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Distribution and Transport of Heavy Metals in Rice Plants in the Jiujiang River Basin

Xinyue XU[1], Chengqi LIN[1,2], Yanli ZHOU[1*], Huabin HUANG[1,2*]

1. College of Environment and Public Health, Xiamen Huaxia University, Xiamen, 361024, China; 2. Key Laboratory of Fujian Universities for Environmental Monitoring, Xiamen, 361024, China

Abstract Inductively coupled plasma mass spectrometry (ICP-MS) was used to analyze the distribution and migration of heavy metals in rice plants in the Jiujiang River Basin, to evaluate the distribution of heavy metals in rice plants and to analyze their migration. The results showed that the distribution of different heavy metal elements in various tissues of rice plants varied greatly. The heavy metal migration factor of rice plant stems and leaves was significantly higher than that of rice husk and brown rice. The distribution of heavy metal content in rice in the Jiujiang River can provide a certain theoretical basis and reference value for the safety and quality of rice in the Jiujiang River Basin.

Key words Rice plants; Heavy metals; Transport; Jiujiang River Basin

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Rice is mainly found in the southern region and is a must-eat food for most Southerners daily. Rice is rich in proteins and carbohydrates, but also contains vitamins, fats, minerals and other components, and is the main food in people's daily diet, which provides the energy needed by the human body and helps to maintain the energy substances necessary for the brain. Therefore, it is important to study and evaluate the heavy metal content in agricultural products[1]. It is therefore important to study and evaluate the contents of heavy metal in agricultural products. When agricultural soils are contaminated with heavy metals, the heavy metals accumulated in the soil will be absorbed by the roots of rice plants growing on them, and migrate and transform between different tissues and organs of the rice plants[2]. In this study, the distribution of heavy metal contents in rice plants in the Jiujiang River Basin was analyzed by inductively coupled plasma mass spectrometry (ICP-MS) to evaluate the heavy metal contamination in rice plants and to analyze the migration of heavy metal contents in rice plants, aiming to provide a certain theoretical basis and reference value for the safety and quality of rice in the Jiujiang River Basin.

Materials and Methods

Sample collection and pretreatment

Rice plant samples: Rice plant samples were collected at the same time as soil samples, and 10 mature rice plants were collected around the sampling site as a mixed sample. The rice plant samples were brought back to the laboratory and rinsed with ultrapure water. Each rice plant sample was divided into root, stem, leaf, husk and brown rice samples and bagged. Each sample of rice plant was dried to constant weight in a thermostatic drier and then pulverized in a pulverizer.

Experimental methods

Extraction of total heavy metals from plants The heavy metal content of rice plant samples was dissolved in a pressure dissolution tank. According to the pre-test, a certain amount of rice plant samples was accurately weighed in the inner tank, 10 ml of nitric acid and 0.5 ml of perchloric acid were accurately added, and the sample was placed in a ventilated kitchen for overnight immersion. The inner lid was covered, and the stainless steel jacket was screwed tightly. The ablation tank was placed in a constant temperature drying oven, the temperature of which was set at 160 ℃ for 5 h. After the end of the ablation, the ablation tank was cooled down naturally in the constant-temperature drying oven, and then taken out and opened to take out the inner tank, and the inner tank was ultrasonically treated in a water bath for 5 min to drive off the brown gas. The solution was filtered through a 0.45 μm membrane and diluted to 50 ml with 2% nitric acid.

Determination of heavy metal content Heavy metals (Be, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Mo, Cd, Ba, Pb, Th, U) in the total heavy metal abatement solution and simulated gastric extracts were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Agilent 7700x). The sample introduction system consisted of a quartz atomisation chamber controlled by a Peltier refrigeration unit, a MicroMist glass concentric nebuliser and a quartz torch tube with an inner diameter of 2.5 mm. The determination was carried out in full quantitative mode using Sc, Ge, Rh, and Bi as internal standards. During the determination, the acquisition mode was mass spectrometry with 3 points of peak shape and 3 repetitions, the integration time of As and Cd was set to 1.0 s[3]. The integration time for As and Cd was set to 1.0 s. The integration time for other elements was set to 0.3 s.

