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Analysis of heavy metals in *Pseudostellaria heterophylla* in Baiyi Country of Wudang District

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ABSTRACT

To understand the correlation between the contents of five heavy metals (including arsenic, As; cadmium, Cd; copper, Cu; mercury, Hg; and lead, Pb) and *Pseudostellaria heterophylla* quality in Baiyi Country of Wudang District, nine samples of *P. heterophylla* and planting soil were collected in the research area. After pre-treatment, the samples were sent to ALS Minerals–ALS Chemex (Guangzhou) Co. Ltd., for inductively coupled plasma atomic emission spectrometry (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS) to determine their heavy metal contents. The average contents of the heavy metals in *P. heterophylla* are not higher than the limited standard value (LSV) of the heavy metals, and they generally conform to quality requirements. Except for Cd, the bioconcentration factors (*BFs*) of the heavy metals are not higher than 0.5, and those for Pb and As are especially low. Cd is slightly enriched in *P. heterophylla* and the other heavy metals are not. There is a significant positive correlation between the Cu and As in planting soil, a more significant positive correlation among of As, Cd and Pb in *P. heterophylla*, and the correlations among the other elements are not significant. The levels of enrichment of As, Cd, Cu and Pb contents are very severe, minor, not enriched and moderate in planting soil, respectively. As and Pb are mainly derived from anthropogenic activities. In particular, very severe As pollution by anthropogenic sources occurs. In addition, Cd and Cu are mainly from naturally occurring sources, and Cd may be impacted by anthropogenic activities.

1. Introduction

Heavy metals generally exist in the crust, rock, soil, water, atmosphere and biosphere, and some heavy metals in some environments may come from natural and anthropogenic sources. People generally defined the heavy metals as a group of elements that has an atomic number greater than 20 and a density higher than 5 $g \cdot cm^{-3}$ (Qadir et al., 2014). Heavy metals are ubiquitous in the environment, and the heavy metals in the soil environment mainly result from both natural and anthropogenic activities (Adriano, 2001; Alloway, 2013; Aelion et al., 2009; Bradl, 2005; Hu et al., 2013; Khan et al., 2008, 2013; Nagajyoti et al., 2010; Senesi et al., 2009; Siegel, 2002). Examples of natural processes that produce heavy metals are weathering, erosion of parent rocks, atmospheric deposition and volcanic activities, and examples of anthropogenic activities that produce heavy metals are sewage irrigation, addition of manures, fertilizers and pesticides (Khan et al., 2013). Qadir et al. (2014) concluded that the cadmium (Cd) in the environment comes from natural and anthropogenic sources. Nanos and Martín (2012) investigated seven heavy metals in the agricultural soils of the Duero river basin, where both anthropogenic activities (mainly agriculture and industry) and natural factors may be responsible for their total concentrations. Chen et al. (2014a) thought that natural and anthropogenic processes were the main sources of heavy metals in marine environments. Chen et al. (2014b) highlighted that grain size influences both elements that are mostly derived from natural sources and elements impacted by anthropogenic activities, and they proposed to name some elements that are commonly used by human activities as "anthropophile" elements.

Heavy metals play a vital part role in the health of plants, animals and human beings, and they directly or indirectly influence the health of plants, animals and humans. Contamination by heavy metals is an essential indicator of environmental health (Chen et al., 2014a). It may not only affect the production and quality of crops, but it may also influence the quality of the atmosphere and water bodies, and it may threaten the health of animals and human beings by the way of the food chain (Cheng, 2003). The accumulation of heavy metals in vegetables may create a potential public health risk (Gebrekidan et al., 2013; Nagajyoti et al., 2010; Pinto et al., 2015), because they are toxic to humans and plant tissues (Khan et al., 2015).

Moreover, the influence of heavy metals in *Pseudostellaria heterophylla* cannot be ignored in our daily life. *P. heterophylla* is vital to human beings, because it has many benefits and applications.

