Tolerance and Accumulation Characteristics of Viburnum odoratissimum to Cadmium in Contaminated Soil (Postprint)

Authors: Zeng Peng, Cao Xia, Guo Zhaohui, Xiao Xiyuan, Liu Yanan, Xin Liqing

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Abstract

A greenhouse pot experiment was conducted to investigate the cadmium (Cd) tolerance and accumulation characteristics of coral tree in soil. The results indicated that coral tree exhibited strong tolerance to Cd in contaminated soil. Within 56 days of cultivation, soil Cd content had no significant effect on coral tree biomass; however, with extended cultivation time (105-203 days), the growth of coral tree was significantly inhibited by soil Cd. Compared with the control treatment (soil Cd content of 3.6 mg/kg), after 154 days of cultivation, the contents of chlorophyll a, chlorophyll b, carotenoids, and malondialdehyde (MDA) in coral tree leaves showed no significant changes under the treatment with soil Cd content of 24.6 mg/kg; after 203 days of cultivation, under the treatment with soil Cd content of 24.6 mg/kg, the contents of carotenoids and MDA in coral tree leaves showed no significant changes, but the contents of chlorophyll a and chlorophyll b in leaves were significantly inhibited, thereby significantly inhibiting leaf growth of coral tree ($P < 0.05$). After 203 days of cultivation, both the bioconcentration factor and translocation factor of Cd in coral tree were greater than 1, indicating that coral tree possesses certain Cd accumulation and translocation capabilities in soil. These results demonstrate that coral tree has potential for phytoremediation of Cd-contaminated soil.

Full Text

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ZENG Peng, CAO Xia, GUO Zhaohui*, XIAO Xiyuan, LIU Yanan, XIN Liqing

Institute of Environmental Engineering, School of Metallurgy and Environment, Central South University, Changsha 410083, China

Abstract

A pot experiment was conducted to investigate the tolerance and accumulation characteristics of *Viburnum odoratissimum* growing in cadmium (Cd)-contaminated soil. The results demonstrated that *V. odoratissimum* possesses strong tolerance to Cd in polluted soils. Within 56 days of cultivation, the biomass of *V. odoratissimum* was only slightly affected by soil Cd content. However, with extended cultivation time (105-203 days), the growth of *V. odoratissimum* was significantly inhibited by soil Cd content. After 154 days of cultivation at a soil Cd concentration of 24.6 mg/kg, the contents of chlorophyll a, chlorophyll b, carotenoid, and malondialdehyde (MDA) in fresh leaves were only marginally different from those of the control. After 203 days, carotenoid and MDA contents increased slightly, whereas chlorophyll a and chlorophyll b contents were significantly inhibited. Notably, leaf growth of *V. odoratissimum* was significantly inhibited ($p < 0.05$) when soil Cd content reached 24.6 mg/kg. Moreover, both the bioconcentration factor and transfer factor for Cd in the soil exceeded 1 after 203 days of cultivation. These results suggest that *V. odoratissimum* is a promising candidate for the phytoremediation of Cd-contaminated soil.

Keywords: Cd; contaminated soil; ornamental plants; phytoremediation; *Viburnum odoratissimum*

1. Introduction

Rapid industrialization and urbanization in China have led to severe soil pollution, particularly heavy metal contamination. Cadmium is a highly toxic heavy metal element that can cause metabolic disorders and structural damage to cells even at low concentrations. Heavy metals like Cd can exert toxic effects on producers and consumers through bioaccumulation and biomagnification. While physical and chemical remediation methods for large-scale contaminated soils are challenging and costly, phytoremediation offers advantages of low cost, in-situ treatment, and simple post-remediation handling.

Hyperaccumulator plants such as *Sedum alfredii*, *Solanum nigrum*, and *Viola baoshansensis* have received considerable attention for heavy metal remediation. However, these plants are often limited by their small size and slow growth rates, restricting their practical application. Although tolerant plants like *Arundo donax*, *Typha orientalis*, and *Artemisia selengensis* exhibit strong tolerance and certain accumulation capacities, they are primarily used in wetland ecosystems. Ornamental plants with strong tolerance, high aesthetic value, and broad ecological adaptability represent a promising alternative for remediating heavy metal-contaminated soils while providing landscape benefits. Species such as *Pittosporum tobira*, *Osmanthus fragrans*, and *Cedrus deodara* have demonstrated resistance to heavy metal pollution.

