



## Original Article

## Trace heavy metals and harmful elements in roots and rhizomes of herbs: Screening level analysis and health risk assessment

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## ABSTRACT

**Objective:** Heavy metal and harmful element contamination are frequently reported in Chinese herbal medicines (CHMs), and roots and rhizomes parts showed a higher content than other parts. To investigate the residue level and assess the potential human health risk of heavy metals and harmful elements in roots and rhizomes, 720 batches of the sample representing 20 species of herbs from different sources were collected.

**Methods:** The content of Pb, Cd, As, Hg, and Cu in the digests was determined using ICP-MS. The chronic hazard index estimate based on non-cancer hazard quotient (HQ) was applied for potential health risk assessment of Pb, Cd, As, Hg, and Cu via consumption of CHMs.

**Results:** Compared with the Chinese limit standard (Chinese Pharmacopoeia Commission, 2020 edition) of Pb, Cd, As, Hg, and Cu in *Ginseng Radix et Rhizoma*, the exceedance percentage of Pb in total samples was 14.1%, which were generally far higher than Cd, As, Hg, and Cu. Health risk assessment results based on hazard quotient calculating showed that total HQ of Cu, Pb, As, Cd, and Hg in *Pulsatillae Radix* and *Clematidis Radix et Rhizoma* exceeded 1, with the value of 1.543 and 1.235. Besides, Arsenic had the highest HQ value (0.957) in *Pulsatillae Radix*.

**Conclusion:** Consuming raw materials of *Pulsatillae Radix* and *Clematidis Radix et Rhizoma* may pose a potential risk and Arsenic residues in *Pulsatillae Radix* deserved special attention.

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## 1. Introduction

Chinese herbal medicines (CHMs) have been applied to manage some diseases in China for 5 000 years (Lin et al., 2018). With sufficient experience in the exploration of clinical research of CHMs, many landmark achievements were promoted. The latest research shows that CHMs brings new hope for the prevention and control of the newly identified strain of Coronavirus Disease 2019 (COVID-19) since there is no specific drug has been discovered (Ang, Lee, Choi, Zhang, & Soo Lee, 2020; Ren, Zhang, & Wang, 2020). For example, the National Health Commission of the People's Republic of China launched the diagnosis and treatment of COVID-19 infection, the recommended prescriptions including Jinhua Qinggan Granules, Lianhua Qingwen Capsules/Granules, Xuebijing Injection, Qingfei Paidu Decoction, Xuanfei Baidu Granules, Huashi Baidu Formula, and others (Chu, Huang, Zhang, Huang, & Wang, 2021). With the worldwide acceptance of CHM, the global demand for CHMs is increasing. The main exporters include South Korea,

Japan, Indonesia, Malaysia, and the United States etc (Lin et al., 2018). In addition to the effectiveness, the safety of CHMs is the fundamental prerequisite for the internationalization of CHMs. The issue of heavy metals and harmful elements in CHMs, which may result in health risk due to their cumulative properties and high toxicity, is one of the main safety concerns (Martín-Domingo et al., 2017).

Heavy metal is a member of elements that exhibits metallic properties and natural components of the earth's crust and the common components of diverse environmental matrices (Singh, Gautam, Mishra, & Gupta, 2011). Some heavy metals, such as iron (Fe), cobalt (Co), copper (Cu), and zinc (Zn) are required by humans. But some others, such as cadmium (Cd), lead (Pb), and mercury (Hg), are toxic and can cause serious illness (Singh, Gautam, Mishra, & Gupta, 2011). Medicinal plants are subjected to heavy metal and harmful element contamination due to both the environment (soil, water, and air) they grow and the anthropogenic sources such as mining activities, waste incineration fertilizer, and vehicle emission (Wu & Xue, 2013; Tripathy, Basak, Varghese, & Saha, 2015). It should be specially explained that due to the wide presence of heavy metals and harmful elements

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in the environment, their residues in medicinal plants have been frequently reported from different origins, such as globe artichoke in Uruguay, *Cetraria Islandica* from the European market, and herbal teas collected in the US (Machado, Dol, Rodríguez-Arce, Cesio, & Pistón, 2016; Giordani et al., 2017; de Oliveira et al., 2018). Harris et al. (2011) examined As, Cd, Pb, and Hg contamination in 334 CHMs (126 species) and found that 34% of the samples had detectable levels of all metals and at least one kind of metal was detected in all samples. Liu et al. (2013) investigated 250 samples (50 species of commercial CHMs) and found that the levels of Cu, Cd, Pb, and Hg in some samples were above the maximum limit standard in the Pharmacopoeia of the People's Republic of China (Chinese Pharmacopoeia Commission, 2010). Li, Wang, Yang, Yu, & Tang (2018) assessed Pb, Cd, Cr, Cu, and Zn in *Moutan Cortex* and found that samples from the mining tailing area accumulated much higher concentrations than other sites. Our previous research compared the heavy metal exceeding rate in herbal drugs from different medicament portions, the results showed that herbs from roots and rhizomes part showed a higher content than other parts (Wu & Xue, 2013). Therefore, it is necessary to analyze and evaluate the residual level of heavy metals and harmful elements in these medicinal materials.

