E-ISSN: 2664-8784
P-ISSN: 2664-8776
Impact Factor: RJIF 8.26
IJRE 2025; 7(2): 11-13

www.engineeringpaper.net
Received: 14-04-2025
Accepted: 17-05-2025

Rajiv Routh
School of Life Sciences, Swami Vivekananda University, Kolkata, West Bengal, India

Subha Mondal
School of Life Sciences, Swami Vivekananda University, Kolkata, West Bengal, India

Sibashish Baksi
School of Life Sciences, Swami Vivekananda University, Kolkata, West Bengal, India

Correspondence
Rajiv Routh
School of Life Sciences, Swami Vivekananda University, Kolkata, West Bengal, India

A review of current understanding regarding bioremediation techniques against pesticides

Rajiv Routh, Subha Mondal and Sibashish Baksi

DOI: https://www.doi.org/10.33545/26648776.2025.v7.i2a.113

Abstract
Hazardous waste bioremediation is a relatively young technique that has seen increased research in recent decades. The goal of this procedure is to eliminate or render harmful waste items immobile. Around the world, pesticides are a widespread threat because they seep into soils, surface and groundwater, posing health risks to several areas. Because pesticides are persistent, it is more vital to remove and detoxify them. In-situ and ex-situ treatment are the two main categories into which pesticide bioremediation falls. There are notable benefits and drawbacks to both approaches.

Keywords: Pesticides, bioremediation, fungi, bacteria

Introduction

Anthropogenic and natural factors are the sources of soil contamination, a global issue. Due to the need for chemicals, substances, and chemical agents brought about by urbanization, industrialization, and rising food consumption, pollutants have been dispersed and accumulated in the environment throughout time. Heavy metals, insecticides, and polycyclic aromatic hydrocarbons (PAHs) are the most prevalent contaminants found in soil (Raffa and Chiampo, 2021) [8]. Chemical substances called pesticides are used to get rid of pests. These are biological or chemical agents that kill, weaken, and incapacitate pests. The pesticides can be categorized into many classes, including insecticides, herbicides, rodenticides, bactericides, fungicides, and larvicides, depending on the kinds of pests they are intended to control (Raffa and Chiampo, 2021) [8].

A portion of pesticides stay in the soil after usage, and the buildup impacts the microbes that reside there. Exposure of humans can happen when they consume pesticide-contaminated food and drink, breathe in pesticide-contaminated air, and straight from domestic, agricultural, and professional use. The insecticides can enter the human body by cutaneous, oral, ocular, and respiratory channels (Kim *et al*., 2017) [5]. The electrical characteristics, molecular structure, dose, and exposure duration all affect how harmful pesticides are.

These factors need lowering the concentration of residual pesticides in the soil, which can only be achieved by employing efficient remediation methods. As an alternative to more costly and hazardous techniques like chemical and physical procedures, bioremediation is an environmentally safe, reasonably priced, and successful solution. The elimination process in biodegradation can be accomplished by taking advantage of microorganisms' microbiological activity. Pesticides are converted by microorganisms, mostly bacteria or fungus, into less complex substances, CO2, water, oxides, or mineral salts that can be utilized as sources of energy, minerals, and carbon. The enzymes play a crucial part in these processes because they serve as catalysts (Doolotkeldieva *et al*., 2018, Erguven, 2018) [2, 3].

Remediation method

Physicochemical Remediation Methods

Adsorption, membrane filtration, chemical oxidation, and advanced oxidative processes are the four main categories into which physicochemical bioremediation techniques may be divided. Through chemical or physical interactions like hydrogen bonds or Van der Waals forces, pollutants (adsorbates) attach to solid surfaces (adsorbents) during the adsorption process. Examples of adsorbent materials utilized in xenobiotic remediation include magnetic adsorbents, polymeric materials (such as cyclodextrins, dendrimers, and hyper-crosslinked polymers), zeolites, clay, activated carbon, and metal-organic frameworks (Wu *et al*., 2023, Martínez-Burgos *et al*., 2024) [15, 7].

