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Hyperaccumulators Redefined: Innovation in Phytoextraction and Phytomining for Resource Recovery

Muhammad Yasir Naeem[1], Najib Altawell[2*], Tulkinzhon Gaipov[3], Dilara K. Sunakbaeva[4], Abdol Ghaffar Ebadi[5]

[1]Department of Agronomy, Animals, Food, Natural Resources and the Environment (DAFNAE), University of Padua, Italy
[2]Energy Management Department, Coventry University, Greenwich campus 6 Mitre Passage, Greenwich, SE10 0ER – UK
[3]Khoja Akhmet Yassawi International Kazakh-Turkish University, Center for Strategic Development, Rating and Quality, Turkestan, Kazakhstan
[4]Faculty of Sciences, Department of Ecology and Chemistry, Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkestan, Kazakhstan
[5]Researcher and Faculty member, Jouybar branch, Islamic Azad University, Jouybar, Iran
*Presenter Author's Email: najibaltawell@gmail.com

Abstract
Hyperaccumulator plants possess the unique ability to absorb exceptionally high concentrations of heavy metals without exhibiting any symptoms of phytotoxicity. This property renders them strong candidates for phytoextraction and phytomining—ecological technologies for the remediation and resource recovery. This review chronicles the latest advances in the discovery, cultivation, and commercialization of hyperaccumulator species such as *Alyssum murale* and *Noccaea caerulescens*. Principal physiological traits, including metal transport mechanisms, chelator production, and vacuolar sequestration, are described. Novel field trials indicate the potential for nickel, cadmium, and rare earth element recovery in mining and post-industrial settings. Economic assessments indicate that phytomining could yield economic advantages to land owners and restore poor soils. Agronomic management, harvesting technologies for increased metal uptake and yield, and soil amendments are also presented in the review. As global demand for critical minerals rises, hyperaccumulators offer a sustainable option to conventional mining, fitting environmental rehabilitation alongside economic viability.

Keywords: Hyperaccumulators, Phytoextraction, Phytomining, Critical minerals, Soil remediation, Resource recovery