Hazard quotient (HQ), which was provided by the US Environmental Protection Agency (US EPA) (U.S. EPA, 1989), was frequently performed to estimate the potential health risks of contaminations. An HQ value below 1 indicates that the level of exposure is unlikely to cause noncarcinogenic effects, and an HQ value exceeding 1 indicates that there is a risk of noncarcinogenic effects. Wang's group investigated 60 CHM samples collected from the commercial market and the results showed that the exceedance percentage of Cd was as high as 38.8% but the HQ value indicates that it did not pose a threat to human health (Wang, Wang, Wang, Li, & Li, 2019). Yang et al. (2021) investigated 279 types of Chinese herbal medicine (CHM) and found that six types of CHMs may have non-carcinogenic health risks by consumption of raw materials based on the hazard quotient calculation (the sum of all HQ were over 1.0).

In this work, 720 samples representing 20 species of roots and rhizomes were collected in the year 2018 from different origins of China, and the contamination levels of Pb, Cd, As, Hg, and Cu were observed. The observed content was summarized and compared with the Chinese limit standard (Chinese Pharmacopoeia Commission, 2020). Moreover, the potential health risks of heavy metals via consumption of the analyzed 20 CHMs were assessed with non-cancer risk assessment methods based on hazard quotient (HQ) (Fig. 1).

## 2. Materials and methods

### 2.1. Chemicals and reagents

The standard solutions (100 µg/mL) were acquired from the National Institute of Metrology (Beijing, China) and were diluted to appropriate concentrations before use. Nitric acid and hydrogen peroxide of trace metal grade were purchased from Fisher Scientific (Thermo Fisher Scientific, USA). The certified reference material of Ginseng (GBW10027 (GSB-18)) was provided by the Institute of Geophysical and Geochemical Exploration (Langfang, China).

### 2.2. Instruments

A microwave digestion system (MARS6, CEM, USA) was used for sample preparation. The concentrations of Pb, Cd, As, Hg, and Cu were identified using an Inductively-Coupled Plasma Mass Spec-

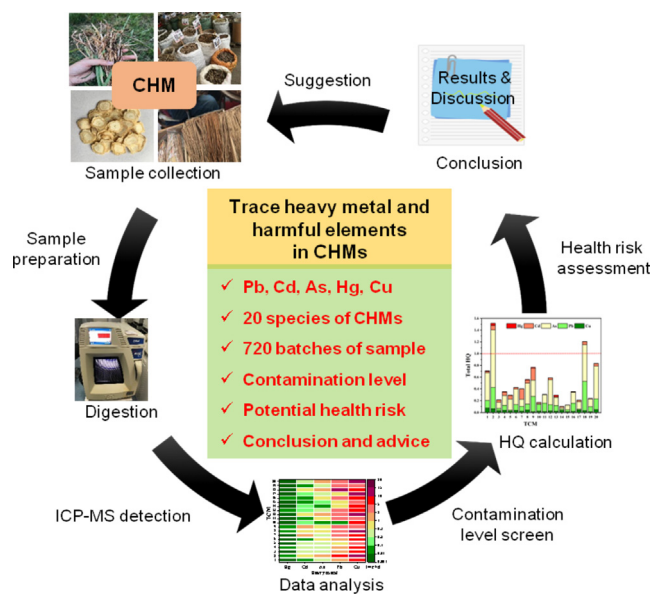


Fig. 1. Trace heavy metals and harmful elements in roots and rhizomes of herbs: Screening level analysis and health risk assessment.

trometer (ICP-MS, ICAP Qc, Thermo Fisher Scientific, Waltham, MA). Ultra-high-quality water (18.2 MΩ/cm) was produced by a Milli-Q advantage, Merck Millipore (Shanghai, China).

### 2.3. Sample collection

A total of 650 batches of the sample representing 20 species of root and rhizome herbs were collected in 2018 from e-commerce companies, commercial herbal markets, and drugstores for the examination of contamination content. Besides, 70 batches of *Dioscoreae Nipponicae Rhizoma*, *Allii Macrostemonis Bulbus*, *Sanguisorbae Radix*, *Sophorae Flavescentis Radix*, *Gentianae Radix et Rhizoma*, *Clematidis Radix et Rhizoma*, and *Asteris Radix et Rhizoma* were collected from wild and cultivated origins (10 batches/species).

The Latin name, medical part, and prescribed daily dosage in Chinese Pharmacopoeia (2020 edition, Volume I) of the 20 species of CHMs are listed in Table 1. Each sample consisted of a bulk sample of 2 kg dry weight of the medicinal part of the plant. All samples were stored at −18 °C before analysis.

### 2.4. Quality assurance

All containers were soaked overnight in 10% HNO<sub>3</sub> and then rinsed with ultra-high-quality water prior to use. The certified reference material (GBW10027 Ginseng), analyzed as samples with each batch, was used to verify the accuracy and precision of the analytical method. LODs were calculated by the equation  $LOD = 3\sigma/s$ , where  $\sigma$  is the standard deviation of 10 successive blank signals and  $s$  is the slope of the calibration curve.

### 2.5. Health risk assessment

Chronic hazard index estimates based on non-cancer hazard quotient (HQ) (U.S. EPA, 1989) and in dietary and non-dietary exposure estimates based on ingestion exposure estimates (U.S. EPA, 2019), which recommended by the US Environmental Protection Agency (US EPA) for potential human health risk assessment, is also a widely used model for medicinal plant exposure routes (Li, Wang, Yang, Yu, & Tang, 2018; Wang, Wang, Wang, Li, & Li, 2019; Nan, et al., 2020). Therefore, it is applied in this study for

**Table 1**  
Latin names, medicinal parts, and prescribed daily dosages in *Chinese Pharmacopoeia* (2020 edition) of 20 species of CHMs.

