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Accumulation Characteristics of Heavy Metals in American Ginseng (*Panax quinquefolium* L.) and Changes in Their Contents after Soaking the Plants

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Abstract: Understanding the accumulation characteristics of heavy metals in the growth process of American ginseng can provide theoretical support for its safe production. In this study, the content of Cu, Mn, As, Pb, Cd, Cr, and Ni in American ginseng (annual, biennial, and triennial) and planting soil were determined using inductively coupled plasma mass spectrometry (LCP-MS). In addition, the change in the content of these heavy metals in American ginseng was evaluated after soaking the plant for various time periods. The results indicated that the content of some heavy metals in American ginseng was correlated with soil heavy metal contents. For example, Ni, Cd, and Mn content in American ginseng was significantly negatively correlated with Ni content in soil. American ginseng exhibited distinct heavy metal accumulation characteristics in different parts at different growth stages. For example, in annual American ginseng, Mn and As are mainly enriched in lateral roots and taproots, while in biennial and triennial American ginseng, they are mainly enriched in reed heads. When American ginseng plant was soaked for various time intervals, its heavy metal content changed to varying degrees. In general, after soaking American ginseng for 30 min, the content of most heavy metals decreased.

Keywords: American ginseng; heavy metals; accumulation characteristics; soaking

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1. Introduction

Heavy metals are ubiquitous in soil environment, and their main source is natural and human activities [1,2]. The addition of chemical fertilizers and pesticides and sewage irrigation in agricultural production can lead to the accumulation of heavy metals in soil [3]. Heavy metals are important indicators of environmental health and are closely related to the health of animals, plants, and humans [2,4]. Accumulation of high concentration of heavy metals in soil leads to decline in soil function and seriously threatens crop growth [5,6]. Moreover, it affects not only crop yield and quality but also the quality of the environment and water bodies, thereby threatening the health of animals and humans through food chain [7]. Soil is the main source of trace elements for plants and pollutants. Soil-to-plant transfer of trace elements is a part of the chemical element cycle in nature. This is a complex process influenced by both natural and human factors [8].

Different plants have different characteristics of absorbing elements, which depend on multiple internal and external factors. For example, *Fagopyrum esculentum* is efficient in accumulating Co, whereas corn and rice efficiently accumulate Cr and Ge [9]. In most cases, the concentration of elements in plants reflects their abundance in the growth medium (soil, nutrient solution, or water) and air. Some trace metals, such as Cu, Fe, Mn, and Zn, play a key role in plant metabolism and are components of various enzymes. However, metal poisoning can occur when a certain threshold is exceeded. Krämer et al. (1999) proposed that excess trace metals cause biochemical changes in plants, which are similar to the responses caused by pathogenic attack [10]. However, during the evolution process, plants have developed mechanisms for adapting to or avoiding stressors. In addition, metal elements absorbed in plants interact with each other and exhibit antagonism and synergy in varying degrees, which may occur within cells, membrane surfaces, and around plant roots. Although this interaction can greatly contribute to the chemical balance in plants, the accumulation of heavy metals in plants can still pose a threat to human health, particularly in case of perennial Chinese herbal medicines [11].

Chinese herbal medicines (CHMs) play an important role in Chinese healthcare and are now widely used globally [12]. American ginseng (*Panax quinquefolium* L.) is a valuable perennial herb. It has various pharmacological effects such as antioxidant, antidiabetic, and anticancer and enhances the central nervous system function [13–17]. Studies have reported that CHM and other herbal supplements can be contaminated with heavy metals, even reaching toxic levels in some cases [18–20]. As an important herbal medicine, American ginseng has attracted much attention for its safety, particularly its potential safety hazards such as heavy metal content exceeding the standard levels. Heavy metal elements such as copper (Cu), manganese (Mn), arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) are frequently detected in CHM. When these heavy metal elements are taken up by human body, they are gradually accumulated and are difficult to eliminate [21–23].

At present, specialized and systematic research on the problem of excessive heavy metal content in CHM is lacking; particularly, the distribution of heavy metals in various parts of plants is rarely studied. In this study, we aimed to assess the content and accumulation characteristics of seven heavy metals including Cu, Mn, As, Pb, Cd, Cr, and Ni in various parts of American ginseng and analyzed this content with reference to the limits given in the *Chinese Pharmacopoeia* promulgated by China. Furthermore, we explored the effect of soaking of American ginseng plant for various time intervals on the heavy metal content. This study provided a reference for heavy-metal-free cultivation of high-quality American ginseng and for sustainable development of the American ginseng industry.

2. Materials and Methods

2.1. Research Area

The material collection sites were selected from four villages in Weihai City, Shandong Province, which is the main area of American ginseng production in China. The four villages were: Yaojia (36°57′35″ N, 122°4′35″ E), Beishadao (37°0′58″ N, 122°14′19″ E), Nanshadao (37°0′56″ N, 122°13′38″ E), and Caiguantun (37°1′45″ N, 122°14′35″ E). The sites are located on the Shandong Peninsula, with annual average temperature of 11.5 °C, precipitation of 762 mm, and mild climate.

2.2. Sample Collection

The American ginseng samples were collected from Yaojia, Beishadao, Nanshadao, and Caiguantun villages in August 2018. Three plots were selected from each village, and 15 representative triennial American ginseng samples were collected from each plot (total 180 samples). In addition, three typical American ginseng fields were selected from a family ginseng farm in Caiguantun village, and 12 representative annual, biennial, and triennial American ginseng plants were evenly selected using the five-point sampling method (total 36 samples). Furthermore, the soil loosely attached to the root system was removed by shaking. Using a small brush, the soil tightly attached to the root system was collected as rhizosphere soil. For each plot in each village, the rhizosphere soil was mixed (total 15 samples). The details of the samples are given in Table S1.

