MYCOREMEDIATION FOR ENVIRONMENTAL RESTORATION AND AGRICULTURAL RESILIENCE

Chitvan Pathania[1] and Divya Gupta[2]

[1]Department of Plant Pathology, Dr. Yashwant Singh Parmar University of horticulture and Forestry College of Horticulture and Forestry, Neri, Hamirpur 177001, India

[2]Senior Project Fellow, Amity Institute of Organic Agriculture
Amity University Noida.

In terms of any communication correspondence is pertained to: *chitvanpathania@gmail.com*

ISSN : 3107 - 9903

www.digitalagrinews.com
Visit our website

EDITION: VOLUME 02, ISSUE 03 , - MARCH 2026

Mycoremediation for Environmental Restoration and Agricultural Resilience

Chitvan Pathania[1] and Divya Gupta[2]

[1]*Department of Plant Pathology, Dr. Yashwant Singh Parmar University of horticulture and Forestry College of Horticulture and Forestry, Neri, Hamirpur 177001, India*

[2]*Senior Project Fellow, Amity Institute of Organic Agriculture Amity University Noida.*

In terms of any communication correspondence is pertained to: ***chitvanpathania@gmail.com***

ISSN No.: 3107-9903
Frequency: Monthly
Month: March
Volume- 2, Issue- 3

Abstract

The rapid expansion of industrial activities and modern agricultural practices has significantly increased environmental contamination, leading to the accumulation of toxic substances like heavy metals, pesticides and persistent organic pollutants in soil and water systems. Traditional remediation methods, although widely used, are often costly, energy-demanding and can negatively impact natural ecosystems. In contrast, mycoremediation has gained attention as a sustainable and environmentally compatible approach that harnesses the natural capabilities of fungi to restore polluted environments. Fungi function as efficient decomposers through mechanisms such as extracellular enzyme-mediated degradation, intracellular transformation of toxic compounds and adsorption or accumulation of heavy metals. Several fungal genera, including Aspergillus, Penicillium, Fusarium and Trametes, have shown remarkable efficiency in degrading diverse contaminants. The utilization of fungal biomass, such as spent mushroom substrate, further enhances its applicability in field conditions. Moreover, recent developments in areas such as fungal-assisted nanoparticle synthesis and molecular tools like gene editing have expanded the scope and effectiveness of this technology. Although certain challenges related to environmental variability and large-scale implementation remain, ongoing advancements suggest that mycoremediation has strong potential as a reliable and eco-friendly solution for long-term environmental management.

Key words: Mycoremediation, Environmental pollution, Heavy metals, Extracellular enzymes Ligninolytic fungi Sustainable remediation

Introduction

With the world's population on the rise and cities growing fast, both land and water ecosystems are being affected by more and more pollution. Because we have relied on conventional farming and let industries run wild, soils and groundwater are packed with heavy metals, synthetic pesticides, and stubborn pollutants that simply do not disappear (Kumar et al., 2021). Traditional clean-up techniques, like digging up contaminated dirt or burning off toxins, cost a fortune, use tons of energy, and wreck the natural communities of microbes living in the soil (Liu, 2025). So, if we want a cleaner environment that lasts, mycoremediation is coming forward as a wiser, environmentally friendly alternative. Fungi, with all their powerful enzymes, break down, capture or utterly remove harmful substances. This approach belongs to the category of "green" biotechnology and it's more than just gentler on the environment as it adapts well to larger scales, is budget-friendly and genuinely aids in restoring soil vitality, ensuring farming is better prepared for the future (Kuppan et al., 2024). Mycoremediation possesses the introduction of particular fungus, also referred to as "bioremediation fungi" or "mycofilters," into the contaminated sites.

Mechanism of Mycoremediation:

The remarkable effectiveness of fungi in environmental remediation stems from their evolutionary function as nature's foremost decomposers. Fungi serve as nature's primary decomposers and they're incredibly effective because they've spent millions of years breaking things down. Their methods for detoxifying pollutants can be generally categorized into three biological processes.:

First, there's what happens outside the cell i.e., the **extracellular enzymatic**

degradation, fungi produce extremely effective enzymes that break down tough chemicals like pesticides or oil spills. These ligninolytic enzymes, like laccase and various peroxidases, decompose complex toxins within the environment itself. That which remains is less complex, less toxic compounds, sometimes simply carbon dioxide and water (Daassi et al., 2025).

