sustainability

Article

Study on Chromium Uptake and Transfer of Different Maize Varieties in Chromium-Polluted Farmland

Xiaotian Zhou [1], Hanxiu Hu [1], Chunyang Ying [1], Jing Zheng [1], Fuhong Zhou [2], Haoyong Jiang [2] and Youhua Ma [1,*]

[1] Key Laboratory of Farmland Ecological Conservation and Pollution Control of Anhui Province, College of Resources and Environment, Anhui Agricultural University, Hefei 230036, China
[2] Agricultural Technology Extension Center, Mingguang, Chuzhou 239400, China
* Correspondence: yhma@ahau.edu.cn; Tel.: +86-0551-65786289

Abstract: The objective of this research was to study the differences in the enrichment and transport capacity of heavy metal chromium in farmland soil by different maize cultivars, and it is of great significance to screen out the maize varieties that meet the food safety standards and repair the heavy metal chromium in farmland soil. To complete the experiment, under the conditions of field experiments, 72 maize cultivars were selected to study the growth of maize in chromium-polluted arable land and the differences in Cr accumulation and transshipment of different maize cultivars. From the experiment, we found that among 72 maize varieties, 49 of them, accounting for 68.06% of the total, had kernel chromium content lower than the China kernel limit standard value of 1.0 mg kg^{-1}. There were significant differences in Cr content in the kernels, stems, leaves and roots of all cultivars, with Cr content in root > stems > kernels. The contents of Cr in roots and stems and kernels were 4.06–93.09 mg kg^{-1} and 5.54–24.13 mg kg^{-1} and 0.46–2.61 mg kg^{-1}, respectively, and the coefficients of variation were 51.21%, 36.36% and 46.11%. By cluster analysis, maize varieties were divided into five groups according to kernel chromium content, and the maize varieties were also divided into three categories according to the content of chromium in stem and leaf. At the same time, we found that the low accumulation of kernel, high accumulation of stem and leaf, seven varieties: Nongyu662, HongyuNO.9, Wankenyu125, Shuxinyu228, Kewei702, Liyu16, JinchengNo.6. The enrichment coefficients (BCF) of each maize cultivar ranged from 0.026 to 0.194, the transport coefficients TF (kernel/stem) and TF (stem/root) were between 0.028 and 0.064, and 0.064 and 0.864, and the enrichment coefficient and transport coefficient were less than 1. In the end, according to the comprehensive evaluation of the maize growth status, kernel Cr content, enrichment coefficient, transport coefficient and other indicators, it is believed that Nongyu662, HongyuNo.9, Wankenyu125, ShuXinYu228, Weike702, Liyu16, and JinchengNo.6 could be promoted as Cr maize cultivars with low kernel and high stem–leaf accumulation; also, planting these seven varieties can achieve the goal of restoring the heavy metal chromium in farmland soil while ensuring maize food security.

Keywords: maize; chromium; kernel; varieties screening; enrichment coefficient; transit factor

check for updates

Citation: Zhou, X.; Hu, H.; Ying, C.; Zheng, J.; Zhou, F.; Jiang, H.; Ma, Y. Study on Chromium Uptake and Transfer of Different Maize Varieties in Chromium-Polluted Farmland. *Sustainability* **2022**, *14*, 14311. https://doi.org/10.3390/su142114311

Academic Editors: Shengsen Wang and Jun Wang

Received: 14 October 2022
Accepted: 31 October 2022
Published: 2 November 2022

1. Introduction

With the progress of science and technology, and the rapid development of China's industry, the scale of factories continues to expand, and the scale of pollution areas is continually expanding, followed by the pollution of farmland soil. As one of the heavy metals that harm farming, chromium inhibits crop photosynthesis, inhibits crop photosynthesis, and the yield is greatly reduced, even resulting, in severe cases, in crop death [1,2]. Not only that, but humans eat maize crops mostly for the kernels. Through dietary intake, excessive chromium will cause acute or chronic poisoning. In severe cases, it can even result in death. At present, there are many restoration technologies for heavy metals in farmland soil in China and abroad, among which the greenest restoration technology is phytoremediation technology, and the screening of low-accumulation varieties is the most convenient and effective farmland heavy-metal-restoration technology [3,4]. However, the commonly used plants, for restoration purposes, have low economic value and are difficult to meet the economic needs of farmers. Therefore, how to effectively apply super-accumulation to actual agricultural activities is worth an in-depth study. One of the important ways to solve this problem is to breed varieties with a low accumulation of heavy metals in edible parts through the selection of crop varieties. The results of the study that belongs to Atif M [5] et al. showed that the effects of As stress on the 10 contrasting maize varieties were significantly different. Habiba U [6] et al. also confirmed the feasibility of screening environmentally friendly maize varieties on Cr-contaminated farmland.

The proportion of the content of crop heavy metals accumulated in various parts of the body is not certain, and it has a certain relationship with the difference between crop types and crop varieties. Maize is one of the most common crops, with the characteristics of a large biomass, the maize roots and stalks having a higher cumulative effect on heavy metals. Additionally, compared with other parts, maize kernels are less affected by heavy metal pollution, and have a good shielding effect on heavy metals [7]. Therefore, the potential for soil remediation by planting maize is huge, and it has the effect of the heavy metal remediation of farmland soil while meeting the farmers' requirements for economic income. Yan X.L. [8] et al. screened the five varieties of XidaNo.8, LudanNo.2, LudanNo.6, QiushuoyuNo.6 and XuanhuangdanNo.5; all of them can be selected as Cd and Pb low-accumulation maize varieties to be promoted and planted in Guanping Village, Lanping Bai Pumi Autonomous County. Wang, A. [9] found that Jixiang2118 and Kangnong18 can be classified as another group with potential applications for phytoremediation in lightly or moderately cadmium-contaminated soils, as cadmium accumulation is high in aboveground tissues. There are few research studies on low-accumulation crop varieties that can not only repair soil chromium pollution, but also ensure the food safety of crops. Low-accumulation varieties selected elsewhere may not be suitable for growing in another area. Therefore, it is necessary to carry out low-accumulation crop varieties screening in this area. The purpose of this study was to study the differences in the enrichment and transport capacity of heavy metal chromium in farmland soil by different maize varieties, and to screen out maize varieties that meet the food-safety standards and repair the heavy metal chromium in farmland soil at the same time. It is of great significance for the protection of human health.