2.3. Preparation of Samples

The aboveground part of the collected American ginseng was removed with scissors, the taproot, lateral roots, and reed head were kept, and then the samples were cleaned, dried at room temperature for 1 day, and placed in an oven. The initial temperature of oven was 25–26 °C for 2–3 days, followed by a gradual increase to 35–36 °C. After the main body of American ginseng became soft, the temperature was increased to 38–40 °C and further gradually lowered to 30–32 °C after 2–3 days until it was dried. The whole drying time was approximately 2 weeks. The dried American ginseng samples were ground in a glass mortar and passed through a 0.25 mm sieve. The sieved samples were thoroughly mixed and stored in a plastic bag until further use. From the collected soil samples, impurities such as plant roots, leaves, and stones were removed. The soil samples were placed in a ventilated place to air-dry naturally, followed by grinding, passing through 0.25 and 2 mm sieves, and storing in plastic bags till further use.

2.4. Soaking Experiment

The samples used for the soaking experiment were prepared according to the ginseng processing method from "the Chinese Pharmacopoeia." The samples were soaked in containers containing ultrapure water from an ultrapure water meter (MING-CHE 24UV, Molsheim AR France) at room temperature for 0 min, 30 min, or 3 h (water added was 4 times the weight of the sample). The cleaning, drying, and baking methods were the same as those described above.

2.5. Assessment of Heavy Metals

Approximately 0.5 g of each ground sample was first microwave digested using 5 mL of 68% concentrated nitric acid (HNO_3) and 2 mL of 30% hydrogen peroxide (H_2O_2) for 40 min. The resulting digestate was analyzed using a Thermo X-Series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) (Thermo Fisher Scientific, Waltham, MA, USA).

2.6. Bioconcentration Factor

Bioconcentration factor (BCF), which expresses the ratio of the concentrations of chemical elements between the plant and soil, was used to evaluate the metal uptake capacity of American ginseng [24]. It was calculated as per the formula given below:

$$\text{BCF} = \frac{\text{Metal concentration in plant (mg/kg)}}{\text{Metal concentration in soil (mg/kg)}}$$

2.7. Data Analysis

All data were expressed as the average of three replicate experiments and plotted using GraphPad Prism 8 (GraphPad Software, San Diego, CA, USA). One-way ANOVA was performed using SPSS Statistics 20 (IBM, New York, NY, USA). Duncan's test was performed to determine the significance of differences among the means, and Pearson's test was used to assess the significance of correlation. The difference among treatments or a correlation between analyzed parameters was defined as significant at $p < 0.05$.

3. Results

3.1. Heavy Metal Content in Soil from American-Ginseng Sampling Area

The heavy metal content in soil at the sampling points is given in Table 1. Among all tested heavy metals, Mn exhibited the highest content in the planting soil. The heavy metal content of the planting soil was in the order Mn > Cr > Pb > Cu > Ni > As > Cd. Their average content was approximately 963.36, 57.13, 22.88, 15.73, 13.42, 8.14, and 0.35 mg/kg, respectively. Considerable difference existed in the heavy metal content among sampling points in different villages. The ranges of Cu, Mn, As, Pb, Cd, Cr, and Ni content in soil was 10.04–18.60, 815.75–1261.77, 5.64–10.17, 21.23–26.53, 0.24–0.45, 36.98–83.64, and 9.64–22.23 mg/kg, respectively. The heavy metal content in soil at the sampling points did not exceed the national standard of soil quality value (SQV) of grade two [25], except Cd content, which was slightly higher than this standard. This indicated that the planting soil contained a moderately high content of Cd at some planting bases. Moreover, the heavy metal content in soil at Yaojia village sampling site was higher than that in soil at other places.

Table 1. Content of heavy metals (average ± standard deviation) in the planting soil from the study area (mg/kg).

	Cu	Mn	As	Pb	Cd	Cr	Ni
YS1	18.55 ± 0.15	1085.06 ± 16.6	8.45 ± 0.33	26.53 ± 0.25	0.43 ± 0.05	74.41 ± 1.46	22.23 ± 0.23
YS2	18.60 ± 0.95	975.44 ± 1.57	9.84 ± 0.12	25.95 ± 1.84	0.40 ± 0.06	71.42 ± 7.26	20.68 ± 1.10
YS3	16.31 ± 0.53	889.40 ± 24.23	8.87 ± 0.99	24.11 ± 0.70	0.38 ± 0.05	83.64 ± 2.96	21.60 ± 0.98
BS1	18.53 ± 0.24	930.80 ± 10.02	9.47 ± 0.84	22.15 ± 0.47	0.35 ± 0.05	51.92 ± 3.21	11.07 ± 0.30
BS2	16.97 ± 0.67	906.31 ± 1.63	7.94 ± 0.28	21.36 ± 1.33	0.34 ± 0.07	53.37 ± 2.62	10.92 ± 0.33
BS3	17.46 ± 0.89	857.68 ± 24.86	7.70 ± 0.39	21.38 ± 0.23	0.30 ± 0.05	46.92 ± 2.07	11.05 ± 0.62
NS1	18.14 ± 0.27	815.75 ± 22.59	5.64 ± 0.82	21.79 ± 0.14	0.24 ± 0.05	54.91 ± 0.76	9.64 ± 0.18
NS2	17.03 ± 0.08	983.38 ± 15.34	8.29 ± 0.32	23.83 ± 0.32	0.41 ± 0.01	43.35 ± 0.99	10.78 ± 0.06
NS3	16.24 ± 0.15	867.49 ± 23.65	7.84 ± 1.03	22.48 ± 0.19	0.45 ± 0.02	63.04 ± 2.19	10.85 ± 0.33
CS1	10.29 ± 0.25	925.00 ± 11.34	7.63 ± 0.38	22.30 ± 0.41	0.33 ± 0.03	58.24 ± 0.87	12.36 ± 0.71
CS2	10.08 ± 0.00	905.78 ± 0.98	6.86 ± 0.72	21.23 ± 0.73	0.34 ± 0.04	46.02 ± 0.12	11.35 ± 0.03
CS3	10.04 ± 0.06	1261.77 ± 39.14	6.19 ± 0.30	24.09 ± 0.80	0.26 ± 0.02	54.84 ± 2.30	13.51 ± 0.15
ACS	19.96 ± 0.66	852.56 ± 46.22	8.10 ± 0.43	21.79 ± 0.82	0.32 ± 0.07	40.05 ± 0.79	10.31 ± 0.12
BCS	12.96 ± 0.18	1178.30 ± 4.48	9.19 ± 0.17	22.28 ± 0.34	0.37 ± 0.04	36.98 ± 1.43	12.28 ± 0.14
TCS	14.76 ± 0.31	1015.69 ± 7.74	10.17 ± 0.48	21.94 ± 0.09	0.38 ± 0.01	77.81 ± 0.76	12.72 ± 0.07
Min	10.04	815.75	5.64	21.23	0.24	36.98	9.64
Max	19.96	1261.77	10.17	26.53	0.45	83.64	22.23
Average	15.73	963.36	8.14	22.88	0.35	57.13	13.42
SQV	50	NF	40	250	0.30	150	40

