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Enrichment of Heavy Metals by Different Varieties of Rice

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Abstract

Pot experiment was carried out to compare the difference of Cr accumulation and distribution in different organs of 3 rice cultivars under different treatment of Cr. The results showed that the average values of Cr concentration in root, stem, leaf, chaff and grain of all cultivars were 7.63~141.09, 2.29~8.58, 14.01~39.93, 3.65~5.21 and 0.46~0.92 mg•kg-1, respectivly. Compared with the control, the accumulation and translocation of Cr in rice was significantly affected by the stress of exogenous Cr. At control treament, most of Cr was distributed in leafs, but the proportion of Cr in roots was significantly increased under the stress of exogenous Cr. At the same Cr application rate level, the distribution of Cr in II You-838 and Yixiangyou-10 followed the pattern: root > leaf > chaff > stem > grain, while it showed root > leaf > stem > chaff > grain in Jinfuyou-270. The distribution of Cr in different parts of rice was very uneven for three rice cultivars. With increasing Cr treatment levels, the proportion of Cr in roots was increasing, while a decrease was observed in aerial parts, and their bioconcentration factors (BCF) and translocation factors (TF) of Cr also declined. The transport ability of Cr from root to leaf was stronger, but weak ability in translocating Cr from root to stem, chaff and grain. There were different in Cr accumulation and distribution in organs of 3 rice cultivars. The falling sequence of accumulation and translocation ability of Cr in rice was Jinfuyou-270 > Yixiangyou-10 > II You-838. The Cr concentration in the grain of Jinfuyou-270 was 0.70~0.92 mg•kg-1, which was quite close to the national food heavy metal limits hygienic standard.

Keywords

Rice (Oryza sativa L.) Cultivars; Cr; Accumulation; Distribution.

1. Introduction

With the rapid development of mining industry, manufacturing, metallurgical industry and transportation, extensive use of agrochemicals and urban sewage discharge, soil heavy metal pollution has become increasingly serious [1]. Chromium is one of the common contaminants in soil heavy metal pollution [2]. Due to the large number of industry sectors involving chromium, distributed widely, and the amount of chromium waste production is great, chromium pollution ranked second, after lead, among all kinds of heavy metal pollution [3]. It has been estimated that nearly 60 thousand tons of chromium residue is discharged annually in China, and the cumulative Cr production was approximately 6 million tons since the 1950s. However, its detoxification or comprehensive utilization rate is less than 17% [4]. Chromium can uptake by crops from the soil through its roots and accumulate in the edible parts, that led to chromium entering the food chain. Cr is an essential trace element for the metabolism of humans and animals; however, excessive Cr will result in strong toxicity to animals and plants.

Which is recognized as a carcinogen that can induce gene mutations for humans [5]. Therefore, the uptake and accumulation mechanism of Cr by crop has attracted more and more attention. Rice is one of the most important staple foods in the world. Compared with other dry crops, rice has higher uptake and accumulation ability of heavy metals, and the content of heavy metals in unhusked rice is higher. It is about 10 percent of rice in China each year, the content of heavy metals which in unhusked rice are exceedingly over the standard [6]. Therefore, the accumulation of heavy metals in rice which may pose a significant public health risk to the local community. There are many ways to solve the problem that heavy metals in rice exceed the standard. Screening heavy metal tolerance or low accumulation rice cultivars, which plays an important role in reducing the amount of heavy metal in rice with the heavy metal pollution in agriculture soil [7]. As many research illustrated, there were greatly different in accumulation and distribution of heavy metals in rice cultivars and their organs [8-9]. Li et al [10] reported that Cd concentrations in brown rice varied among rice genotypes, and the sequence was in an order: indica > new plant type > japonica. Shi et al [11] study showed that Cd and Zn uptake and accumulation in different cultivars of hybrid rice had obvious variation, and pointed the uptake of Cd and Zn in different rice species. Northern Guangxi is one of the important rice production areas in China, where has made great contribution to rice production in our country. However, there are few reports on the Cr accumulation characteristics of rice varieties in this region. Therefore, this study was to investigate the difference of Cr accumulation and distribution in different organs of 3 rice cultivars, for screening out rice cultivars with lower accumulation of Cr.

2. Materials and Methods

2.1. Experimental Materials

The soil used for pot experiment in this study was collected from a paddy field located in Guilin institute of agricultural sciences, China. The soil contained 25.3% clay, 32.7g•kg^{-1} total organic matter, 1.82g•kg^{-1} total N, 1.22g•kg^{-1} total P, 9.7mg•kg^{-1} available P, 30.81mg•kg^{-1} Cr and had a pH value of 6.9. Soil was sampled from 0 to 20cm depth. The collected soil was air-dried and passed through 2-mm sieves. Then the screened soil was put into 45-cm diameter and 55-cm height plastic pots. The rice which named II You-838, Yixiangyou-10 and Jinfuyou-270 were used for pot experiment, and they are broadly cultivated in the local fields.

