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Full Length Article

Accumulation of Heavy Metals in Different Parts of Wheat Plant from the Yangtze River Delta, China

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Abstract

With the rapid economic development and increased human activities, the soil heavy metal pollution has become a serious environmental problem in the world. This study investigated the heavy metal accumulation in soil and bioaccumulation in wheat in the Yangtze River Delta, particularly in Suzhou-Kunshan, to provide theoretical guidance for economic development and pollution control. Wheat plants were collected and divided into four parts: root, stem, leaf, and grain. The concentrations of eight heavy metals (Hg, As, Cr, Cu, Ni, Pb, Zn and Cd, As is a metalloid) in each wheat plant part were evaluated, and the accumulation and relationship of these heavy metals (HMs) were analyzed. Results indicated that the roots had the greatest accumulating capability among the four plant parts, also the roots are the main channel of heavy metal accumulation in wheat plant. The most and least accumulated HMs were Cd and Cr, respectively. Correlation analysis revealed a relationship between heavy metal concentration in the grains and other plant parts of wheat. However, no consistent pattern was found. This result could be attributed in part to the atmosphere-derived HMs in wheat; thus, outer contaminants and reactions might exist in the plants. © 2016 Friends Science Publishers

Keywords: Heavy metal pollution; Wheat plant parts; Accumulation; Correlation

Introduction

Rapid economic development and increased human activities have deeply impacted the soil environment by increasing the accumulation of heavy metals (HMs) in soil (Wei *et al.*, 2010; Li *et al.*, 2014), the soil heavy metal pollution has become a serious environmental problem in the world (Solgi *et al.*, 2012). When potentially toxic heavy metals accumulated in environment, they can induce a potential contamination of food chain and endanger the ecosystem safety and human health (Finžgar N *et al.*, 2006; Lei *et al.*, 2010; Teng *et al.*, 2010). The HMs enter the plant through the soil, atmosphere and other media; these HMs then transport and accumulate and may enter the human body through the food chain, thus endangering human life and health (Ladonin *et al.*, 2002; Zhong *et al.*, 2007; Zhu *et al.*, 2009). The accumulation of HMs in plant will produce toxic effects on plant transpiration, photosynthesis and antioxidant system (Wahid *et al.*, 2010; Cao *et al.*, 2013; Liu *et al.*, 2013), and when the HMs enter the human body, they will harm to human body in many aspects (Jarup, 2003; Wang *et al.*, 2013). The accumulation of Cd in the human body will induce osteoporosis, kidney damage, or even damage the immune system, nervous system and reproductive system (Peralta-Videa *et al.*, 2009). High levels of lead in human body can cause adverse effects on the nervous system, kidney and blood pressure, which is particularly serious harm to children (Needlemmi, 2004; Li *et al.*, 2015). Therefore, Food and Agriculture Organization (FAO) and Word Health Organization (WHO), United States Environment Protection Agency (US EPA) and other regulatory bodies of other countries strictly regulate the allowable concentrations or maximum permitted concentrations of toxic HMs in foodstuffs (FAO/WHO, 1984; US EPA, 2000). Over half of the world's population uses wheat as the main food source; therefore, the "purity" of wheat seriously affects people's health (Shao *et al.*, 2005).

Because of the increasingly serious situation of soil pollution, in order to study the regularity of migration and accumulation of HMs between soil and crop, many scholars around the world have investigated the translocation and accumulation of HMs in plants. For example, Ren *et al.* (2012) studied the effects of concentration of single heavy metal Zn or Cd on growth of wheat and rice by a pot experiment; Nie *et al.* (2012) studied effects of 5 HMs (Cd, Pb, As, Hg, Cr) stress on wheat yields and ingredient in farmlands; Su *et al.* (2010) explored the heavy metal pollution and migration in soil-wheat system under the condition of using different livestock manure. Based on

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existing research, main conclusions of accumulation in soil-crop system are as follows: Different plants have different heavy metal accumulation ability, Different plants have different translocation and accumulation ability to the same heavy metals (Ro Mkens *et al.*, 2009; Norton *et al.*, 2010; Ye *et al.*, 2013). Now, the current research on HMs mainly focused on the repair and treatment of HMs, physiological mechanisms of pollution remediation and risk assessment of pollution etc. (Khan *et al.*, 2008; Abdolkarim *et al.*, 2009; Julien *et al.*, 2009; Kwon *et al.*, 2010). However, the accumulation, distribution and relationship of various HMs in different plant parts were rarely researched simultaneously.

