The Mechanism of Plant Resistance to Cadmium in Soil

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Abstract. In recent years, soil heavy metal pollution has caused serious harm to human beings and the environment. Phytoremediation has become the main means of soil remediation because of its advantages such as low cost, obvious effect and low secondary pollution. In this paper, the status quo and harm of soil cadmium pollution in China and the mechanism of phytoremediation of cadmium were summarized.

1. Introduction
Soil is an important resource on which human beings depend for survival, and the problems of environment, resources and food in the world are closely related to soil [1]. With the rapid development of socio-economic, a large number of industrial production waste enters the soil environment, so soil pollution is increasingly serious. The results of the survey of the first soil pollution status in my country show that the heavy metal overbase rate of contaminated soil reached 16.1%. Eight heavy metal elements such as Cd, Cu, Hg, As, Pb, Cr, Ni, and Zn exhibited different degrees, where the degree of contamination of Cd is the highest, and the point exceeding the standard is 7% [2]. Cadmium has a large mobility, long decomposition cycle, high toxicity and difficult to understand, is one of the five poisonous elements contaminated with heavy metal [3]. The main source of cadmium in soil is: the use of pesticides, fertilizers and plastic films; sewage watering, sludge fertilization; settlement of cadmium in the air; free discharge of metal mine acid wastewater; any stack of cadmium-containing waste [4]. In the cadmium entry environment, it not only affects the growth of food crops, but also has great harm to human health. Therefore, prevention and treatment of soil cadmium pollution is a huge challenge in the world.

2. Hazard of cadmium pollution
Cadmium is highly soluble in water and is considered to be the most toxic trace metal in the environment [5]. Cadmium accumulation in plants will cause a series of physiological metabolic disorders, such as reduced photosynthetic intensity and enzyme activity, blocked synthesis of chlorophyll, sugar, and protein, etc., leading to slow growth of plants, yellowing of leaves and other symptoms, and eventually leading to reduced crop yield and quality, or even death [6]. The study of Jiwansingh et al. [5] showed that the relative water content (RWC), chlorophyll content and protein content of soybean plant leaves...
were significantly reduced under cadmium stress. Song Alin et al. found that the growth of Chinese cabbage was inhibited under high concentration of cadmium stress, the cadmium concentration in the plant increased with the increase of treatment concentration, and the cadmium content in the root was significantly higher than that in the shoot part of the plant [7].

Cadmium is accumulating toxic elements, half-life in the human body is generally 20 to 30 years [8]. Cadmium mainly enters the human body through a digestive tract and respiratory tract, and accumulates in the liver and kidney [9]. Cd is stronger than the toxicity of the human body, especially for the liver, placenta [10], kidney, lung, brain and bone [11]. Long-term exposure to Cd and their complex lead to the accumulation of Cd in the kidneys, if the organ concentration exceeds the critical threshold, the renal tubular cell is damaged, and the renal function will also be affected. The main reason for Japan's *Itai-itai disease* is that local residents take a large amount of rice contaminated rice, affecting vitamin D metabolism, disturbing the balance of calcium in the body, leading to a decrease in mineral content in the bone, thus led osteoporosis and Bone softening. Therefore, the United Nations Environment Program uses cadmium as a global significant hazardous chemical substance [12].

3. Remediation of cadmium contaminated soil

At present, heavy metal remediation technologies mainly include bioremediation, physical engineering remediation, chemical remediation and combined remediation [13]. Among them, chemical and physical restoration methods have better effect and shorter time; But the cost is high, and it is easy to damage the physical and chemical properties of soil, resulting in secondary environmental pollution. When the pollution area is large, these methods are difficult to achieve, and can not fundamentally solve the problem. Phyto remediation has become a technology with wide application prospect because of its advantages such as low cost, easy to operate, little impact on the environment and suitable for large-scale use [14].

4. Phytoremediation of cadmium pollution

In 1983, American scientist CHANEY [15] first put forward the theory of phytoremediation, that is, using the enrichment ability of green plants to transfer heavy metals in soil to plants or to degrade and utilize pollutants so as to reduce the concentration of heavy metals in soil [16]. Cadmium super-enrichment plants refer to those plants that have strong tolerance to Cd, and the heavy metals in stems or leaves (or aboveground parts) reach the critical content standard 100mg/kg, and the enrichment coefficient and transfer coefficient are both greater than 1. At present, the Cd hyperaccumulators found in China are *Brassica napus* L., *Sedum alfredii*, *Phytolacca Americana* L., *Sedum plumbizincicola*, *Solanum nigrum* L., *Viola verecunda*, etc.

