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Heavy metals distribution and accumulation characteristics of 16 species plants on ecological floating-bed

Chengxia Jia[1,2], Mu Yang[1,2], Jiangqi Qu[1,2], Pan Liu[1,2], Zhiming Xin[1,2], Qingjing Zhang[1,2,*]

[1]Beijing Key Laboratory of Fishery Biotechnology, Beijing, China;

[2]Academy of Agriculture & Forestry Sciences, Beijing, China;

*Corresponding author e-mail: 545031646@qq.com

Abstract. Distribution and accumulation characteristics of copper (Cu), zinc (Zn), mercury (Hg), and lead (Pb) in the aerial and underground parts of 16 species of plants on ecological floating-bed were studied in the present study, and they showed significant differences. Most translocation factors for Cu, Zn, Hg, and Pb were smaller than 1. Coleus blumei had a considerable absorption and accumulation effect on Zn, Hg, and Pb; Hylotelephium erythrostictum had a good absorption and accumulation effect on Zn and Hg. Arundo donax var. versicolor, Lythrum salicaria, and Iris pseudacorus which had remarkable absolute accumulation in the aerial part due to their massive biomass, and were expected to have a promising prospect in applying floating-bed technology.

Keywords: Floating bed; heavy metals; distribution characteristics; accumulation effect;

1. Introduction

In recent decades, ecological floating-bed technology has been widely used as an effective method to remove pollutants from water. It can reduce the pollutants in water, and form a beautiful natural landscape on the water. Absorption and transport of plants are the main pathways for pollutant removal. By regularly harvesting the aerial parts of the plants on floating-bed, pollutants can be efficiently removed from the water.

Studies have shown that the purification effect of different plants on pollutants varies significantly. The distribution of pollutants in the roots, stems, and leaves of plants is also widely divergent [1-3]. Lead and cadmium entering Phragmites australis retained in roots, instead of transfered to stems and leaves due to the specific resistance to lead of stems. However, Typha angustifolia had a developed rhizome, and lead and zinc entered Typha angustifolia mainly enriched in cytoderm of cortical cells. Yet, only a tiny amount enters protoplasm [4]. In this study, we studied the distribution and accumulation characteristics of Cu, Zn, Hg, and Pb in the aerial and underground parts of 16 plants on floating-bed, and compared the translocation and accumulation capacity of 16 plants to heavy metals, with the aim to provide scientific data for applying ecological floating-bed technology.

2. Material and Methods

2.1 Tested plants

A total of 16 species of plants, including Calathea veitchiana, Canna warszewiczii, Coleus blumei, Canna glauca, Arundo donax var. versicolor, Lythrum salicaria, Iris pseudacorus, Iris lactea var. chinensis, Schefflera octophylla, Dracaena sanderiana, Dieffenbachia picta, Phnom Penh Chlorophytum, Anthurium andraeanum, Philodendron congo, Hylotelephium erythrostictum, and Chamaedorea elegans were tested in this experiment.

2.2 Methods

The experiment was carried out for 110 days in industrialized circulating aquaculture for breeding Cyprinus carpio in Beijing during the peak breeding period from June to October. The

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initial culture density of fish was 20 kg·m-3, and the feeding ratio was 1% of body weight. Feeding time points were at 9:00, 13:00, and 17:00 each day. The size of floating-bed made of polyethylene foam board was 100.0 cm(L) × 100.0 cm(W) × 13.8 cm(H). Each floating bed had 16 holes, and the hole diameter and distance were 7.5 cm and 7.2 cm, respectively. The floating bed was planted with 16 plants of the same species per square meter, and placed on the surface of the culture pond. At the end of the experiment, the plants were cleaned with double distilled water three times. Every plant was divided into underground parts (roots) and aerial parts (stems and leaves). Wet weights of two parts were also measured one by one. Then they were placed in the laboratory for the natural drying process, and dried at 105℃ in a 101-2AB electric blast drying oven until constant weight. After that, the dry weights were measured again. Finally, the divided parts of plants were ground, and the contents of Cu, Zn, Hg, and Pb were measured by atomic absorption spectrophotometry (AAS). Results were calculated through means of triplicate measurements.

2.3 Data Analysis

The data were analyzed by Microsoft Excel 2007 and SPSS 16.0. Translocation factor (TF) and effective translocation factor (ETF) between aerial part and underground part were calculated [5].