2.2. Pot Experimental

The amount of screened soil was 10kg per pot and cow manure was the source of organic matter. Cr solution were added to the pots as $CrCl_3$ with treatment levels of 0, 100, 300, and 500mg•kg^{-1}. Each pot received uniform basal application of 8 g•kg^{-1} of complex manure, and the soil was mixed thoroughly. Prior to planting, the soil was flooded and allowed to equilibrate. After 10 days, 3 rice seedlings were transplanted into the pot soil submerged with a 2-3 cm layer of water. The pots were placed in an open-air network indoors and the rice plants were kept flooded during the whole growing period. The experimental plots were treated in the same way as the local fields, fertilizers were applied and the soil was irrigated as usual during experiment.

2.3. Sample Collection and Analysis

During the harvest time, plants were gently removed from soil and washed first with tap water followed by deionized water three times. Root, stem, leaf and grain were separated and then killed out. Then oven dried to a constant weight at 80°C. After drying, roots, stems and leaves were ground to powders using a Wiley Mill, and grain divided into grain and chaff. All of the samples were treated with concentrated HNO_3 and $HClO_4$ (4:1, v/v), and diluted to 25mL with 0.2% HNO_3 solution. A quality control was implemented which included guaranteed reagent,

reagent blank, duplicate sample, national reference material (GBW07604) and all required containers, glass wares etc. were previously soaked in 10% HNO_3 and rinsed with deionized water. The concentration of Cr in the digested solution was measured by a flame atomic adsorption spectrophotometer (PE-AA700, Perkin Elmer, USA).

3. Results and Discussion

3.1. Cr Cocentration and Distribution in Different Rice Cultivars

At the different Cr application rate level, the concentrations and distribution coefficients of Cr in different parts of rice at mature period are shown in Table 1 and Table 2, respectively.

Table 1. Cr concentrations in different parts of rice under Cr treatments

Rice cultivars	Cr treatment/ (mg•kg^{-1})	*w*(Cr)/(mg•kg^{-1})				
		Grain	Chaff	Leaf	Stem	Root
II You-838	CK	0.55	3.65	14.01	2.41	7.63
	100	0.67	4.65	20.72	2.29	36.78
	300	0.46	4.24	21.43	3.01	67.24
	500	0.52	4.36	30.55	5.57	141.09
Yixiangyou-10	CK	0.52	4.20	23.98	4.22	10.07
	100	0.52	5.02	14.44	2.64	37.16
	300	0.64	4.87	23.99	3.60	76.90
	500	0.53	4.50	26.60	4.29	117.12
Jinfuyou-270	CK	0.68	4.43	39.93	4.36	9.33
	100	0.92	4.62	21.05	4.68	44.36
	300	0.70	3.89	28.80	6.79	97.24
	500	0.87	5.21	32.29	8.58	108.66

Tab. 1 indicates that the total amount of Cr in paddy plants and roots were all significantly increase with increasing Cr treatment levels, while the changes of Cr content in different aerial parts of rice was not entirely consistent, which had ups and downs but changed slightly. At the same Cr application rate level, the Cr content in the same parts of 3 rice cultivars was different. For example, at Cr treatment level of 300mg•kg^{-1}, the Cr contents in the roots of II You-838, Yixiangyou-10 and Jinfuyou-270 were 67.24, 76.90, 97.24mg•kg^{-1}, respectively, and there were obvious Cr content difference among 3 rice cultivars, with the highest value/the lowest value of 1.4. The corresponding Cr contents in the leaves were 21.43, 23.99, 28.80mg•kg^{-1}, respectively, as the ratio of the highest value/the lowest value was 1.3. The corresponding Cr contents in the stems were 3.01, 3.60, 6.79mg•kg^{-1}, respectively, as the ratio of the highest value/the lowest value was 2.3. The corresponding Cr contents in the chaffs were 4.24, 4.87, 3.89mg•kg^{-1}, respectively, as the ratio of the highest value/the lowest value was 1.3. The corresponding Cr contents in the grains were 0.46, 0.64, 0.70mg•kg^{-1}, respectively, as the ratio of the highest value/the lowest value was 1.5. Furthermore, it can be seen that the concentration of Cr in the grain under maturity stage were 0.46~0.92mg•kg^{-1}, and had not exceeded the national food heavy metal limits hygienic standard (1.0mg•kg^{-1}, GBT2762-2005).