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Xinyue XU (2003 –), female, P. R. China, devoted to research about environment monitoring technology.

* Corresponding author.

Heavy metal Hg in the total heavy metal digest and simulated gastric extract was determined by atomic fluorescence spectroscopy (AFS, AFS-820). A 5% hydrochloric acid solution was used as the carrier gas and a 10 g/L potassium borohydride solution as the reducing agent. The lamp current was 30 mA; the sub-high voltage was 270 V; the carrier gas flow rate was 300 ml/min; the shielding flow rate was 800 ml/min; the height of the atomiser was 8 mm; the reading time was 10 s; and the delay time was 1.0 s. The measurement method was the standard curve method, and the reading mode was peak area.

Quality control

To reduce the impact of errors introduced during the experimental analysis, strict quality control was carried out from various aspects.

Standard curve For the content determination of each heavy metal, a standard curve was first plotted, and the standard curve correlation coefficient should reach 0.999 or more.

Blank experiment For each batch of samples analyzed, a laboratory blank was made simultaneously, with the same reagents and steps except no sample was added to reduce error interference.

Parallelogram The precision of the analysis during the experiment was quality-controlled using parallel samples. The precision of the sample analysis process was determined by using parallel double samples, 10% of the samples in each batch of sample processing were selected for parallel double sample determination, and the relative deviation was controlled at 10%. The precision of instrumental determination was in the form of repeated determination, and each sample was repeated three times for the determination of heavy metal content, and the relative standard deviation was controlled at 5 percent.

Data processing In this study, the distribution maps of sampling points of soil and rice samples, spatial distribution maps of the content of each heavy metal and the results of analysis were plotted using ArcGIS 10.8software. Statistical analysis, such as the mean and standard deviation of the measured data, were carried out using Excel 2016. Scatter plots, box-and-line plots and bar stacking plots were drawn using Origin 2021b.

Evaluation of heavy metal transport in rice plants

The transport factor (TF) is the ability of heavy metals to be transferred from the plant root system to locations such as stems, leaves, seeds, *etc.*, and can reflect the movement of heavy metals from the plant root system to other above-ground organs of the plant[4]. Its calculation formula is:

$$TF = C_s / C_r$$

Where: TF is the transport factor; C_s is the heavy metal content in different tissues (stem, leaf, husk and brown rice) of rice plants; C_r is the heavy metal content in the roots of rice plants.

Results and Discussion

Distribution of heavy metal contents in rice plants

Heavy metals in rice plants may be transported and transformed among different organs (roots, stems, leaves, brown rice and rice husk). The heavy metal contents in different organs of rice plants in the Jiujiang River Basin were analyzed and the percentage of heavy metal concentration in each organ was calculated, and the results are shown in Fig. 1. Based on the calculation results, it could be seen that there was a large difference in the distribution of the different heavy metal elements in each organ of the rice plants. According to the distribution of heavy metals in each organ of rice plants, these heavy metals could be roughly divided into three categories, the first category of heavy metal elements absorbed by the plant mainly accumulated in the roots of the plant and less migrated to the above-ground part, including As and Pb, the content of these heavy metals in the roots of the plant accounted for the percentage of the heavy metal content of the plant as a whole were 86.7% and 83.8%, respectively; and the second category of heavy metals absorbed by the plant partially accumulated in the plant, and the content of heavy metals in the roots of the plant was 86.7% and 83.8%, respectively. After being absorbed by plants, some of the heavy metal elements in the second group accumulated in the roots of plants and some of them migrated to the above ground, and the percentages of the contents in the roots and above ground were comparable, including Cr, Ni, Cu, Cd and Hg, and the percentages of the contents of these heavy metals in the roots of plants in the whole plants were 47.0%, 56.4%, 53.8%, 54.4% and 45.1%, respectively; and the contents of the heavy metals in the third group after being absorbed by plants from the roots to the above-ground were 86.7% and 83.8%, respectively. The third group of heavy metal elements has a stronger ability to migrate from the roots to the above-ground part of the plant after uptake, including Zn, whose content in the roots of the plant as a percentage of the heavy metal content of the whole plant was only 25.3 percent, while 74.7 percent of the heavy metal migrated to the above-ground part of the plant.