In the complex natural environment, the accumulation of HMs by plants is synergistically affected by various environmental factors (Dudka and Adriano, 1997; Bauelos, 2006; Liu *et al.*, 2009). The accumulation of HMs on different plant parts of wheat is an extremely complex process that is affected by element combination, relative concentration, element proportion, and environment factors (Yang *et al.*, 2005; Ji *et al.*, 2006). Therefore, the accumulation, distribution and relationship of HMs in different plant parts must be explored to provide theoretical guidance on heavy metal translocation in soil–plant systems.

Materials and Methods

Study Area

Kunshan County (120°48′—121°09′E, 31°06′—31°32′N), is situated in the southeast of Jiangsu province, belong to Yangzi River Delta which is known as "The Land Flowing with Milk and Honey," is rich in natural resources (Fig. 1). The total area of Kunshan is 927 km^2, and the population 600 thousand. Kunshan is only 50 km far away from Shanghai municipality which is the biggest city in China. Based on this obvious location advantage, chemical and electronic industries have become the pillar industries of the economy in this area, the economy developed rapidly and ranked first among all counties in China. Previous study showed that, the contribution of textile, chemical, printed circuit board manufacturing and building materials industries are 45.73% of the total contamination in Kunshan (Liu *et al.*, 2005), and with the development of industrialization and urbanization, the study area will suffer a big risk of heavy metal pollution (Huang *et al.*, 2008).

Sampling and Analysis

Soil and plant sampling: On May 2009 just before the wheat harvest, with the using of GPS we collected 40 wheat samples and soil samples at the corresponding point in different agricultural areas of Kunshan City. The wheat cultivar Yangmai-16 was selected as the sampling target, which is the main wheat cultivar in study area.

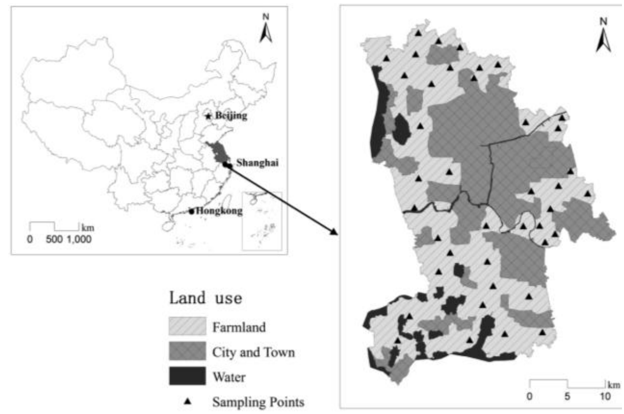

Fig. 1: Study area locations and soil sampling designs in Kunshan

Soil samples were taken with a 5 cm diameter stainless steel auger on the 0–20 cm layer in the central area of farmland. At each sampling point, we collected 5 soil samples in 10 m radius, then uniformly mixed the 5 samples, and take out 1kg soil as the soil sample of this point. The soil samples were placed in plastic bags and brought back to laboratory.

Plant samples of each sampling point were taken at the 5 corresponding point, we collected 4 wheat plants which have the same growth vigor and no significant plant disease at each point, so a total of 20 wheat plants were taken as the plant sample of this point. In order to avoid damaging the wheat roots, we used a large shovel to deeply dig out the 4 wheat plant, and carefully cleaned the soil attached to the wheat roots with distilled water. The plant samples were also placed in special plastic bags and brought back to laboratory.

Soil analyses: The collected soil samples were air-dried and sieved through a 2 mm polyethylene sieve to remove stones and plant roots. Soil pH was measured in suspension (soil: water: 1:2.5) with pH glass electrodes. The concentration of organic carbon in soil was determined by the method of potassium bichromate. Laser Grain-size Analyzerwas used to analyze soil mechanical composition.

We determined the Hg and As concentrations by using AFS AF-640. Sample solutions of Cr, Cu, Ni, Pb, Zn, and Cd were prepared by using $HF-HNO_3-HClO_4$ digestion. As an exception, Cd was determined by graphite furnace atomic absorption spectrometry. The concentrations of other HMs were determined by ICP-AES.

Plant analyses: First, the wheat samples were washed with tap water to clean, and rinsed three times with distilled water. Then, the clean wheat samples were divided into four parts of root, stem, leaf and grain, then put the root, stem, leaf and grain in the oven drying to constant weight at 40^{o}C ±5^{o}C. Last, weighed and recorded the weight of dry matter, and then grinded the samples to less than 0.25 mm for analyses.

