REVIEW ARTICLE

Organic Contaminants are Degraded by Rhizospheric Microorganisms: A Review

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Abstract

Organic pollutants have grown to be a serious global problem because of their massive creation, widespread application, and eventual discharge. Due to biomagnification, accumulation, and their harmful acute and chronic impacts on all living things, these substances significantly increased the load on the ecosystem and its potential threats. Reducing the risk factors associated with organic contaminants through rhizospheric microfilms is crucial. Rhizoremediation is phytoremediation that removes toxins from the soil using plant roots and the rhizospheric microorganisms living on them. Research has shown that one of the best techniques is bioremediation utilizing plants. Utilizing bacteria from plants offers a lot of potential for rhizoremediation. Dangerous environmental contaminants include toxic industry byproducts, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorine insecticides, and polychlorinated biphenyls (PCBs). These substances are categorized as global concern chemicals due to their propensity to travel long distances, remain in the environment, and potential for bio-accumulation and bio-magnification through the food chain. Organic pollutants can be broken down from the soil by soil microflora, which can also promote plant development in stressful environments. Plant-microbe interaction is essential for removing contaminants from the soil. Cleaning up these and harmful pollutants is therefore essential together with microbes; phytoremediation is an economical way to remove the pollutants from the soil, air, and water that is also environmentally acceptable.

Keywords: Rhizoremediation, organic pollutants, degradation, Plant-microbe interaction, soil microflora

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Introduction

Every day, more new chemicals are entering the environment as a result of our way of life. According to statistics, more than 80,000 organic synthetic compounds are reportedly utilized every day. The production of food, textiles, petrochemicals, insecticides, and herbicides, as well as cosmetics, pulp and paper, steel and iron manufacturing, and many other industries, makes extensive use of organic materials. Organic pollutants have developed into a serious global problem due to their mass manufacturing, extensive usage, and eventual disposal (Wani *et al.,* 2018a; Wani *et al.,* 2018b). These compounds significantly raised the load and potential dangers to the ecosystem through biomagnifications and accumulation, having hazardous acute and chronic effects on all living things. It is crucial to reduce the risk factors associated with organic pollutants using rhizospheric microbiomes. Organic pollutants, including polyaromatic compounds and organochlorine insecticides, have started to catch the attention of scientists and the general public on a global scale (Bano *et al.,* 2018; Geetha and Nagarajan, 2021).

Organic Pollutants: Types and Properties

When organic pollutants reach the allowed limits, they transform into toxic chemical compounds that can make humans sick in a number of different ways (Wani *et al.,* 2018c; Bhat *et al.,* 2021; Hussain *et al.,* 2021). These organic materials can be found in many industrial products, such as detergents, plastics, organic solvents, insecticides, and dyes. They live in various habitats. Furthermore, because of their short-lived negative effects and complex chemical composition, these organic pollutants are detrimental to both wildlife and humans. Since the nineteenth century, POPs have drawn a lot of attention because of their exceedingly risky bioaccumulative characteristics (Geetha & Nagarajan, 2021).

Carbon-based contaminants, known as organic pollutants, have been found to affect one or more specific environmental parameters only negatively. Organic pollutants can be categorized into three groups: hydrocarbons, chemicals combining oxygen, phosphorus, and nitrogen, and organometallic compounds. The most prevalent types of agricultural pollutants include hydrocarbons and associated substances, including polycyclic aromatic hydrocarbons (PAHs), dioxins, and dichlorodiphenyltrichloroethane (DDT) (Goodhead & Tyler, 2009; Malik *et al*., 2018; Padder et al., 2021).

Categorized as Dangerous Because of the Probable toxicological effects

- They are sensitive to long-distance transportation since they have been widely spread across the environment due

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to anthropogenic activities, including soil, water, and, most crucially, air, which is dangerous to humans and animals.

- Acquired in the fatty tissue of living things, such as humans, and are seen in greater quantities at relatively high levels of the food chain; they mainly differ in the number of chlorine replacements and persist in the atmosphere for long periods of time, particularly in soils, sedimentary rocks, and air.