2. Materials and Methods

2.1. Test Site

The test site was located in Zilaiqiao Village, Zilaiqiao Town, Mingguang City, Chuzhou City, Northeast Anhui Province, China, which belongs to the north side of the Jianghuai watershed, 32.78° N, 117.98° E, and 101 m above sea level. The continental monsoon climate in the region is remarkable, mild and humid, with concentrated plum rainfall, four distinct seasons, and abundant rainfall. The terrain of the community is plain, and the soil type is paddy soil. The physicochemical properties of soil (0–20 cm) were pH 6.23, organic matter 32.3 g kg^{-1}, total nitrogen 0.46 g kg^{-1}, alkalized nitrogen 58.56 mg kg^{-1}, available phosphorus 26.54 mg kg^{-1}, available potassium 160 mg kg^{-1}, and total chromium content of 255.73 mg kg^{-1} before the trial, exceeding the soil pollution risk screening value of agricultural land in GB 15618-2018 "China Soil Environmental Quality" [Soil (Cr) $\leq$ 250 mg kg^{-1}] [10].

2.2. Test Materials and Experimental Design

Wanyu708, Fucheng796, Suyu34 and other 72 varieties of maize for trial are all approved (introduced) locally applicable varieties by the Anhui Provincial Crop Approval Committee, purchased from the local seed sales market.

Each cell area was 5 m^2 (2 m $\times$ 2.5 m), 3 replicates, randomly arranged in blocks. On 7 June 2021, by the local maize high-yield cultivation technology, the seeds were dried for 2 days before sowing, and the soil moisture content was maintained at 60%~75% of the maximum field water holding. On 9 June 2021, the maize was planted, with a planting density of 55,500 plants/hm^2 (60 m × 30 m), a formula fertilizer (15-15-15) 600 kg/hm^2, and a urea 150 kg/hm^2 at V12 stage. On 7–8 September 2021, maize plant and soil samples were collected.

2.3. Indicators and Methods

The measurement index and its method of adoption were as follows: the total Cr content of the plant was digested by microwave metho; soil active chromium was carried out by the M3 method [11]; and total chromium, a heavy metal in soil, was spectrophotometrically performed by flame atom.

Bio-concentration factors and transport factors were used to calculate the chromium enrichment capacity of plants. Enrichment coefficient = heavy metal chromium mass ratio in plant kernel/heavy metal effective chromium mass ratio in soil. Transport coefficient = plant kernel (stem and leaf) heavy metal chromium mass ratio/plant stem and leaf (root) heavy metal chromium mass ratio. Coefficient of variation CV = (SD/mean Mean) × 100% [12].

2.4. Data Processing

Data collation was used by Microsoft Excel 2017 software, statistical analysis using IBM SPSS Statistics 23 software, and chart analysis using OriginPro 2018C 64-bit software. The test data were expressed by using average ± standard error (SE).

3. Results

3.1. Differences in Cr Content of Roots, Stems, Leaves and Kernels of Different Maize Cultivars

The differences in Cr content of the kernel, stem, leaf and root system of different maize varieties are shown in Figures 1–3:

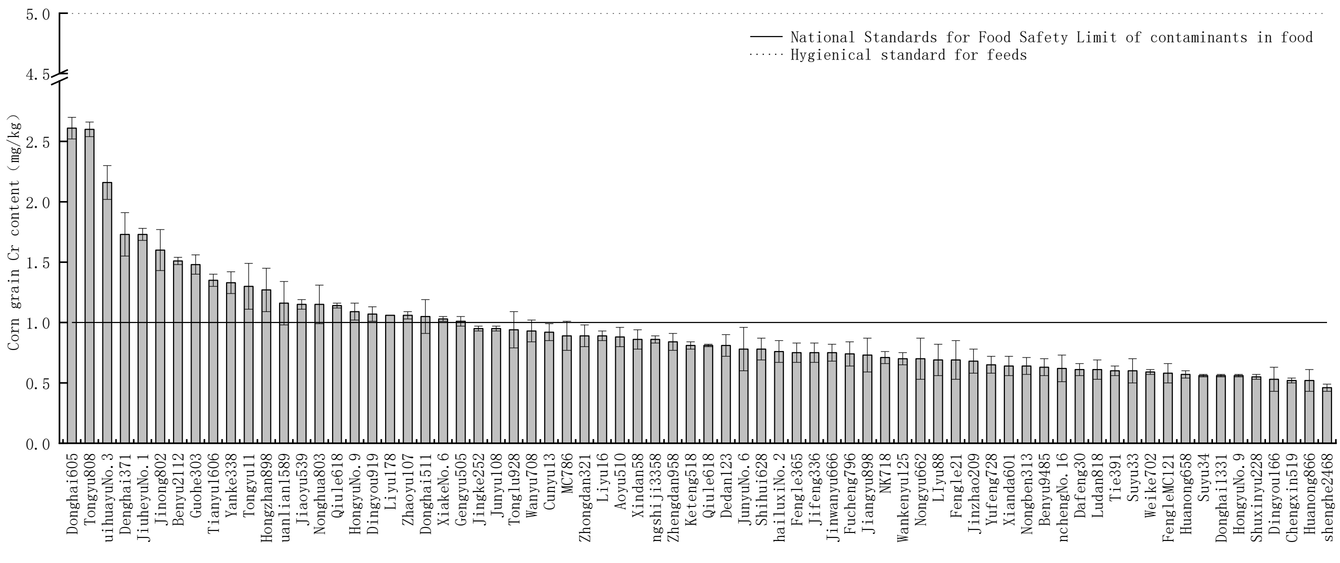

Figure 1. Differences in Cr content of kernel in different maize cultivars.