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Taizishen (*P. heterophylla*), which belongs to *Caryophyllaceae*, is also known as Haiershen (*Pseudostellaria ginseng*), Tongshen and so forth, and its scientific name is *Pseudostellaria heterophylla* (*Miq.*) *Pax ex Pax et Hoffm.* (Xiao, 2002; Chinese Pharmacopoeia Commission, 2010). Dried *P. heterophylla* root is one of the most commonly-used materials in traditional Chinese medicine. It has efficacy for replenishing qi to invigorate the spleen and for promoting fluid production to nourish the lungs, and it is mainly used to treat symptoms such as spleen deficiency and fatigue, inappetence, weakness after illness, qi and yin deficiency, sweating, thirst, and coughing due to dryness of the lungs (Chinese Pharmacopoeia Commission, 2010). In our daily life, *P. heterophylla* has several main applications (Wu and Lin, 2004; Yan, 2008), including medicinal value, edible value, nutritional and healthy value, and application in cosmetics.

Therefore, it is necessary to carry out research on the heavy metals in *P. heterophylla.* With the improvement of living standards of people and the development of society, people pay increasing amounts of attention to their health, and they are increasingly concerned for the safety of

Fig. 1. Location of research area.

Table 1
Contents of heavy metals in the planting soil of the research area ($mg \cdot kg^{-1}$, except for Al: %).

	TR1	TR2	TR3	TR4	TR5	TR6	TR7	TR8	TR9	Minimum	Maximum	Average	CCA	SQV
As	76.6	84.2	33.3	61.2	36.9	50.0	29.9	45.0	40.4	29.9	84.2	50.83	1.8	40
Cd	0.40	0.39	0.21	0.20	0.33	1.04	0.21	0.23	0.22	0.20	1.04	0.36	0.2	0.30
Cu	57.8	58.0	28.0	50.9	38.9	46.9	37.9	54.7	26.0	26.0	58.0	44.34	55	50
Pb	99.4	131.0	40.3	90.6	120.5	124.5	94.9	83.1	62.0	40.3	131.0	94.03	12.5	250
Hg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.08	0.30
Al	10.35	9.29	7.12	9.66	8.82	9.20	8.78	9.40	6.28	6.28	10.35	8.77	8.23	NF

ND means that the value was not measured. NF means that the value was not found. SQV refers to the soil quality value of grade two (Chinese Environmental Protection Agency and Chinese Technical Supervision Agency, 1995). CCA is the average abundance of chemical elements in the continental crust (Taylor, 1964).

their food and drugs. At the same time, although China has played a vital part role in the WTO, the contamination of heavy metals in Chinese medicinal materials may hinder it from being used globally. Chinese Pharmacopoeia Commission (2013) issued a draft standard of the heavy metals and other limited indexes in Chinese medicinal materials to further enhance their quality and safety. Traditional Chinese medicine (TCM) plays an important role in the health care systems in many parts of the world (Ueng et al., 1997). We should pay attention to the heavy metals in the medicines and their influence. Heavy metal poisoning had been repeatedly associated with TCM in some reports or cases (Ernst and Coon, 2001). Through evidence from various countries, Ernst (2002) implied that toxic heavy metals and undeclared prescription drugs in Asian herbal medicines might constitute a serious health problem. Therefore, it is important and necessary to implement assessment indexes for the contents of the heavy metals, including arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg) and lead (Pb). Our research group conducted analyses of the trace element characteristics (Peng et al., 2014b, 2015a) and *Heterophyllin* B (HB) content (Peng et al., 2015b) of *P. heterophylla* and heavy metals of *Houttuynia cordata* (Peng et al., 2014a) in Baiyi Country of Wudang District, Guiyang, Guizhou Province. Some other researchers have investigated the heavy metals of *P. heterophylla* in the other planting bases of Guizhou Province, such as Xifeng (Wu et al., 2008) and Shibing (Wang et al., 2013) counties. However, the sites were only evaluated in terms of the content of heavy metals in *P. heterophylla*, and the correlations between heavy metal contents in planting soil and *P. heterophylla* were not systemically analyzed. Thus, the sources of heavy metals remain uninvestigated. In the current study, these are systemically analyzed in the research area, thus, providing the basic trace element data and guidance for using *P. heterophylla* safely.