No. of CHMs	Latin names	Medicinal parts	Daily intake (g)
1	<i>Imperatae Rhizoma</i>	roots	9–30
2	<i>Pulsatillae Radix</i>	roots	9–15
3	<i>Attractylodis Rhizoma</i>	rhizomes	3–9
4	<i>Dioscoreae Nipponicae Rhizoma</i>	rhizomes	9–15
5	<i>Rhei Radix et Rhizoma</i>	roots and rhizomes	3–15
6	<i>Sanguisorbae Radix</i>	roots	9–15
7	<i>Curcumae Rhizoma</i>	roots	6–9
8	<i>Ligustici Rhizoma et Radix</i>	roots and rhizomes	3–10
9	<i>Drynariae Rhizoma</i>	rhizomes	3–9
10	<i>Ginseng Radix et Rhizoma Rubra</i>	roots and rhizomes	3–9
11	<i>Sophorae Flavescentis Radix</i>	roots	4.5–9
12	<i>Gentianae Radix et Rhizoma</i>	roots and rhizomes	3–6
13	<i>Ephedrae Radix et Rhizoma</i>	roots and rhizomes	3–9
14	<i>Ginseng Radix et Rhizoma</i>	roots and rhizomes	3–9
15	<i>Cistanches Herba</i>	stems	6–10
16	<i>Sophorae Tonkinensis Radix et Rhizoma</i>	roots and rhizomes	3–6
17	<i>Inulae Radix</i>	roots	3–9
18	<i>Clematidis Radix et Rhizoma</i>	roots and rhizomes	6–10
19	<i>Allii Macrostemonis Bulbus</i>	stems	5–10
20	<i>Asteris Radix et Rhizoma</i>	roots and rhizomes	5–10

potential health risk assessment of Pb, Cd, As, Hg, and Cu via the consumption of CHMs. The HQ of Pb, Cd, As, Hg, and Cu by ingestion of CHMs was estimated in the following equation:

$$HQ = \frac{ADD}{RfD} \quad (1)$$

$$ADD = \frac{C \times IR}{BW} \quad (2)$$

where ADD is the average daily intake dose of heavy metal and harmful element (mg/kg/d), *RfD* is the reference daily oral reference dose via ingestion ( $\mu\text{g}/\text{kg}/\text{d}$ ), *C* is the average concentrations of heavy metal and harmful element in CHM ( $\mu\text{g}/\text{g}$ ), *IR* (g/d) is the maximum recommended daily intake consumption of CHM in Chinese Pharmacopoeia (Chinese Pharmacopoeia Commission, 2020) and *BW* is the average body weight (62.7 kg for adults in China) (Wang, Wang, Wang, Li, & Li, 2019). *RfD* values for chronic oral exposure to inorganic As (0.3  $\mu\text{g}/\text{kg}/\text{d}$ ) and Cd in food (1  $\mu\text{g}/\text{kg}/\text{d}$ ) are derived from EPA Integrated Risk Information System (IRIS) (U.S. EPA, 2010). The *RfD* values for Pb (0.35  $\mu\text{g}/\text{kg}/\text{d}$ ) (Shaheen et al., 2016), Hg (0.3  $\mu\text{g}/\text{kg}/\text{d}$ ) (Wang, Wang, Wang, Li, & Li, 2019), and Cu (40  $\mu\text{g}/\text{kg}/\text{d}$ ) (Shaheen et al., 2016) are

source from literature. The overall potential noncarcinogenic risk was assessed by calculating the sum of all the HQ values of Pb, Cd, As, Hg, and Cu. The total hazard quotient (HQ) =  $HQ_{Pb} + HQ_{Cd} + HQ_{As} + HQ_{Hg} + HQ_{Cu}$ . The total HQ below 1 means there is no overall potential noncarcinogenic risk, whereas the total HQ greater than 1 indicates that the exposed population may experience health risks.

### 3. Results and discussion

#### 3.1. Method validation

The linearity, limits of detection (LOD), accuracy, and precision of the method were listed in Table 2. The LODs of Cu, Cd, Pb, Hg, and As were 0.1, 0.01, 0.2, 0.002, and 0.05 ng/mL, respectively. Good linearity was obtained with correlation coefficients (*r*) greater than 0.9950. The certified reference material of Ginseng (GBW10027) was analyzed to check the accuracy of the method and the results agreed with the certified values. Precision studies were taken by five replicates of the certified reference material and the results showed that the recoveries ranged from 83.3% to 103.0% and the RSDs ranged from 3.2% to 8.9%.

#### 3.2. Heavy metal and harmful element contents in CHM

The concentrations of Cu, Pb, As, Cd, and Hg in CHMs were shown in Fig. 1 and the min, max, mean, and median concentrations were summarized in Table 3. Based on Chinese Pharmacopoeia (Chinese Pharmacopoeia Commission, 2020), the maximum limits of Cu, Pb, As, Cd, and Hg some CHMs are 20, 5, 2, 1, and 0.2 mg/kg, respectively, such as in *Ginseng Radix et Rhizoma*. Although the maximum limits in the other kinds of CHMs have not yet been officialized by the Chinese Pharmacopoeia Edition 2020, they were stipulated in its exposure drafts. In this work, the detected content of the five elements in 20 types of root and rhizome herbs were compared with the maximum limits in *Ginseng Radix et Rhizoma*.