3. Results and Analysis

3.1 Contents of heavy metals in the aerial and underground parts of plants

Cu, Zn, Hg, and Pb contents in the aerial and underground parts of 16 species plants are shown in Figure 1. A significant difference was observed. Cu contents in the aerial part ranged from 2.75mg·kg-1 to 19.96mg·kg-1, among which Cu content in the aerial part of Dieffenbachia picta was extremely significantly higher than those of other plants (P<0.01), followed by Lythrum salicaria, and Phnom Penh Chlorophytum had the lowest. In the underground part, Cu contents ranged from 6.22mg·kg-1 to 18.75mg·kg-1. Among which Cu contents in the underground part of Coleus blumei, Lythrum salicaria, Philodendron congo, and Canna glauca were significantly higher than those of other plants (P<0.05). Cu content in the underground part of Dieffenbachia picta was significantly lower than those of other plants (P<0.05). Zn contents in the aerial part ranged from 1.12mg·kg-1 to 14.06mg·kg-1, among which Zn content in the aerial part of Lythrum salicaria was extremely significantly higher than those of other plants (P<0.01). Calathea veitchiana had the lowest. In the underground parts, Zn contents ranged from 2.52mg·kg-1 to 14.73mg·kg-1. Among which Zn content in the underground part of Lythrum salicaria was extremely significantly higher than those of other plants (P<0.01), followed by Iris pseudacorus, and those in the underground part of Coleus blumei was significantly lower than those of other plants (P<0.05). Hg contents in the aerial part ranged from 0.012mg·kg-1 to 0.085mg·kg-1. among which Hg content in the aerial part of Hylotelephium erythrostictum was higher than those of other plants, followed by Coleus blumei. Iris pseudacorus had the lowest. In the underground parts, Hg contents ranged from 0.010mg·kg-1 to 0.063mg·kg-1. Among which Hg contents in the underground part of Lythrum salicaria and Coleus blumei were extremely significantly higher than those of other plants (P<0.01), followed by Hylotelephium erythrostictum, and that of Chamaedorea elegans was the lowest. Pb contents in the aerial part of 16 species plants ranged from 0.05mg·kg-1 to 0.54mg·kg-1. Pb contents in the aerial part of Lythrum salicaria and Arundo donax var. versicolor were higher than those of other plants, and the lowest was Schefflera octophylla. In the underground parts, Pb contents ranged from 0.08mg·kg-1 to 0.91mg·kg-1. Among which Pb content in the underground part of Canna glauca was extremely significant higher than those of other plants (P<0.01), followed by Arundo donax var. versicolor, and those in the underground part of Dracaena sanderiana and Dieffenbachia picta were significantly lower than those of other plants (P<0.05).