NF means that the value was not found. SQV refers to the soil quality value of grade two [25].

3.2. Heavy Metal Content in American Ginseng

The content of the heavy metals in American ginseng was within the safety limits. The content of heavy metals in American ginseng followed the order Mn > Ni > Cu > Cr > As > Cd, and Pb was not detected (Table 2). The ranges of Cu, Mn, As, Cd, Cr, and Ni contents were 2.24–5.81, 20.34–336.44, 0–1.34, 0.06–0.40, 0.58–4.07, and 2.09–9.43 mg/kg, respectively. Their averages were approximately 4.00, 120.78, 0.87, 0.19, 1.99, and 4.61 mg/kg, respectively. Compared with the limited standard value (LSV) of CHM [26], all heavy metal content was lower than the LSV, except Cd content in two samples (NG1 and NG2). The content of Mn in American ginseng was relatively high, and considerable difference was observed among all samples.

Table 2. Content of heavy metals (average ± standard deviation) in American ginseng in the study area (mg/kg).

	Cu	Mn	As	Pb	Cd	Cr	Ni
YG1	4.26 ± 0.10	25.77 ± 2.10	1.10 ± 0.17	ND	0.14 ± 0.02	2.37 ± 0.31	2.12 ± 0.07
YG2	3.85 ± 0.20	33.06 ± 3.14	0.83 ± 0.04	ND	0.06 ± 0.01	2.26 ± 0.11	2.32 ± 0.15
YG3	2.24 ± 0.20	20.34 ± 1.50	1.23 ± 0.10	ND	0.12 ± 0.02	0.58 ± 0.16	2.98 ± 0.17
BG1	3.19 ± 0.32	78.81 ± 1.72	ND	ND	0.23 ± 0.01	1.52 ± 0.24	3.77 ± 0.17
BG2	5.48 ± 0.50	66.80 ± 2.46	1.08 ± 0.15	ND	0.14 ± 0.03	1.10 ± 0.22	3.80 ± 0.31
BG3	3.81 ± 0.20	71.18 ± 1.78	1.34 ± 0.22	ND	0.21 ± 0.03	0.73 ± 0.09	4.12 ± 0.18
NG1	4.94 ± 0.13	283.53 ± 2.86	ND	ND	0.40 ± 0.03	1.22 ± 0.21	5.03 ± 0.38
NG2	4.98 ± 0.34	250.01 ± 8.53	1.09 ± 0.10	ND	0.35 ± 0.02	1.33 ± 0.19	9.43 ± 0.49
NG3	5.15 ± 0.13	336.44 ± 0.82	1.17 ± 0.25	ND	0.26 ± 0.01	3.17 ± 0.26	6.42 ± 0.49
CG1	3.46 ± 0.11	148.97 ± 8.29	0.73 ± 0.20	ND	0.25 ± 0.03	3.66 ± 0.32	7.24 ± 0.40
CG2	2.26 ± 0.11	92.60 ± 2.86	1.21 ± 0.05	ND	0.16 ± 0.03	4.07 ± 0.33	5.97 ± 0.36
CG3	3.42 ± 0.16	41.88 ± 2.00	1.19 ± 0.18	ND	0.14 ± 0.02	2.70 ± 0.28	2.09 ± 0.15
Average	4.00	120.78	0.87	0.00	0.19	1.99	4.61
LSV	20.00	NF	2.00	5.00	0.30	NF	NF

ND means that the value was not detected. NF means that the value was not found. LSV means the limited standard value [26].

3.3. Bioconcentration Factor (BCF) of Heavy Metals in American Ginseng

Unlike other heavy metals, Cd content was slightly high in American ginseng. The BCF of heavy metals was <0.5 except for Cd, and that of Cr was particularly low (Table 3). The ranges of the BCFs of Cu, Mn, As, Cd, Cr, and Ni were 0.14–0.37, 0.02–0.39, 0–0.19, 0.15–1.69, 0.01–0.09, and 0.10–0.87, and their averages were approximately 0.26, 0.13, 0.10, 0.57, 0.04, and 0.39, respectively. Among them, Cr had the lowest BCF value. Therefore, except Cd, the heavy metal content was not high in American ginseng.

Table 3. Bioconcentration factors of heavy metals in American ginseng.