Fig. 2 showed that the concentrations of Hg, As, and Cu in most CHMs were lower than the maximum limit in *Ginseng Radix et Rhizoma*, but Cd and Pb in some CHMs exceeded the maximum limit. Fig. 2A showed that the concentrations of Hg found in all CHMs were almost less than 0.2 mg/kg. Fig. 2B showed that the concentrations of Cd in *Curcumae Rhizoma* (No. 7) and *Drynariae Rhizoma* (No. 9) were significantly higher than that in other CHMs, with the corresponding average concentrations of 1.2 mg/kg and 1.4 mg/kg, respectively (Table 3). Fig. 2C showed that some individual samples in *Pulsatillae Radix* (No. 2), *Gentianae Radix et Rhizoma* (No. 12), *Clematidis Radix et Rhizoma* (No. 18), and *Asteris Radix et Rhizoma* (No. 20) accumulated higher As concentrations than the maximum limit. It is interesting to note that the concentrations of Pb had a wide variation in the analyzed CHMs (Fig. 2D). On one hand, *Clematidis Radix et Rhizoma* (No.18) accumulated the highest concentration of Pb with the range of 1.5–26.5 mg/kg and the average concentration of 12.4 mg/kg (which is 2.5 times above the maxi-

**Table 2**  
Linearity, limits of detection (LOD) and precision studies of methods.

Elements	Rang (ng/mL)	LOD (ng/mL)	Certified (mg/kg)	Detected (mg/kg)	Recovery (%)	RSD (% , n = 5)
Cu	2.5–500	0.1	5.9 ± 0.4	6.0 ± 0.2	101.7	3.2
Cd	0.1–10	0.01	0.033 ± 0.005	0.034 ± 0.001	103.0	3.8
Pb	1–100	0.2	0.12 ± 0.04	0.10 ± 0.01	83.3	8.9
Hg	0.01–4	0.002	4.0 ± 0.8 <sup>a</sup>	3.8 ± 0.3 <sup>a</sup>	95.0	8.2
As	1–100	0.05	0.03 <sup>b</sup>	0.029 ± 0.001	96.7	4.2

Note: <sup>a</sup>Unit of Hg is  $\mu\text{g}/\text{kg}$ , <sup>b</sup>Certified reference value of As.

**Table 3**  
Content of Pb, Cd, As, Hg, and Cu in CHMs.

No. of CHMs	Cu (mg/kg)			As (mg/kg)			Cd (mg/kg)			Hg (µg/kg) <sup>a</sup>			Pb (mg/kg)		
	Min-Max	Mean	Median	Min-Max	Mean	Median	Min-Max	Mean	Median	Min-Max	Mean	Median	Min-Max	Mean	Median
1	2.4–13.6	6.2	4.3	0.1–1.1	0.3	0.2	0.02–0.09	0.05	0.04	ND <sup>b</sup> –78.7	6.0	1.7	0.1–4.9	1.1	0.2
2	6.7–15.2	10.5	11.0	0.2–2.7	1.2	1.0	0.04–0.6	0.3	0.3	0.5–208.7	47.2	15.3	0.5–40.3	6.0	3.8
3	5.9–13.0	8.2	7.7	0.1–0.8	0.2	0.2	0.1–0.9	0.3	0.2	ND–152.5	7.4	2.2	ND–18.2	1.1	0.3
4	0.9–8.6	6.1	6.5	0.1–0.8	0.2	0.2	0.1–0.7	0.2	0.2	ND–63.6	11.7	5.5	0.1–9.6	1.4	0.3
5	1.8–5.5	4.1	4.4	0.04–2.4	0.2	0.2	0.02–3.4	0.3	0.1	ND–120.4	7.6	ND	0.1–3.1	0.3	0.2
6	2.7–15.3	6.0	6.2	0.1–1.8	0.3	0.3	0.01–0.6	0.1	0.1	ND–23.8	4.9	0.9	0.1–20.1	1.6	0.4
7	3.4–15.8	6.5	6.2	0.1–0.5	0.3	0.2	0.1–5.2	1.2	1.0	0.7–19.3	4.5	2.5	0.4–5.9	2.2	1.7
8	5.9–16.2	11.2	10.9	0.2–2.9	0.7	0.5	0.02–1.4	0.3	0.1	0.3–324.1	21.3	4.9	0.1–19.8	2.4	1.0
9	1.5–10.3	4.1	3.4	0.1–4.9	0.6	0.4	0.02–4.0	1.4	1.6	0.6–86.6	30.2	29.7	0.2–8.0	2.2	1.9
10	4.3–8.7	6.7	7.0	0.01–0.06	0.03	0.03	0.1–0.2	0.1	0.1	0.1–6.4	3.9	4.2	0.1–0.2	0.1	0.2
11	2.6–9.8	4.8	4.4	0.1–1.1	0.3	0.2	0.01–0.2	0.04	0.03	ND–16.4	1.6	0.4	0.1–13.1	2.6	2.1
12	2.1–23.8	11.2	8.3	0.1–9.9	1.3	0.5	0.1–0.8	0.3	0.3	0.5–178.8	9.5	3.7	0.1–15.6	4.4	1.4
13	4.3–17.4	6.1	5.5	0.1–0.9	0.3	0.2	0.1–0.3	0.1	0.1	0.3–406.3	50.6	6.9	0.1–19.5	2.6	0.5
14	4.5–15.9	9.7	9.4	0.01–0.1	0.05	0.05	0.03–0.4	0.1	0.1	ND–36.7	5.2	3.9	ND–12.0	0.6	0.1
15	0.8–9.1	3.9	3.3	0.04–0.5	0.1	0.1	0.003–0.05	0.02	0.01	ND–10.5	2.1	1.5	0.03–10.6	0.8	0.1
16	3.6–18.7	8.2	7.5	0.2–1.8	0.6	0.5	0.03–0.3	0.1	0.1	ND–218.1	16.9	5.1	0.4–36.9	3.8	0.9
17	6.8–17.0	11.9	11.9	0.1–0.8	0.3	0.2	0.1–0.3	0.2	0.1	ND–30.6	6.2	1.6	0.1–1.2	0.4	0.3
18	4.8–12.4	7.8	7.6	0.4–2.6	1.2	0.9	0.1–0.6	0.3	0.3	0.7–38.6	7.9	4.8	1.5–26.5	12.4	13.4
19	2.5–6.7	3.7	3.6	0.05–0.5	0.2	0.2	0.02–0.2	0.1	0.0	ND–9.8	1.4	0.3	ND–26.1	2.1	0.3
20	4.8–19.8	12.8	13.4	0.2–3.9	1.0	0.8	0.1–0.8	0.3	0.2	ND–64.9	5.2	2.5	0.6–24.3	4.5	2.4