2. Materials and method

2.1. Research area

Wudang District is one of the important bases for planting Chinese medicinal materials in Guiyang City, Guizhou Province, in the southwest of China (Fig. 1). Additionally, Huanglian (*Coptis chinensis*), Tianma (*Gastrodia elata*), Tianmendong (*Asparagus cochinchinensis*), Baishu (Largehead Atractylodes Rhizome), *P. heterophylla*, Xiyangshen (*Panax quinque folium*) and other Chinese medicinal materials are planted in Xinchang Country, Baiyi Country, as well as in Yangchang Town, where a research area is located (Peng et al., 2013). This area has a type of subtropical monsoon climate with characteristics of a plateau climate, such as a lack of severe cold in winter, a lack of extreme heat in summer, rain in the warm season, and clearly perpendicular gradients in climate characteristics. The area has an annual average rainfall ranging from 1 179.8 to 1 271 mm, an annual average relative humidity of 78%, an annual average temperature of 14.6 °C, an annual extreme maximum temperature of 35.1 °C and a minimum temperature of −7.3 °C. The area mainly consists of mountainous territory, with higher elevations in the north and lower elevations in the south. The slopes are gentle in the west and steeper in the east, and its elevation ranges from 872 to 1659 m. Thus, the area meets the growth requirements for many Chinese medicinal materials. There are many landform types in the area, such as mountains and hills, valleys, intermontane basin and low-lying land. They formed with a variety of elevation, slope, aspect, and terrain creating different regional microclimates that can create a good environment for the growth of different medicinal plant species, and they especially provide the possibility for the growth of genuine medicinal materials (Peng et al., 2013).

2.2. Plant and soil sample collection

A total of 18 samples of *P. heterophylla* and planting soil were collected. They were collected from nine bases of planting of Chinese medicinal materials in Baiyi Country in late July of 2013. The soil samples were collected at 0–20 cm soil depth at each point, and the plant samples were collected from the roots of *P. heterophylla.*

2.3. Analysis of *P. heterophylla*

The fresh *P. heterophylla* roots were washed with high-pressure tap water until all soil and other foreign substance was removed. Pretreated roots were rinsed with the water after being cleaned for 10 min by an ultrasonic cleaner in clean water at a 39% power ratio and a frequency of 25 kHz. Then, the samples were exposed to the sun for two days (Xiao, 2002) and dried at 30 °C until constant weight in a thermostatic air-blower-driven drying closet. The samples were then ground in a glass mortar and sieved in a stainless steel sieve (≤74 um). We sent 5 g each of sieved samples to an accredited laboratory (ALS Minerals–ALS Chemex (Guangzhou) Co. Ltd.) for determination of the heavy metal contents by inductively coupled plasma atomic emission spectrometry (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS).

Table 2
Contents of heavy metals in *P. heterophylla* in the research area ($mg \cdot kg^{-1}$).

	TZS1	TZS2	TZS3	TZS4	TZS5	TZS6	TZS7	TZS8	TZS9	Minimum	Maximum	Average	LSV
As	0.21	1.02	0.24	0.25	12.70	0.87	0.19	0.64	0.89	0.19	12.70	1.89	5
Cd	0.499	0.459	0.330	0.179	1.535	0.555	1.000	0.487	0.694	0.179	1.535	0.64	1
Cu	3.89	3.92	3.80	3.34	4.60	3.52	3.88	9.24	3.25	3.25	9.24	4.38	20
Pb	0.77	1.65	0.43	1.44	3.82	1.12	1.88	1.34	0.93	0.43	3.82	1.49	10
Hg	0.009	0.026	0.123	0.018	0.029	0.006	0.019	0.021	0.013	0.006	0.123	0.03	1

LSV means that the limited standard value after (Chinese Pharmacopoeia Commission, 2013).