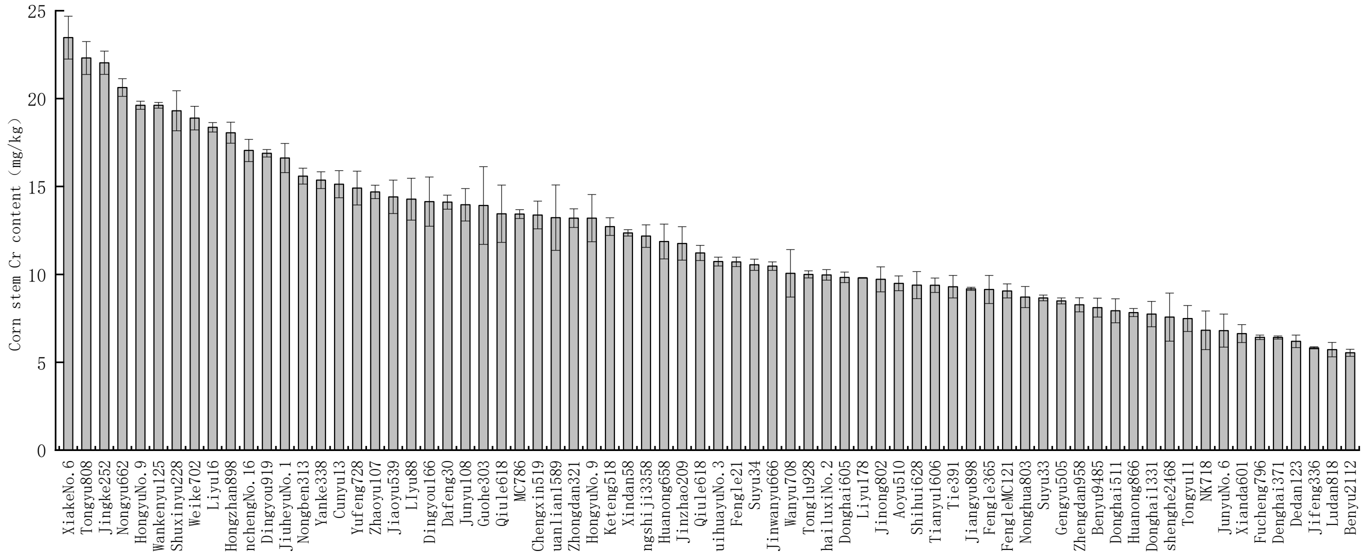

Figure 2. Differences in Cr content between stems and leaves of different maize cultivars.

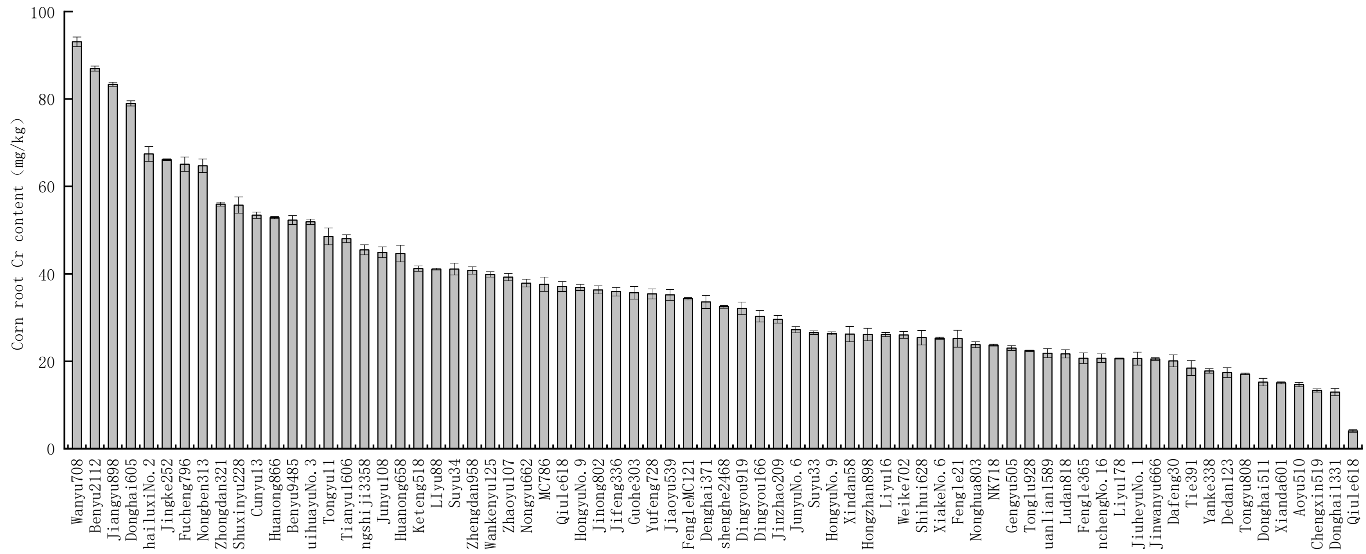

Figure 3. Differences in Cr content in roots of different maize cultivars.