Afterwards arrives the inside job that is the **intracellular biotransformation.** If toxic compounds penetrate the fungal cell, the fungus activates rapidly. Recent transcriptomic studies show fungi significantly increase certain protective proteins and specialized enzymes (like haloalkane dehalogenases) when they're stressed by chemicals. This lets them break down nasty pollutants from the interior outward, cutting apart toxic bonds and making the invaders harmless (Ali et al., 2025).

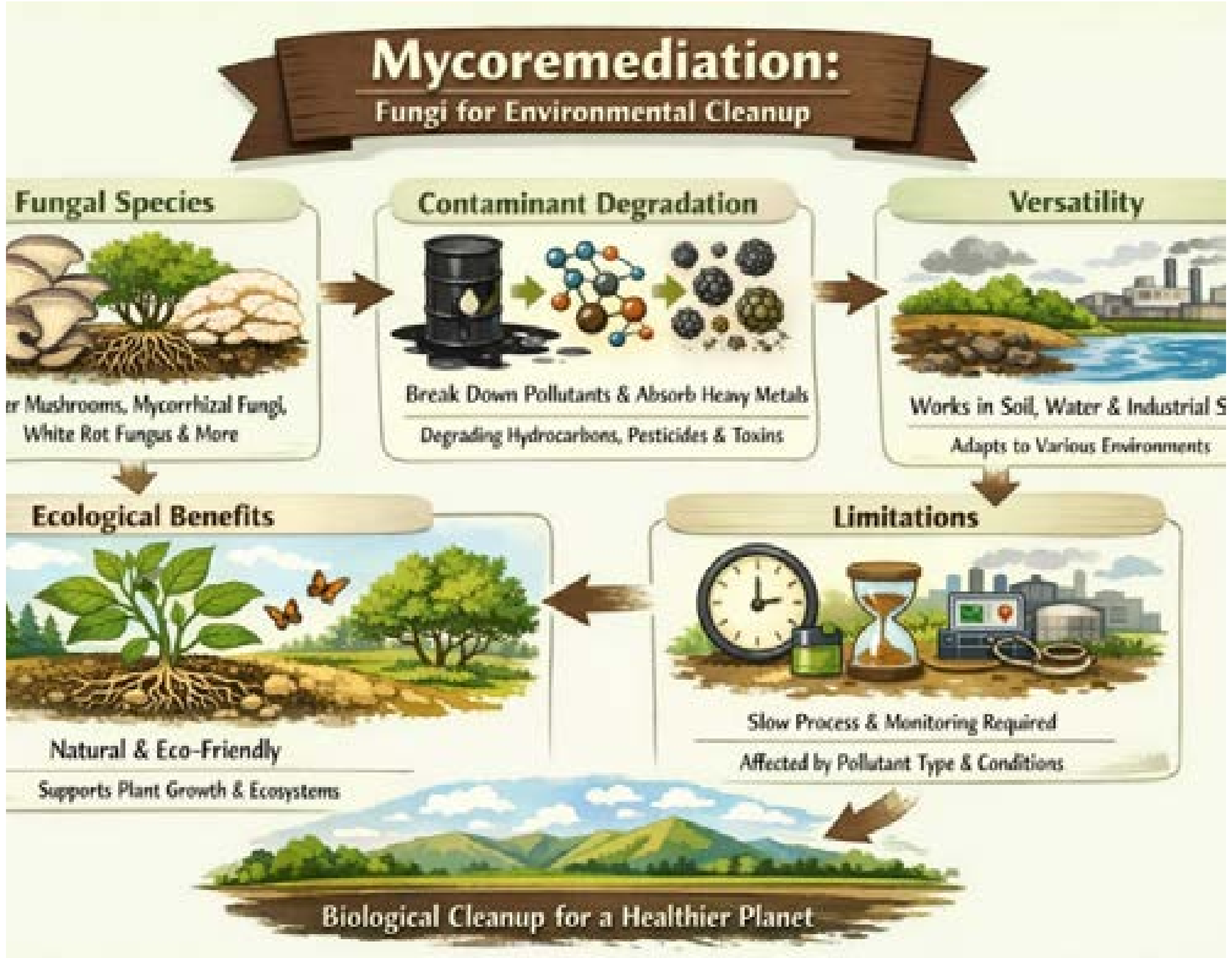

Figure 1. Conceptual diagram of mycoremediation and its mechanisms, applications and limitations.