Differences in the distribution of heavy metals among different organs of the rice plant may be related to the nature of the heavy metals themselves and the physiological mechanisms of the rice plant. Excessive levels of heavy metals in rice plants may adversely affect the normal growth and development of the plant, and then the rice plant will regulate itself to reduce its toxic effects by reducing root uptake or retaining the absorbed heavy metals in the soil roots instead of migrating them to the aboveground parts[5-6]. For example, the rice plant absorbs P, Pb and As absorbed by rice plants are mainly accumulated in the roots of the plants and are less transported to aboveground parts such as stems, leaves and brown rice. In this study, the percentages of Pb and As accumulated in the roots of rice plants were 83.8% and 86.7%, which is consistent with the results of existing studies[7-8].

For elements that are essential to the plant, rice plants are more likely to transport them above ground. For example, after absorbing Zn, rice plants are less likely to accumulate it in the roots and provide nutrients to the whole plant by transporting it to the above-ground part. In this study, Zn was mainly distributed in the stem of rice plants with a percentage of 44.1%. Other elements such as Cr, Ni, Cd and Hg, although their distribution in the aboveground part was comparable to that in the roots, were also mainly distributed in the stems and leaves in the aboveground part, while they were less distributed in the rice, a result that is in agreement with the existing studies[9-10]. It is worth noting that Cd has a greater toxic effect on rice plants, and in this study, it was also found that nearly 50% of Cd was distributed in the aboveground part, which may cause a certain toxic effect[11].