The concentrations of Cd, Cr, Pb, Cu and Zn in the wheat samples were analyzed by using the mixed acid (HNO_3–$HClO_4$) digestion and then determined by using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). By using HNO_3–$HClO_4$–H_2SO_4 to prepare the sample solution, the author determined the total Hg and As concentrations by atomic fluorescence spectrometry (AFS, AF-640).

Results

Statistical Characteristics of HMs

Soil HMs: The results of the soil analysis show that: the soil is slightly acidic, average value of pH in soil is 6.42±0.09 (Average value±Standard error). The content of clay (<0.01 mm) ranges from 20.47% to 48.61%, and the average value is 31.59%±4.31%. Average value of soil organic matter (SOM) is 28.29±0.06 g/kg. The soils report moderate cation exchange capacity (CEC) (17.83±0.29 cmol/kg), which ranges between 10.3 and 29.7.

Data of eight HMs in the soil and the corresponding background values in this area are presented in Table 1. The background values of heavy metals were obtained according to a previous study (Liao *et al.*, 2011). Among the eight HMs, the variability of Zn concentration in soil is highest (Coefficient of Variation, CV is 115.89%), and the variability of Cd concentration (CV is 77.85%) is just below Cd, which showing a remarkable effect of environmental input on Zn and Cd concentration in soil. The variability of other six HMs concentrations is relatively low, and the Cr is lowest.

Compared with the background values, eight HMs have both been accumulated in varying degrees in the study area. The rates of over background value (ROBV) for Hg and Cd of the forty soil samples are both reached 100%, even the average value of Hg exceeds 10 times the background value, which shows that the accumulation of Hg and Cd has reached a very serious extent in the study area. The As, Cu, Ni, Pb and Zn also have been seriously accumulated, the ROBVs of them are more than 70%. The ROBV of Cr is the lowest, however the average value of Cr is very close to the background value. The maximums of all the eight HMs are much large than the background values, which shows that the pollution of the HMs in some areas has been very serious.

Plant HMs: The plant analysis results (Table 2) show that wheat roots and grains contain the maximum and minimum varieties of HMs (except for Cu), respectively. Aside from Hg and Cu, the distribution of six other HMs in wheat roots, stems, leaves, and grains is as follows: root > leaf > stem > grain. This distribution reflects that the roots are in direct contact with the soil. Thus, the heavy metal concentration is obviously higher in the roots than in the other plant parts. The heavy metal concentration is higher in the leaves than in the stems and grains.

The coefficients of variation (*CVs*) of HMs in whole wheat plants are small. The root has the largest *CV* for As (59.93%). This result indicates that the accumulation of As in wheat roots is significantly influenced by the external environment. The variability of Cu and Pb in the stems is more than 80%, thus indicating that the accumulation and distribution of the two HMs are affected by many factors. This result may be attributed to the combined effects of the external environment and wheat plant function. The *CV*s of Cr in the leaves and grains were 87.6 and 91.8%, respectively, and the *CV* of Pb in the grains is 87.3%. The different wheat plant parts have more obvious variability of HMs than a whole wheat plant. Therefore, further research on wheat plant parts is important to study the transport and accumulation of HMs in wheat.

Bioconcentration Factor of HMs in Different Wheat Plant Parts

Bioconcentration factor (BCF) is a common parameter often used in the study of environmental contaminations (Adel *et al.*, 1998). BCF is the ratio of concentration of heavy metal in wheat and that in soil (Eq. (1):

$$BCF_{ij} = P_{ij}/S_j \qquad (1)$$

Where, BCF_{ij} is the *BCF* of metal-j in wheat plant part-i, P_{ij} is the heavy metal concentration of metal-j in wheat plant part-i, and S_j is the heavy metal concentration of metal-j in soil.

The *BCF* of HMs reflects the ease of translocation of elements in soil–plant systems and represents the enrichment condition of HMs in plants. A larger *BCF* corresponds to higher plant capacity for accumulating HMs.

The accumulation capacity of various HMs in the roots and stems is arranged in the following order: Cd > Cu > Zn>Hg>Ni>Pb>As>Cr (Table 3). The order in the leaves and grains is Cd>Zn>Cu>Hg>Pb>Ni>AS>Cr. The *BCF* of Cd is the highest in all wheat plant parts. This result indicates that Cd is the most highly accumulated, and transported heavy metal. The *BCF* of Cr is the smallest among the HMs tested. This result indicates that Cd and Cr are the most and the least accumulated heavy metal in wheat.