Viburnum odoratissimum, an evergreen shrub or small tree in the Caprifoliaceae family, is widely used in urban landscaping and roadside greening due to its high ornamental value and broad ecological adaptability. Previous studies have indicated that *V. odoratissimum* exhibits strong resistance to Cd, with leaf Cd accumulation reaching 1.043 mg/kg and enrichment coefficients of 1.834. However, systematic research on the tolerance and accumulation characteristics of *V. odoratissimum* in Cd-contaminated soils remains limited. This study investigates the effects of soil Cd on *V. odoratissimum* biomass, photosynthetic pigments, and MDA content, as well as Cd accumulation and distribution patterns in different plant tissues, to provide a scientific basis for the application of this species in remediating heavy metal-contaminated soils.

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2. Materials and Methods

2.1 Soil and Plant Materials The test soil was collected from the surface layer (0–20 cm) of a typical mining and smelting area in Hengyang, Hunan Province. Its basic physicochemical properties are presented in Table 1 , with a background Cd content of 3.37 mg/kg. Healthy *V. odoratissimum* seedlings were purchased from a nursery in Changsha.

2.2 Experimental Design The test soil was air-dried and passed through a 2 mm sieve. Plastic pots (18 cm top diameter, 13 cm bottom diameter, 17 cm height) were filled with 3.5 kg of soil. Cadmium was added as Cd(NO) · 4H O to establish three treatment levels based on the Soil Environmental Quality Standard (GB15618-1995) and the Soil Environmental Quality Assessment Standard for Exhibition Sites (HJ350-2007): 0 mg/kg (CK, 3.6 mg/kg background), 6 mg/kg (T1, total 9.6 mg/kg), and 21 mg/kg (T2, total 24.6 mg/kg). Each treatment had three replicates. The soil was equilibrated for one week before transplanting uniform, healthy *V. odoratissimum* seedlings. The experiment was conducted in a greenhouse beginning in May 2015. Plants were irrigated with deionized water to maintain soil moisture at field capacity. Dynamic sampling was performed at 56, 105, 154, and 203 days. Greenhouse conditions were maintained at 30/20°C day/night temperature with a 10-hour photoperiod.

2.3 Analytical Methods Soil physicochemical properties were determined according to Lu Rukun [22]. Soil pH was measured using a Mettler Toledo 420 pH meter. Organic matter content was determined by low-temperature external heating potassium dichromate oxidation-colorimetry. Available nitrogen was measured by alkali hydrolysis diffusion-sulfuric acid titration. Available phosphorus was extracted with sodium bicarbonate and analyzed by Mo-Sb colorimetry. Available potassium was extracted with ammonium acetate and measured by atomic absorption spectrophotometry. Chlorophyll and MDA contents in leaves were determined spectrophotometrically [23]. Plant samples were digested using HNO -HClO (3:1) [24], while soil samples were digested with HNO -HCl-H O using an MDS-8G microwave digestion system. Cadmium concentrations in all digests were measured by atomic absorption spectrophotometry (TAS-990). The bioconcentration factor (BCF) and transfer factor (TF) were calculated as follows:

- BCF = Cd concentration in plant tissue / Cd concentration in soil
- TF = Cd concentration in shoots / Cd concentration in roots

2.4 Data Processing All data were processed using Microsoft Excel 2010. One-way ANOVA was performed using SPSS 16.0 software, with differences considered significant at $p < 0.05$. Canonical correspondence analysis (CCA) was conducted using CANOCO software (Version 4.5) to analyze relationships between Cd content in *V. odoratissimum* and plant physiological characteristics.

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3. Results and Discussion

3.1 Effects of Cd on Plant Biomass Plant biomass serves as an important indicator of tolerance to soil contaminants. Within the first 56 days of cultivation, no significant differences in *V. odoratissimum* biomass were observed across Cd treatments ranging from 3.6 to 24.6 mg/kg, indicating minimal initial impact on growth. However, with extended cultivation (105–203 days), growth inhibition became increasingly apparent. At 105, 154, and 203 days, biomass in the T1 treatment decreased by 16.2%, 37.3%, and 19.7% compared to the control, respectively, while the T2 treatment showed reductions of 40.6%, 39.7%, and 20.2%, respectively. These findings align with previous research [27], though *V. odoratissimum* exhibited an overall increasing biomass trend under the experimental conditions, suggesting good growth performance in Cd-contaminated soils up to 24.6 mg/kg.

After 203 days of cultivation, root and stem biomass showed no significant differences from the control across all treatments, while leaf biomass responded differentially. The T1 treatment (9.6 mg/kg) significantly increased leaf biomass by 13.9% ($p < 0.05$), whereas the T2 treatment (24.6 mg/kg) decreased leaf biomass by 20.9%. Despite this reduction in leaf biomass, total plant biomass decreased only modestly, demonstrating that *V. odoratissimum* can maintain relatively normal growth even at high Cd concentrations (24.6 mg/kg), thus exhibiting strong tolerance.