	YG1	YG2	YG3	BG1	BG2	BG3	NG1	NG2	NG3	CG1	CG2	CG3	Min	Max	Average
Cu	0.23	0.21	0.14	0.17	0.34	0.24	0.27	0.29	0.32	0.37	0.22	0.34	0.14	0.37	0.26
Mn	0.02	0.03	0.02	0.08	0.07	0.08	0.35	0.25	0.39	0.16	0.10	0.03	0.02	0.39	0.13
As	0.13	0.00	0.14	0.00	0.12	0.17	0.00	0.00	0.15	0.10	0.16	0.19	0.00	0.19	0.10
Cd	0.15	0.15	0.31	0.57	0.41	0.69	1.69	0.78	0.58	0.76	0.43	0.35	0.15	1.69	0.57
Cr	0.03	0.02	0.01	0.02	0.02	0.02	0.02	0.03	0.05	0.07	0.09	0.05	0.01	0.09	0.04
Ni	0.10	0.11	0.14	0.34	0.35	0.37	0.52	0.87	0.59	0.59	0.53	0.15	0.10	0.87	0.39

3.4. Correlation Analysis of Heavy Metals between American Ginseng and Planting Soil

A significant correlation existed between the heavy metal content in American ginseng and planting soil, suggesting that American ginseng can absorb heavy metals from the soil. To understand the relationship between heavy metal content of American ginseng and planting soil, we calculated the Pearson's correlation coefficient (Table 4). It was observed that significant positive correlations existed among Cr, Pb, and Ni in the planting soil and among Cd, Mn, and Ni in American ginseng, and significant negative correlations existed between Cu in soil and Cr in American ginseng and between Ni in soil and Cd in American ginseng. This may be attributed to the synergistic effects in the absorption and metabolism among Mn, Cd, and Ni in American ginseng.

Table 4. Correlation coefficients of heavy metal content between American ginseng and planting soil.

	AG_As	AG_Cd	AG_Cr	AG_Cu	AG_Mn	AG_Ni	Soil_As	Soil_Cd	Soil_Cr	Soil_Cu	Soil_Mn	Soil_Ni	Soil_Pb
AG_As	1.000												
AG_Cd	−0.420	1.000											
AG_Cr	0.228	−0.058	1.000										
AG_Cu	−0.204	0.416	−0.196	1.000									
AG_Mn	−0.303	0.859 **	0.182	0.530	1.000								
AG_Ni	−0.262	0.732 **	0.320	0.265	0.735 **	1.000							
Soil_As	−0.233	−0.429	−0.330	−0.134	−0.371	−0.180	1.000						
Soil_Cd	0.021	−0.258	0.078	0.099	0.080	0.156	0.695 *	0.999					
Soil_Cr	0.202	−0.488	−0.138	−0.241	−0.334	−0.544	0.422	0.420	1.000				
Soil_Cu	−0.403	0.101	−0.774 **	0.423	0.067	−0.210	0.509	0.319	0.252	1.000			
Soil_Mn	0.155	−0.540	0.226	−0.153	−0.419	−0.383	−0.066	−0.026	0.085	−0.342	1.000		
Soil_Ni	0.164	−0.707 **	−0.135	−0.370	−0.604 *	−0.601 *	0.521	0.449	0.874 **	0.223	0.324	1.000	
Soil_Pb	−0.097	−0.536	−0.062	−0.106	−0.351	−0.420	0.446	0.490	0.664 *	0.256	0.585 *	0.848 **	1.000

AG: American ginseng; * Correlation is significant at the 0.05 level (2 tailed); ** Correlation is significant at the 0.01 level (2 tailed).

3.5. Heavy Metal Content in Various Parts and Growth Stages of American Ginseng

The content of Cu, Mn, As, Pb, Cd, Cr, and Ni in the taproots, lateral roots, and reed head of American ginseng was significantly different over various growth periods (Figure 1). In annual American ginseng, Cu, Cr, and Ni were mainly concentrated in the taproots, with average concentrations of 2.60, 1.78, and 7.35 mg/kg, respectively. Mn, Pb, and As were mainly concentrated in the lateral roots, with average concentrations of 139.16, 101.95, and 79.66 mg/kg, respectively. Interestingly, in biennial American ginseng, Mn, As, and Pb were concentrated in the reed head, with average concentrations of 312.96, 17.58, and 27.00 mg/kg, respectively. Cu and Ni accumulated in both taproots and lateral roots, with average concentrations of 5.70 and 4.82 (taproots) and 7.76 and 5.61 (lateral roots) mg/kg, respectively. Mn and As were still mainly accumulated in the reed head, with average concentrations of 340.74 and 6.98 mg/kg, respectively. In triennial American ginseng, the content of Pb was very little. Cu and Ni were slightly accumulated in the taproots, lateral roots, and reed head. Cr accumulated in the lateral roots and reed head for the first time in the 3 year growth of American ginseng, with an average content of 0.94 and 1.35 mg/kg, respectively. In addition, most of the heavy metals in this study were easily accumulated in the reed head in the third year. The heavy metal content was compared with the LSVs of Chinese medicinal material. Cu content met the LSV standard during the 1–3 years of growth of American ginseng; however, the contents of As in annual American ginseng and those of Cd in biennial and triennial American ginseng were relatively high, and both exceeded the LSV standard. Pb content fell below the LSV limit in the third year.