The physical and chemical techniques of remediating polluted matrices have several significant drawbacks, such as lengthy treatment times, the production of hazardous waste, the short usable lives of oxidizing agents, high operating costs, and implementation complexity. Additionally, some oxidants, like hydroxyl radicals, have a nonspecific mode of action and end up altering the biological matrix they are given to, which has a negative impact on the biota and natural environmental processes (Martínez-Burgos *et al*., 2024, Kumar *et al*., 2022) [7, 6].

Biological remediation methods

By using biological agents including bacteria, fungus, microalgae, macroalgae, terrestrial plants, and enzymes, bioremediation methods can biodegrade pesticides. Compared to physicochemical approaches, these procedures are more cost-effective. They also produce less pollution because, once the pollutant has mineralized, the end products are CO2 and H2O. However, the choice of an appropriate biological agent and the kind of xenobiotic target for bioremediation are critical to the process's effectiveness (Tarla *et al*., 2020) [13].

Pesticides and their hazardous metabolites can be effectively biodegraded by environmental microorganisms and their enzymatic complexes. There are a number of ways to carry out pesticide bioremediation. One of the primary bioremediation techniques is biodegradation, in which pollutants are broken down by microorganisms and their enzymes into less harmful or non-toxic chemicals through metabolic processes; certain microbes even use the pollutants as carbon sources. When xenobiotic substances are biodegraded using isolated enzymes, this process is also evident. Bioadsorption is an additional bioremediation technique. The interactions between contaminants and the functional categories of organisms form the basis of this process. Both microbial biomass and inert biomasses, such as eggshells or lignocellulosic materials, exhibit it (Bhatt *et al*., 2021) [1].

Changing the cell surface with chemical compounds is one of the main ways to improve bioadsorption. Bioaccumulation is an additional process by which substances enter cells and build up inside them without experiencing major changes. During nutrition metabolism, the pollutant's transit can be aided and controlled by protein association. This is an active process as the pesticide must be transported to the cell's inside using a lot of energy (Silva *et al*., 2019) [10].

Remediation using biocatalysts

The majority of pesticides can undergo enzymatic detoxification via oxidation and hydrolysis processes. Therefore, hydrolases, which include lipases, cellulases, carboxylesterases, and phosphotriesterases among others, are the primary potential enzymes for bioremediation. To a lesser degree, oxidoreductases can also be employed. The phosphoester or carboxylester linkages, which are found in the malathion pesticide, must primarily be hydrolyzed in order to detoxify organophosphate insecticides. When it comes to pesticides like carbamates, detoxification happens when amine groups or comparable bonds are hydrolyzed (Russell *et al*., 1998) [9].

Malathion and parathion are hydrolyzed by carboxylesterase to produce malathion monocarboxylic acid, and dicarboxylic acid hydrolases are frequently employed in the detoxification of pesticide spills including carbamates and organophosphates. Since oxidoreductases may oxidize aromatic chemicals by adding one or more oxygen molecules, they are used in the detoxification process for organochlorine insecticides. Additionally, these enzymes have a role in the hydroxylation, desulfurization, and dehalogenation of aromatic molecules (Singh *et al*., 2012, Martínez-Burgos *et al*., 2024) [11, 7].

Microbe-Assisted Remediation

A number of variables, such as soil pH, moisture content, organic matter, carbon and nitrogen concentration, and temperature, affect how quickly bacteria and other microbes break down pesticides in soil. Furthermore, microbial diversity and activity as well as the physical, chemical, and biological characteristics of the soil can be greatly impacted by agricultural activities like tillage and manure application. When it comes to microbial bioremediation in soils or groundwater, the concentration of dissolved oxygen is a crucial consideration. Studies examining the bacterial bioremediation capabilities under various situations have been undertaken since the dissolved oxygen content might vary depending on the environment. For instance, it was demonstrated that the bacterial species Ps. *plecoglossicida* could break down the widely used organophosphorus pesticide, profenofos, in both aerobic and anoxic environments, indicating the bacteria's broader relevance to groundwaters (Subsanguan *et al*., 2020, Kaur *et al*., 2023) [12, 4].

Microorganisms that can bioremediate pesticides are often isolated from settings that contain the desired substance.

Samples from polluted soil were utilized to isolate bacteria using the enrichment culture method. The species were described after the bacteria that grew on minimal media containing bifenthrin were likewise sub-cultured on minimal media with cypermethrin. The organisms that were obtained were members of the genera Pseudomonas and Acinetobacter (Uzma *et al*., 2023) [14].