3.2 Physiological Response Characteristics

3.2.1 Photosynthetic Pigment Content Chlorophyll is the primary photosynthetic pigment, and its content directly reflects photosynthetic capacity. Carotenoids protect chlorophyll molecules from photo-oxidative damage, while the chlorophyll a/b ratio indicates light energy utilization efficiency. During the early growth stage (56 days), chlorophyll a, chlorophyll b, and carotenoid contents decreased significantly in both T1 and T2 treatments, with reductions of 18.8-37.4%, 22.7-34.2%, and 13.6-24.8%, respectively. This initial inhibition may be attributed to Cd binding with sulfhydryl groups (-SH) in chlorophyll synthesis enzymes, altering enzyme structure and inhibiting activity [30,31].

By 105 days, chlorophyll a, chlorophyll b, and carotenoid contents in T1 treatment had decreased by 32.9%, 30.1%, and 18.0%, respectively, while T2 treatment values were similar to the control. At 154 days, no significant differences were observed between treatments and the control. However, after 203 days, carotenoid content remained unaffected, whereas chlorophyll a and chlorophyll b contents were significantly inhibited by soil Cd. The chlorophyll a/b ratio showed an overall decreasing trend with cultivation time, indicating that *V. odoratissimum* possesses a certain level of tolerance to Cd stress at the photosynthetic level, possibly through enhanced protective mechanisms that maintain normal photosynthetic function.

3.2.2 Malondialdehyde Content MDA is a toxic product of cell membrane lipid peroxidation and serves as an important indicator of free radical-induced damage. At 105 days, MDA content in leaves decreased by 16.3% in T1 and 31.3% in T2 compared to the control, likely reflecting protective responses that inhibit membrane lipid peroxidation and maintain membrane integrity [36]. By 154 days, MDA content increased by 35.6% in T1 and 32.9% in T2, suggesting that prolonged Cd exposure caused oxidative damage. However, at 203 days, MDA content showed no significant increase compared to the control, indicating that the toxic effects of Cd remained within the plant' s tolerance range. This may be attributed to protective mechanisms within *V. odoratissimum*, such as antioxidant enzyme systems (SOD, POD, CAT), that scavenge reactive oxygen species and mitigate membrane damage [38].

3.3 Cd Accumulation and Distribution in *V. odoratissimum* Cd content in *V. odoratissimum* increased progressively with both cultivation time and soil Cd concentration. After 203 days, Cd concentrations in different plant parts were:

- **CK treatment**: root 4.38-4.65, stem 3.64-3.94, leaf 4.69-6.76, whole plant 4.89-7.01 mg/kg
- **T1 treatment**: root 11.86, stem 6.65-11.87, leaf 5.05-12.38, whole plant 2.52-15.46 mg/kg
- **T2 treatment**: root 15.02-25.61, stem 6.23-25.66 mg/kg

The increasing trend was more pronounced in stems and leaves than in roots. The bioconcentration factor (BCF) is a critical index for evaluating heavy metal accumulation capacity, with values >1 indicating that plant tissue concentrations exceed soil concentrations. Both above-ground and below-ground BCF values for *V. odoratissimum* exceeded 1 after 203 days and increased with cultivation time. The transfer factor (TF), which reflects the translocation capacity from roots to shoots, also exceeded 1 at 203 days and showed an increasing trend over time. These results demonstrate that *V. odoratissimum* can effectively accumulate Cd from soil and efficiently translocate it to above-ground tissues.

Canonical correspondence analysis (CCA) revealed strong correlations between Cd content in *V. odoratissimum* and physiological indicators, particularly chlorophyll a/b ratio and carotenoid content. Cd uptake promoted MDA production while inhibiting chlorophyll synthesis, thereby affecting light energy utilization. However, the plant' s ability to maintain carotenoid levels and control MDA accumulation suggests the presence of protective mechanisms that enable tolerance to Cd stress.

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4. Conclusion

Within the first 56 days of cultivation, soil Cd content (3.6–24.6 mg/kg) had no significant effect on *V. odoratissimum* biomass, demonstrating strong initial tolerance. With extended cultivation (105–203 days), growth inhibition became evident, particularly at 24.6 mg/kg Cd, which significantly inhibited leaf growth. Throughout the entire cultivation period, *V. odoratissimum* maintained good overall growth, with both bioconcentration factors and transfer factors exceeding 1. The plant exhibited consistent tolerance and accumulation capacity across treatments, with BCF and TF values generally greater than 1, indicating efficient Cd uptake and translocation. These findings suggest that *V. odoratissimum* holds significant potential for the phytoremediation of Cd-contaminated soils, offering both ecological restoration benefits and ornamental value.

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Note: Figure translations are in progress. See original paper for figures.