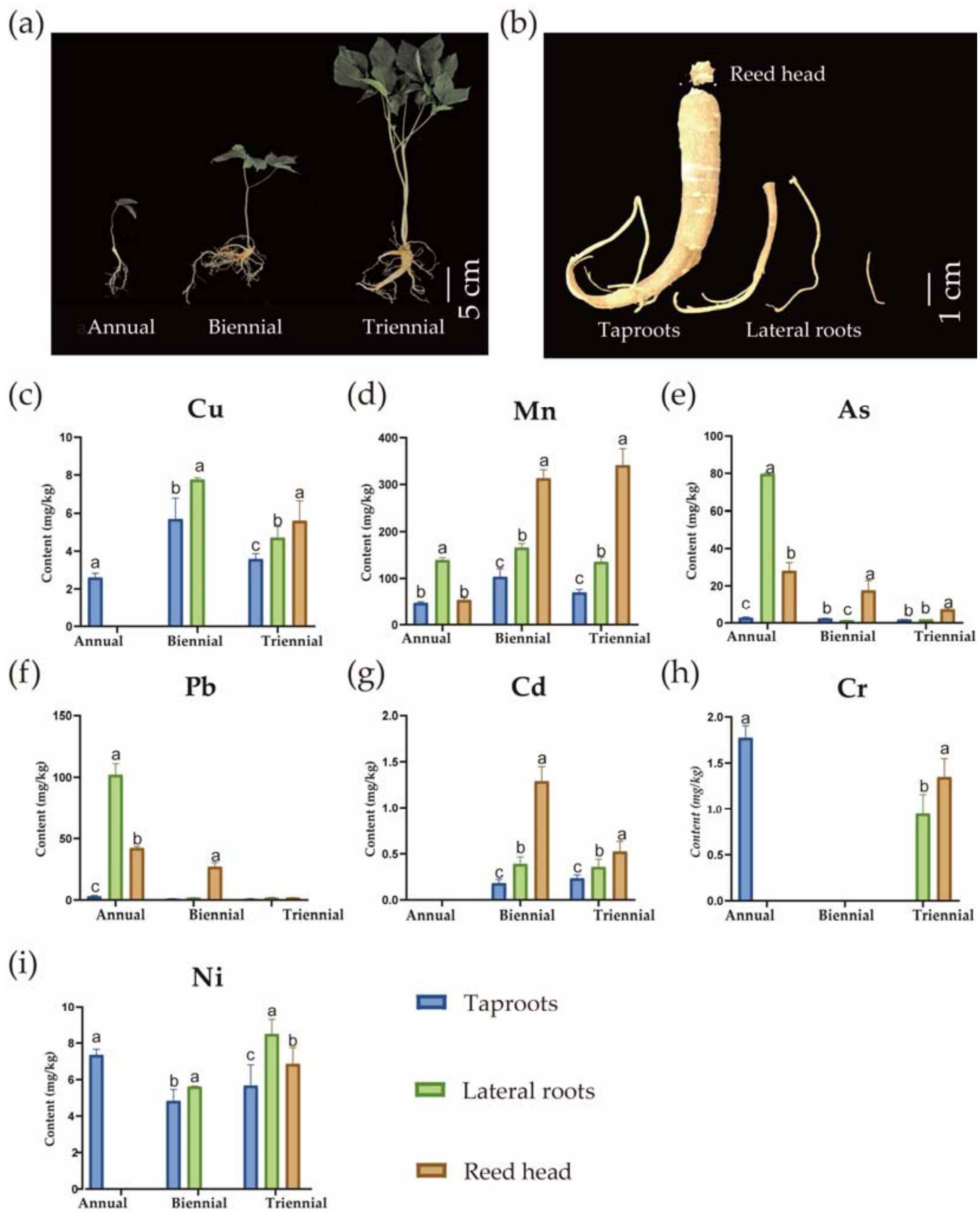

Figure 1. Analysis of heavy metal content in various parts and growth stages of American ginseng. (**a**) The image of annual, biennial, and triennial American ginseng plants; (**b**,**c**) The image of the whole and dissected root of triennial American ginseng; (**d**–**i**) the content of Cu, Mn, As, Pb, Cd, Cr, and Ni in the taproots, lateral roots, and reed head of annual, biennial, and triennial American ginseng. Various letters above the bars in a single bar graph indicate significant differences among the treatments at $p < 0.05$.

3.6. Correlation of Heavy Metal Accumulation in Various Parts of American Ginseng

Some correlation existed among heavy metal content in various parts of American ginseng (Figure 2). Interestingly, as the growth year of American ginseng increased, the correlation among the accumulation of heavy metals in various plant parts became more obvious. In annual American ginseng, Cu content in the taproot positively correlated with Mn and As content in the lateral roots. Mn content in the taproots positively correlated with Pb content in the lateral roots. Ni content in the taproots negatively correlated with Pb content in the reed head. In biennial American ginseng, Mn and Pb content in the taproots was positively correlated. A positive correlation existed between Cu and Ni content in the lateral roots, whereas a negative correlation existed between them and As content in the taproots. Ni content in the taproots negatively correlated with As content in the reed head. In triennial American ginseng, Mn content in the taproots positively correlated with Cr content in the lateral roots and Cu content in the reed head. At the same time, Ni content in the taproots was positively correlated with As content in the reed head. Cd content in the lateral roots was positively correlated with Pb content in the reed head. However, Pb content in the taproots negatively correlated with Cd content in the reed head.