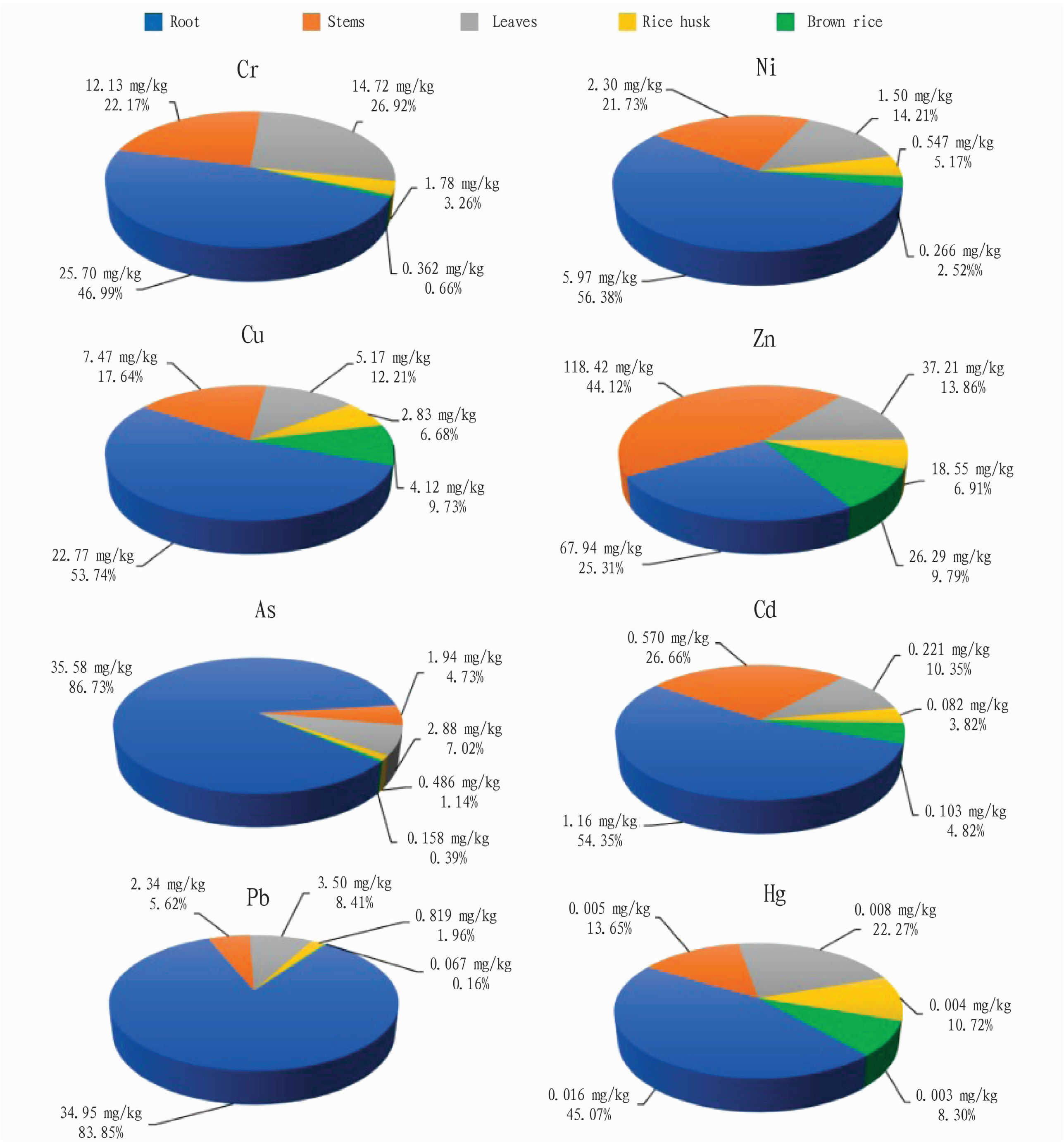

Fig. 1 Distribution of heavy metals (in percentage) in different organs of a rice plant

Migration of heavy metals in rice plants

The transport factors (TF) of heavy metals in the aboveground parts of rice plants in the Jiujiang River Basin were calculated separately, and the results are shown in Fig. 2. From the calculation results, it could be seen that there were large differences in the transport factors of different heavy metal elements in the same organs, and the transport factors of the same heavy metals in different organs. Overall, the heavy metal migration factors of rice plant stems and leaves were significantly higher than those of rice husk and brown rice.

