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PYROPHILOUS FUNGI: A NEW FRONTIER IN HYDROCARBON BIODEGRADATION

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Abstract

Hydrocarbon contamination poses a significant threat to soil and water ecosystems, particularly in developing regions with limited waste management infrastructure. While physical and chemical remediation methods such as thermal desorption, chemical oxidation, and soil vapor extraction offer solutions, these approaches are costly, energy-intensive, and environmentally detrimental due to secondary pollution. Bioremediation, leveraging microorganisms or their enzymatic pathways to degrade pollutants, provides an eco-friendly and cost-effective alternative. Fungal bioremediation is gaining traction due to fungi's resilience in diverse environments and their ability to produce extracellular enzymes capable of breaking down complex hydrocarbons.[1,2] This article suggests that, similar to other fungi, Pyrophilous fungi can be effectively utilized for hydrocarbon degradation due to their unique enzymatic capabilities and adaptability to challenging conditions. Their potential application highlights an innovative and sustainable approach to addressing hydrocarbon contamination.

Key Words: Hydrocarbon Contamination, Bioremediation, Fungal Bioremediation, Pyrophilous Fungi, Extracellular Enzymes, Sustainable Remediation

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Source of Hydrocarbons and its Environmental Impact

Hydrocarbons, composed of hydrogen and carbon, are categorized as aliphatic or aromatic. Derived from crude oil, production-related leaks can lead to subsurface contamination, with pollutants such as BTEX, naphthalene, and fluorine. Refinery and industrial effluents are the primary sources of subsurface hydrocarbons, negatively impacting ecosystems by impeding the flow of moisture, nutrients, and oxygen to the subsoil.[2] Hydrocarbon products increase due to anthropogenic activity into the environment. Prevalent contaminants include petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), halogenated hydrocarbons, pesticides etc. These hydrocarbons affect the quality of water and soil by altering quality parameters and thus create pollution.[3]

Hydrocarbon Degradation by Fungi

Fungi have shown potential in the degradation of hydrocarbons, including total petroleum hydrocarbons (TPHs) and polycyclic aromatic hydrocarbons (PAHs).[4,5]Several fungal strains, such as *Aspergillus niger*, *tubingensis*, *Syncephalastrum* sp., *Paecilomycesformosus*, *Fusarium chlamydosporum*, and *Coniochaeta* sp., have been identified as effective hydrocarbon degraders.[5,6] These fungi have demonstrated high rates of TPH degradation in contaminated soil microcosms, with *Paecilomycesformosus* showing the highest degradation rate of 97%. *Purpureocilliumlilacinum* and *Penicillium chrysogenum* have also been identified as hydrocarbon-degrading fungi, with the ability to biodegrade hydrocarbons in oil sludge. Fungi achieve hydrocarbon degradation through mechanisms such as biosurfactant production and the use of fungal enzymes. Bist et. al., 2019screened twenty fungi for their potential to degrade the Chlorinated organic pesticide endosulfan and chlorpyrifos obtained from soil contaminated with pesticides collected from sal and pine forest, Forest Research Institute, Dehradun. Results showed that all fungi tested degraded a-endosulfan more efficiently than B-endosulfan. Endosulfan sulfate was found to be a major degradation product with all tested fungi.[16]

Biodegradation Mechanisms

Fungi biodegrade hydrocarbons through the production of extracellular enzymes and the involvement of specific metabolic pathways. The degradation process begins with the secretion of enzymes by the fungi, which fragment the hydrocarbon polymers into smaller oligomers.[12]These oligomers can then be taken up by the fungi and metabolized as a carbon and energy source.[13]

The metabolic pathways involved in hydrocarbon degradation vary depending on the type of hydrocarbon and the specific fungal species. For example, in aerobic bacteria, the degradation of chloroacetamide herbicides is initiated by an N/C-dealkylation reaction, followed by aromatic ring hydroxylation and cleavage processes.[14] In the case of polyesters, certain fungi are capable of completely depolymerizing the plastic, enabling the reformulation of the polymer with properties comparable to the virgin polymer.[15]