In Figures 1–3, it can be seen that there are significant differences in the Cr content of the kernel, stem and leaf and root system of different maize cultivars, and the Cr content of different parts shows the root > stem > kernel. The Cr contents of roots stems and kernels of 72 maize cultivars were 4.06–93.09 mg kg^{-1}, 5.54–24.13 mg kg^{-1} and 0.46–2.61 mg kg^{-1}, respectively, with coefficients of variation of 51.21%, 36.36% and 46.11%, respectively. Among them, Donghai605, Tongyu808, RuihuayuNo.3, Denghai371, JiuheyuNo.1, Jinong802, Benyu2112, Guohe303, Tianyu1606, Yanke338, Tongyu11, Hongzhan898, Quanlian1589, Jiaoyu539, Nonghua803, Qiule618, HongyuNo.9, Dingyou919, Liyu178, Zhaoyu107, Donghai511, XiakeNo.6 and Gengyu505 kernel Cr contents exceed the GB 2762-2017 China Food Safety Standards [Kernel (Cr) $\leq$ 1.0 mg kg^{-1}] [13]. The Cr content of other varieties of kernel is lower than the China standard for food safety. The remaining varieties with kernel chromium content lower than the China kernel limit standard value of 1.0 mg kg^{-1} were screened out, accounting for 68.06% of the total amount, of which the maize kernel chromium content of Jiusheng and 2468 was the lowest, with a content of 0.46 mg kg^{-1}. The kernel content of all maize varieties complies with the provisions of GB 13078-2017 "China Feed Standard" [Kernel (Cr) $\leq$ 5.0 mg kg^{-1}] [14].

3.2. Clustering Analysis of Cr Content of Kernel and Stem of Different Maize Cultivars

The Cr content in kernels of 72 maize varieties tested was in accordance with the China feed hygiene standard (GB 13078-2017). In order to screen out maize varieties that meet the food safety standards, produce kernels that are safe to eat, reduce the risk of Cr exceeding the standard in maize kernels, and repair Cr in farmland soil, we conducted a cluster analysis of Cr content in the kernels, stems and leaves of all maize varieties as shown in Figures 4 and 5.

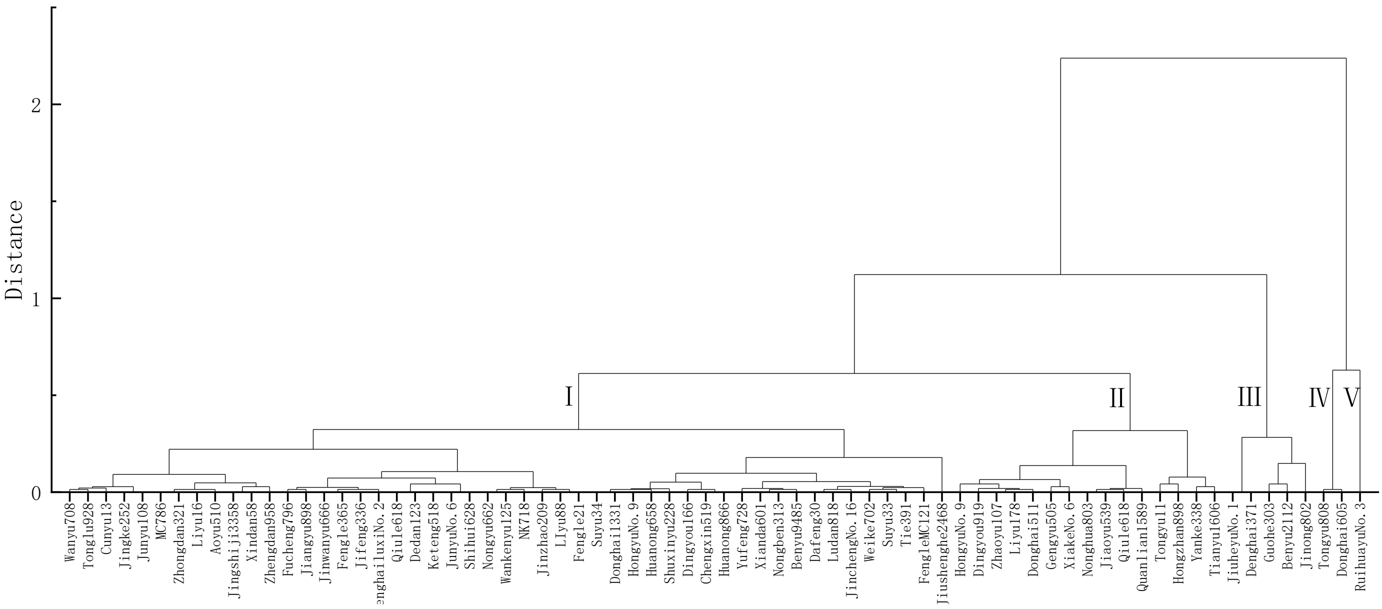

Figure 4. Cluster analysis of Cr content in kernels of different maize varieties.