The *BCF* of different wheat plant parts for the same heavy metal is the largest in the root because soil is the main source of wheat HMs and the roots are directly in contact with the soil. The *BCF* values of As, Cr, Ni, Pb, and Cd in the different plant parts are arranged in the order of roots > leaves>stems>grains. In Hg, the order is roots>stems> leaves>grains. In Cu, the order is roots > grains > stems > leaves. In Zn, the order is roots > leaves > grains > stems.

The *BCF* values of various HMs in the whole wheat are arranged in the order of Cd > Zn > Cu > Hg > Ni > Pb > As > Cr. The *BCF* values of all metals in the whole wheat, leaves, and stems are smaller than those in the roots. This result indicates that the different HMs in wheat mainly accumulate in the roots.

Table 1: Concentrations of HMs in soil

	Hg	As	Cr	Cu	Ni	Pb	Zn	Cd
Min	0.10	8.63	46.58	18.07	24.67	12.34	59.32	0.10
Max	0.81	20.95	162.96	61.88	56.67	48.13	1064.12	1.01
AV	0.25	12.43	73.33	29.14	36.33	29.23	134.61	0.18
CV	49.42%	22.16%	32.12%	33.62%	15.30%	33.11%	115.89%	77.85%
BV	0.025	9.40	75.60	23.40	32.80	22.00	64.80	0.085
ROBV	100.00%	85.00%	30.00%	77.50%	80.00%	72.50%	97.50%	100.00%

The unit of concentration is mg/kg. *Min*: Minimum; *Max*: Maximum; *AV*: Average Value; *CV*: Coefficient of Variation; *BV*: Background Value; *ROBV*: Rate of Over Background Value, The same as below

Table 2: Concentrations of HMs in wheat

Plant parts		Hg	As	Cr	Cu	Ni	Pb	Zn	Cd
Total	*AV*	0.019	0.175	0.253	5.880	1.305	0.718	26.666	0.107
	CV	33.12%	31.50%	35.10%	36.34%	41.24%	43.25%	29.29%	38.98%
Root	*AV*	0.073	1.472	1.227	22.436	9.107	3.356	68.284	0.349
	CV	33.78%	59.93%	31.08%	27.18%	32.74%	38.35%	33.12%	40.58%
Stem	*AV*	0.029	0.124	0.202	4.962	1.435	0.677	18.193	0.109
	CV	46.41%	36.86%	32.62%	85.49%	73.06%	82.77%	41.83%	52.26%
Leaf	*AV*	0.024	0.513	0.386	3.911	2.547	2.522	35.985	0.180
	CV	25.23%	37.23%	87.49%	39.80%	39.28%	41.53%	40.76%	52.70%
Grain	*AV*	0.004	0.040	0.178	5.204	0.178	0.237	28.931	0.070
	CV	16.38%	26.52%	98.24%	17.32%	63.63%	87.83%	34.02%	66.72%

Table 3: Heavy metal bioconcentration factor of different wheat plant parts

Plant parts	Hg	As	Cr	Cu	Ni	Pb	Zn	Cd
Root	0.341	0.117	0.018	0.819	0.257	0.125	0.641	2.122
Stem	0.131	0.010	0.003	0.176	0.039	0.028	0.171	0.701
Leaf	0.110	0.043	0.006	0.141	0.072	0.098	0.332	1.110
Grain	0.017	0.003	0.003	0.192	0.005	0.009	0.278	0.413
whole wheat	0.088	0.014	0.004	0.213	0.036	0.029	0.252	0.662

Correlations of HMs in Different Wheat Plant Parts

Correlation analysis is a statistical method that determines the degree of correlation between two elements. In wheat, grain is the direct human-edible part. Therefore, the heavy metal levels in grains affect human health. Therefore, the correlation of heavy metal concentrations in grains should be analyzed with heavy metal concentrations in the roots, stems, and leaves to determine the transporting relationship of various HMs. The correlation coefficients between the HMs of grain and the HMs of roots, stems, and leaves are shown in Tables 4 and 5, wherein the roots, stems, leaves, and grains are represented by -r, -s, -l, and –g, respectively.

The correlations of the same heavy metal between different wheat plant parts: For the heavy metal Hg, the results show no significant correlation between the concentrations of the four plant parts, which is similar to As, Cr and Cu. The Ni concentration in grain is correlated with root Ni at the 0.01 confidence level, and the correlation coefficient is 0.402. The Pb concentration in grain is correlated with stem Pb at a 0.1 confidence level. The concentration of Zn in grain and stem is significantly related at the 0.01 confidence level, the correlation coefficient reaches 0.634. The Cd concentration in grain shows significant correlation with Cd in root and leaf, the correlation coefficients are 0.515 and 0.371.