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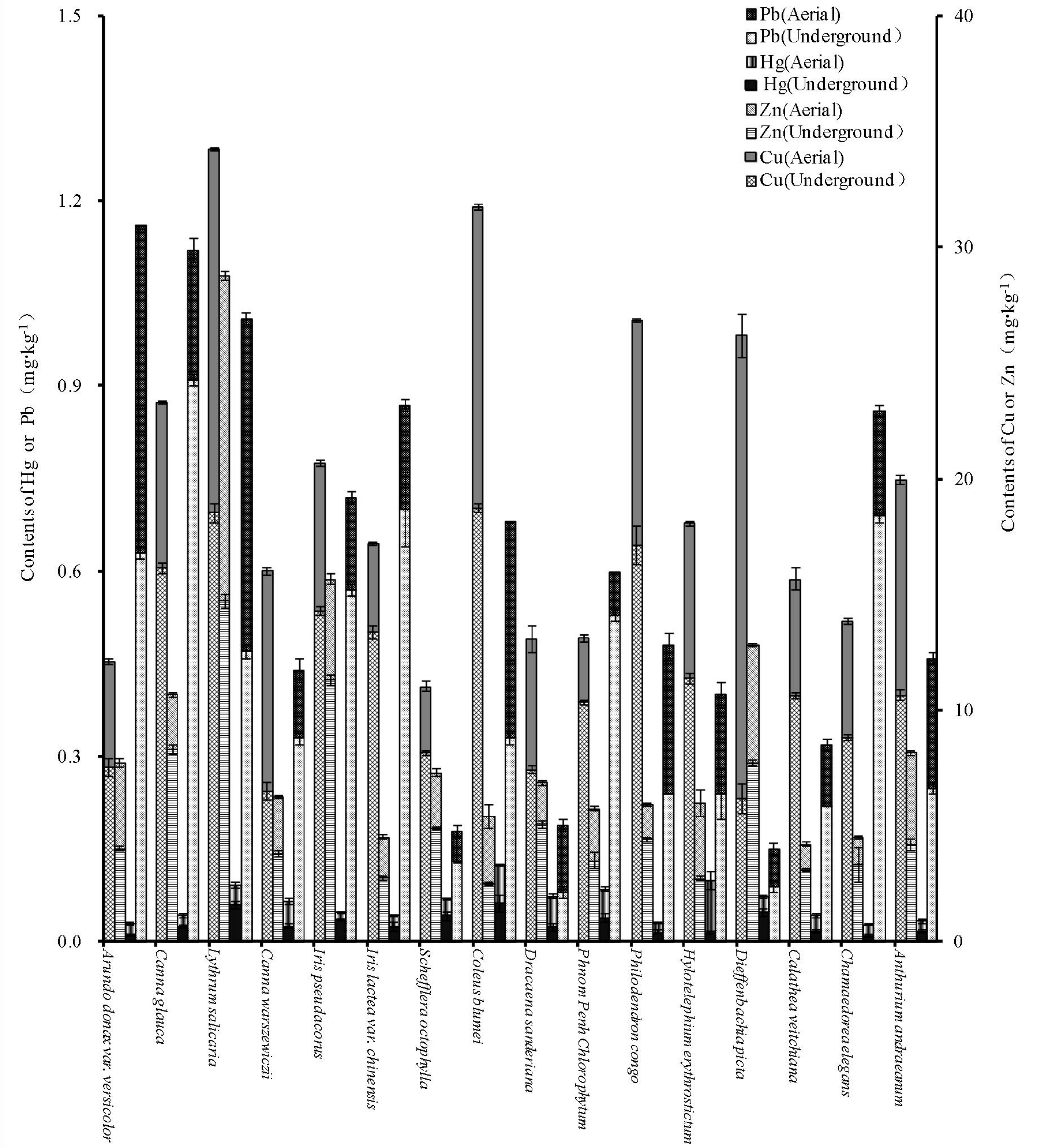

Figure 1. Content of heavy metals in the aerial and underground parts of plants

3.2 Accumulation of heavy metals in the aerial and underground parts of plants

Cu, Zn, Hg, and Pb accumulation in the aerial and underground parts of 16 species plants are shown in Figure 1, and they showed significant differences. Cu accumulation in the aerial parts ranged from 0.79mg·m-2 to 5.25g·m-2. Cu accumulation in the aerial parts of Lythrum salicaria was extremely significantly higher than those of other plants ($P<0.01$), followed by Canna warszewiczii, Arundo donax var. versicolor, and Canna glauca. Phnom Penh Chlorophytum had the lowest. In the underground parts, Cu accumulation ranged from 0.21mg·m-2 to 3.8mg·m-2. Cu accumulation in the underground parts of Lythrum salicaria was extremely significantly higher than those of other plants ($P<0.01$), followed by Iris pseudacorus and Iris lactea var. chinensis, and that of Dieffenbachia picta was the lowest. Zn accumulation in the aerial parts ranged from 0.26mg·m-2 to 4.71g·m-2. Zn accumulation in the aerial parts of Lythrum salicaria was extremely significantly higher than those of other plants ($P<0.01$), followed by Arundo donax var. versicolor. Coleus blumei had the lowest. In the underground parts, Zn accumulation ranged from 0.08mg·m-2 to 3.02mg·m-2. Zn accumulation in the underground parts of Lythrum salicaria was extremely significantly higher than those of other plants ($P<0.01$), followed by Iris pseudacorus. The lowest was Coleus blumei. Hg accumulation in the aerial parts ranged from 2.57μg·m-2 to 18.55μg·m-2.