Note: <sup>a</sup>Because the concentrations of Hg are generally low, the unit of Hg is µg/kg for better presenting the result. <sup>b</sup>ND: Not detected.

imum limit). On the other hand, most samples of *Rhei Radix et Rhizoma* (No. 5), *Ginseng Radix et Rhizome Rubra* (No. 10), *Ginseng Radix et Rhizoma* (No. 14), *Cistanches Herba* (No. 15), *Inulae Radix* (No. 17) were less than 1 mg/kg. Fig. 2E showed that the concentrations of Cu were all less than 20 mg/kg except for a few of *Gentianae Radix et Rhizoma* (No. 12) samples.

The average contamination levels of Cu, Pb, As, Cd, and Hg were shown in Fig. 2F. The results showed that the overall average concentrations of Cu were the highest, the second was Pb, followed by As and Cd, and the least was Hg. The average concentrations of Hg were in the range of 0.001 to 0.1 mg/kg, which were all far lower than the maximum limit (0.2 mg/kg). Both the average concentrations of Cd and As were the range of 0.01–2 mg/kg, but the concentrations in *Curcumae Rhizoma* (No. 7, 1.2 mg/kg) and *Drynariae Rhizoma* (No. 9, 1.4 mg/kg) were above the maximum limit for Cd (1 mg/kg). Most of the analyzed CHMs were contaminated with Pb concentration in the range of 0.3–5 mg/kg, except *Pulsatillae Radix* (No. 2, 6.0 mg/kg) and *Clematidis Radix et Rhizoma* (No. 18, 12.4 mg/kg). Although Cu has the highest contamination level range of 2–20 mg/kg, they are all lower than the maximum limit (20 mg/kg). To summarize, the average contaminations of Hg, As, and Cu in all analyzed CHMs were lower than the Chinese limit standard but Cd and Pb in some CHMs exceeded the Chinese limit standard.

### 3.3. Exceedance number/percentage of heavy metals and harmful elements in CHMs

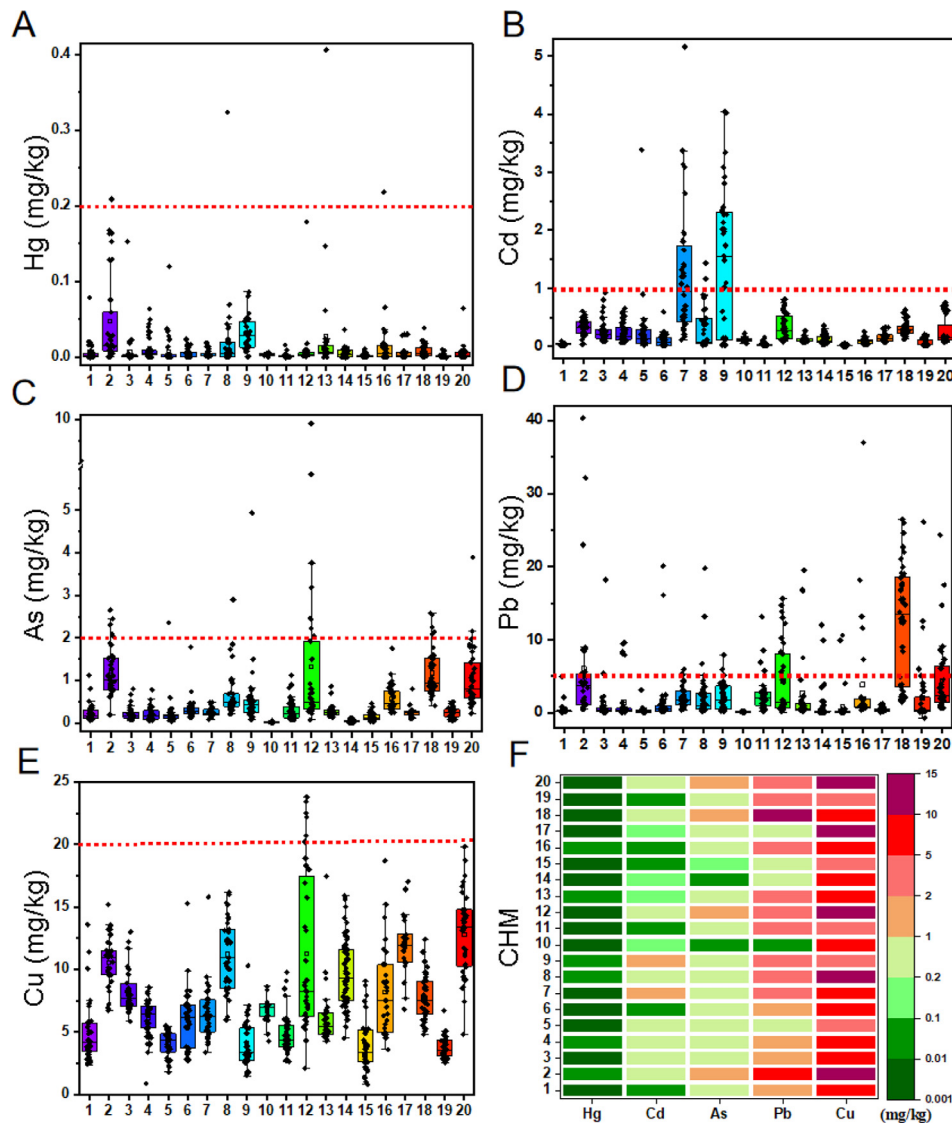
The concentrations of Cu, As, Cd, Hg, and Pb in 720 batches of the sample representing 20 species of CHMs were compared with the Chinese limit standard. Exceedance numbers and percentages of Cu, As, Cd, Hg, and Pb in the analyzed CHMs were summarized in Table 4. In aggregate, the exceedance percentage of Pb exceeded

