Review on Heavy Metal Cadmium Remediation in Soil

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Abstract

In recent years, the harm of heavy metal cadmium in soil environment is gradually concerned, and the treatment of cadmium has been a hot issue all over the world. Based on the analysis of cadmium remediation, this study mainly discussed the mechanism of plant-microbial remediation, the factors affecting remediation, related applications, and the relationship between organism resistance mechanism and plant-microbial remediation. Meanwhile, the future research prospects of this technique were also discussed.

Keywords

Plant-microbial remediation; Heavy metal cadmium; Resistance mechanism; Application.

1. INTRODUCTION

As a non-essential biological element, cadmium is characterized by strong migration ability, strong toxicity, long half-life and difficulty in degradation, etc., and its content is low in natural environment soil. The natural sources of cadmium are mainly soil parent material, while the man-made sources are mainly industrial waste gas emission, smelting, fertilizer, sewage irrigation, etc. In recent years, due to the heavy metal Cd in soil in the continuous accumulation, is beyond the scope of the environmental self-purification capacity, soil physical and chemical properties change, the metabolism of microbes in soil and the ecological environment is threatened, the heavy metal Cd will enter organisms through the food chain and cause harm to the health of organisms and human beings. If people consume cadmium for a long time, a large amount of Cd will accumulate in the body, which has a serious impact on the urinary system, cardiovascular system, nerves and so on, and may lead to chronic poisoning and even cancer. As early as 1930-1960, cadmium pollution in part of the Shintogawa River Basin in Toyama Prefecture, Japan, caused the residents in the area to suffer from the "Itai-itai disease" [1]. According to the Bulletin of National Soil Pollution Survey released by China in 2014, cadmium ranks the first in the heavy metal pollution survey, accounting for 7% of the total territory of China [2]. In 2016, China promulgated the "Ten Regulations on Soil Pollution", which systematically controls heavy metal pollution from source to remediation, indicating that the Chinese government is gradually attaching importance to the prevention and control of heavy metals [3]. For the remediation and control of heavy metal Cd, there are physical, chemical and bioremediation technologies, among which the plant-microbial combined remediation technology has advantages such as better remediation effect, lower cost and less secondary pollution compared with the traditional technology, and has become a hot research technology for domestic and foreign scholars in recent years.

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2. MECHANISMS OF PLANT - MICROBIAL JOINT REMEDIATION OF HEAVY METAL CD

Plant-microbial synergy mechanism is a new technology developed from the original single heavy metal remediation mechanism. Plants promote the growth of microorganisms by providing nutrients, and microbes promote the development of plants by secreting plant hormones. Both of them take what they need and combine with each other to extract, enrich and fix heavy metal Cd [4], so as to reduce the migration ability and toxicity of Cd to the soil, then control the concentration of Cd to a certain extent. Table 1 shows the related experiments of plant-microbial joint remediation of heavy mental Cd. In soils contaminated with heavy metal Cd, the resistance mechanism of organisms controlled by resistance genes increases the tolerance of heavy metals through efflux and enrichment. At the genetic level, there are roughly two types of Cd efflux systems, one is through the “cad” efflux system of Gram-positive bacteria in Staphylococcus aureus, and the other is the czcCBA system of Gram-negative bacteria [11]. The efflux system is of great significance for microorganisms to resist the toxicity of Cd, but it is not conducive to the enrichment and precipitation of Cd by microorganisms. Enrichment is mainly due to the formation of metallothionin-like and heavy metal chelating peptides by microbial fungi through thionin and other chelating agents under the induction of cadmium [12], which can enrich and fix Cd, playing an important role in remediation. The plant-microbial remediation mechanism mainly includes rhizobium-legumes, arbuscular mycorrhiza-plants, obligate isolates-plants, and endophytic bacteria-plants [13], and mainly reduces the soil pollution caused by heavy metal cadmium through the following three ways.