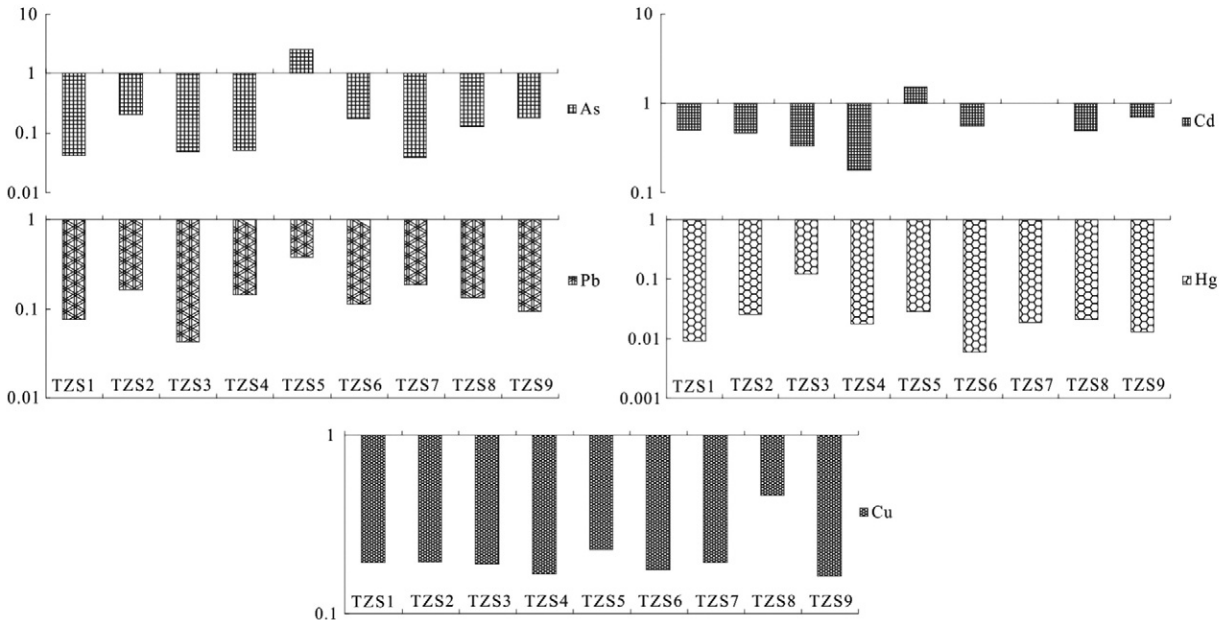

Fig. 2. Ratios of the contents of heavy metals in *P. heterophylla* to the limited standard values of the heavy metals.

2.4. Soil analysis

Soil samples (approximately 1 kg each) were halved by applying the quartering method after removing foreign substances. One half of each sample was dried at 30 °C until constant weight in the thermostatic air-blower-driven drying closet. In addition, we sent the 100 g each of the dry samples to the accredited laboratory (ALS Minerals–ALS Chemex (Guangzhou) Co. Ltd.) for ICP-AES and ICP-MS to determine the heavy metal contents.

2.5. Bioconcentration factors

Bioconcentration factor (*BF*), which expresses the ratio of the concentrations of chemical elements between the plant and its growing soil, is measured by the abundance and effectiveness of the chemical elements in the plant. For measuring the effectiveness of a plant in concentrating As into its biomass, *BF* is defined as the ratio of the concentration of As in the plant to that in the soil (Fayiga et al., 2004).