Kottbet. al., 2019 studied the biodegradation of petroleum hydrocarbons using locally isolated fungi from hydrocarbons polluted area in Suez Bay. Study reveals that fungi have several advantages than other microorganisms in biodegradation because of their ability to cultivate on a large group of substrates. They also produce extracellular enzymes, which can penetrate contaminated soil and remove pollutants. Fungal enzymes have the ability to degrade PAHs are cytochrome P450 monooxygenases, dioxygenases, proteases and lipases. Number of species are reported like *Aspergillus*, *Penicillium*, and *Cunninghamella*, are more efficient in degradation of PAHs.[17]

Overall, the mechanisms of fungal hydrocarbon degradation involve the secretion of enzymes and the subsequent utilization of the hydrocarbon fragments as a carbon and energy source through specific metabolic pathways.

Adaptation of Pyrophilous Fungi

Pyrophilous fungi, known for thriving in burned areas, were tested for their ability to aggregate soil. The study found that three specific pyrophilous fungi (*Geopyxiscarbonaria, Pyronemaomphalodes, and Morchella septimelata*)significantly increased soil aggregation over 40 days, suggesting their role in stabilizing soil after forest fires. This discovery implies that these fungi may reduce soil erosion and enhance soil moisture, crucial factors in early post-fire recovery. Additionally, pyrophilous fungi contribute to decomposition, carbon sequestration, and nitrogen capture.[18]

Hughes et al. 2020 study investigates the impact of a late fall wildfire in 2016 on pyrophilous fungi in the Great Smoky Mountains National Park, documenting their presence over 2 years based on burn severity and phenology. Using Nuc rDNA internal transcribed spacer (ITS) barcodes for confirmation, 41 taxa of Ascomycota and Basidiomycota were identified, with 22 species of Pezizales (Ascomycota) and 19 species of Basidiomycota, including five pyrophilousspecies (*Coprinellus angulatus, Gymnopilusdecipiens, Lyophyllumanthracophilum*, *Pholiotacarbonicola*, and *Psathyrella pennata*) were considered to be obligate pyrophilous taxa. Fruiting peaked 4–6 months post-fire, with some species continuing to fruit up to 2.5 years later. The study contributes 27 previously unrecorded taxa to the All-Taxa Biodiversity Inventory (ATBI) database, revealing both cosmopolitan and Northern Hemisphere distribution patterns, as well as detecting cryptic endemic lineages in Anthracobia and Sphaerosporella. Additionally, a new combination, *Hygrocybespadicea* var. *spadicea* f. *odora*, is proposed.[19]

Pyrophilous fungi have adapted to environments affected by fire and possess unique characteristics that contribute to their effectiveness in hydrocarbon degradation.[7] Understanding the genetic and physiological adaptations of these fungi in the context of hydrocarbon degradation is an important area of research.[8] These fungi are fire-responsive colonizers of post-fire soil and have historically been found fruiting on burned soil, indicating their ability to process pyrolyzed compounds.[9] Comparative genomic analyses have revealed an enrichment of gene families involved in stress response and the degradation of pyrolyzed organic matter.[10] Additionally, these fungi exhibit adaptations in protein sequence lengths and G+C content, similar to those observed in mesophilic/non-pyrophilous and thermophilic fungi.[11] The study of pyrophilous fungi, their adaptations, and their role in hydrocarbon degradation offers valuable insights into their potential applications in environmental remediation and biotechnology."

Prospective Insights

The use of Pyrophilous fungi for hydrocarbon biodegradation represents a promising, sustainable approach to environmental remediation. Their unique ability to thrive in fire-affected areas and degrade complex hydrocarbons highlights their potential in biotechnological applications. Future research should focus on understanding the genetic and physiological mechanisms of these fungi to optimize their use in hydrocarbon remediation efforts, particularly in resource-limited setting.

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