Table 1. Application of plant - microbial joint remediation Cd

Plant	Inoculated microorganism	Postinoculation state	Author
Nightshade	Endophyte EB L14	75-78% of cadmium with an initial value of 10mg/L is removed	Xiao Xiao
Corn or rape fields	Bacillus	Activate cadmium and make cadmium be enriched	Mulligan, C.N. [5]
Sorgo	Strain produced by siderophores	Increase the content of Cd in sweet sorghum and accelerate the enrichment of Cd	Barzanti, R. [6]
Oat	Blocculus mildew	The concentration of Cd in roots increases, making it easier to enrich and absorb	R.Bar- bara [7]
Oilseed rape	Root microorganism agrostis capillaris	The survival rate and biomass of rapeseed increases	Grobelak[8]
Sinensis-leguminous plants	Nodule bacteria	Mycorrhizal symbionts can promote the accumulation of cadmium in nodules, increasing the accumulation of cadmium by 17%-20%	Richen
Wheat rhizosphere	Azotobacter	The binding of wheat to Cd can be reduced by 50%, and the growth and development of wheat can be promoted	JOSHIPM [9]
Ryegrass	Arbuscular-mycorrhizal	Alleviate the toxic effect of heavy metal Cd and promotes the growth of ryegrass	Xia Li [10]

2.1. Combined Plant-microbial Fixation/Passivation of Heavy Metal Cadmium

Microorganisms can chelate or precipitate Cd in the soil through some chelating agents, metabolites, iron carriers and macromolecular acid substances [14] produced by metabolism

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to change the form of heavy metals, thus reducing the migration ability and toxicity of Cd in the soil, and playing a role in the fixation of the heavy metal Cd. For example, endophytic bacteria can produce iron carriers and chelating organic acids in the endophytic-plant joint remediation, which can accumulate and fix Cd in the plant through binding with Cd and assist host plants to enrich heavy metals [15]; Microorganisms can also fix free Cd through their own active or passive adsorption. The active adsorption is through the active affinity of microorganisms to heavy metals. Under the action of hydrolase, Cd will enter microbial cells. And the passive adsorption is through the active group on the surface of microbial cells to adsorb heavy metal. Both of these methods slow down the migration ability of heavy metal Cd, thus slowing down the toxic effects on plants and microorganisms, increasing the biomass of plants, promoting plant growth, increasing the surface area of plant roots, and enhancing the repair ability of heavy metal Cd. Microorganisms can also reduce the toxicity of Cd through redox, methylation, dehydrocarbon and other reactions, so that the valence state of Cd can be transformed into a stable, non-toxic or low-toxic form, so that Cd can be passivated, reducing the bioavailability of Cd, protecting plants from excessive pollution of Cd, and effectively controlling Cd [16]. Madhaiyan et al. made Cd move to the ground of the plant and transfer to the stem and leaves through endophytic Burkburghella and Methylbacillus Oryzae to promote Cd enrichment [17].

2.2. Plant - microbial Activation of Heavy Metal Cadmium

Microorganisms use organic acids and surface active substances to change Cd into effective states relative to plants to promote the absorption of Cd by plants and make plants have better absorption capacity for Cd. In this way, the biological effectiveness of Cd can be improved and the speed of remediation can be accelerated. Studies on the joint remediation of Cd by dual-resistant strains and vetiver grass showed that dual-resistant strains could not only transform Cd into an effective state for vetiver to absorb and use, but also make the repair effect more effective [18].

2.3. Effects of Microorganisms on Plant Growth Promotion in Remediation of Heavy Metal Cadmium

Microorganisms promote plant growth by secreting iron carriers, plant growth hormone, organic acids and carboxylic acid deaminase [19], etc., increase plant absorption of Cd and promote plant root growth, so that there is enough root area in plant roots to absorb Cd and improve the efficiency of cadmium restoration. Root microorganisms secrete organic acids to participate in soil formation and enrich minerals in the soil, which can be absorbed and utilized by plants and provide nutrients for plant absorption and utilizatio. Iron carrier is a small protein substance with high specificity for ferric ion. It can promote the absorption of iron by plants, increase plant biomass, inhibit excessive absorption of Cd by plants to a certain extent, and reduce the toxicity of Cd to plants [20]. Plant growth hormones secreted by microorganisms, such as indole acetic acid, gibberellin and cytokinin, are beneficial to the development, growth and maturity of plants, and stimulate the development and growth of roots, thus increasing the accumulation of Cd in plant. During endobiotic-phytoremediation, endophytic bacteria secrete organic acids, amino acids and some substances that accelerate the dissolution of minerals, change the physicochemical property of the soil and make minerals absorbed and utilized by plants, thus increasing the root area of plants to accelerate the remediation of cadmium.Rhizobia-phytoremediation, rhizobia can secrete plant hormones and disease-resistance hormones to promote plant growth and fight against disease, increase plant biomass and promote plant growth [21]. Studies have shown that after adding magnetotactic bacteria to the soil contaminated with heavy metals, the content of heavy metals in the soil will reach the safe range under the combination of magnetic field and leaching.[22]