The correlations of different heavy metals between different wheat plant parts: The Hg concentration in grain is correlated with stem As and leaf Cd at a 0.1 confidence level. The correlation coefficients between As concentration in grain and Cu in stem, Zn in leaf are 0.420 and 0.449, indicating significantly positive correlation. The Cr concentration in the grains is positively correlated with the Cu and Cd in the grains at the 0.01 confidence level. The Cu concentration in the grains is not correlated with various HMs in the roots, stems, and leaves. The Ni concentration in the grains is significantly correlated with the Cd in the roots at the 0.01 confidence level. The Pb concentration in the grains is only significantly correlated with Pb in the stems, i.e., Pb has no correlations with other HMs in the roots, stems, leaves, and grains. The Zn concentration in the grains is significantly positively correlated with Cu in the grains at the 0.01 confidence level with correlation coefficient of 0.584, respectively. The Cd concentration in the grains is significantly correlated with Pb and Cd in the roots and Cu and Ni in the grains. Therefore, the correlation coefficient with Ni in the grains is 0.696 at the 0.01 confidence level. Finally, the Cd concentration in the grains is significantly correlated with Hg and As in the stems, Cd in the leaves, and Hg and As in the grains.

Table 4: Correlations of heavy metal concentrations in wheat grain, root, and stem

	Hg-r	As-r	Cr-r	Cu-r	Ni-r	Pb-r	Zn-r	Cd-r	Hg-s	As-s	Cr-s	Cu-s	Ni-s	Pb-s	Zn-s	Cd-s
Hg-g	0.017	-0.001	0.001	0.007	0.228	0.211	0.022	0.116	0.176	-0.324*	0.022	-0.146	0.073	0.070	0.014	0.159
As-g	-0.158	0.155	0.109	0.138	0.058	0.344*	0.054	0.076	0.025	0.302*	0.186	0.420**	0.204	0.032	0.158	-0.044
Cr-g	0.001	-0.075	-0.119	0.052	-0.031	0.167	0.301	0.526**	0.132	0.013	-0.116	0.132	-0.044	-0.002	0.134	0.164
Cu-g	0.076	-0.073	-0.304*	0.007	0.089	0.045	0.037	0.201	0.154	0.057	-0.116	0.093	0.059	-0.013	0.208	-0.020
Ni-g	-0.005	0.239	0.120	0.122	0.402**	0.315*	-0.009	0.403**	0.283*	0.191	0.237	0.037	0.190	-0.015	0.185	0.170
Pb-g	-0.119	-0.114	-0.197	0.002	-0.194	0.045	0.011	-0.202	0.005	0.029	0.024	-0.131	-0.128	0.337*	-0.241	-0.123
Zn-g	-0.087	-0.073	-0.195	-0.115	-0.026	-0.004	0.215	0.184	0.030	-0.058	-0.127	0.010	0.024	-0.103	0.634**	0.020
Cd-g	-0.010	0.278*	0.103	0.173	0.229	0.544**	0.088	0.515**	0.335*	0.035	0.309*	0.021	0.060	-0.070	0.137	0.163

*Correlation is significant at the 0.1 level; *Correlation is significant at the 0.01 level, the same below

Table 5: Correlations of heavy metal concentration in wheat grain, leaf and grain

	Hg-l	As-l	Cr-l	Cu-l	Ni-l	Pb-l	Zn-l	Cd-l	Hg-g	As-g	Cr-g	Cu-g	Ni-g	Pb-g	Zn-g	Cd-g
Hg-g	0.083	-0.047	-0.071	-0.092	-0.016	0.263*	-0.086	0.011	1							
As-g	-0.048	0.012	-0.055	-0.087	0.072	0.182	0.449**	0.213	-0.035	1						
Cr-g	0.206	-0.057	-0.020	0.018	0.108	0.152	-0.024	0.111	0.085	-0.117	1					
Cu-g	-0.012	-0.172	-0.057	-0.071	-0.184	-0.032	-0.090	0.101*	0.246	-0.076	0.466**	1				
Ni-g	0.037	-0.010	0.136	-0.117	0.233	0.191	-0.067	0.363	0.208	0.232	0.239	0.451**	1			
Pb-g	-0.202	-0.070	0.026	-0.048	-0.103	0.033	-0.008	-0.252	-0.044	0.079	0.093	-0.110	-0.115	1		
Zn-g	0.273*	-0.083	-0.130	-0.200	-0.063	0.111	0.017	0.001	0.162	-0.112	0.225	0.584**	0.249	-0.161	1	
Cd-g	0.132	-0.157	-0.159	-0.102	-0.026	0.254	-0.068	0.371*	0.329*	0.338*	0.270*	0.443**	0.696**	-0.126	0.263*	1