Conclusion

Using techniques including bioabsorption, biotransformation, and phytoremediation, bioremediation is a potent way to fight environmental contamination, especially pesticide pollution. Microorganisms, enzymes, and plants are essential to its success, therefore genetic optimization and bioprospecting are essential for finding efficient agents. Optimizing biomass production, using modern bioreactor systems, and using strategic inoculation are crucial for increasing efficiency and scalability, particularly in locations with high pollution levels. Applying and scaling these techniques in practical contexts still presents difficulties, though. In order to address these, comprehensive technical, environmental, and economic assessments, private sector cooperation, multidisciplinary research, and supporting policies are needed.

References

1. Bhatt P, Bhatt K, Sharma A, Zhang W, Mishra S, Chen S. Biotechnological basis of microbial consortia for the removal of pesticides from the environment. Critical Reviews in Biotechnology. 2021;41:317-38.
2. Doolotkeldieva T, Konurbaeva M, Bobusheva S. Microbial communities in pesticide-contaminated soils in Kyrgyzstan and bioremediation possibilities.

Environmental Science and Pollution Research. 2018;25:31848-62.
3. ERGUVEN GO. Comparison of some soil fungi in bioremediation of herbicide acetochlor under agitated culture media. Bulletin of environmental contamination and toxicology. 2018;100:570-5.
4. Kaur R, Singh D, Kumari A, Sharma G, Rajput S, Arora S, *et al*. Pesticide residues degradation strategies in soil and water: a review. International Journal of Environmental Science and Technology. 2023;20:3537-60.
5. Kim K-H, Kabir E, Jahan SA. Exposure to pesticides and the associated human health effects. Science of the total environment. 2017;575:525-35.
6. Kumar L, Chugh M, Kumar S, Kumar K, Sharma J, Bharadvaja N. Remediation of petrorefinery wastewater contaminants: A review on physicochemical and bioremediation strategies. Process Safety and Environmental Protection. 2022;159:362-75.
7. Martínez-Burgos WJ, De Souza Vandenberghe LP, De Mello AFM, De Carvalho JC, Valladares-Diestra KK, Manzoki MC, *et al*. Bioremediation strategies against pesticides: an overview of current knowledge and innovations. Chemosphere. 2024;364:142867.
8. RAFFA CM, CHIAMPO F. Bioremediation of agricultural soils polluted with pesticides: A review. Bioengineering. 2021;8:92.
9. Russell R, Harcourt R, Oakeshott J. Bioremediation of pesticides using enzymes. ACIAR PROCEEDINGS. 1998;341-8.
10. Silva A, Delerue-Matos C, Figueiredo SA, Freitas OM. The use of algae and fungi for removal of pharmaceuticals by bioremediation and biosorption processes: a review. Water. 2019;11:1555.
11. Singh B, Kaur J, Singh K. Biodegradation of malathion by Brevibacillus sp. strain KB2 and Bacillus cereus strain PU. World Journal of Microbiology and Biotechnology. 2012;28:1133-41.
12. Subsanguan T, Vangnai AS, Siripattanakul-Ratpukdi S. Aerobic and anoxic degradation and detoxification of profenofos insecticide by Pseudomonas plecoglossicida strain PF1. Ecotoxicology and Environmental Safety. 2020;190:110129.
13. Tarla Dn, Erickson LE, Hettiarachchi Gm, Amadi SI, Galkaduwa M, Davis LC, *et al*. Phytoremediation and bioremediation of pesticide-contaminated soil. Applied Sciences. 2020;10:1217.
14. Uzma B, Ali F, Qureshi N, Shakeela Q, Asima B, Ahmed S, *et al*. Isolation and characterization of synthetic pyrethroids-degrading bacterial strains from agricultural soil. Brazilian Journal of Biology. 2023;83:e271790.
15. Wu Y, Liu Y, Kamyab H, Rajasimman M, Rajamohan N, Ngo GH, *et al*. Physico-chemical and biological remediation techniques for the elimination of endocrine-disrupting hazardous chemicals. Environmental Research. 2023;232:116363.