Table 2. Distribution coefficients of Cr in different parts of rice

Rice cultivars	Cr treatment/(mg•kg^{-1})	Grain	Chaff	Leaf	Stem	Root
II You-838	CK	0.019	0.129	0.496	0.085	0.270
	100	0.010	0.071	0.318	0.035	0.565
	300	0.005	0.044	0.222	0.031	0.698
	500	0.003	0.024	0.168	0.031	0.775
Yixiangyou-10	CK	0.012	0.098	0.558	0.098	0.234
	100	0.009	0.084	0.242	0.044	0.622
	300	0.006	0.044	0.218	0.033	0.699
	500	0.003	0.029	0.174	0.028	0.765
Jinfuyou-270	CK	0.012	0.075	0.680	0.074	0.159
	100	0.012	0.061	0.278	0.062	0.587
	300	0.005	0.028	0.210	0.049	0.708
	500	0.006	0.033	0.208	0.055	0.698

In the control treatment, the amount of Cr accumulated was determined to be 15.9%~27.0% and 73.0%~84.1% in roots and aerial parts of rice, respectively (Tab. 2). However, the proportion of Cr (56.5%~77.5%) in roots increased significantly, while the proportion of Cr (22.5%~43.5%) in aerial parts decreased obviously under exogenous Cr stress. At the same treatment level of Cr, the distribution coefficients of Cr in II You-838 and Yixiangyou-10 decreased in the order: root > leaf > chaff > stem > grain, while it showed root > leaf > stem > chaff > grain in Jinfuyou-270. The distribution of Cr in different parts of rice was very uneven for 3 rice cultivars. Amount of Cr accumulated was 56.5%~77.5%, 2.8%~6.2%, 16.8%~31.8%, 2.4%~8.4% and 0.3%~1.2% in root, stem, leaf, chaff and grain, respectively. It can be seen that Cr was accumulated mainly in root of rice, while the Cr that migrated to the aerial parts of rice was mainly accumulated in the leaves. With increasing Cr treatment levels, the distribution coefficients of Cr in roots were increasing, while a decrease was observed in aerial parts. This showed that Cr was mainly concentrate in root of rice, and it was not easy to transfer to stem, leaf, chaff and grain. Results of the study are in line with the works by Chen et al [6].

3.2. Cr Accumulation and Translocation in Different Rice Cultivars

The absorption, accumulation and migration characteristics of heavy metals in the soil-rice system could be assessed by the bioconcentration factors (BCF) and translocation factors (TF). The greater BCF and TF, the stronger accumulation and migration. The bioconcentration factors (BCF) is the ratio of the heavy metal concentration in different parts of plants to that in soil [12], and the translocation factors (TF) is the ratio of the heavy metal concentration in aerial parts of plants to that in roots [13]. Table 3 shows the BCF and TF of Cr in different parts of 3 rice cultivars.

The accumulation and translocation ability of Cr in organs of rice cultivars were obviously different (Tab. 3). The BCF of Cr in root, stem, leaf, chaff and grain were 0.203~0.339, 0.008~0.142, 0.050~1.296, 0.008~0.144, 0.001~0.022, respectively. The TF of stem, leaf, chaff and grain were 0.037~0.467, 0.217~4.279, 0.031~0.478, 0.004~0.037, respectively. In control treatment, the BCF and TF of Cr in leaves were significantly larger than those in other parts, and there were also differences among rice cultivars. However, the BCF of Cr in roots were significantly larger than those in aerial parts under exogenous Cr stress. These results indicated that most of Cr were concentrated in roots of rice, and the accumulation ability of th aerial parts of rice was weak. At the same Cr application rate level, the BCF of Cr in different parts of rice followed root > leaf > chaff > stem > grain, and the TF of Cr in aerial parts of rice showed leaf > chaff > stem > grain. With increasing Cr treatment levels, the BCF and TF of Cr in aerial parts were all on the decline. This showed that Cr was mainly concentrate in the roots of rice, and it was not easy to transfer to stem, leaf, chaff and grain. By comparing the BCF and TF of Cr in different parts of 3 rice cultivars, it can also be found that the accumulation and translocation ability of Cr in rice was in the order: Jinfuyou-270 > Yixiangyou-10 > II You-838.