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Hg accumulation in the aerial parts of Canna warszewiczii was extremely significantly higher than those of other plants (P<0.01), followed by Hylotelephium erythrostictum and Arundo donax var. versicolor. Dieffenbachia picta had the lowest. In the underground parts, Hg accumulation ranged from 0.76μg·m-2 to 12.59μg·m-2. Hg accumulation in the underground parts of Lythrum salicaria was extremely significantly higher than those of other plants (P<0.01), followed by Iris pseudacorus, and that of Dracaena sanderiana was the lowest. Pb accumulation in the aerial parts ranged from 6.43μg·m-2 to 441.8μg·m-2. Pb accumulation in the aerial parts of Arundo donax var. versicolor was extremely significantly higher than those of other plants (P<0.01), followed by Lythrum salicaria and Canna glauca. Dieffenbachia picta had the lowest. In the underground parts, Pb accumulation ranged from 2.04μg·m-2 to 233.3μg·m-2. Pb accumulation in the underground parts of Arundo donax var. versicolor was extremely significantly higher than those of other plants (P<0.01), followed by Iris lactea var. chinensis and Iris pseudacorus, and that of Dieffenbachia picta was the lowest.

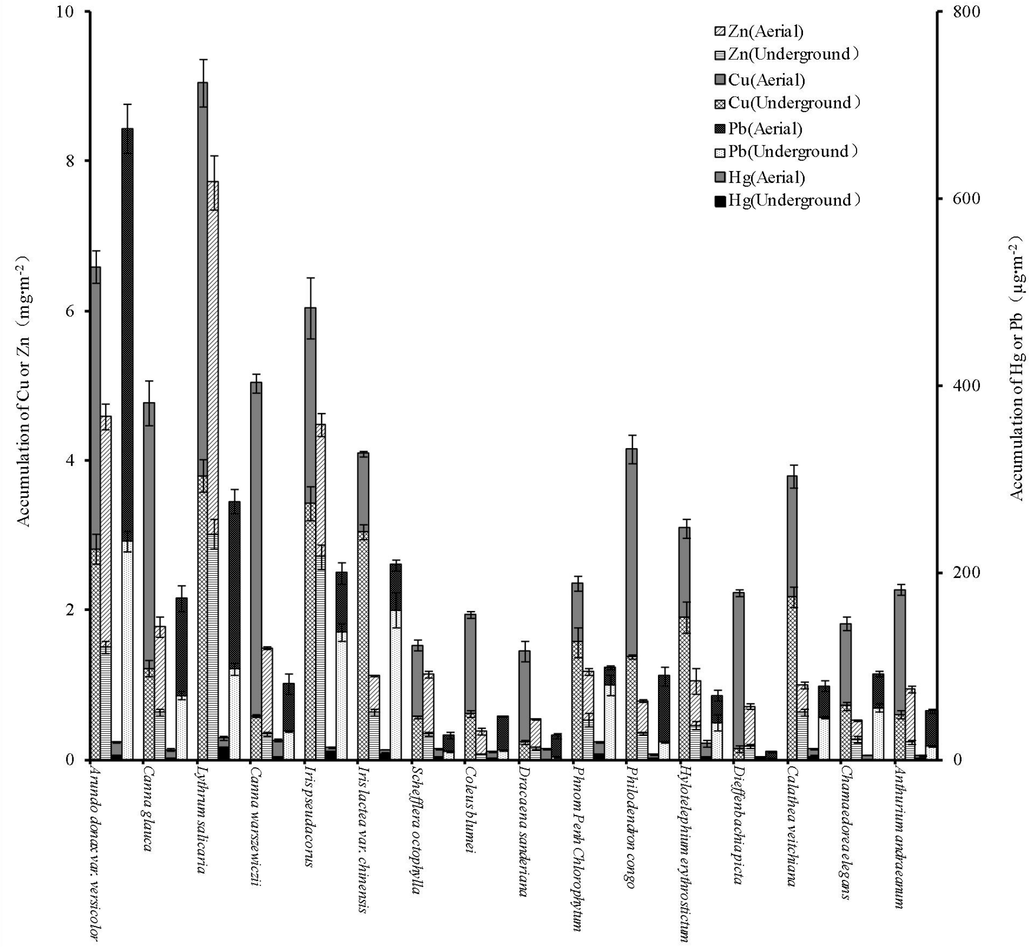

Figure 2. Accumulation of heavy metals in the aerial and underground parts of plants

