菌根化育苗修复土壤镉污染机制的研究

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摘要：重金属矿区开采严重破坏了原有的植被生态系统，冶炼过程中也产生大量有毒矿渣，释放出大量的有毒重金属元素，造成严重的土壤污染。植物—菌根联合修复技术，具有绿色、环保和可持续性的特点，被认为是重金属土壤生态修复的最具潜力手段。本研究以马尾松（*Pinus massoniana*）幼苗为材料，采用培养杯共培养，在温室中人工接种二十种不同基因型 Cd 抗性较强的外生菌根真菌（Ectomycorrhizal fungi, EMF）菌株—土生空团菌(*C. geophilum*)，培育菌根化马尾松幼苗；通过在土壤中中添加不同浓度的 $CdCl_2.5/2H_2O$（0 mg/kg、20 mg/kg），对菌根化马尾松幼苗和非菌根化幼苗进行 Cd 胁迫试验，将菌根化马尾松与非菌根化马尾松放入基质中胁迫五个月，通过测定侵染率、生长指标，组织营养元素含量、Cd 分布以及形态、抗氧化系统，并进一步采用菌根组织转录组测序技术，从生理和分子两个层次研究 Cd 胁迫下菌根化马尾松的响应机制，为利用外生菌根—马尾松进行 Cd 土壤污染治理提供理论依据和技术支撑。综上所述，本研究阐明了接种 EMF，可以显著提高马尾松幼苗的抗 Cd 胁迫能力，菌根马尾松可以吸附更多的镉元素；菌根共生可以全面提高马尾松的营养状况，提高保护酶活性等生理过程，提高宿主植物的抗性；此外，镉胁迫下，菌根共生可以保障马尾

松幼苗根系基因的正常表达，通过马尾松植株-菌根菌的双方大量基因的共同表达，从而缓解了镉对植株的胁迫。因此，菌根化马尾松具有在镉污染区域土壤进行植物修复的应用潜力。

Mechanism of Mycorrhizal Seedling Remediation of Cadmium Soil Pollution

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Abstract: Mining in heavy metal mining areas has severely destroyed the original vegetation ecosystem, and a large amount of toxic slag is also produced during the smelting process, releasing a large amount of toxic heavy metal elements, causing serious soil pollution. Plant-mycorrhizal joint remediation technology has the characteristics of green, environmental protection and sustainability, and is considered to be the most potential means for the ecological remediation of heavy metal soils. In this study, Pinus massoniana (Pinus massoniana) seedlings were used as materials, and co-cultivation in a culture cup was used to artificially inoculate 20 different genotypes of Cd-resistant ectomycorrhizal fungi (Ectomycorrhizal fungi,EMF) strains—earth-grown in the greenhouse. C. geophilum, to cultivate mycorrhizal masson pine seedlings; add different concentrations of CdCl2.5/2H2O (0 mg/kg, 20 mg/kg) to the soil to treat mycorrhizal masson pine seedlings Cd stress test with non-mycorrhizal seedlings. Put the mycorrhizal masson pine and non-mycorrhizal masson pine into the matrix to stress for five months. By measuring the infection rate, growth index, tissue nutrient element content, Cd distribution and Morphology, antioxidant system, and further use of mycorrhizal tissue transcriptome sequencing technology to study the response mechanism of mycorrhizal masson pine under Cd stress from both physiological and molecular levels, in order to use ectomycorrhizal-masson pine for Cd soil pollution Governance provides theoretical basis and technical support. To sum up, this study clarified that inoculation with EMF can significantly improve the resistance

of masson pine seedlings to Cd stress, mycorrhizal masson pine can absorb more cadmium; mycorrhizal symbiosis can comprehensively improve the nutritional status of masson pine and improve protection Enzyme activity and other physiological processes improve the resistance of host plants; in addition, under cadmium stress, mycorrhizal symbiosis can protect horsetail The normal expression of root genes of pine seedlings, through the co-expression of a large number of genes from both the masson pine plant and mycorrhizal fungus, alleviates the stress of cadmium on the plant. Therefore, the mycorrhizal masson pine has the potential to be used for phytoremediation in the soil contaminated by cadmium.