Table 3. The bioconcentration factors (BCF) and translocation factors (TF) of Cr in different parts of 3 rice cultivars

Rice cultivars	Cr treatment/ (mg•kg^{-1})	Grain		Chaff		Leaf		Stem		Root
		BCF	TF	BCF	TF	BCF	TF	BCF	TF	BCF
II You-838	CK	0.018	0.072	0.118	0.478	0.455	1.836	0.078	0.316	0.248
	100	0.005	0.018	0.036	0.126	0.158	0.563	0.018	0.062	0.281
	300	0.001	0.007	0.013	0.063	0.065	0.319	0.009	0.045	0.203
	500	0.001	0.004	0.008	0.031	0.058	0.217	0.010	0.039	0.266
Yixiangyou -10	CK	0.017	0.052	0.136	0.417	0.778	2.382	0.137	0.420	0.327
	100	0.004	0.014	0.038	0.135	0.110	0.389	0.020	0.071	0.284
	300	0.002	0.008	0.015	0.063	0.073	0.312	0.011	0.047	0.232
	500	0.001	0.005	0.008	0.038	0.050	0.227	0.008	0.037	0.221
Jinfuyou -270	CK	0.022	0.073	0.144	0.475	1.296	4.279	0.142	0.467	0.303
	100	0.007	0.021	0.035	0.104	0.161	0.474	0.036	0.106	0.339
	300	0.002	0.007	0.012	0.040	0.087	0.296	0.021	0.070	0.294
	500	0.002	0.008	0.010	0.048	0.061	0.297	0.016	0.079	0.205

4. Conclusion

There were different in Cr accumulation and distribution in organs of 3 rice cultivars. The accumulation and translocation ability of Cr in rice was in the order: Jinfuyou-270 > Yixiangyou-10 > II You-838. The distribution of Cr in different parts of rice was very uneven for 3 rice cultivars. Amount of Cr accumulated was 56.5%~77.5%, 2.8%~6.2%, 16.8%~31.8%, 2.4%~8.4% and 0.3%~1.2% in root, stem, leaf, chaff and grain, respectively. With increasing Cr treatment levels, the proportion of Cr in roots was increasing, while a decrease was observed in aerial parts, and their BCF and TF of Cr also declined. This showed that Cr was mainly concentrate in the roots of rice, and it was not easy to transfer to aerial parts of rice.

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References

[1] J. Zhang, G.L. Zhang, D.Q. Cai, Z.Y. Wu, Immediate remediation of heavy metal (Cr(VI)) contaminated soil by high energy electron beam irradiation, J. Hazard. Mater. 285(2015)208-211.

[2] J.N. Wu, J. Zhang, C.Z. Xiao, Focus on factors affecting pH, flow of Cr and transformation between Cr (VI) and Cr(III) in the soil with different electrolytes, Electrochim. Acta. 211(2016) 652-662.

[3] Q. Wang, Y. Li, P. Sun, X. Hua, Y.Y. Bai, W.M. Zhang, The treatment technology and research progress of hexavalent chromium-containing wastewater, Environmental Science & Technology, 36(2013) 150-156.

[4] W. Liu, Z.Q. LI, Progress on Research of Treating Cr Containing Wastewater, Guangdong Trace Elements Science,14(2007)5-9.

[5] A.K. Shanker, B. Venkateswarlu, Chromium: Environmental Pollution, Health Effects and Mode of Action, Encyclopedia of Environmental Health, (2011)650-659.

[6] H.R. Chen, Y.L. Dong, Q. Wang, B.M. Liu, Y.J. Wu, Y. Wang, Distribution and transportation of Cd, Cr, Pb in rice with contamination in soil, Chinese Agricultural Science Bulletin, 31(2015)236-241.

[7] X. Chen, Cadmium toxicity to rice and its preventions, Guangdong Trace Elements Science, 17(2010)1-7.

[8] C.G.Yang, X.Y. Liao, X. F. Zhang, Z.W. Zhu, M.X. Chen, D.Y. Wang, R.X. Mou, W.F. Chen, S.Q. Zhou, Genotypic difference in cadmium accumulation in brown rice, Chinese Journal of Rice Science, 20(2006)660-662.

[9] J.G. Liu, K.Q. Li, Z.J. Zhang, X. L. Lu, B.Y. Xu, Y.X. Cai, J.C. Yang, Q.S. Zhu, Difference of lead uptake and distribution in rice cultivars and its mechanism, Chinese Journal of Applied Ecology, 15(2004)291-294.

[10] K.Q. Li, J.G. Liu, X.L. Lu, J.C. Yang, Z.J. Zhang, Q.S. Zhu, Uptake and distribution of cadmium in different rice cultivars, Journal of Agro-Environment Science, 22(2003)529-532.

[11] J. Shi, G.X. Pan, N.M. Zhang, Effect of cadmium stress on Cd and Zn uptake and accumulation of different cultivars of hybrid rice, Acta Scientiae Circustantiae, 33(2013)2904-2910.

[12] D.E. Salt, M. Blaylock, N.P. Kumar, V. Dushenkov, B.D. Ensley, I. Chet, I. Raskin, Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants, Nature Biotechnology, 13(1995)468-474.

[13] S. Cui, Q.X. Zhou, L. Chao, Absorption and accumulation of heavy metals by plants around a smelter, Chinese Journal of Applied Ecology, 17(2006)512-515.