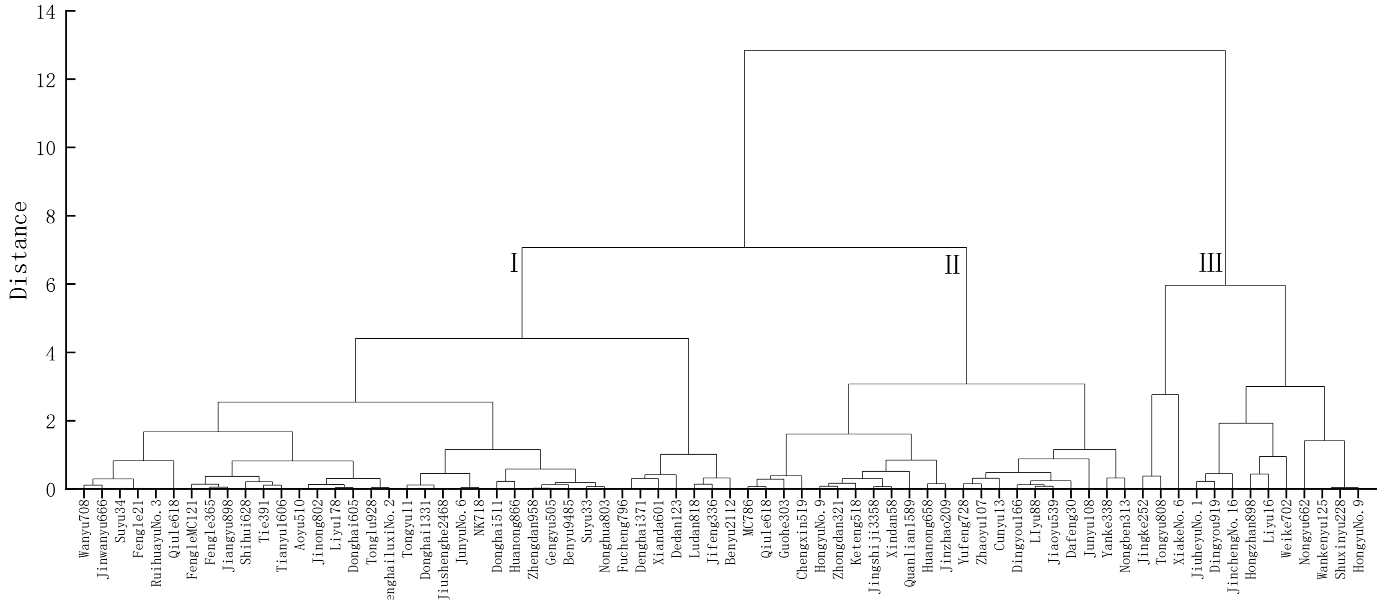

Figure 5. Cluster analysis of Cr content in stems of different maize varieties.

Cluster analysis is the process of classifying different maize varieties into different classes, with objects in the same class having great similarities, but not objects of the same kind having great differences [15]. The cluster analysis of the Cr content of maize kernels of different varieties are shown in Figure 4, and it can be seen from Figure 4 that the cluster analysis of maize kernel Cr content can divide 72 different maize varieties into

Class I (low kernel accumulation varieties), Class II (low kernel accumulation varieties), Class III (seed accumulation varieties), Class IV (high kernel accumulation varieties), and Class V (high kernel accumulation varieties). Among them, Class V(high kernel accumulation variety) has a variety of RuihuayuNo.3, and the chromium content of maize kernel is 2.16 mg kg^{-1}; Class IV (varieties with higher kernel accumulation) has two varieties of Tongyu808 and Donghai605, and the chromium content of maize kernel is 2.60 and 2.61 mg kg^{-1}, respectively. Class III (varieties accumulated in the kernel) has five varieties: Denghai371, JiuheyuNo.1, Jinong802, Benyu2112, and Guohe303, and the chromium content of maize kernel is between 1.48~1.73 mg kg^{-1}. Class II (varieties with low kernel accumulation) includes Junyu108, Jingke252, Gengyu505, ShakeNo.6, Donghai511, Zhaoyu107, Liyu178, Dingyou919, HongyuNo.9, Qiule618, Nonghua803, Jiaoyu539, Quanlian1589, Hongzhan898, Tongyu11, Yanke338, Tianyu16061 chromium varieties, and the maize kernel chromium content is between 0.95~1.35 mg kg^{-1}. The rest are Class I (low kernel accumulation varieties), and the chromium content of the maize kernels is between 0.46 and 0.94 mg kg^{-1}. All maize kernel Cr contents are in accordance with the provisions of GB 13078-2017 "Feed Hygiene Standard" [kernel (Cr) $\leq$ 5.0 mg kg^{-1}], and the compliance rate is 100%. Class I (low kernel accumulation varieties) has 47 varieties that belong to the low accumulation Cr group, where the Cr content reaches the China food safety standards, accounting for 65.28% of the total, indicating that most of the maize varieties belong to the low-accumulation Cr group.

The cluster analysis of the Cr content of stems and leaves of different varieties of maize is shown in Figure 5, and it can be seen from Figure 5 that the Cr content of maize stems and leaves can be grouped into 72 different maize cultivars into Class I (low stem and leaf accumulation varieties), Class II (stem and leaf accumulation varieties), and Class III (stem and leaf high accumulation varieties). Among them, Class III (stem and leaf high accumulation varieties) includes ShakeNo.6, Tongyu808, Jingke252, Nongyu662, HongyuNo.9, Wankenyu125, Shuxinyu228, Weike702, Liyu16, Hongzhan898, Jincheng6, Dingyou919 and JiuheyuNo.1, for a total of 13 varieties, and the maize stem and leaf chromium content is between approximately 16.89 and 24.13 mg kg^{-1}. Class II (varieties accumulated in stems and leaves) includes Nongben313, Yanke338, Cunyu13, Yufeng728, Zhaoyu107, Jiaoyu539, Liyu88, Dingyou166, Dafeng30, Junyu108, Guohe303, Qiule618, MC786, Chengxin519, Quanlian1589, Zhongdan321, HongyuNo.9, Keten518, Xindan58, Jinshiji3358, Huanong658, Jinzhao209 for a total of 22 varieties, and maize kernel chromium content is between approximately 11.76 and 15.59 mg kg^{-1}. The rest are Class I (stem and leaf low accumulation varieties), and the chromium content of the maize stems and leaves is between 5.54 and 11.22 mg kg^{-1}.

Maize varieties with low accumulation of grain, high accumulation of stem and leaf, maize are in line with both Class I (low kernel accumulation variety) and Class III (high stem and leaf accumulation variety). There are seven varieties that meet the conditions: Nongyu662, HongyuNo.9, Anhui Kenyu125, Shuxinyu228, Weike702, Liyu16, JinchengNo.6. These can ensure the food security of maize while achieving the restoration of heavy metal chromium in farmland soil and can be given priority to promoting planting.