3.3 Translocation factor and effective translocation factor of plants

The translocation factors of Cu, Zn, Hg, and Pb of 16 species of plants are shown in Figure 3, and they showed significant differences. Cu translocation factor ranged from 0.26 to 3.23. Translocation factor of Dieffenbachia picta was extremely significantly higher than those of other plants (P<0.01), followed by Canna warszewiczii, and translocation factors of other plants were smaller than 1. Zn translocation factor ranged from 0.29 to 1.09. There was no significant difference among 16 species (P>0.05). Only translocation factor of Hylotelephium erythrostictum and Coleus blumei were greater than 1. Translocation factor of Hg ranged from 0.34 to 5.40. There were seven species of plants that had high translocation factor greater than 1. Translocation factor of

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Hylotelephium erythrostictum reached 5.40, which was extremely significantly higher than those of other plants (P<0.01). Translocation factor of Pb ranged from 0.12 to 1.25. There were three species of plants, included Dracaena sanderiana, Lythrum salicaria, and Coleus blumei, which had higher translocation factors greater than 1. In addition, the translocation factor of Dracaena sanderiana was significantly higher than those of other plants (P<0.05).

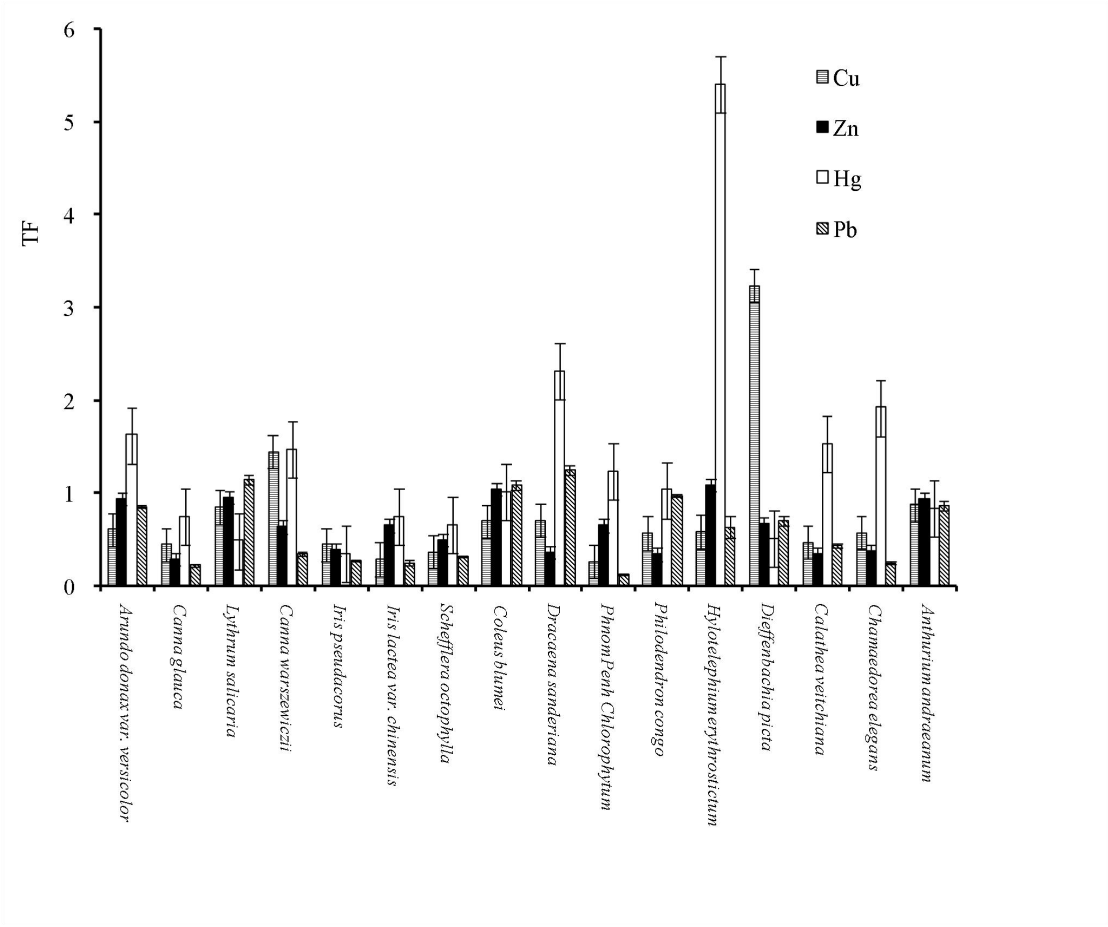

Figure 3. Translocation factor of heavy metals

Effective translocation factors of Cu, Zn, Hg, and Pb of 16 species plants are shown in Figure 4. The result showed significant difference between effective translocation factors and translocation factors of 16 species plants either for Cu, Zn, Hg, and Pb. Effective translocation factors of Cu ranged from 0.34 to 14.7. Except for Iris lactea var. chinensis, Phnom Penh Chlorophytum, Hylotelephium erythrostictum, Calathea veitchiana, and Iris pseudacorus, effective translocation factors of Cu of other 11 species plants were all exceeded 1. Effective translocation factor of Cu of Dieffenbachia picta was extremely significantly higher than those of other plants (P<0.01), followed by Canna warszewiczii. Effective translocation factors of Zn ranged from 0.56 to 3.61. Besides, there was no significant difference in effective translocation factors of Zn among 16 species plants (P>0.05). Except for Calathea veitchiana, Iris pseudacorus, Iris lactea var. chinensis, Calathea veitchiana, and Chamaedorea elegans, effective translocation factors of Zn of other 12 species plants were all greater than 1. Effective translocation factor of Zn of Coleus blumei was the highest. Effective translocation factors of Hg ranged from 0.57 to 15.0. Except for Iris pseudacorus, Lythrum salicaria, and Iris lactea var. chinensis, effective translocation factors of Hg of other 13 species plants were all greater than 1. Effective translocation factor of Hg of Dracaena sanderiana was extremely significantly higher than those of other plants (P<0.01), followed by Canna warszewiczii. Effective translocation factors of Pb ranged from 0.30 to 8.86. There were six species

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of plants which had smaller effective translocation factors smaller than 1. Effective translocation factor of Pb of Dracaena sanderiana was extremely significantly higher than those of other plants (P<0.01), followed by Philodendron congo and Dieffenbachia picta.