Rhizosphere and Microbial Activity:

The nutrient-rich area of soil around plant roots, known as the rhizosphere, is regulated by microbial biomass and root exudates. The metabolism of amino acids, flavonoids, proteins, and fatty acids in root exudates attracts microbes to the rhizosphere and rhizoplane, where they can either passively or actively form microcolonies or biofilms. Therefore, the main factors affecting the rhizosphere's and rhizoplane's microbiomes are root exudates.

The spatial and temporal configuration of soil microorganisms is extremely dynamic. As a result, root area and season may affect the colonization of the rhizosphere and rhizoplane. Observations suggest that different plant genotypes select for distinct rhizospheric communities, suggesting that genetic changes among plant species can continue driving discrepancy employment of beneficial microorganisms. This is true even though the community structure of the bulk soil influences the recruitment efforts of rhizospheric and rhizoplane microbes by plants.

Degradation of Organic Pollutants by Rhizospheric microbiomes:

Rhizospheric microorganisms use the process of rhizoremediation to break down organic pollutants (Fig. 1). Rhizoremediation, a type of phytoremediation, employs plant roots and the rhizobial microbes that live on them to remove toxins from the soil. Soil microorganisms can eliminate organic pollutants from the soil while also acting as dangerous chemical degradation products or promoting plant development in stressful conditions. Interaction between plants and microbes is essential for removing contaminants from the soil (Bano *et al.,* 2021; Bano *et al.,* 2022).

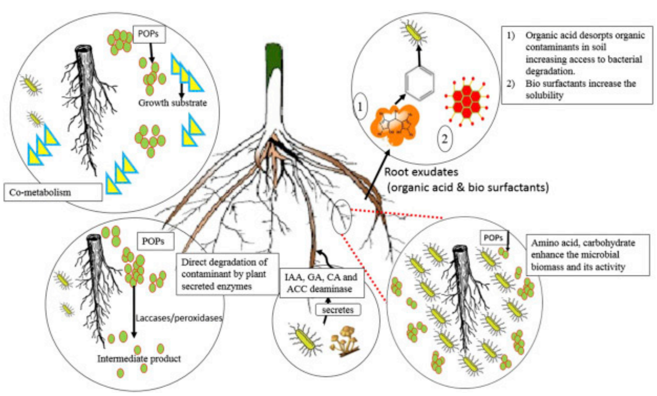

Fig. 1: Degradation of organic pollutants by rhizospheric microbiomes (Gupta *et al.,* 2020)

One of the most well-known POPs that are categorized as dangerous environmental contaminants includes toxic industry byproducts, polychlorinated biphenyl (PCB), polycyclic aromatic hydrocarbons (PAHs), organochlorine insecticides, and polychlorinated biphenyl (PCB). These substances are categorized as global concern chemicals due to their propensity to travel long distances, remain in the environment, and potential for bio-accumulation and bio-magnification through the food chain (Padder *et al.,* 2022; Rather *et al.,* 2022a). Due to their characteristics, POPs have a detrimental effect on the global ecosystem, wildlife, and human health. Cleaning up these harmful pollutants is, therefore, essential. Together with microbes, phytoremediation is an economical way to remove POPs from soil, air, and groundwater that is also environmentally acceptable.

In phytoremediation, plants are used for rhizofiltration, phytostabilization, phytovolatilization, phytoextraction, and phytotransformation to eliminate harmful chemicals (Prasad, 2011; Rather *et al*. 2022b) (Fig. 2).

Phytoextraction

All of the pollutant absorption and concentration in harvestable biomass is buried or burned. In phytotransformation, the enzymatic modification is inactivated, and the pollutants are either destroyed (phytodegradation) or immobilized (phytostabilization). Phytovolatilization removes soil contaminants, which are then released into the leaves with evapotranspiration.

Rhizofiltration

Rhizofiltration is when a root mass filters water by removing contaminants.