3.3. Differences in Cr enrichment and Transport Coefficient of Different Maize Cultivars

The ability of crops to absorb, enrich and transfer heavy metals is mainly reflected by the enrichment coefficient (BCF) and transport coefficient (TF), which directly affect the content of heavy metals in kernels [16]. The higher the enrichment coefficient and transport coefficient, the higher the absorption capacity of heavy metals and the transport capacity of heavy metals between organs [17]. Differences in Cr enrichment and the transport coefficient of different maize varieties are shown in Table 1.

Table 1. Differences in Cr content in roots of different maize cultivars.

Maize Varieties	$TF_{(Kernel/Stem)}$	$TF_{(Stem/Root)}$	BCF	Maize Varieties	$TF_{(Kernel/Stem)}$	$TF_{(Stem/Root)}$	BCF
Wanyu708	0.088	0.113	0.137	Liyu16	0.048	0.704	0.065
Fucheng796	0.115	0.099	0.153	Fengle365	0.082	0.441	0.067
Suyu34	0.052	0.261	0.151	Shihui628	0.082	0.374	0.061
Jingke252	0.043	0.333	0.194	Fengle21	0.065	0.426	0.070
MC786	0.067	0.356	0.059	Suyu33	0.070	0.326	0.078
JiuheyuNo.1	0.102	0.819	0.130	Nonghua803	0.132	0.366	0.090
HongyuNo.9	0.088	0.337	0.078	Tie391	0.065	0.504	0.056
Tongyu11	0.169	0.159	0.085	Aoyu510	0.090	0.663	0.058
Tongyu808	0.117	0.602	0.153	Xindan58	0.071	0.467	0.057
Denghai371	0.269	0.191	0.116	Quanlian1589	0.092	0.582	0.088
Hongzhan898	0.070	0.692	0.074	Donghai1331	0.071	0.605	0.040
Huanong658	0.048	0.266	0.035	Ludan818	0.106	0.264	0.045
Jingshiji3358	0.071	0.268	0.049	Gengyu505	0.117	0.373	0.063
Yufeng728	0.044	0.421	0.049	Jiushenghe2468	0.059	0.241	0.026
Dingyou919	0.063	0.531	0.073	XiakeNo.1	0.043	0.684	0.071
Guohe303	0.109	0.382	0.087	Jinong802	0.164	0.268	0.101
Nongyu662	0.034	0.545	0.033	Liyu178	0.108	0.475	0.065
Dingyou166	0.036	0.481	0.035	Keteng518	0.066	0.300	0.047
Wankenyu125	0.036	0.492	0.043	Tonglu928	0.094	0.446	0.047
Jinzhao209	0.058	0.397	0.042	HongyuNo.9	0.028	0.744	0.026
Zhaoyu107	0.071	0.377	0.040	Junyu108	0.067	0.314	0.055
Dafeng30	0.042	0.720	0.041	Benyu2112	0.272	0.064	0.087
Qiule618	0.061	0.362	0.062	Benyu9485	0.074	0.162	0.035
Liyu88	0.047	0.356	0.051	Jiangyu898	0.080	0.110	0.049
Zhongdan321	0.071	0.224	0.064	Qiule618	0.101	0.330	0.068
JinchengNo.16	0.036	0.836	0.044	Jifeng336	0.129	0.162	0.056
Weike702	0.031	0.726	0.038	Chengxin519	0.040	0.396	0.031
Jinwanyu666	0.071	0.514	0.062	Nongben313	0.041	0.241	0.039
Yanke338	0.086	0.864	0.088	Huanong866	0.064	0.153	0.033
Xianda601	0.097	0.440	0.052	Cunyu13	0.061	0.282	0.043
FengleMC121	0.064	0.264	0.031	Shuxinyu228	0.028	0.352	0.040
Donghai511	0.127	0.543	0.082	DenghailuxiNo.2	0.076	0.148	0.055
JunyuNo.6	0.105	0.274	0.059	Jiaoyu539	0.078	0.418	0.068
Zhengdan958	0.097	0.210	0.078	RuihuayuNo.3	0.201	0.207	0.110
Dedan123	0.131	0.356	0.072	Tianyu1606	0.144	0.195	0.087
NK718	0.094	0.316	0.045	Donghai605	0.266	0.124	0.122

The enrichment and transport coefficients of Cr by different maize cultivars are shown in Table 1. The enrichment coefficient of Cr in the soil of different maize varieties ranged from 0.026 to 0.194 with an average of 0.068. The accumulation capacity of Cr by different maize varieties and organs varied greatly. The TF (kernel/stem) and TF (stem/root) of different maize cultivars were 0.028–0.272 and 0.064–0.864, respectively, and the coefficients of variation were 58.67% and 49.13%, respectively. The Cr enrichment coefficient, TF (kernel/stem) and TF (stem/root) of the 72 varieties were all less than 1. The kernel transport coefficient of different maize varieties was less than 1, indicating that the Cr content in the plant was expressed as the root system > stems and leaves > the kernel.