![Figure 1. Phytoremediation(red matter represent pollutants)](image)
5. Mechanism of cadmium tolerance in plants
Under the stress of high concentration of cadmium, the growth and development of some plants will not be affected, while some plants will stop growing under the condition of low concentration of heavy metal pollution, which indicates that there is a certain resistance mechanism to heavy metals in plants. When stressed by heavy metals, plants will form specific detoxification and tolerance mechanisms to reduce the toxicity of heavy metals [17]. Current studies have shown that the mechanism of cadmium tolerance in plants mainly includes chelation, compartmentalization, antioxidation, emergency response and other aspects [18]. Among them, partition and chelation are the main mechanisms of plant tolerance to cadmium.

5.1 Chelation
Chelation means that heavy metal ions enter the plant and chelate with phytochelatin, metallothionein, organic acids and amino acids to form stable chelates, thus reducing the toxicity of heavy metals [19]. The detoxification mechanism of heavy metals is generally that the coordination groups form complexes with heavy metal ions through chelation, and then store them in plant vacuoles [20]. Different chelating peptides play different roles in the detoxification mechanism of heavy metals. Heavy metals generally need to be chelated by ligands through the cell membrane in order to reduce unnecessary contact with cell complexes. Compared with non-hyperaccumulative species, heavy metal hyperaccumulative species have higher ability of plant chelating peptides accumulation, which indicates that plant chelating peptides play an important role in heavy metal isolation, heavy metal detoxification and heavy metal elimination. Li Hui and other researchers found that under Cd$^{2+}$ stress, tomato significantly increased the expression of phytochelatin gene, thus enhancing the chelation of Cd$^{2+}$ [21]. Zhang Haiyan Cloned AsMT2b gene from garlic into Arabidopsis thaliana, which significantly enhanced the tolerance of Arabidopsis thaliana to Cd and increased its Cd accumulation [22].

5.2 Compartmentalization
Compartmentalization plays an important role in the accumulation and detoxification of heavy metals in plants. Plant cells can transport Cd to organs with inactive metabolism, such as vacuoles or fixed outside the cell wall, so as to reduce the toxic effect of Cd on plant cells. Cd in cells can pass through the tonoplast membrane and enter the vacuole through Cd$^{2+}$ / H$^+$ bidirectional transport system and Cd binding peptide [23]. David et al. found that the concentration of Cd accumulated in the vacuole of plant cells was 38 times higher than that outside the vacuole [24]. Yang Deng also confirmed that Cd in several plant cells, such as Eichhornia crassipes, Canna glauca, Arundo donax 'Versicolor', mainly exists in the cell walls and vacuoles of plants in the form of protein binding peptide, pectin hydrochloric acid or adsorption state, so as to reduce the toxicity of Cd to plant organelles [25].

5.3 Antioxidation
Under heavy metal stress, a large number of reactive oxygen species are produced in plants, which denaturates nucleic acids, proteins and other biological macromolecules, and causes membrane lipid peroxidation, affecting the normal metabolism of plants. Antioxidant system plays an important role in plant tolerance to heavy metal stress [26]. In response to oxidative stress, plant cells produce a series of antioxidants, including non enzyme antioxidants (GSH, ASA, etc.) and antioxidant enzymes (SOD, POD, CAT, APX, etc.) to eliminate free radicals and resist ROS damage to cells [27]. The results showed that Cd stress aggravated the oxidative stress in Boehmeria nivea(L.) and increased the activities of SOD and pod enzymes [28]. For example, under cadmium stress, the activities of CAT, SOD and other enzymes in various organs of Phragmites australis increased, and the content of GSH increased. The enhancement of antioxidant activity improved the tolerance of the plant to Cd [29].

5.4 Emergency response
When plants are exposed to high temperature, heavy metal stress or other chemical stimulation, plant cells will synthesize Heat Shock Proteins, also known as emergency proteins [30]. Different stress
proteins maintain the normal metabolism of cells through synergistic action. They protect plants from Cd stress by improving the tolerance of cells to Cd [31]. Studies have shown that when the concentration of Cd is 1.0 mmol/L, tomato cells will produce a large number of emergency proteins [32]. Shim et al. found that knockout of heat shock protein transcription factors in rice and wheat reduced their cadmium tolerance [33].

6. Conclusion

Cadmium is one of the most biologically toxic heavy metals, and it is also the most important soil pollutant in China. Its harm to plants is not only shown in the effects of physiological metabolism, but also affects the quality and yield of crops and makes them enter the human body through the food chain, posing a threat to human health. Therefore, the remediation of cadmium-contaminated soil is particularly important. At present, although the technology of using super-enriched plants to remediate soil cadmium pollution shows a good prospect, it needs to be further studied and solved because of its long remediation time, limited efficiency, disposal of remediation plants and so on.

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