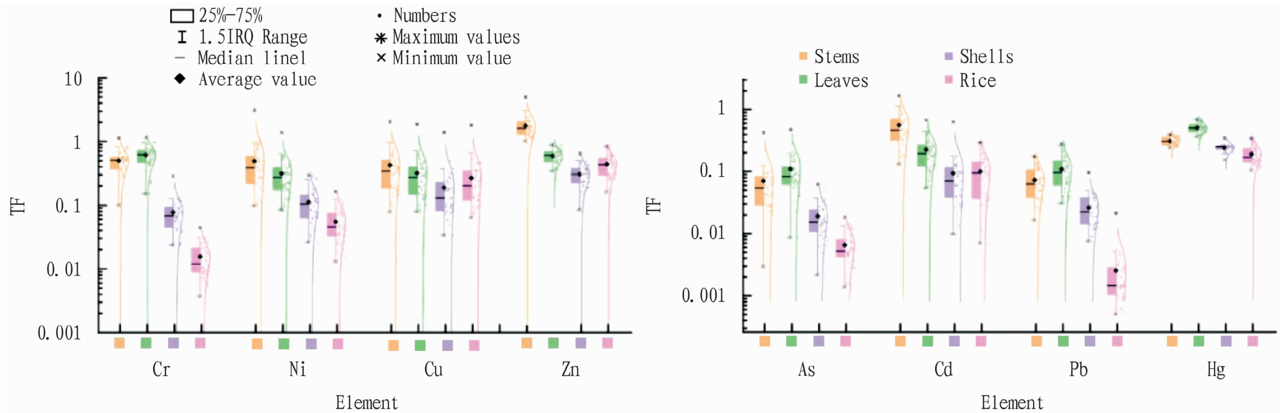

Fig. 2 Heavy metal transport factors of rice plants in the study area

The difference in the magnitude of transport capacity of heavy metal elements between different organs of rice plants may be related to the nature of the heavy metals themselves and the physiological mechanisms of the rice plants. Cu and Zn are essential elements for plants, and their transport capacity in rice plants is higher[12]. Cu and Zn are essential elements for plants, and their migration ability is stronger in rice plants. A comparison of the migration factors of different parts of rice plants showed that the differences in migration factors of Cu and Zn in each part were small, and Cd and Hg had similar characteristics. Rice absorbs Cd from the soil mainly through the root cells and transfers it to other sites, where it eventually accumulates in the rice. In the process of Cd uptake, the xylem plays an important role in the transport process, and Cd is more likely to migrate from roots to aboveground parts in rice plants[13]. It has been pointed out that rice has a strong enrichment capacity for Hg, *i. e.*, Hg absorbed by rice plants is more easily transferred to rice[14]. It could be seen that Cr, N, Hg and Hg could be easily transferred to rice. It could also be seen that the migration factors of Cr, Ni and Pb varied greatly among the parts, especially the comparison between roots and rice. This result suggests that the roots of rice plants are less likely to migrate to the aboveground part after absorbing Cr, Ni and Pb from agricultural soils. This result is consistent with the existing studies[15-16]. The results were consistent with existing studies. The migration capacity of rice plants for As is also small, and some studies have shown that the uptake of As by plants depends mainly on the type of arsenate, which tends to be blocked outside the root cells, its uptake is very small, and the uptake of As is mainly concentrated in the roots and xylem, and rarely migrates to the seeds.

Conclusions and Discussion

The distribution of different heavy metal elements in various tissues of rice plants varied considerably. Among them, after the uptake of Pb and As by rice plants, they were mainly accumulated in the roots of the plants, and less transported to the aboveground parts such as stems, leaves brown rice, *etc.* Zn was mainly transported to the aboveground parts, while Cr, Ni, Cu, Cd and Hg had comparable abilities to accumulate in the roots and transported to the aboveground parts[17]. Zn mainly migrates to the aboveground part, while Cr, Ni, Cu, Cd and Hg have comparable ability to accumulate in roots and migrate to the aboveground part.

The results of the migration factors showed that there were large differences in the migration factors of different heavy metal elements in the same tissues, and the migration factors of the same heavy metals in different tissues, and in general, the migration factors of heavy metals in the stems and leaves of rice plants were significantly higher than those of rice hulls and brown rice.

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Conclusions and Discussion

Seed stems are the key factor affecting the quality of medicinal materials. Studies have shown that the content of lobetyolin was positively correlated with the grade of seedlings, but negatively correlated with the content of polysaccharides[7], and the content of cichoric acid in *Brauneria purpurea* treatment of secondary seedlings was the highest in flowers, leaves and stems[8]. Zhang *et al.*[9] found that the difference of seed stems affected the difference of plant morphology and yield during the growth and development of *Pinellia pedatisecta* Schott, so it is appropriate to choose first-class seed stems. Consistent with the research, different kinds of stems can affect the quality and quality of *F. thunbergii* Miq.[10].

Soil fertility provides nutrients for the growth and development of *F. thunbergii* Miq. After the introduction of *F. thunbergii* Miq. from different provenances, the detection of soil available elements at different growth stages is conducive to studying the law of fertilizer demand of *F. thunbergii* Miq., which can improve the ratio of output to input to thereby obtain higher economic and environmental benefits. Song *et al.*[11] pointed out that the yield of *F. thunbergii* Miq. was positively correlated with the K content in soil and the K accumulation in plants. In this study, the stem size of different provenances also affected the availability of soil elements. The availability of elements N, P and K in the soil of SSG3 from Ningbo, Zhejiang Province was significantly higher than that of groups SSG1 and SSG2.

In this study, only field experiments were designed, but there was no correlation analysis on the effects of different stems on the effective components of *F. thunbergii* Miq. Further quality analysis is needed to provide more reference for high-yielding and efficient cultivation of introduced *F. thunbergii* Miq.

To sum up, in the introduction process of *F. thunbergii* Miq. to Wanzhou, Chongqing, small stems of Pan'an and Ningbo provenances (SSG3, 121 – 160/kg) and middle stems of Nantong and Fengjie provenances (SSG2, 81 – 120/kg) showed higher soil availability.

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