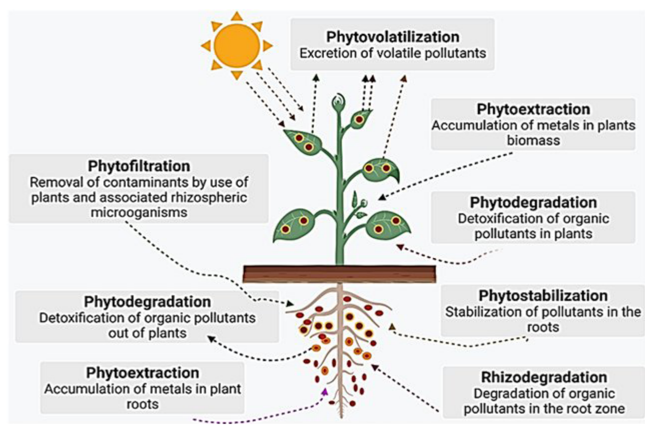

Fig. 2: Phytoremediation plants are used for different techniques to eliminate harmful chemicals (Basit *et al.,* 2021).

Bioremediation

The cost-effective solution for many locations currently facing expensive cremation or long-term liabilities due to land deterioration is made possible through the bioremediation of contaminated soils (Rather *et al*., 2022c). Technology was discovered to be more efficient in the field when whole site restoration was required. Different biological mechanisms are involved in bio attenuation, bio-stimulation, and bioaugmentation.

Bio-attenuation, or Natural Attenuation

Bio-attenuation process transforms pollutants into less harmful or immobile forms (natural attenuation). These transformation and immobilization mechanisms are primarily brought on by microbial biodegradation and, to a lesser extent, by interactions with natural chemicals and proximal geological sorption.

Bio-stimulation

Through environmental modification, bio-stimulation promotes microbial growth as a decontamination method for contaminated soils. The demand for and availability of nutrients, including carbon, nitrogen, potassium, oxygen, an appropriate pH, redox capabilities, and the kind and concentration of organic pollutants all significantly impact the amounts of dangerous chemical concentrations that microorganisms can break down. Manure, slow-release, and oleophilic nutrients are used to encourage microbial decomposition.

Bio-augmentation

Utilizing microbial flora to hasten the elimination of pollutants is known as bio-enhancement. Contaminated soil particles produce microflora that can withstand significant concentrations of organic contaminants. Microbes isolated from hydrocarbon-polluted soil sediments may be used to treat recently contaminated soil. The microbial degradation of soil PAH components treated with gasoline oil has been seen to be facilitated by the 2% microbial soil primer.

Research has shown that one of the best techniques is bioremediation utilizing plants. Utilizing bacteria from plants offers much potential for rhizoremediation. According to studies on the phyllosphere, the inner area of crops, and rhizobial levels of exposure (Rather *et al.,* 2022d), the relationship between plants and bacteria is essential for the remediation of organic pollutants or pollutants.

Rhizoremediation

The most effective method for eradicating PAHs from the soil is rhizoremediation (Mohan *et al.,* 2006). In xenobiotic rhizoremediation, the soil microbiota is crucial (Barac *et al.,* 2009; Rather *et al.,* 2022e). The rhizosphere process controls or regulates the interaction between plants, soil microorganisms that act as degraders, and PAHs (Ma *et al.,* 2009). The cooperation of specific plants and microbial populations residing around the root region was necessary for PAH rhizoremediation (Barac *et al*., 2009). The rhizosphere process aids the degradation of PAHs. Plants release harmful organic waste through their roots, increasing microbial hydrocarbon degraders' activity in the root zone (de Carcer *et al*., 2007).

For pollution clearance to be successful, organisms like bacteria must be able to generate, biodegrade, and maintain themselves in the rhizobia (Phillips *et al*., 2012). Therefore, in rhizoremediation and phytoremediation, bioremediation is crucial (Fig. 3). It can be used to eliminate pollutants from the ecosystem and strongly influences the outcome of hazardous desecrates (Mohan *et al*., 2006; Ma *et al*., 2009; Rather *et al*. 2022f). Researchers contend that rhizoremediation is the best way to remove PAHs from the soil (Ma *et al*., 2009). Rhizospheric bacteria are plant-associated microbes that play a key role in the biodegradation of hazardous organic compounds from contaminated soils. They might support phytoremediation (David & Sharon, 2009).

Rhizoremediation is a naturally occurring process. However, it may be influenced by deliberately cultivating rhizospheric bacteria using the right equipment, and it can react by utilizing the right plant-microbe combination (Fig. 3). By integrating plant and PGPR technology, toxic degradation can be accomplished.