Finally, there exists the problem of heavy metals, substances fungi are unable to decompose like they do with natural materials Thus comes the biosorption and bioaccumulation. Here, the cell wall plays a role, grabbing and trapping heavy metals using its chitin and other natural polymers. Some fungi even release sticky molecules called exopolysaccharides that form a biofilm, catching more metals and stopping them from getting inside the cell, where they'd cause real damage (Kumar et al., 2021).

Therefore, whether it is breaking down oil, neutralizing chemicals or immobilizing metals, fungi possess a remarkable set of abilities for restoring the environment.

Classification of microorganisms

Although there are 69,000 species of fungi worldwide, only a limited number have been linked to mycoremediation (Figure 2) (Pala et al., 2014).

Figure 2: A visual map showing "which fungus can clean which pollutant" in mycoremediation

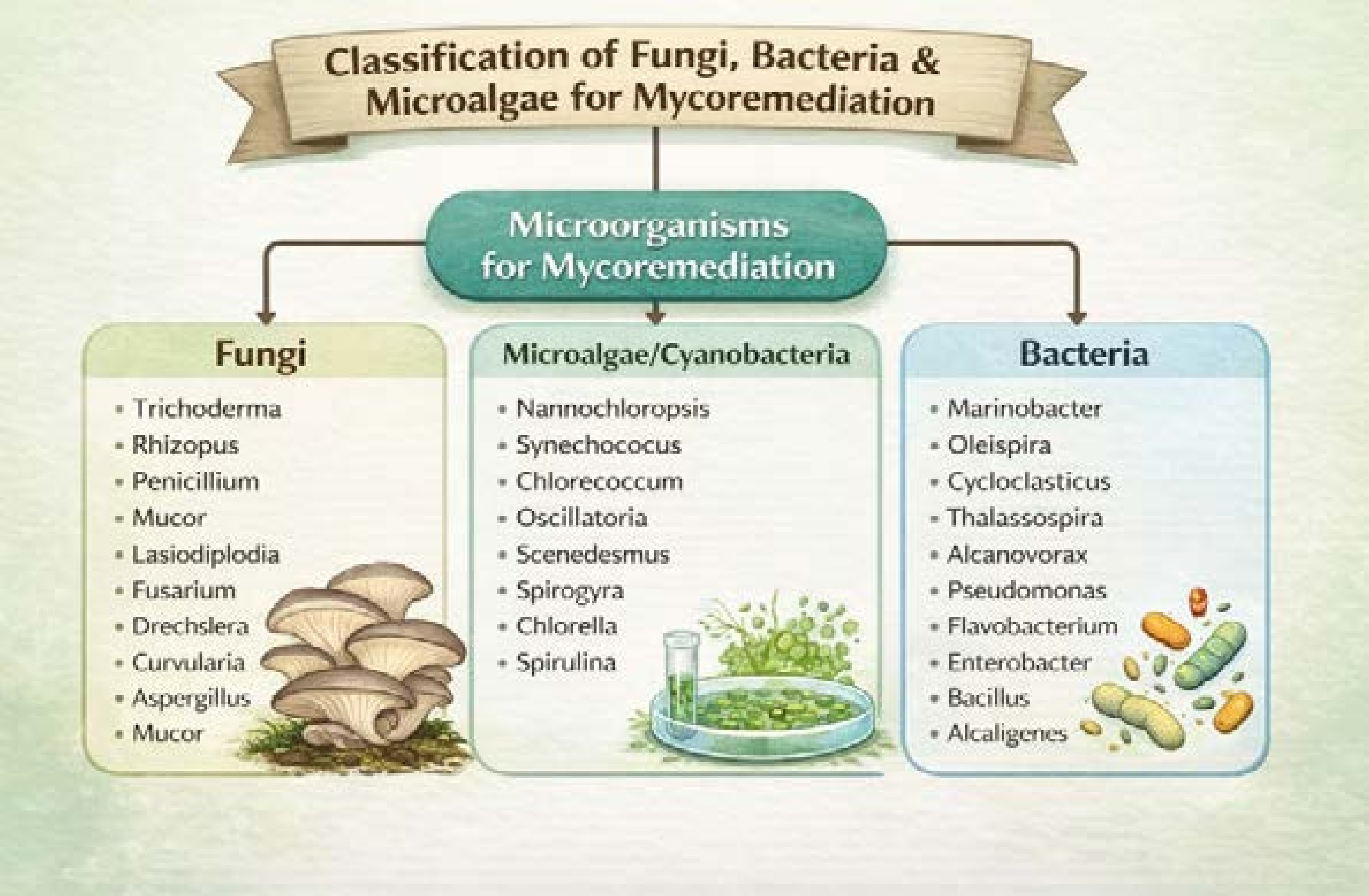

Figure 3: Classification of fungi, bacteria and microalgae (Self designed)

Highlights various key genera of fungi, bacteria and microalgae that play a role in bioremediation. Various factors, such as moisture, aeration, temperature, metal ion concentration, phosphorus availability, nitrogen, carbon and the growth and presence of fungi, are influenced by interspecific microbial competition (Lavelle and Spain, 2002).

Utilisation as a Sustainable Approach

The transition of mycoremediation from laboratory research to field-scale utilization represents a major step forward in building a circular bioeconomy and ensuring sustainable land governance. A primary utilization of this technology is the application of Spent Mushroom Substrate (SMS). SMS is the residual compost left over after the commercial cultivation of edible mushrooms. Because it remains thoroughly colonized by fungal mycelia and retains a high concentration of

extracellular enzymes, SMS can be applied directly to degraded agricultural lands. This in-situ bio-amendment effectively degrades lingering pesticide residues while simultaneously improving soil structure and nutrient cycling (Nandini and Srinivasulu, 2025). Furthermore, the implementation of mycoremediation is increasingly supported by modern environmental policy. For instance, India's recent Environment Protection (Management of Contaminated Sites) Rules, 2025, establishes a strict statutory framework for identifying chemically contaminated sites and mandates rigorous remediation plans based on the "polluter pays" principle (MoEFCC, 2025). By integrating mycoremediation into standard agricultural and industrial waste management practices, ecosystems can be detoxified naturally. This biological approach completely eliminates the massive carbon footprint associated with traditional remediation, effectively returning degraded landscapes to a baseline state of health capable of supporting sustainable, climate-resilient agriculture (Akpasi et al., 2023).