4. Discussion

The enrichment coefficient of maize varieties with low kernel accumulation and high accumulation of straw should be less than 1. In this study, the Cr enrichment coefficient of 72 maize cultivars was less than 1, indicating that the kernel absorption capacity of Cr in each maize variety was weak, which was consistent with the results of Chen Yan et al. [18] who studied the characteristics of heavy-metal accumulation in different organs of maize and concluded that maize grew normally on Cr-contaminated soil, the Cr concentration was small, and the resistance to Cr was shown as an avoidance pathway. There are obvious differences in the kernel chromium content between varieties, and the reasons for the difference may be the difference between the field test and the pot test as well as the difference between different planting environments, but the field test can better reflect the authenticity of maize enrichment and transshipment Cr [19]. Moreover, the distribution of Cr in maize plants will directly affect the content of Cr in the kernel, resulting in the content of Cr exceeding the China food safety standard. Some scholars have found that [20] the adsorption capacity of heavy metal Pb by the root cell wall of the low accumulation maize variety is stronger than that of the high accumulation maize cultivar, which indicates that the high and low contents of heavy metals in the maize kernel are also related to the distribution of heavy metals in the root cells and the transport capacity to the aboveground part. Maize has a variety of differences in the Cr enrichment and transport coefficient; when subjected to heavy metal stress, it will change the rhizosphere environment by changing the composition and quantity of root secretions, and the types and quantities of root secretions of different varieties will affect the biological availability of heavy metals in rhizosphere soil, thereby changing the enrichment and transport of heavy metals in maize [21]. The transport coefficient of the 72 maize varieties for the test in this study is less than 1, so it can be seen that the content of Cr in the roots, stems and leaves and kernels is gradually decreasing, and the distribution rules of Cr in the maize plants in the 72 maize varieties are all roots> stems > kernels, which is consistent with the Cr content determination of different parts of maize plants by Li Danyang et al. [22]. It was consistent with the distribution of other heavy metals to root > stem > ear in maize [23]. Maize enriches the heavy metal Cr at the roots, reducing the amount of Cr in the kernel by inhibiting Cr transport from the stem and leaf to the kernel. In this study, the Cr content of the kernel and stem and leaf of the maize supplied to the test was clustered, and the varieties were divided into five categories according to the kernel Cr content. The varieties with a low accumulation of grain and high accumulation of stem and leaf were studied, that is, the maize varieties that met Class I (low kernel accumulation varieties) and Class III (stem and leaf high accumulation varieties) included Nongyu662, HongyuNo.9, Wankenyu125, ShuXinYu228, Weike702, Liyu16, and JinchengNo.6.

This experiment was carried out in the field. The comprehensive field growth state performance, Cr content, enrichment coefficient, transport coefficient and cluster analysis of 72 maize varieties were used as the standard to measure the Cr accumulation of different maize varieties. For the test of 72 maize varieties, 7 varieties, including Nongyu662, HongyuNo.9, Wankenyu125, ShuXinYu228, Weike702, Liyu16, and JinchengNo.6, had a kernel Cr content lower than the GB 2762-2017 "China Standard for Food Safety", and the enrichment and transport coefficient was less than 1. Additionally, the seven varieties satisfied the low kernel accumulation stem and leaf accumulation requirements, achieving food safety standards. At the same time, these seven varieties can restore heavy metal chromium in farmland soil. Therefore, the above seven varieties can be prioritized to be planted in chrome-polluted cultivated soil and promoted.

5. Conclusions

There were significant differences in the Cr content of the kernel, stem and leaf and root of the 72 maize cultivars in the test. The Cr contents of the roots, stems and leaves and kernels were 4.06–93.09 mg kg^{-1}, 5.54–24.13 mg kg^{-1} and 0.46–2.61 mg kg^{-1}, respectively, with the coefficients of variation of 51.21%, 36.36% and 46.11%, respectively. There were 49 varieties with kernel chromium content lower than the China kernel limit standard value of 1.0 mg kg^{-1}, accounting for 68.06% of the total.

Through cluster analysis, maize varieties, according to the kernel chromium content, can be divided into five categories; those according to the stem and leaf chromium content maizeare divided into three categories. The low kernel accumulation stem and leaf high accumulation varieties were studied, that is, the maize varieties that simultaneously met Class I (low kernel accumulation varieties) and Class III (high stem and leaf accumulation varieties), including the following seven varieties: Nongyu662, HongyuNo.9, Wankenyu125, ShuXinYu228, Weike702, Liyu16, and JinchengNo.6.

The enrichment coefficients of each maize cultivar ranged from 0.026 to 0.194. The transport coefficients TF (kernel/stem) and TF (stem/root) were between 0.028 and 0.272, and 0.064 and 0.864. The enrichment coefficient and transport coefficient were less than 1. The kernel absorption capacity of Cr in all varieties of maize was weak, and the Cr content in different parts showed roots > stems > kernels.

According to the comprehensive evaluation of maize growth status, kernel Cr content, enrichment coefficient, transport coefficient and other indicators, it is believed that the seven varieties, including Nongyu662, HongyuNo.9, Wankenyu125, ShuXinYu228, Weike702, Liyu16, and JinchengNo.6, can be planted in chromium-polluted arable land soil as Cr-kernel stem low-accumulation and leaf high-accumulation maize varieties, and promoted. The seven varieties can achieve the goal of food safety standards and repair the heavy metal chromium in farmland soil.