2.6. Enrichment factors

The enrichment factor (*EF*) expresses the relative abundance of an element, and it is a good tool for differentiating the source of a chemical element, whether it is anthropogenic or naturally occurring. Rahn (1971) as a useful way to determine whether a particular element was found in greater abundance than what which might be expected from crustal sources introduced the concept of “enrichment factors”. *EF* is used to distinguish between anthropogenic and naturally occurring sources, with trace metal concentrations in airborne particulate (Bilos et al., 2001) and heavy metals in sediments and soil (Chen et al., 2007; Oliva and Espinosa, 2007). The reference element mainly originated from soil parent material and suffered little contamination by anthropogenic activities (Wu et al., 2015). Elements that are commonly considered as references for crustal material include Al, Sc, Zr and sometimes Fe (Bilos et al., 2001; Chester and Stoner, 1973; Oliva and Espinosa, 2007; Schiff and Weisberg, 1999; Rahn, 1971), V (Wu et al., 2015) or Ti (Pacyna and Winchester, 1990) or Sc (Hernandez et al., 2003; Lee et al., 1994; Liu et al., 2003; Shotyk et al., 2000). Many researchers used Al as the reference element to calculate the enrichment factors in sediment, atmosphere and soil (Chen et al., 2007, 2009, 2014b; Duce et al., 1975; Khorasanipour and Aftabi, 2011; Viers et al., 2009; Zhang et al., 1994; Zoller et al., 1974). This is because the Al element is mainly derived from natural sources, and it can cancel any dilution effect caused by natural composites such as carbonate, quartz, or organic matter (Chen et al., 2009, 2014b). In this study, Al is considered as the crustal material reference element. According to Rahn (1971) and Lee et al. (1994), the *EF* is defined as:

$$EF = \frac{\left(\frac{Me}{Al}\right)_{soil}}{\left(\frac{Me}{Al}\right)_{crust}}$$

where $(Me/Al)_{soil}$ and $(Me/Al)_{crust}$ refer to the soil and mean crusty concentration (Taylor, 1964) ratios, respectively, of the metal and Al. According to Sutherland (2000) and Chen et al. (2007), $EF < 1$, $1 \le EF < 3$, $3 \le EF < 5$, $5 \le EF < 10$, $10 \le EF < 25$, $25 \le EF < 50$ and $EF \ge 50$ correspond to no enrichment, minor enrichment, moderate enrichment, moderately severe enrichment, severe enrichment, very severe enrichment, and extremely severe enrichment, respectively.

3. Results and discussion

3.1. Heavy metal contents of planting soil

The planting soil contains a moderately-high content of As and Cd at some planting bases for Chinese medicinal materials. The heavy metal contents of the planting soil were in the order Pb > As > Cu > Cd, and the content of Hg was not measured (Table 1). The ranges of the contents of As, Cd, Cu and Pb are 29.9–84.2, 0.20–1.04, 26.0–58.0 and 40.3–131.0 mg·kg^{-1}, respectively. Moreover, their averages are approximately 50.83, 0.36, 44.34 and 94.03 mg·kg^{-1}, respectively.

Table 3
Contents of heavy metals in *P. heterophylla* at some planting bases (mg·kg^{-1}).

	As	Cd	Cu	Pb	Hg	Data source
Baiyi Country	1.89	0.64	4.38	1.49	0.029	Average
Xifeng County	0.16	0.06	4.4	0.38	0.02	(Wu et al., 2008)
Shibing County	NF	0.08	7.48	1	NF	(Zhang et al., 2003)
Fujian Province	NF	0.07	5.58	2.1	NF	(Zhang et al., 2003)
Jiangsu Province	0.103	0.002	5.85	1.36	0.027	(Ceng et al., 2008)

NF indicates that the value is not found.

Table 4
Bioconcentration factors of heavy metals in *P. heterophylla*.