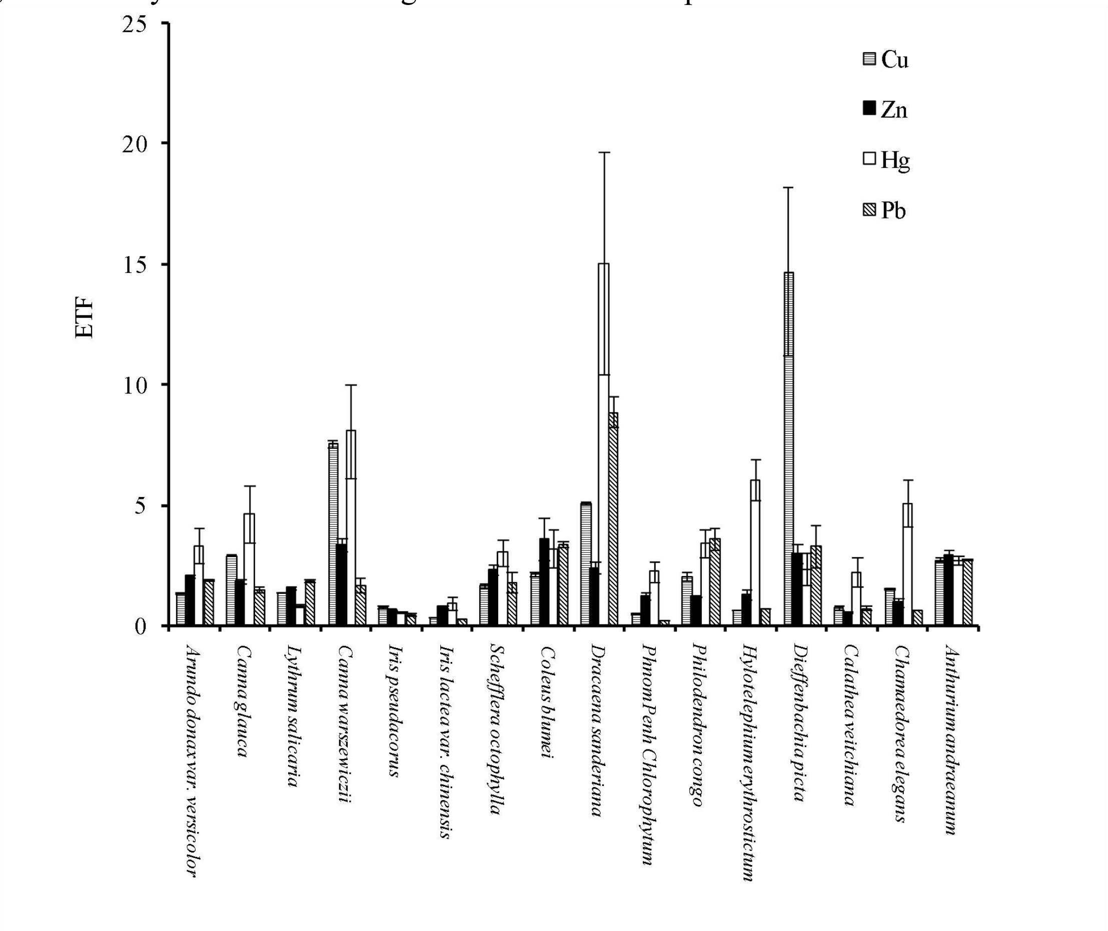

Figure 4. Effective translocation factors of heavy metals of 16 species of plants

4. Discussion

Heavy metals in water will seriously endanger aquatic organisms, and damage human health through accumulation in the food chain because of its characteristics such as refractory degradation, easy accumulation, and high toxicity. The ecological floating-bed technology utilizes the absorption of the roots during the growth of plants, as well as the translocation from roots to stems and leaves. After the aerial parts of plants were harvested, those pollutants in the plants also be transfered. Studies have demonstrated significant differences of the absorption and translocation of pollutants in different plants, so do their contents in various plant organs [6,7].

In this study, all these 16 species can absorb Cu, Zn, Hg, and Pb. They were distributed in the aerial and underground parts of plants. However, four heavy metals distribution and accumulation characteristics in 16 species plants were differed significantly. Most translocation factors for Cu, Zn, Hg, and Pb were smaller than 1, indicating that most heavy metals would be trapped in the roots of the plants after being absorbed by roots and entering the plant body. And a tiny part would be transfered to the aerial parts. The roots were the main enrichment organs. Translocation factors can reflect the ability of plants to transfer pollutants from roots to stems and leaves. It is an important indicator to evaluate the transfer capacity and phytoremediation potential [8]. Translocation factors of Coleus blumei tested in this study for Zn, Hg, and Pb tend to be more than 1, indicating its role as an efficient transfer system that enables the translocation of those heavy metals from roots to stems and leaves. Generally, the content of heavy metals in plant tissues is the highest in the underground parts, followed by stems, and the least in leaves. This may be due to the endothelial tissue in the underground part of plant that can prevent heavy metals from translocation to aerial parts [9,10]. In addition, it was found that Hylotelephium erythrostictum had a considerably favorable enrichment and transfer effect on Zn and Hg [5,11], which was consistent