10%, with the value of 14.1% (102 batches). While the exceedance percentages of Cd, As, Cu, and Hg were only 6.0%, 3.2%, 0.8%, and 0.6%. The results indicated that contamination levels of Pb in the analyzed CHMs were generally higher than Cd, As, Cu, and Hg.

It is worth reminding that the six exceedance samples of Cu were all from *Gentianae Radix et Rhizoma* (No. 12), which reconcile the results of Fig. 2E, indicating it may accumulate higher content of Cu relative to other CHMs. In addition to Cu, *Gentianae Radix et Rhizoma* (No. 12) also had a higher exceedance percentage (22.2%) of As than the other CHMs. It was remarkable that half of the samples contaminated with Cd in *Curcumae Rhizoma* (No. 7) and *Drynariae Rhizoma* (No. 9) exceeded the Chinese limit standard, with the value of 50.0% and 61.1%, respectively. On the contrary, very rare samples were observed with Hg concentrations exceeded the Chinese limit standard, thus only four batches in 720 batches. As mentioned above and shown in Fig. 2, the concentrations of Pb vary from sample to sample. Therefore, the exceedance percentage of Pb was also widespread over the CHMs species with the value from 0% to 67.5%. Considering there were nine species of CHMs exceeded 10%, contamination of Pb in CHMs should be paid with more attention.

### 3.4. Health risk assessment

CHMs are consumed by patients widely in China owing to their low risk, mild features, and relatively low cost. However, exposure to heavy metal and harmful element contamination in CHMs has potential health risks to human health. Non-cancer risk assessment based hazard quotient (HQ), which was set by the US Environmental Protection Agency (U.S. EPA, 1992; U.S. EPA, 2019), have also been used for medical plant exposure routes (Li, Wang, Yang, Yu, & Tang, 2018; Wang, Wang, Wang, Li, & Li, 2019; Nan et al., 2020), therefore it is also applied in this study. The total HQ was



**Fig. 2.** Concentrations of average concentrations of five elements in 20 species of CHM. Red dashed lines are the Chinese maximum limit (Chinese Pharmacopoeia, 2020 edition) of Pb, Cd, As, Hg, and Cu in *Ginseng Radix et Rhizoma*.

the mathematical sum of Cu, As, Cd, Hg, and Pb. HQ values and the total HQs of Cu, As, Cd, Hg, and Pb via consuming of the analyzed CHMs were calculated and listed in Table 5.

Fig. 3A showed that the main components of total HQ were As and Pb. On the whole, the order of the HQ levels of heavy metals in the analyzed CHMs was found to be As > Pb > Cd > Cu > Hg (Fig. 3A). Table 5 showed that Hg and Cu had lower HQ levels with the range of 0.001–0.037 and 0.015–0.074, respectively, indicating their contamination in the CHMs poses a negligible threat to human health. Hg had lower HQs due to their low contamination levels in CHMs. It was worth noting that although the concentrations of Cu were the highest (Fig. 2F), they pose less risk to human health because Cu is one of the elements required by humans and have a relatively larger RfD value (Singh, Gautam, Mishra, Gupta, 2011). And besides, the HQs of Cd were in the range of 0.003–0.201, which indicated it also poses little threat to human health. Pb ranked fourth with the HQ range of 0.004–0.565. Considering it has overall higher concentrations and exceedance percentage (14.1%), the concern should be paid for contamination of Pb in CHMs. Last but not least, As has the highest HQ level with the value

from 0.014 to 0.957. Considering the adverse health effects through high As intake, special attention should be paid to As contamination in CHMs. Fig. 3B showed that almost all of the total HQs were less than 1 except *Pulsatillae Radix* (No. 2) and *Clematidis Radix et Rhizoma* (No. 18), with the value of 1.543 and 1.235, respectively. The result suggests that consuming raw materials of the two CHMs may cause potential non-carcinogenic concerns.