	TZS1	TZS2	TZS3	TZS4	TZS5	TZS6	TZS7	TZS8	TZS9	Minimum	Maximum	Average
As	0.0027	0.0121	0.0072	0.0041	0.3442	0.0174	0.0064	0.0142	0.0220	0.0027	0.3442	0.0478
Cd	1.2475	1.1769	1.5714	0.8950	4.6515	0.5337	4.7619	2.1174	3.1545	0.5337	4.7619	2.2344
Cu	0.0673	0.0676	0.1357	0.0656	0.1183	0.0751	0.1024	0.1689	0.1250	0.0656	0.1689	0.1029
Pb	0.0077	0.0126	0.0107	0.0159	0.0317	0.0090	0.0198	0.0161	0.0150	0.0077	0.0317	0.0154

Compared with the soil quality value (SQV) of grade two (Chinese Environmental Protection Agency and Chinese Technical Supervision Agency, 1995), the Cu and Pb element contents are not higher than the SQV, except for Cu in a few planting soil samples, and As and Cd are slightly higher than the SQV. This shows that the planting soil contains a moderately-high content of As and Cd at some planting bases. Therefore, enriching in heavy metals in Chinese medicinal materials should be prevented after planting in the research area.

3.2. Heavy metal content of P. heterophylla

The contents of all of the investigated heavy metals in *P. heterophylla* are under the safety requirements. The relative abundances of heavy metals of *P. heterophylla* followed the order Cu > As > Cd > Hg > Pb (Table 2). The ranges of the contents of As, Cd, Cu, Pb and Hg are 0.19–12.70, 0.179–1.535, 3.25–9.24, 0.43–3.82 and 0.006–0.123 mg·kg^{-1}, respectively. Moreover, their averages are approximately 1.89, 0.64, 4.38, 1.49 and 0.03 mg·kg^{-1}, respectively. Compared with the limited standard value (LSV) of Chinese medicinal materials (Chinese Pharmacopoeia Commission, 2013), there are no contents higher than the LSVs, except for As in the TZS5 sample and Cd in two samples (TZS5 and TZS7). The contents of Cu, Pb and Hg are relatively low (Fig. 2).

High amounts of heavy metals accumulated in *P. heterophylla* may be detrimental to human health. In contrast with the heavy metal contents at some other planting bases, such as Xifeng (Wu et al., 2008) and Shibing (Zhang et al., 2003) counties in Guizhou Province, Fujian Province (Zhang et al., 2003) and Jiangsu Province (Ceng et al., 2008) (Table 3), the contents of As, Cd, Pb and Hg are higher than their contents at other planting bases in China, and the contents of Cu are lower. Additionally, the LSV of Cd in food color specified by the Food and Drug Administration (FDA) in America (Sarkar, 2002) is lower than 15 mg·kg^{-1}. The correlation coefficient between the content of Cd in planting soil and HB in *P. heterophylla* (Peng et al., 2015b) is positively significant at 0.05 level. Regardless, a mineral or a chemical element could be detrimental or helpful to health, depending on the dosage, speciation and route of exposure, such as excess exposure to potentially toxic elements (e.g., As and Hg) (Rapant et al., 2014). Therefore, although they are in compliance with the LSVs and the correlation coefficient between the Cd content in planting soil and HB content is positive and significant at the 0.05 level, attention should be paid to the effects of their high accumulations in *P. heterophylla* on human health.

3.3. Abundance effectiveness

Cd is slightly enriched in *P. heterophylla* and other heavy metals are not. The *BFs* of heavy metals are not higher than 0.5 except for Cd, and those of Pb and As are especially low (Table 4). The ranges of the *BFs* of As, Cd, Cu and Pb are 0.0027–0.3442, 0.5337–4.7619, 0.0656–0.1689 and 0.0077–0.0317, respectively, and their averages are approximately 0.0478, 2.2344, 0.1029 and 0.0154. Moreover, values for Pb are very low, and those of all elements investigated are below 0.05. The As is almost below 0.05, although the As has a value slightly higher than the SQV in some planting soils, and Cd has values much higher than others. Therefore, this shows that the heavy metals are not enriched in *P. heterophylla*, except for Cd, which is slightly enriched in *P. heterophylla*.

