environmental Science, 2015.

[17] Yu R , Wang Y , Wang C , etal. Health risk assessment of heavy metals in soils and maize (\r, *Zea mays*\r, L.) from Yushu, Northeast China[J]. Human and Ecological Risk Assessment: An International Journal, 2017:0-0.

[18] Cunyu Z . Characteristics and evaluation of heavy metal pollution in vegetables in Guangzhou[J]. Huan jing ke xue= Huanjing kexue, 2017, 38(1):389.

[19] Chang C Y , Yu H Y , Chen J J , etal. Accumulation of heavy metals in leaf vegetables from agricultural soils and associated potential health risks in the Pearl River Delta, South China[J]. Environmental Monitoring & Assessment, 2014, 186(3):1547-1560.

[20] Fu G , Zeng Q , Zhao L , etal. Health Risk Assessment of Drinking Water Quality in Tianjin Based on GIS[J]. Huan jing ke xue= Huanjing kexue / [bian ji, Zhongguo ke xue yuan huan jing ke xue wei yuan hui "Huan jing ke xue" bian ji wei yuan hui.], 2015, 36(12):4553-4560.

[21] Giri S , Singh A K . Human health risk assessment via drinking water pathway due to metal contamination in the groundwater of Subarnarekha River Basin, India[J]. Environmental Monitoring and Assessment, 2015, 187(3):63.

[22] QIN Yusheng, YU Hua, FENG Wenqiang, etal. Assessment on heavy metal pollution status in paddy soils in the northern Chengdu Plain and their potential ecological risk[J]. Acta Ecologica Sinica, 2013, 33(19):6335-6344.

[23] Fu Q L , Li L , Achal V , etal. Concentrations of Heavy Metals and Arsenic in Market Rice Grain and Their Potential Health Risks to the Population of Fuzhou, China[J]. Human and Ecological Risk Assessment: An International Journal, 2015, 21(1):117-128.

[24] Yan Z , Fa-Dong L I , Zhu O , etal. Distribution and Health Risk Assessment of Heavy Metals of Groundwaters in the Irrigation District of the Lower Reaches of Yellow River[J]. Environmental Science, 2013.

[25] Cao C , Chen X P , Ma Z B , etal. Greenhouse cultivation mitigates metal-ingestion-associated health risks from vegetables in wastewater-irrigated agroecosystems[J]. Science of The Total Environment, 2016, 560-561:204-211.

[26] US EPA. Risk assessment guidance for superfund volume Ihuman health evaluation manual (part A)［R］. EPA /540 /1-89 /002. Washington,DC: Environmental Protection Agency,1989. 256-263.

[27] Duan X , Zhao X , Wang B , etal. Highlights of the Chinese Exposure Factors Handbook(Adults)[M]. ELSEVIER, 2015.

[28] US EPA. Superfund public health evaluation manual [R]. EPA /540 /1- 86 /060. Washington,DC: Environmental Protection Agency, 1986. 1-52.

[29] CAS R N 7439-92-1, Lead and compounds (inorganic) ［S］.

[30] US EPA. Supplemental guidance for developing soil screening levels for superfund site[M]. Washington, DC: Washington Office of Solid Waste and Emergency Response, US Environmental Protection Agency, 2001. 4-24.

[31] Xia X , Yang Z , Cui Y , etal. Soil heavy metal concentrations and their typical input and output fluxes on the southern Song-nen Plain, Heilongjiang Province, China[J]. Journal of Geochemical Exploration, 2014, 139:85－96.

[32] Wang L F , Bai Y X , Gai S N . Single-Factor and Nemerow Multi-Factor Index to Assess Heavy Metals Contamination in Soils on Railway Side of Harbin-Suifenhe Railway in Northeastern China[J]. Applied Mechanics and Materials, 2011, 71-78:3033-3036.

[33] Xiao-Bing L , Li-Jun Z , Hui-Ming W , etal. Accumulation of Heavy Metals in Different Rice Varieties[J]. Environmental Science, 2018.

[34] Li Z , Zhang Y , Pan G , etal. Grain contents of Cd, Cu and Se by 57 rice cultivars and the risk significance for human dietary uptake[J]. Huan jing ke xue= Huanjing kexue / [bian ji, Zhongguo ke xue yuan huan jing ke xue wei yuan hui "Huan jing ke xue" bian ji wei yuan hui.], 2003, 24(3):112-115.

[35] Jianhui Z , Fangbin W , Xiali W , etal. Relationship between Cd and Zn in Soil and Cd in Rice Grain[J]. Food Science, 2015.

[36] Wang X , Song Z G , Wu H B , etal. Effects of elevated CO2 on the rice quality of Japonica rice in copper and cadmium contaminated soil[J]. Chinese Journal of Ecology, 2014, 33(5):1319-1326.

[37] Reddy C N , Patrick W H . Effect of Redox Potential and pH on the Uptake of Cadmium and Lead by Rice Plants[J]. Journal of Environmental Quality, 1977, 6(3).

[38] Dutta, D. , Mandal, B. , & Mandal, L. N. Decrease in availability of zinc and copper in acidic to near neutral soils on submergence.Soil Science . (1989).,147(3), 187-195.

[39] Haldar M , Mandal L N . Influence of soil moisture regimes and organic matter application on the extractable Zn and Cu content in rice soils[J]. Plant and Soil, 1979, 53(1):203-213.

[40] Kashem M A , Singh B R . Metal availability in contaminated soils: I. Effects of floodingand organic matter on changes in Eh, pH and solubility of Cd, Ni andZn[J]. Nutrient Cycling in Agroecosystems, 2001, 61(3):247-255.

[41] Sajwan K S , Lindsay W L . Effects of Redox on Zinc Deficiency in Paddy Rice1[J]. Soil Science Society of America Journal, 1986, 50(5):1264.

[42] Mclaughlin M , Tiller K , Smart M . Speciation of cadmium in soil solutions of saline/sodic soils and relationship with cadmium concentrations in potato tubers[J]. Australian Journal of Soil Research, 1996, 35(1):1101-1102.

[43] Haldar M , Mandal L N . Effect of phosphorus and zinc on the growth and phosphorus, zinc, copper, iron and manganese nutrition of rice[J]. Plant and Soil, 1981, 59(3):415-425.

[44] Jung M C , Thornton I . Environmental contamination and seasonal variation of metals in soils, plants and waters in the paddy fields around a Pb ・ Zn mine in Korea[J]. 1997, 198(2):0-121.

[45] Basta N T , Ryan J A , Chaney R L . Trace Element Chemistry in Residual-Treated Soil: Key Concepts and Metal Bioavailability[J]. Journal of Environmental Quality, 2005, 34(1):49-63.

[46] Dudka S , Piotrowska M , Terelak H . Transfer of cadmium, lead, and zinc from industrially contaminated soil to crop plants: A field study[J]. 1996, 94(2):0-188.

[47] Mcbride M B . Cadmium uptake by crops estimated from soil total Cd and pH[J]. Soil Science, 2002, 167(1):62-67.

[48] Zhao K , Zhang W , Zhou L , etal. Modeling transfer of heavy metals in soil－rice system and their risk assessment in paddy fields[J]. Environmental Earth Sciences, 2009, 59(3):519-527 .