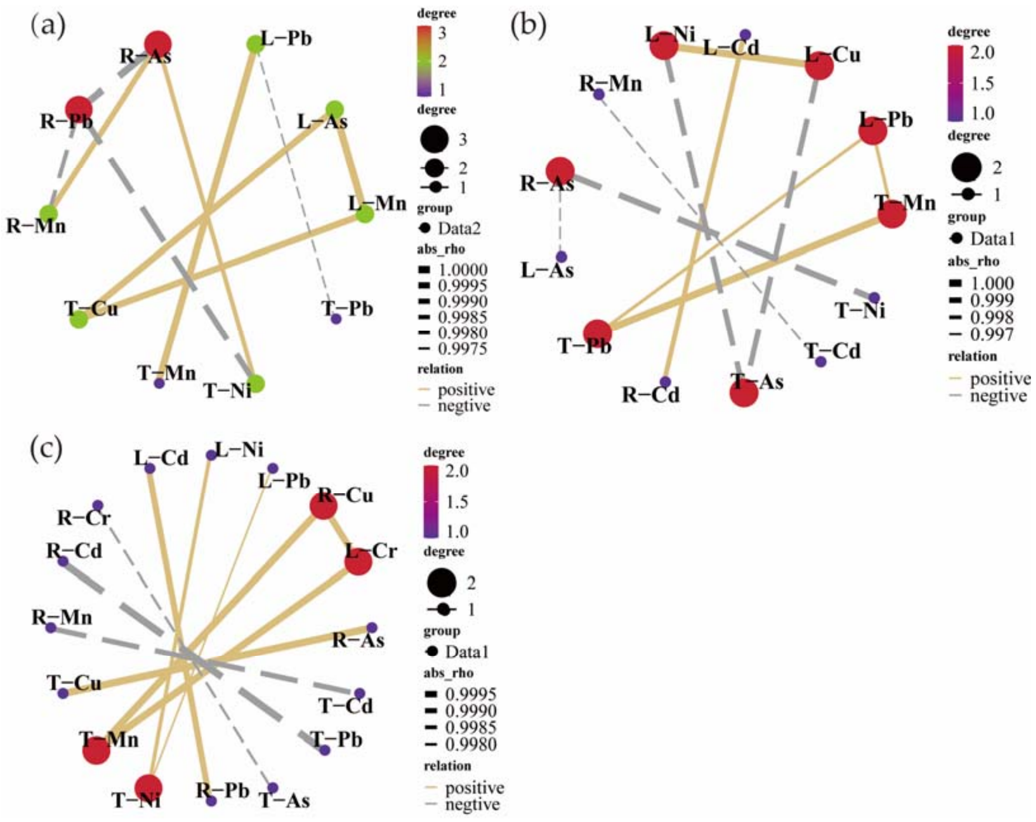

Figure 2. Correlation among the content of heavy metals in various parts of annual (**a**), biennial (**b**), and triennial (**c**) American ginseng. T represents taproots, L represents lateral roots, and R represents reed head. The yellow solid lines or blue dotted lines represent positive or negative correlation, respectively. The size of soil circle and color range represent the number of related objects, and thickness of the line represents the strength of the correlation.

3.7. The Accumulation Characteristics of Heavy Metals in Various Parts of American Ginseng

The BCF values of Mn, As, and Pb in the lateral roots of annual American ginseng were higher than those in the taproots and reed head. The BCF values of As in the lateral roots were the highest among all heavy metals, followed by Pb in the lateral roots (Table 5). Furthermore, the BCF values followed the order first year > second year > third year. The accumulation ability of Pb in the reed head of annual American ginseng and of As and Pb in the reed head and Cd in the lateral roots of biennial American ginseng was 1.90, 2.79, 1.06, and 1.15, respectively. The results indicated that the heavy metal accumulation ability of American ginseng roots decreased with the increase of growth period, and the heavy metals transferred from the roots to the aerial parts. Higher accumulation ability was exhibited by As, Pb, and Cd in the lateral roots of American ginseng.

Table 5. The average BCF values of heavy metals in various parts of American ginseng.

Metal	Years	Taproots	Lateral Roots	Reed Head	Total
Cu	Annual	0.15	0.00	0.00	0.15
	Biennial	0.44	0.60	0.00	1.04
	Triennial	0.22	0.30	0.40	0.92
Mn	Annual	0.05	0.16	0.06	0.27
	Biennial	0.08	0.14	0.26	0.48
	Triennial	0.07	0.00	0.30	0.37
As	Annual	0.37	9.84	0.00	10.21
	Biennial	0.25	0.46	2.79	3.50
	Triennial	0.17	0.21	0.59	0.97
Pb	Annual	0.13	5.29	1.90	7.32
	Biennial	0.04	0.17	1.06	1.27
	Triennial	0.04	0.08	0.07	0.19
Cd	Annual	0.00	0.00	0.00	0.00
	Biennial	0.49	1.15	0.37	2.01
	Triennial	0.44	0.76	0.38	1.58
Cr	Annual	0.04	0.00	0.00	0.04
	Biennial	0.02	0.02	0.00	0.04
	Triennial	0.00	0.00	0.00	0.00
Ni	Annual	0.68	0.00	0.00	0.68
	Biennial	0.37	0.46	0.00	0.83
	Triennial	0.46	0.68	0.58	1.72

3.8. Effects of Soaking of American Ginseng on the Content of Heavy Metals

After soaking American ginseng for various time intervals, Pb was not detected in any sample. Figure 3 shows that after soaking American ginseng for 30 min and cleaning, the content of Cu, As, Cd, Cr, and Ni in most samples exhibited a decreasing trend; however, some samples exhibited an increasing trend after soaking for 3 h. The content of Mn in most samples did not change significantly after soaking. The heavy metal content of the samples from Nansha Island village was significantly higher than that of the samples from other three villages. Cu, As, Cd, and Cr content in most samples met the limits. Although Cd content in a small number of samples from Nansha Island village exceeded the standard limits, their content decreased after soaking for 30 min.