One point should be noted that these results do not consider the dissolution rates of heavy metal in the decoctions. Considering the transfer rates of Pb, Cd, As, Hg, and Cu in the reference were all less than 35% (Wang, Wang, Wang, Li, & Li, 2019; Zuo et al., 2020), the total HQ of *Pulsatillae Radix* (No. 2) and *Clematidis Radix et Rhizoma* (No.18) may be less than 0.5. Therefore, considering the transfer rates of heavy metal in the decoctions, the risk may be much lower.

### 3.5. Comparison with previous study

The literatures published in recent decades about heavy metal determination and health risk assessment in Chinese medical plants were summarized in Table 6. It showed that although there

**Table 4**  
Exceedance number/percentage of Cu, As, Cd, Hg, and Pb in CHMs compared with maximum limit in *Ginseng Radix et Rhizoma* (Chinese Pharmacopoeia, 2020 edition).

No. of CHMs	Batches	Cu	As	Cd	Hg	Pb
1	36	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
2	33	0 (0)	5 (15.1%)	0 (0)	1 (3.0%)	11 (33.3%)
3	38	0 (0)	0 (0)	0 (0)	0 (0)	2 (5.3%)
4	40	0 (0)	0 (0)	0 (0)	0 (0)	5 (12.5%)
5	37	0 (0)	1 (2.7%)	1 (2.7%)	0 (0)	0 (0)
6	36	0 (0)	0 (0)	0 (0)	0 (0)	2 (5.6%)
7	36	0 (0)	0 (0)	18 (50.0%)	0 (0)	3 (8.3%)
8	35	0 (0)	1 (2.9%)	2 (5.7%)	1 (2.9%)	4 (11.4%)
9	36	0 (0)	1 (2.8%)	22 (61.1%)	0 (0)	3 (8.3%)
10	17	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
11	41	0 (0)	0 (0)	0 (0)	0 (0)	4 (9.8%)
12	36	6 (16.7%)	8 (22.2%)	0 (0)	0 (0)	13 (36.1%)
13	31	0 (0)	0 (0)	0 (0)	1 (3.0%)	4 (12.9%)
14	63	0 (0)	0 (0)	0 (0)	0 (0)	2 (3.2%)
15	35	0 (0)	0 (0)	0 (0)	0 (0)	2 (5.7%)
16	30	0 (0)	0 (0)	0 (0)	1 (3.3%)	5 (16.7%)
17	22	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
18	40	0 (0)	5 (12.5%)	0 (0)	0 (0)	27 (67.5%)
19	42	0 (0)	0 (0)	0 (0)	0 (0)	5 (11.9%)
20	36	0 (0)	2 (5.6%)	0 (0)	0 (0)	10 (27.8%)
Total	720	6 (0.8%)	23 (3.2%)	43 (6.0%)	4 (0.6%)	102 (14.1%)

has been some research focused on the heavy metal contamination in CHMs, there are still some limitations. Firstly, heavy metal contamination in CHMs did not get much international attention like in food and the environment since there was only a few literatures have been published (Li, Song et al., 2018; Zheng, Wang, Yuan, & Sun, 2020; Rai, Lee, Zhang, Tsang, & Kim, 2019). Secondly, few of the literature took large scale investigation, which would not be enough to reflect the real contamination level of CHMs since heavy metal accumulation source is complex and varies with environment and CHM species. For example, although Harris et al (Harris et al., 2011) covered 126 species of CHM, the average batch of each species was less than 3. The latest research imported 10 245 samples of CHM from various certified pharmaceutical factories and divided them into seventeen subgroups of medicinal parts. Their results show that some types of CHM exhibited a high-degree risk of Pb, Cd, As, and Hg, and the calculated HQ or total HQ of Pb, Cd, As, and Hg in some CHM above 1 (Yang, Chien, Chao, Huang, & Chen, 2021).

In this work, 720 batches of samples representing 20 species of root and rhizome herbs (the average batch of each species is 36) from different sources were collected for comprehensively investigating Pb, Cd, As, Hg, and Cu content. The research results also confirmed that heavy metals and harmful elements content varies with CHM species and consuming some of CHM may pose a potential risk to human health.

**4. Conclusion**

This work investigated the contamination levels of Pb, Cd, As, Hg, and Cu in 20 species of CHMs with a large scale of samples and the results were used for assessment of potential risks to human health. The results showed that: (1) the concentrations of heavy metals had a wide variation and the order of the concentration levels of heavy metals in the analyzed 20 CHMs was Cu > Pb > As > Cd > Hg; (2) exceedance percentages of Pb in the

**Table 5**  
Hazard quotient (HQ) of Cu, Pb, As, Cd, Hg and their total HQ.

No. of CHMs	HQ					Total HQ
	Cu	Pb	As	Cd	Hg	
1	0.074	0.150	0.478	0.024	0.010	0.742
2	0.063	0.410	0.957	0.072	0.037	1.543
3	0.029	0.045	0.096	0.043	0.003	0.217
4	0.036	0.096	0.159	0.048	0.009	0.350
5	0.025	0.021	0.159	0.072	0.006	0.283
6	0.036	0.109	0.239	0.024	0.004	0.413
7	0.023	0.090	0.144	0.172	0.002	0.432
8	0.045	0.109	0.372	0.048	0.011	0.588
9	0.015	0.090	0.287	0.201	0.014	0.608
10	0.024	0.004	0.014	0.014	0.002	0.059
11	0.017	0.107	0.144	0.006	0.001	0.275
12	0.027	0.120	0.415	0.029	0.003	0.595
13	0.022	0.107	0.144	0.014	0.024	0.313
14	0.035	0.025	0.024	0.014	0.002	0.100
15	0.016	0.036	0.053	0.003	0.001	0.110
16	0.020	0.104	0.191	0.010	0.005	0.331
17	0.043	0.016	0.144	0.029	0.003	0.235
18	0.031	0.565	0.585	0.048	0.004	1.235
19	0.015	0.096	0.106	0.016	0.001	0.234
20	0.051	0.205	0.532	0.048	0.003	0.845