with our research. The translocation factor for Hg was as high as 5.67 in this study, and demonstrated that Hylotelephium erythrostictum had a commendable ability of translocation for Hg. The distribution of different elements in plant tissues is closely related to plant species, coexisting ions, or complexes [12-14]. Sedum L. had strong endurance and recovery ability to polluted water, which can be adjusted by the rapid adaptability of the protective enzyme system. It is noteworthy that, under heavy metal stress, the contents of small molecular organic acids, sugars, amino acids, and other secondary metabolites secreted by underground parts increase obviously, which tends to elevate metal chelating ligands obviously , thus improving the adaptability of plants[15,16].

Cu and Zn are necessary physiological requirements for plant growth [10]. Besides, Pb and Hg are harmful elements to plant growth. Heavy metals are of great likelihood to damage the photosynthetic system of plants, inhibit plant growth, and reduce plant biomass after they enter the targeted plants [11]. In this regard, the accumulation of Pb and Hg depends both on the absorption capacity of plant, and on the resistance of plants to toxic heavy metals. Studies have shown that genes expression of Populus×canescens will be significantly up-regulated under Pb stress, which will promote the absorption of Pb by root and translocation to aerial part [12]. In this study, Hylotelephium erythrostictum had a good absorption and accumulation effect on Hg, showing its effective absorption of Hg by root, and a specific detoxification mechanism. Still, further studies are needed for the sake of figuring out its molecular mechanism.

Biomass of plants significantly affects the efficiency of removal of heavy metals. Results showed the effective translocation factors for Cu, Zn, Hg, and Pb of Dracaena sanderiana were all high, while the absolute accumulation in stems and leaves was low because of its low biomass per unit area. Arundo donax var. versicolor, Lythrum salicaria, and Iris pseudacorus showed high absolute accumulated amount due to their high biomass, either underground part or aerial part. They were expected to have a promising prospect in applying floating-bed technology.