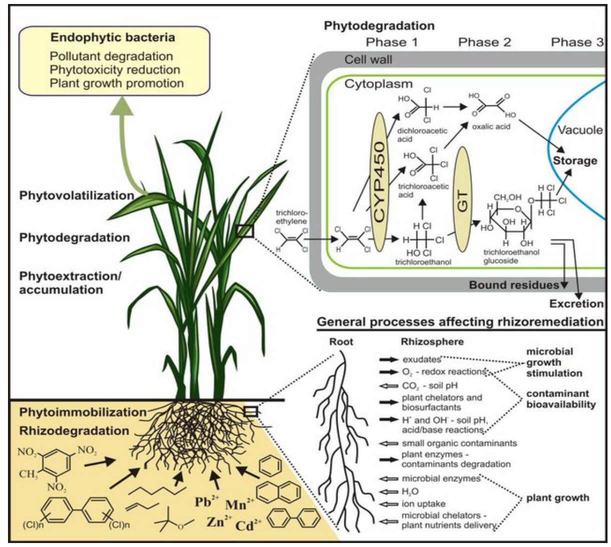

Fig. 3: Phytoremediation of various organic and inorganic pollutants in soil (Truua *et al.,* 2015)

In addition to carrying and concentrating chemical contaminants in the plant's extractable tissue (phytoextraction/accumulation), plant roots have the ability to remove them from the soil. Stomata on leaves can occasionally be used to release moisture into the surroundings (phytovolatilization). By using enzymes like CYP450 (cytochrome P450; GT-glycosyltransferase), pollutants can be metabolized in plants in three stages (phase 1: transformation; phase 2: conjugation; and phase 3: compartmentalization), which lead to the storage of the pollutant in the vacuole, assimilation into the cell wall, or efflux from the compartment.

Additionally, bacteria linked with plants in the rhizosphere can degrade organic pollutants (rhizodegradation). Plants contribute to the biodegradation of pollutants by having to discharge root exudates and other substances into the underlying soil as well as by providing a surface for microbial colonization. Rhizosphere effect: this boosts pollutant bioactivity and the quantity and metabolic activity of bacteria. Plants stimulate catabolic gene expression, and fungal endophytes need their resources. Lowering phytotoxicity is achieved through endophytic bacteria's degradation of organic pollutants and production of plant growth hormones.

In Phytoremediation, Rhizoremediation and Microbe-Plant Interactions are Important

Rhizoremediation, often referred to as rhizodegradation, microbiota phytoremediation, or rhizobial bioremediation, is a sophisticated process through which bacteria, rhizosphere soil, roots, and root exudates interact to change pollutants into less harmful or non-toxic ones. Plant roots also offer a surface for bacterial colonization and niches that protect them from desiccation and other abiotic and biotic challenges, in addition to aerating the soil and releasing nutrients and exoenzymes through root exudates (Kuiper *et al.,* 2004).

Plant growth is influenced by nitrogen fixation, nutrient mobilization (such as phosphorus), the creation of growth regulators, the suppression of hormonal changes brought on by stress on plants, phytopathogen defences, and the breakdown of toxins before they injure the plant (Fig. 3). Segura *et al.* (2009); Chaudhry *et al.,* 2005. When compared to bulk soil, these interdependent interactions, sometimes referred to as the rhizosphere effect, result in an increase in the variety and metabolic activity of microorganisms that can degrade pollutants or promote plant development close to roots (Ramos *et al.,* 2000; Kent & Triplett, 2002). Usually, the primary agents in the breakdown of contaminants occur in the rhizosphere.

- Choosing plants for rhizoremediation that have the qualities you want.
- Utilizing and changing the plant microbiome by using an inoculum containing either hydrocarbon-degrading microbes, plant growth-promoting rhizobacteria (PGPR), or a combination of both organisms.
- Increasing our understanding of how the host plant creates and manages a beneficial microbiome while it is under the stress of pollution.