Discussion

Accumulation of HMs in Wheat

The accumulation capacity of different wheat plant parts on identical or different HMs varies, because of the different functions of various wheat plant parts or the different natures of various HMs in wheat (Romkens *et al.*, 2009; Norton *et al.*, 2010; Ru *et al.*, 2010). Among the studied plant parts, the roots have the strongest accumulation capacity for HMs. Cd is the most accumulated heavy metal in all four wheat plant parts. This result can be attributed to the high Cd concentration in soil. Cd can promote wheat growth to some extent. Research has shown that Cd at low concentration can promote root activity (He *et al.*, 2009; Wang and Zheng (2009). Roots are always under conditions with high heavy metal concentration, and Cd is a non-mobile ion, thus explaining the accumulation of Cd in the roots. Cr is the least accumulated heavy metal in all plant parts. These results suggest that the accumulation of Cd in soil and wheat is significant in Kunshan City and the potential risks of Cd to humans are higher than that of other HMs because Cd can easily complex with OH^- and Cl^- in soil (Norton *et al.*, 2010).

Relationship between HMs in Wheat

Some correlations exist between different HMs in various wheat plant parts, but no consistent patterns are found. In the wheat grains, the correlations between various HMs are complicated by many external and internal factors, such as climate, water, wheat varieties, the growth status of other wheat parts, and transport mechanisms of HMs in wheat.

Overall, the Cd concentration in the grains has significantly higher correlations with other HMs than the Cd concentration in the other plant parts. This indicates that the accumulation of Cd in the grains is significantly affected by other HMs in the roots, leaves, stems, and grains. The heavy metal concentration in the grains is not correlated with the heavy metal concentration in the other plant parts. This result shows that the heavy metal accumulation in wheat grain is not only relevant to identical or different heavy metal concentration but is also significantly affected by other factors and physiological, biochemical, and natural conditions. The main factors influencing the translocation of HMs in soil–plant systems include soil physical and chemical properties, microbial activity, and the physiological mechanisms of plant species. These factors can determine the combined form and transfer capability of HMs in soil–plant systems (Dai *et al.*, 2009; Zheng *et al.*, 2015). The heavy metal accumulation capability of plants in soil mainly depends on the heavy metal concentration in soil and the genetic characteristics of plants (Huang *et al.*, 2008; Norton *et al.*, 2010; Ye *et al.*, 2013). The accumulation of HMs in various plant parts is also related to the transport mechanisms of HMs in plants. Under the comprehensive effects of complex factors, the heavy metal concentration in wheat grain is less significantly correlated with the heavy metal concentration in other plant parts (Du *et al.*, 2012; Ma *et al.*, 2014).

Prevention of Wheat Heavy Metal Pollution

HMs not only affect the physiological and biochemical processes of plants but also damage human metabolism and plant parts through the food chain, thus resulting in incalculable hazards to human health and ecological balance in the long term (Xie *et al.*, 2006). Wheat plants harvested from soils with high heavy metal concentrations must be uprooted to avoid high heavy metal concentrations in the root residues. The stems, leaves, and other waste parts of wheat should not be re-used for feed or compost to prevent HMs from re-entering the food chain. Whether in atmosphere or in water, the final destination of HMs should be in the soil. Heavy metals in the soil are the main source of wheat HMs (Wu *et al.*, 2013; Xue *et al.*, 2014). Therefore, the input control of soil HMs is important to control the heavy metal accumulation of wheat. Integrated environmental management (including the governance of water environment and atmospheric environment) is necessary in Kunshan City, which is an industry- and population-intensive city, to control HMs in plants.

Conclusion

1. Plant roots have the strongest accumulation capacity for all the HMs, which are the parts of the direct contact with soil, also are the main channel of heavy metal accumulation in wheat plant.
2. Among the eight HMs, Cd is the most accumulated heavy metal in all four wheat plant parts, and the Cr is the least accumulated heavy metal in all plant parts.
3. In different wheat plant parts, there are some correlations between the different HMs, but no consistent patterns are found, which Shows that the enrichment process of different heavy metals in wheat is very complex.

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