5. Conclusion

The distribution and accumulation characteristics of Cu, Zn, Hg, and Pb in the aerial and underground parts of 16 species of plants on ecological floating-bed showed significant differences. Most translocation factors for Cu, Zn, Hg, and Pb were smaller than 1, indicating most heavy metals were trapped in the roots of the plants instead of transferred to the aerial parts. Coleus blumei had a considerable absorption and accumulation effect on Zn, Hg, and Pb; Hylotelephium erythrostictum had a good absorption and accumulation effect on Zn and Hg. Arundo donax var. versicolor, Lythrum salicaria, and Iris pseudacorus which had remarkable absolute accumulation in the aerial part due to their massive biomass, were expected to have a promising prospect in applying floating-bed technology.

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References

[1] Kumar P B, Dushenkov V. Phytoextraction: The use of plants to remove heavy metals from soils. Environmental Science and Technology, 1995, 29(5): 1232-1238.

[2] Yaashikaa P R, Kumar P S, Jeevanantham S, et al. A review on bioremediation approach for heavy metal detoxification and accumulation in plants. Environmental Pollution, 2022, 301:1-15.

ISSN:2790-1688 DOI: 10.56028/aetr.1.1.62

[3] Jeevanantham S, Saravanan A, Hemavathy M V, et al. Removal of toxic pollutants from water environment by phytoremediation: A survey on application and future prospects. Environmental Technology & Innovation, 2019, 13: 264-276.

[4] Li S C. Remediation and evaluation of different plants on typical heavy metal contaminated sediment. Tianjin: Tianjin University, 2014.

[5] Yang J R. Study on heavy metal enrichment effect of sedum macrophylla-citrus under different planting patterns. Xi'an: Chang'an University, 2019.

[6] Islam E, Yang X, Li T. Effect of Pb toxicity on root morphology, physiology and ultrastructure in the two ecotypes of Elsholtzia argyi. Journal of hazardous materials, 2007, 147(3): 806-816.

[7] Archer M J G, Caldwell R A. Response of six Australian plant species to heavy metal contamination at an abandoned mine site. Water, Air, and Soil Pollution, 2004, 157(1-4):257-267.

[8] Lago-Vila M, Arenas-Lago D, Rodríguez-Seijo A, et al. Ability of Cytisus scoparius for phytoremediation of soils from a Pb/Zn mine: Assessment of metal bioavailability and bioaccumulation. Journal of Environmental Management, 2019, 235: 152-160.

[9] Li Q H. Spatial distribution and accumulation characteristics of heavy metals in constructed wetlands plants. Xi'an: Chang'an University, 2014.

[10] Lu Y, Xiao M, Zhang W H, et al. Case project of phytoremediation of heavy metal contaminated soil by rotation Sedum spectabile with Triticum aestivum. Environmental Ecology, 2020, 2(8), 74-81.

[11] Dai B Q, Xin S G, Kang Y H, et al. Physiological responses and absorption of heavy metals by sedum spectabile boreau under the stress of combined heavy metal pollution. Journal of Agro-Environment Science, 2008, 27(3): 1051-1056.

[12] Ramos I, Esteban E, Lucena J J, et al. Cadmium uptake and subcellular distribution in plants of Lactuca sp. Cd-Mn interaction. Plant Science, 2002, 162(5): 761-767.

[13] Jiang W, Liu D. Pb-induced cellular defense system in the root meristematic cells of Allium sativum L. Plant Biology, 2010, 10(1): 1-8.

[14] Ying C, Liu S, Yang R, Zhang S, Luo C D. Effects of cadmium on growth, plasma membrane ATP activity, and absorption of N, P and K in Solanum nigrum L. Chinese Journal of Applied and Environmental Biology, 2015, 21(01): 121-128.

[15] Nouairi I, Ben Ammar W, Ben Youssef N, et al. Antioxidant defense system in leaves of Indian mustard (Brassica juncea) and rape (Brassica napus) under cadmium stress. Acta Physiologiae Plantarum, 2009, 31(2): 237-247.

[16] Assche F V, Clijsters H. Effects of metals on enzyme activity in plants. Plant Cell and Environment, 2010, 13(3): 195-206.