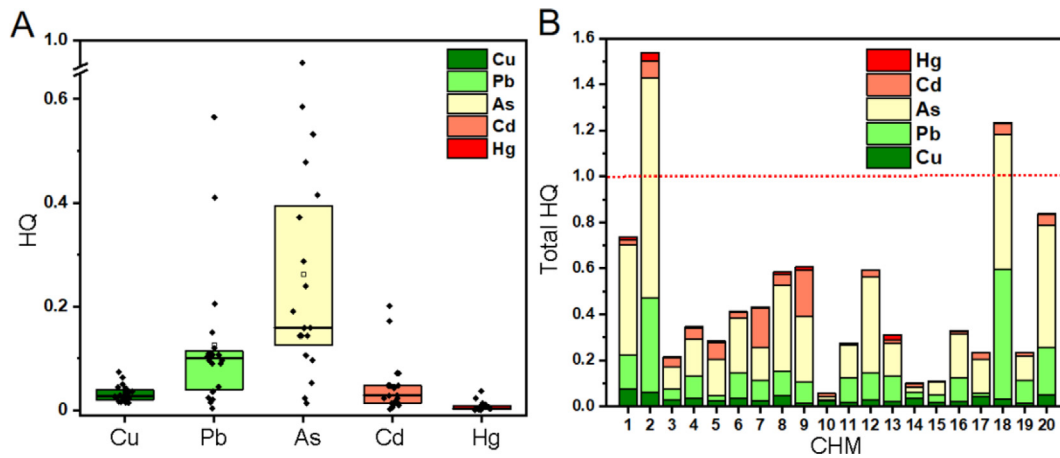


Fig. 3. HQ (A) and total HQ (B) of Cu, As, Cd, Hg, and Pb in the analyzed 20 species of CHMs.

**Table 6**  
Comparison with previous studies on heavy metal determination and health risk assessment of CHMs.

CHM species	Batches	Average batch	Sample source	Heavy metals	Risk assessment	Main results	References
126	334	2.7	Cultivated and wild	As, Cd, Cr, Pb, and Hg	Yes	99% of samples are likely to be of negligible concern; more research and monitoring of Cd and Cr are advised	Harris et al., 2011
50	250	5	Commercial	Cu, Cd, As, Pb, and Hg	No	heavy metal contents were found at different levels; the level of As did not exceed the Chinese standard, whereas Cu, Cd, Pb, and Hg were above permitted levels in some samples	Liu et al., 2013
<i>Moutan Cortex</i>	90	15	Six typical sites	Pb, Cd, Cr, Cu, and Zn	Yes	HQ in the hillside near the copper tailings were higher; more attention should be paid to the planting area near the mining tailing	Li, Wang, Yang, Yu, & Tang, 2018
60	60	1	Market in Kunming, Yunnan Province, China	Cu, Cd, Pb, As, Hg, and Zn	Yes	Cd pollution was relatively high, followed by Hg; HQ results for Cd and Hg showed that the CHMs did not pose a threat to human health.	Wang, Wang, Wang, Li, & Li, 2019
6	60	10	Market in Xi'an, Shaanxi, China	Pb, Cd, Hg, and Cu	Yes	the content of Cd, Pb, and Hg exceeded the limit standards in some CHMs; potential health risks could occur by taking these CHMs	Nan et al., 2020
279	10 245	3–181	Certified pharmaceutical factories in different provinces of China	Pb, Cd, As, and Hg	Yes	Five types of CHM ( <i>Cibotii rhizoma</i> et al.) exhibited high-degree risk of Pb contamination. Three types possessed high-degree risk of As contamination. Six types displayed high-degree risk of Cd contamination. <i>Toxicodendri resina</i> has high-degree risk of Hg contamination. Six types may have non-carcinogenic health risks.	Yang et al., 2021
20	720	36	Wild, indicated cultivation regions, commercial herbal markets, drugstore, and e-commerce companies	Cu, Cd, As, Pb, and Hg	Yes	Exceedance ratios of Pb in the 20 CHMs were 14.1%; consuming raw materials of <i>Pulsatillae radix</i> and <i>Clematidis radix</i> et <i>rhizoma</i> may pose a potential risk to human health	This work

20 CHMs were generally far higher than the other four elements; (3) consuming of *Pulsatillae Radix* (total HQ = 1.543) and *Clematidis Radix* et *Rhizoma* (total HQ = 1.235) may cause potential non-carcinogenic concern based on HQ calculation and the main components of total HQ were As and Pb. It should be specially explained that the results only reflect the heavy metal levels in the analyzed CHMs and cannot be extrapolated to predict all contaminant levels of CHMs. We do hope our findings can offer a reference for future research on the establishment of safeguards to both the Chinese government and other importing countries.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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