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3. INFLUENCING FACTORS OF CD REMEDIATION BY PLANT-MICROORGANISM IN SOIL

3.1. Polluting Property of Cd in Soil

The bioavailability of heavy metals in soil varies with the state of heavy metals in different energy states. Different chemical forms of Cd will lead to different toxicity to organisms in different bioavailability. Meanwhile, various forms of Cd lead to different characteristics of mobility, chemical effects and bioavailability, and have different effects on soil [23]. For the effective state of cadmium is toxic to organisms, as for the magnitude of the toxic state according to the form of different effective states. Cadmium in different states can be transformed into each other through redox, adsorption and precipitation, complexation and dissolution reactions. Cadmium in soil is mostly a compound, CdCO3 is mostly present in dry soil [24], but when the soil is reduced by flooding, Cd mostly combines with S element to form Cd compound. At present, there are several forms of Cd: carbonate bound, exchange, adsorption, organic bound, residue [25]. Different forms have different degrees of influence on plant-microbial remediation.

3.2. Physicochemical Property of Plants

Plant is an important component in the core of the plant-microbial joint remediation technology, which directly affects the effect of remediation. Therefore, plants with high heavy metal enrichment capacity, fast absorption rate of Cd, fast growth, strong toxicity resistance to Cd, disease resistance and insect resistance, and strong transportation capacity should be selected for Cd remediation. Generally speaking, plants can be divided into three types: super-enriched plants, transgenic plants and tolerant plants [26]. Super-enriched plants have a strong ability to accumulate Cd and are not threatened by the toxicity of Cd, and their absorption of heavy metals is more than 100 times that of ordinary plants. For example, Solanum nigrum, Sedum sendrium [27], Viola cerana, Brassica juncea, Viola conica and Viola Baoshan are found in recent studies to be super-enriched of Cd. The enrichment ability of tolerant plants is not as strong as that of super-enriched plants, but they have strong tolerance to Cd and have great repair potential. For example, ramie ryegrass, sunflower, purslane, and hemp [28] can have strong tolerance to Cd and less toxic pollution by Cd. Although transgenic plants can combine the advantages of different plants to repair cadmium, they are potentially dangerous to the ecology, so they should be used with caution. Studies have shown that Chinese rose has a strong ability to accumulate cadmium and will not enter the biological chain of human existence. As it absorbs 1.7576mg/L cadmium every day, which can be used as a cadmium enrichment plant [29].

3.3. Soil Rhizosphere Environmental Factors

Soil is an important site for plant-microbial remediation. Once the soil is contaminated by heavy metals, the rhizosphere is a good place for remediation. The ability of plants to enrich Cd is affected by the rhizosphere environment. The pH of the rhizosphere, the moisture content of the rhizosphere, the types of organic matter, chemical reagents, and the partial pressure of gas in the soil [30] all have different effects on the enrichment of Cd. In the presence of chemicals that dissolve and activate Cd in the soil, the rhizosphere environment facilitates the remediation of Cd and accelerates its accumulation and fixation by plants. Through the stress on plants, Cd increases the pH value of plant rhizosphere and forms a pH barrier to inhibit the entry of heavy metal Cd into the protoplasm [31].

4. CONCLUSIONS

In recent years, the plant-microbial remediation of cadmium has advantages such as relatively short remediation period and good economic benefits. However, this technology has

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some limitations. Therefore, for the remediation of heavy metal Cd, the plant-microbial joint remediation technology can be further studied and developed in the following aspects: (1) Due to the lack of understanding of the interaction mechanism between plants, microorganisms and soil at present, it is necessary to further study and search for Cd super-enriched plants and microorganisms with strong remediation ability. (2) Most research sites of plant-microbial remediation technology are carried out in the laboratory, but there are many uncontrollable factors in the real environment. Therefore, various factors should be considered in this technology, and a complete system should be constructed, so that the technology can be mature and put into a large number of applications in the industrial chain. (3) Combined with the genes of super-enriched plants and microorganisms with high remediation ability, the optimized strains were screened and cultivated to enhance the remediation ability of Cd. However, the potential ecological harm of gene recombination should be considered in the application of gene recombination technology.

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