3.4. Correlation coefficient

There is no significant correlation of the heavy metal contents between *P. heterophylla* and planting soil. To understand the relationship of heavy metal contents between *P. heterophylla* and planting soil, we calculated their Pearson correlation coefficients (Table 5). They show that there is a significant positive correlation between Cu and As in the planting soil, there are more significant positive correlations among As, Cd and Pb in *P. heterophylla*, and there are no significant correlations among the other elements. This may result from synergistic effects in the absorption and metabolism among As, Cd and Pb in *P. heterophylla*.

3.5. Sources of heavy metals in planting soil

The *EF* of the heavy metals can help further trace their sources in the soil. Hu et al. (2013) identified the heavy metal sources in the surface soil in the Pearl River Delta through calculating their enrichment levels. The *EF* ranges of As, Cd, Cu and Pb are 15.57–41.44, 0.85–4.65, 0.59–0.93and 3.73–9.28, respectively, and their averages are approximately 26.28, 1.67, 0.75 and 6.98 (Table 6). This shows that the enrichment of As, Cd, Cu and Pb are very severe, minor, not enriched and moderately severe, respectively, in planting soils in the research area.

In general, the trace elements of soil are deprived from the nature of weathering of the parent material, and the parent material is mainly from weathered bedrock. There were various differences in the trace element contents in soil from five rock-type regions in Guizhou Province,

Table 5
Correlation coefficients of heavy metal contents between *P. heterophylla* and planting soil.

	Soil(As)	Soil(Cd)	Soil(Cu)	Soil(Pb)	Plant(As)	Plant(Cd)	Plant(Cu)	Plant(Hg)	Plant(Pb)
Soil(As)	1.000								
Soil(Cd)	0.199	1.000							
Soil(Cu)	0.793*	0.246	1.000						
Soil(Pb)	0.494	0.560	0.630	1.000					
Plant(As)	−0.250	−0.005	−0.159	0.364	1.000				
Plant(Cd)	−0.456	−0.020	−0.309	0.332	0.827**	1.000			
Plant(Cu)	−0.129	−0.193	0.332	−0.051	0.050	0.016	1.000		
Plant(Hg)	−0.350	−0.313	−0.484	−0.625	−0.029	−0.188	−0.052	1.000	
Plant(Pb)	−0.190	−0.066	0.022	0.554	0.893**	0.836**	0.101	−0.249	1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 6
Enrichment factors of heavy metals in planting soil.

	TR1	TR2	TR3	TR4	TR5	TR6	TR7	TR8	TR9	Minimum	Maximum	Average
As	33.84	41.44	21.38	28.97	19.13	24.85	15.57	21.89	29.41	15.57	41.44	26.28
Cd	1.59	1.73	1.21	0.85	1.54	4.65	0.98	1.01	1.44	0.85	4.65	1.67
Cu	0.84	0.93	0.59	0.79	0.66	0.76	0.65	0.87	0.62	0.59	0.93	0.75
Pb	6.32	9.28	3.73	6.18	9.00	8.91	7.12	5.82	6.50	3.73	9.28	6.98

and they are controlled by the different types of soil and rock that are weathering (Yang et al., 2011). Additionally, the contents of the elements were mainly affected by parent rock types (Yang et al., 2010). However, the contamination of heavy metals in soil may also be easily affected by anthropogenic activities (including the application of commercial fertilizers, sewage sludge and pesticides, mining activities, and production activities), especially in the topsoil. The elemental anomalies are mainly affected by the specific natural geographical backgrounds or the effects of human activity (Yu et al., 2014).