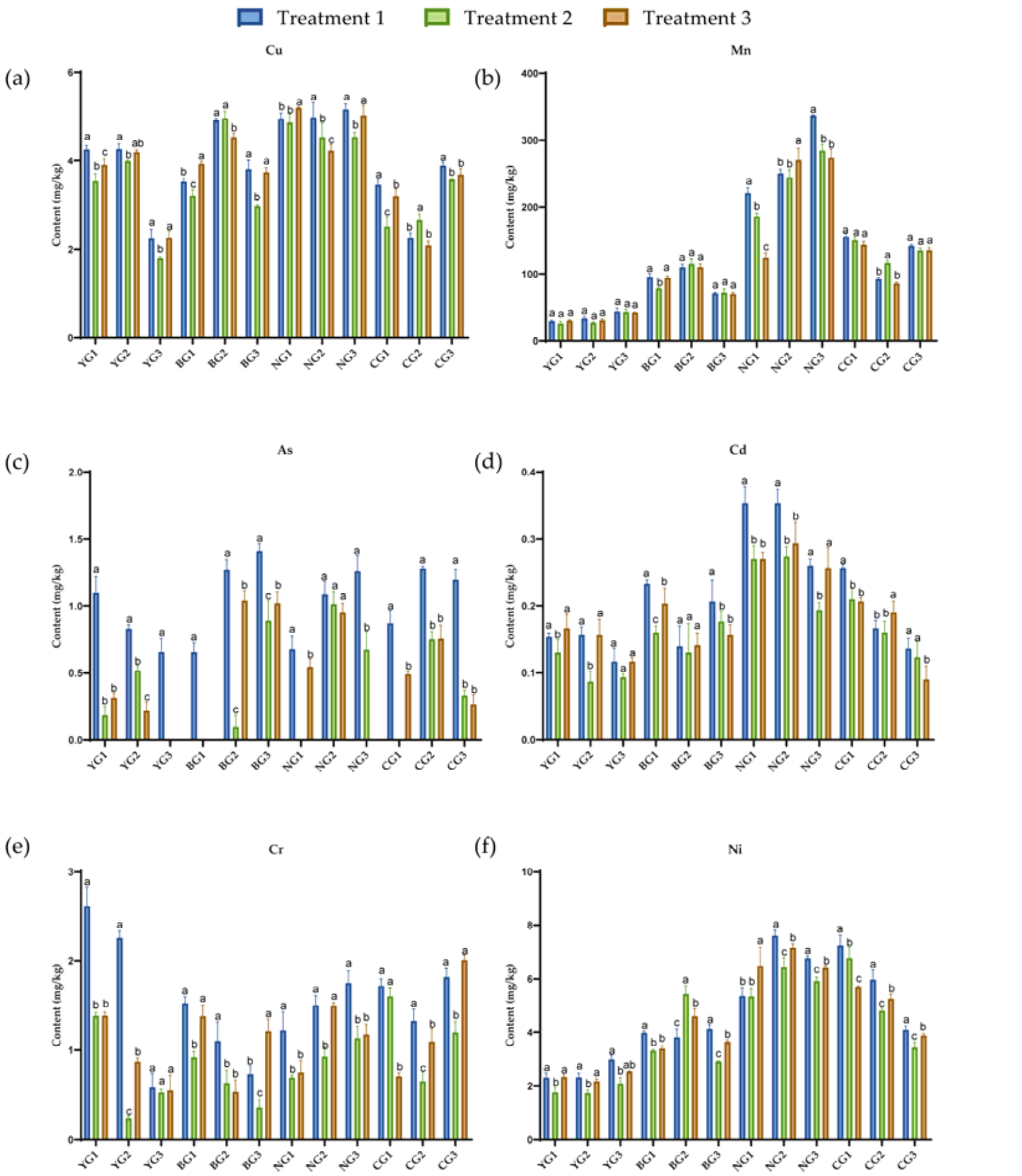

Figure 3. Content of Cu (**a**), Mn (**b**), As (**c**), Cd (**d**), Cr (**e**), and Ni (**f**) after soaking American ginseng for 0 min (treatment 1), 30 min (treatment 2), or 3 h (treatment 3). Various letters above the bars in a single bar graph indicate significant differences among the treatments at $p < 0.05$.

4. Discussion

The content of heavy metal in the soil may be a useful indicator for ginsenoside and heavy metal content in ginseng [27]. The content of heavy metals in plants is mainly related to their content in soil and the heavy metal accumulation abilities of plants [28,29]. Some studies reported that the enrichment coefficient of heavy metals in soil is related to sand content, organic matter content, pH, and anthropogenic activities. These factors may have led to high content of heavy metals in the soil at Yaojia village [30,31]. In this study, the content of six heavy metals (Cu, Mn, As, Pb, Cr, and Ni) in the sampling area were lower than the SQV, except Cd (Table 1). The global average soil Cd concentration is estimated to be between 0.06 and 1.1 mg/kg, and in most soils, 99% of Cd binds to soil colloids; thus, its significant portion is found in soil solutions, mainly in the form of the free metal ion Cd^{2+} [32]. However, due to the overapplication of pesticides and fertilizers, the accumulation of Cd in farmland soil is rapidly increasing, which would seriously affect the quality of American ginseng [3]. Moreover, the Cd content in the planting soil of some sampling sites was high relative to the SQV. Therefore, the accumulation of heavy metals in the planting soil of American ginseng should be monitored.