Case studies: *Fusarium proliferatum* CF2 has demonstrated a high ability for the degradation of the insecticide allethrin, achieving up to 95% removal under aerobic conditions within five days, highlighting its potential application in pesticide-contaminated environments (Bhatt et al., 2020). Similarly, the ligninolytic fungus Trametes versicolor has shown significant ability in the removal of pharmaceutical pollutants such as ketoprofen, with approximately 80% reduction under controlled conditions, primarily due to its efficient laccase and peroxidase enzyme systems (Coelho et al., 2020). These studies clearly indicate that fungal-mediated processes are highly versatile and effective for the remediation of diverse environmental contaminants.

Emerging Aspects of Mycoremediation

In recent times, mycoremediation has taken notable improvements. Researchers are combining fungal systems and nanotechnology they refer to this as myco-nanotechnology and it's effectively extending the limits of how effectively we can eliminate pollutants. With this approach, fungi contribute to forming nano particles, that are all the same size, maintaining stability and proves to be an effective method to eliminate heavy metals and various dangerous compounds in the environment. Fungi like Fusarium, Aspergillus and Penicillium are already known for making nanoparticles including silver, gold, and platinum, thus they serve a dual purpose, aiding both environmental cleanup and the fabrication of useful nanomaterials. Fungi don't stop there. They furthermore decrease metal toxicity through biosorption and transformation, basically locking up dangerous metals or turning them into something less harmful. Alongside this, new molecular tools are making a difference. With genetic engineering and CRISPR-Cas systems, researchers are tuning fungi to be even better at breaking down pollutants. Introduce next-generation sequencing alongside gene editing to the mix, resulting in a clearer understanding of how fungi work at a metabolic level. This lets scientists develop even more effective fungal strains for cleaning up the environment. All these new strategies show how mycoremediation is growing not just as an eco-friendly fix, but as a high-tech, sustainable answer to our pollution problems.