Additionally, for some elements, $EF > 2$ in the current study would be considered an indication of enrichment corresponding mainly to anthropogenic inputs (Oliva and Espinosa, 2007). An *EF* of less than or close to 1, which is found in over half of the surface soils, indicates that these metals originated predominantly from natural activities (Hu et al., 2013). An *EF* of greater than or close to 3 suggests that the soils had been polluted by anthropogenic activities (Hu et al., 2013). An *EF* of greater than 5 and less than 10 suggests that the soils had been moderately to severely polluted by anthropogenic activities. An *EF* of greater than 10 and less than 25 suggests that the soils had been severely polluted by anthropogenic activities. An *EF* of greater than 25 and less than 50 suggests that the soils had been very severely polluted by anthropogenic activities. An *EF* of greater than 50 suggests that the soils had been extremely severely polluted by anthropogenic activities.

Therefore, the soil is clearly enriched in As and Pb compared with the average abundance of chemical elements in the continental crust. Thus, they are mainly derived from anthropogenic activities, especially As, with which the soil is very severely polluted by anthropogenic sources. Moreover, Cd and Cu are mainly from naturally occurring sources, and Cd may be impacted by anthropogenic activities.

4. Conclusions

After our investigation of heavy metals in *P. heterophylla* and planting soil in the research area, we drew the following conclusions. Five heavy metals have average contents in *P. heterophylla* that are not higher than their LSVs. Although the planting soil contains moderately-high contents of As and Cd at some bases for planting Chinese medicinal materials, they generally conform to quality requirements. The *BFs* of heavy metals are not higher than 0.5, except for Cd, and those of Pb and As are especially low. Cd is moderately enriched in *P. heterophylla* because its *BF* average is approximately 2.23. There is a significant positive correlation between the contents of Cu and As in the planting soil, and there are also more significant positive correlations among As, Cd and Pb in *P. heterophylla*; none of the other elements have significant correlations. This may result from synergistic effects in the absorption and metabolism among As, Cd and Pb in *P. heterophylla*. The levels of enrichment of As, Cd, Cu and Pb in the planting soil are very severe, minor, not enriched and moderate, respectively. Moreover, the planting soil is clearly enriched in As and Pb compared with the average abundance of chemical elements in the continental crust, especially As, which is very severely polluted by anthropogenic sources. In addition, Cd and Cu are mainly from naturally-occurring sources, and Cd may be impacted by anthropogenic activities.

However, it is not very clear how the heavy metals were accumulated or absorbed in the plant and how the accumulation of heavy metals in the plant can be impeded or alleviated. Although the average contents of heavy metals are generally conformed to quality requirements, attention should be paid to prevent As, Cd and Pb from accumulating to a high degree in *P. heterophylla* to avoid detriment to animals and human beings via the food chain. Because Cd is slightly enriched in *P. heterophylla* and As and Pb are clearly enriched in the planting soil and mainly derived from anthropogenic activities, there may be synergistic effects in the absorption and metabolism among As, Cd and Pb in *P. heterophylla*. On the other hand, liming and adding of adaptive content of fused calcium–magnesium phosphate or organic fertilizer or S may improve the soil quality and reduce the uptake of some heavy metals by the plant. Adding an adaptive content of S in soil, involving ascorbate and glutathione, may ameliorate Cd toxicity and protect growth and photosynthesis of mustard (Anjum et al., 2008). The plant may improve its antioxidant defense against heavy metals through increasing the enzymes of the ascorbate–glutathione (Paradiso et al., 2008). Adding an adaptive content of fused calcium–magnesium phosphate or organic fertilizer to soil could also do accomplish this goal (Chen et al., 1996). Liming is a practice that reduces uptake of heavy metals by crop plants (Chen et al., 1996; Pendias, 2010). However, as the soil pH is altered towards basic by liming, other heavy metals (such as Mo) may be mobilized (Siegel, 2002). Therefore, an adaptive content of organic fertilizer or fused calcium–magnesium phosphate or S may be approximately added to the planting soil to improve its quality, possibly reducing the accumulation of heavy metals in *P. heterophylla*. Nevertheless, more researches need to be done on the transfer of heavy metals into plants and their accumulation, as well as on effective action for impeding or alleviating the accumulation of heavy metals in the plants and the damage that it causes.

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