The accumulation of heavy metals in ginseng may be harmful to human health. Compared with the heavy metal content of *P. notoginseng* in Yunnan (Ou et al., 2016) and *P. heterophylla* in Guizhou (Wu et al., 2008) and Jiangsu (Zeng et al., 2008), the content of Cd and As was higher than that at other planting bases, whereas the content of Cu and Pb was lower [33–35]. Ou et al. (2016) reported that As and Cd are toxic metals for plants [35]. Plants have no metabolic need for Cd and As, and their relatively easy availability to plants poses serious health risks. Cd and As poisoning can affect plant physiological functions and lead to plant death [36–38]. At the same time, various plants, including rice, *P. heterophylla*, and *P. notoginseng* have been reported to accumulate Cd [2,35,39]. In this study, in triennial American ginseng, although Cd exhibited slightly high accumulation (Tables 2 and 3), the Cd content exceeded the limit only in one of the four sampling sites, and no significant correlation existed between Cd content in the plant and soil (Table 4). Xiang et al. (2021) reported that Cd and As content in crops negatively correlated with Cd and As content in soil, which is inconsistent with this study. Moreover, American ginseng did not accumulate the other six heavy metals. However, the content of Ni, Cd, and Mn in American ginseng was negatively correlated with Ni content in soil. Huang and Gui reported that Ni content in corn roots and soil were negatively correlated [40], which indicated that plants have a certain selectivity in soil Ni absorption. The absorption of Ni, Cd, and Mn by plants is mainly in the form of divalent cations, which may be the reason for the competition between them (Table 4). The content of Ni and Cd in American ginseng exhibited a significant positive correlation, whereas the content of Cd in the Reed head of biennial and triennial American ginseng negatively correlated with the content of Mn in the taproots. Similarly, negative correlation existed between Cd and Mn in rice, which may be due to complex interactive relationships, including synergistic and antagonistic effects, among these heavy metals [2,41–43]. This interaction promotes plants' chemical balance.

Generally, plants readily absorb metal elements from soil and transport them upward through their roots; however, in many higher plants, mechanisms to adapt to or avoid stress factors have been developed [44]. These mechanisms include restricted influx through the plasma membrane, release by leaching from foliage, efflux of element excess from roots, etc. [11]. In our study, Mn, As, and Pb content in the lateral roots of American ginseng was the highest in the first year (Figure 1e,f,g), and their content in reed head gradually increased from the second year. This indicated that these heavy metals began to transfer to the aboveground part. Furthermore, Cu, Mn, Cr, and Ni content in the reed head of American ginseng exhibited an increasing trend in 1–3 years (Figure 1d,e,h,i). This indicated that these four heavy metals would be transferred to the aboveground part during the whole growth period so that their content in the root remained relatively stable. Therefore, in triennial American ginseng, the content of heavy metals distributed by the reed head increased. Cd, Pb, and As are toxic to plants and usually have adverse effects on the growth, metabolism, and water status of plants [45,46]. In this study, with the increase of growth years, the content of Cd, Pb, and As decreased in triennial American ginseng (Figure 1f,g). Pb is mainly transported in plants via passive transportation, and only a small part of it could move to the aboveground part [47,48]. Plants prevent Pb ions from entering the interior of plant cells through external repulsion mechanisms, avoid accumulation of Pb at sensitive sites in cells, or pump excess Pb ions out of cells [49,50]. Plant roots selectively take up specific As species via distinct pathways and transporters. Moreover, Plants inhibit As uptake through As transporters and allow As to flow out of roots to protect themselves [38]. Therefore, we speculated that the absorption of As and Pb in American ginseng was mainly high in the first year, and their concentrations would gradually decrease with increasing root growth.

The heavy metal accumulation is toxic for the human body. To further reduce the content of heavy metals in American ginseng, we adopted a soaking method, which is the traditional processing method of American ginseng. Some studies reported that certain active components of traditional Chinese medicine may change due to temperature, enzymes, moisture, and other factors during the processing [51,52], and with the prolongation of soaking time, the drying rate and saponin content decreased in American ginseng; however, some studies have reported that with soaking time of less than 1 h, the ginsenoside content reduced slightly [53]. In our study, soaking American ginseng in ultrapure water for 30 min could reduce the content of multiple heavy metals (Figure 3). This may be because heavy metals adsorbed on the free space on plant roots are difficult to wash off; however, they may slowly diffuse into water after soaking for short time. Moreover, the ion concentration in the plant cell membrane is higher than that in the surrounding, and after soaking in ultrapure water, the metal ions in the membrane would enter in the water through the transporter or ion channel on the membrane [54]. However, the water potential in the cell membrane is low, which will continue to absorb water [55]. With the increase of soaking time, ions will return to the cell along with the water absorption by the cell; this will again lead to the accumulation of heavy metals in American ginseng. Precise soaking is helpful for reducing heavy metal content in American ginseng.

5. Conclusions

In this study, we assessed the accumulation characteristics of heavy metals in American ginseng and planting soil and the effect of soaking of American ginseng on the heavy metal content in it. We observed that content of some heavy metals in American ginseng was affected by heavy metal content in soil; e.g., Ni, Cd, and Mn content in American ginseng at harvest stage was significantly negatively correlated with Ni content in soil, and the Cr content in plant was negatively correlated with Cu content in soil. At various growth stages, some correlation existed among heavy metal content accumulated in various parts of American ginseng. Moreover, the BCF value as a whole followed the order of first year > second year > third year, and the BCF values of As, Pb, and Cd were higher only during first 2 years. Specifically, the content of Cu, Cd, Cr, and Ni in annual American ginseng was very low, and only a small amount was accumulated in the taproots. The content of Mn, Pb, and As were significantly high in the lateral roots. In biennial American ginseng, Mn, As, and Pb were mainly accumulated in the reed head, whereas Cu and Ni were mainly accumulated in the main root and lateral roots. Cu, Mn, As, Pb, Cd, and Cr mainly accumulated in the reed head in triennial American ginseng. It is particularly noteworthy that the content of Pb in American ginseng was very low in the third year.

In addition, soaking could effectively reduce the content of Cu, As, Pb, Cd, and Cr in American ginseng, and the decrease was the largest after soaking for 30 min. This difference may be related to the method, and the specific reasons need to be further studied. The results of this study provided a scientific basis for further research on the safety and processing methods of American ginseng.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13095676/s1, Table S1: Grouping of American ginseng and soil samples.

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