Author Contributions: X.Z., Y.M. contributed to the conception of the study; X.Z., H.H., C.Y., J.Z., F.Z., H.J. contributed significantly to analysis and manuscript preparation; X.Z., H.H., C.Y., J.Z. performed the data analyses and wrote the manuscript; X.Z., H.H., C.Y., J.Z., Y.M. helped perform the analysis with constructive discussions. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Anhui Provincial Science and Technology Major Research Project of Engineering: "Development and Application of Efficient Nano Remediation Materials for Heavy Metal Pollution in Farmland" (No. 17030701053).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Thanks to Anhui Province major science and technology project for providing fund support for this research. We thank Fuhong Zhou and Haoyong Jiang of the Agricultural Technology Extension Center of Mingguang for their contributions to the field experiments of this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sun, Y.Y.; Chen, J.; Wang, Y.; Cheng, J.N.; Han, Q.Q.; Zhao, Q.; Li, H.R.; Li, H.P.; He, A.L.; Gou, J.Y.; et al. Research progress on the pro-vitality of rhizosphere pro-biotics and their enhancement of plant stress resistance. *J. Meadows* **2020**, *28*, 1203–1215.
2. Zhou, X.Q.; Ji, Q.H. Effects of chromium stress on the physiology of seed germination in different maize cultivars. *Hubei Agric. Sci.* **2005**, *4*, 41–45. [CrossRef]
3. Chen, T.B.; Wei, C.Y.; Huang, Z.C.; Huang, Q.; Lu, Q.G.; Fan, Z.L. Arsenic hyperaccumulator *Pteris vittata* L. and its arsenic accumulation. *Sci. Bull.* **2002**, *47*, 902–905. [CrossRef]
4. Sarwar, N.; Imran, M.; Shaheen, M.R.; Ishaque, W.; Kamran, M.A.; Matloob, A.; Rehim, A.; Hussain, S. Phytoremediation strategies for soils contaminated with heavy metals: Modifications and future perspectives. *Chemosphere* **2017**, *171*, 710–721. [CrossRef] [PubMed]
5. Atif, M.; Perveen, S. Comparison of Alteration in Growth, Physiological and Biochemical Attributes of Ten Maize (*Zea mays* L.) Varieties under Arsenic Stress: Susceptibility and Tolerance. *Pol. J. Environ. Stud.* **2021**, *30*, 4913–4923. [CrossRef]
6. Habiba, U.; Ali, S.; Hafeez, F.; Rizwan, M.; Rehman, M.Z.U.; Hussain, A.; Asad, S.A. Morpho-Physiological Responses of Maize Cultivars Exposed to Chromium Stress. *Int. J. Agric. Biol.* **2019**, *21*, 140–148.
7. Hernández-Allica, J.; Becerril, J.M.; Garbisu, C. Assessment of the phytoextraction potential of high biomass crop plants. *Environ. Pollut.* **2007**, *152*, 32–40. [CrossRef] [PubMed]
8. Yan, X.L.; Ma, H.L.; Li, Y.; Chen, J.J. Screening of corn varieties with low accumulation of Cd and Pb in farmland around the lead-zinc mining area. *J. Yunnan Agric. Univ.* **2019**, *34*, 1076–1083.
9. Wang, A.Y.; Wang, M.Y.; Liao, Q.; He, X.Q. Characterization of Cd translocation and accumulation in 19 maize cultivars grown on Cd-contaminated soil: Implication of maize cultivar selection for minimal risk to human health and for phytoremediation. *Environ. Sci. Pollut. Res.* **2016**, *23*, 5410–5419. [CrossRef] [PubMed]
10. *GB 15618-2018*; Soil Environmental Quality Risk Control Standard for Soil Contamination of Agricultural Land. Chinese Standard GB/T: Beijing, China, 2018.

11. Jin, X.; Wang, L. Determination of soil available states Cd, Cr, Pb and Ni by the M3 method. *China Environ. Monit.* **2013**, *29*, 116–124.
12. Zhang, L.; Zhang, Y.X.; Song, B.; Wu, Y.; Zhou, Z.Y. Heavy metal enrichment characteristics and application potential of dominant plants in Lanping lead-zinc mining area in Yunnan. *Environ. Sci.* **2020**, *41*, 4210–4217.
13. *GB 2762-2017*; China Standards for Food Safety Limit of Contaminants in Food. Chinese Standard GB/T: Beijing, China, 2017.
14. *GB13078-2017*; Hygienical Standard for Feeds. Chinese Standard GB/T: Beijing, China, 2017.
15. Liu, F.; Mi, B.B.; Wei, R.M.; Zou, X.X.; Zhou, H.Q.; Wang, D.H.; Wei, X.Z. Based on cluster analysis, low cadmium accumulation pepper cultivars were screened. *J. Hortic.* **2017**, *44*, 979–986.
16. Zhang, Y.X.; Zhou, L.; Xiao, N.C.; Pang, R.; Song, B. *Bidens pilosa* L. remediation potential for cadmium-contaminated farmland. *Acta Ecol. Sin.* **2020**, *40*, 5805–5813.
17. Ge, Y.L.; Chen, X.S.; Huang, D.Y.; Ge, D.B.; Deng, Z.M.; Li, F.; Xie, Y.H. Polygonum hydropiper L. Enrichment characteristics and physiological response to cadmium. *J. Ecotoxicol.* **2020**, *15*, 190–200.
18. Chen, Y.; Liu, W.G.; Zheng, X.L.; Yuan, H.; Li, S.Q. Enrichment and distribution of heavy metals in maize plants. *Maize Sci.* **2006**, *14*, 93–95.
19. Zhang, Y.; Wang, J.S.; Dong, E.W.; Wu, A.L.; Wang, Y.; Jiao, X.Y. Comprehensive evaluation of barrenness tolerance of major sorghum cultivars in middle and late maturing areas. *Chin. Agric. Sci.* **2021**, *54*, 4954–4968.
20. Shen, Y.X.; Li, Y.; Zu, Y.Q.; Dan, F.D.; Chen, J.J. Different corn (*Zea mays* L.) Response of cultivar root cell wall polysaccharides to Pb stress. *J. Ecol. Environ.* **2018**, *27*, 950.
21. Mo, S.Q.; Cao, Y.N.; Tan, Q. Research progress on the mechanism of root secretions in the ecological remediation of heavy metal contaminated soils. *J. Ecol.* **2022**, *41*, 382–392.
22. Li, D.Y.; Cheng, H.Y.; Wang, X.Q.; Hao, Q.P.; Chang, J.N.; Huang, F.; Yan, M.; Zhang, G.S. Effects of fungal bran wood vinegar solution on physiological and biochemical indexes and heavy metal enrichment and transport of maize in copper-chromium contaminated soil. *Henan Agric. Sci.* **2019**, *48*, 65–72.
23. Ren, C.; Xiao, J.H.; Li, J.T.; Du, Q.Q.; Zhu, L.W.; Wang, H.; Zhu, R.Z.; Zhao, H.Y. Accumulation and transshipment characteristics of different maize cultivars Cd, Pb, Zn and As. *Environ. Sci.* **2022**, *43*, 4232–4252.