Rhizospheric microbes can break down most environmental pollutants, but the process ends when the microbe is starved of food. The primary food source in the soil, root exudates, is easily accessible to these microorganisms. Instead of using the term "phytoremediation," they have used the term "rhizoremediation" to highlight the importance of root exudates and rhizoplane-capable bacteria. By dissolving cellular organelles and rupturing cell walls, acting as a genotoxic substance (Sharma & Talukdar, 1987), and attempting to disrupt the physiological photosynthetic process, metals in high concentrations in the soil and their uptake by plants negatively affect yields, symbiosis, and crop expansion (Wani *et al.,* 2007). They can all be turned off as well as respiration, protein synthesis, and glucose metabolism.

The biological control of pests and rhizoremediation of pollutants may benefit from *Pseudomonas putida*, a root colonizer. Theoretically, when a suitable plant is infected with a suitable rhizosphere strain (for example, coating bacteria on plant seed), these well-equipped bacteria may colonize the root alongside the typical native population, improving the bioremediation process. Herbicides and insecticides were primarily the focus of the early studies on chemical breakdown in the rhizosphere (Eerd *et al*., 2003). Rhizodegradation, also known as phytostimulation, rhizosphere biodegradation, or plant-assisted bioremediation/degradation, is a method for improving the bioactivity of contaminants by expanding microbial populations using the rhizosphere of plants (Prasad, 2011; Padder *et al.,* 2022).

The plant gains from microbial pollutant breakdown in the rhizosphere for two reasons: the decrease in hazardous gas concentration near the roots and the capacity to flourish more favorably than in contaminated areas (Natsch *et al.,* 1996). Because of the reciprocal benefit of having different genotypes in their roots, plants may be present.

Conclusion And Future Prospects

Due to the extensive application, organic pollutants (OPs) have damaged the air, land, and water. Due to their persistence and harmful effects, persistent organic pollutants (POPs) found in food have become a significant concern for food safety. Therefore, it is crucial to manage the concentration of toxicants in the environment. Microorganisms in our environment have upgraded their capacity to transform harmful chemicals into less hazardous byproducts. For pollution remediation to be successful, organisms like bacteria must be able to generate, biodegrade, and maintain themselves in the rhizosphere. Bioremediation is, therefore, crucial in phytoremediation and rhizoremediation. It significantly impacts the consequences of dangerous desecrations and can be used to remove contaminants from the ecosystem. Rhizosphere bacteria can decompose the majority of environmental pollutants. Microbial enzymes are necessary for the biodegradation of organically polluted soils, including diesel, petroleum, and PAHs. Future generations of microbiologists will probably abandon these enzymes, ushering in a new era of research that will support various methods for environmental remediation. Bioremediation can rehabilitate polluted areas affordably and successfully. Uncertainty arises from an inadequate understanding of how different environmental conditions affect the rate and amount of biodegradation. Considering their economic viability, wider pollutant degradation capacity, improved public acceptance, and also a high rate of contaminant reduction or degradation, phytoremediation is preferable to microbial remediation.

In many developed nations, rhizosphere bacterial strains are recognized as a sustainable agricultural technology. Native plant microbiomes are crucial for boosting plant survival due to biotic and abiotic stressors. Through the use of innovative genetic engineering techniques, the desired plant growth-promoting characteristics could be incorporated into rhizosphere bacterial strains to increase crop yield. A few helpful bacterial strains can be isolated, modified, and applied to crops. However, it is challenging to screen the majority of rhizosphere bacterial strains in order to identify favorable features under stress situations. By expanding their applications, rhizosphere bacteria have the potential to have a significant impact on environmental restoration. By educating the public about the benefits of rhizosphere bacteria, misconceptions and ignorance must be overcome. To maintain agricultural productivity and the environment, novel approaches for formulating and transporting rhizosphere bacterial biofertilizer at the laboratory, greenhouse, field, and market scales must be investigated. Precise mechanistic investigations on the capacity to promote development and bio-remediate habitats polluted with contaminants must have laboratory support. To reduce future risks, genetically create more mechanistically efficient strains that would be subject to approved regulations.

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Author Contribution

In this review, contributions from different published work and information are collected from the literature like types and properties of various Organic Pollutants, Rhizosphere, Microbial Activity, and Degradation of Organic Pollutants by Rhizospheric Microbioms, and all the information were analyzed and summarized.

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