Conclusion

Mycoremediation offers a promising, environment friendly and a sustainable solution to the increasing issues of environmental pollution. Fungi, known for their enzymatic systems and adaptability, are essential in degrading, transforming and immobilizing various contaminants, such as heavy metals, pesticides and industrial waste. In contrast to traditional remediation techniques, mycoremediation is more cost-effective, energy-efficient and less disruptive to natural ecosystems. Additionally, recent innovations like myco-nanotechnology and molecular tools have significantly improved its effectiveness and expanded its potential applications. Although there are some limitations concerning environmental conditions and scalability, ongoing research and technological advancements are anticipated to address these challenges. In summary, mycoremediation presents significant promise as a vital approach for rehabilitating contaminated environments and fostering sustainable ecosystem management in the future.

REFERENCES

- Akpasi, S. O., Anekwe, I. M. S., Tetteh, E. K., Amune, U. O., Shoyiga, H. O., Mahlangu, T. P., & Kiambi, S. L. (2023). Mycoremediation as a potentially promising technology: Current status and prospects—A review. *Applied Sciences,* 13(8), 4978. https://doi.org/10.3390/app13084978
- Ali, Z., Abdullah, M., Hafeez, F., et al. (2025). Advances in myco-remediation strategies for emerging contaminants: A comprehensive review. *Bioremediation Journal*. https://doi.org/10.1080/10889868.2025.2507431
- Bhatt, P., Zhang, W., Lin, Z., Pang, S., Huang, Y., & Chen, S. (2020). Biodegradation of allethrin by a novel fungus Fusarium proliferatum strain CF2 isolated from contaminated soils. *Microorganisms*, 8(4), 593. https://doi.org/10.3390/microorganisms8040593
- Coelho, E., Reis, T., Cotrim, M., Mullan, T., & Corrêa, B. (2020). Resistant fungi isolated from a contaminated uranium mine in Brazil show a high capacity to uptake uranium from water. *Chemosphere,* 248, 126068. https://doi.org/10.1016/j.chemosphere.2020.126068

- Daâssi, D., Bouassida, M., Almaghrabi, F., & Chamkha, M. (2025). Mycoremediation: An innovative and sustainable approach. In *Bioremediation for environmental sustainability.* IntechOpen. https://doi.org/10.5772/intechopen.1009012

- Kumar, A., Yadav, A. N., Mondal, R., et al. (2021). Myco-remediation: A mechanistic understanding of contaminants alleviation from natural environment and future prospects. *Chemosphere*, 284, 131325. https://doi.org/10.1016/j.chemosphere.2021.131325

- Kuppan, N., Padman, M., Mahadeva, M., Srinivasan, S., & Devarajan, R. (2024). A comprehensive review of sustainable bioremediation techniques: Eco-friendly solutions for waste and pollution management. *Waste Management Bulletin,* 2(3), 154–171. https://doi.org/10.1016/j.wmb.2024.07.005

- Lavelle, P., & Spain, A. V. (2002). *Soil ecology*. Springer Science & Business Media.

- Liu, X. (2025). Fungi used with mycoremediation as a sustainable solution for environmental pollution. *Microbial Bioactives,* 8(1), 1–11. https://doi.org/10.25163/microbbioacts.8110463

- Ministry of Environment, Forest and Climate Change (MoEFCC). (2025). *Environment protection (management of contaminated sites) rules*, 2025. Government of India. https://moef.gov.in/storage/tender/1753451385_S.O.3401(E)_Rules_2025.pdf

- Nandini, M. L. N., & Srinivasulu, B. (2025). Spent mushroom substrate: A resource for sustainable crop production and plant disease management. *Advances in Crop Research and Innovation*. https://journalacri.com/index.php/ACRI/article/view/1535

- Pala, S. A., Wani, A. H., Boda, R. H., & Wani, B. A. (2014). Mushroom refinement endeavor auspicate non-green revolution in the offing. *Nusantara Bioscience,* 6, 173–185.