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Mini Review

Functional Responses of Dark Septate Endophytes Fungi to Anthropogenic Stress: Implications for Agroecosystem Resilience

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Abstract

Anthropogenic stresses caused by pesticides use and petroleum-derived pollutants from oil spills are widespread in agroecosystems, yet their direct effects on soil fungi remain poorly understood. This mini-review examines the responses of root-associated Dark Septate Endophytes (DSE) to these contaminants based on experimental evidence from isolated strains. Results show highly variable, strain-dependent responses, ranging from strong growth inhibition to metabolic adaptation and contaminant utilization. Pesticides generally exert more pronounced inhibitory effects, particularly at high concentrations, whereas some fungi display the capacity to degrade both pesticides and hydrocarbons. These findings highlight the functional plasticity of DSE fungi and suggest that anthropogenic stressors can alter fungal activity promoting effects on plant-fungus interactions and ecosystem processes. The adaptive responses of these fungi may play a key role in agroecosystem resilience under increasing environmental pressure.

Introduction

Anthropogenic disturbances, including the widespread use of pesticides and the release of petroleum-derived pollutants, represent major drivers of environmental change in both natural and agricultural ecosystems. Fungi, as key components of soil microbiota, play essential roles in nutrient cycling, organic matter decomposition, and plant health. However, research on fungi under anthropogenic stress has predominantly emphasized their capacity for bioremediation or plant protection, rather than their own physiological and ecological responses [1,2,3]. Root-associated fungi, particularly Dark Septate Endophytes (DSE), are of special interest due to their ubiquitous distribution and their ability to colonize a wide range of host plants under stressful conditions. These fungi are known to contribute to plant tolerance against abiotic stress and to participate in nutrient dynamics [4,5]. Nevertheless, the extent to which anthropogenic stressors affect DSE performance and functionality remains poorly understood [6]. This review focuses on the direct effects of pesticides and oil derivatives on DSE fungi, adopting a strain-based experimental perspective. Furthermore, it explores the broader ecological implications of these interactions within agroecosystems.

Effects of Pesticides on DSE Fungi

Pesticides are designed to target undesirable organisms such as weeds, pathogens, and insect pests, which compete with, harm, or cause or spread diseases to humans, domestic animals, natural vegetation, crops, or even structures. However, their effects extend beyond target species, impacting non-target soil microorganisms, including beneficial fungi. The response of DSE fungi to pesticides is highly variable and depends on multiple factors, including fungal species or strain, chemical structure of the compound, environmental conditions, and exposure duration [7]. Experimental evidence indicates that commonly used pesticides generally inhibit fungal growth, with effects intensifying at higher concentrations. Growth inhibition may range from mild to severe, suggesting that these compounds interfere with key physiological processes, such as membrane integrity, enzymatic activity, and oxidative balance. DSE strains exhibit partial tolerance and some of them even the ability to utilize pesticide compound as carbon sources. This performance increases as contact time passes. This metabolic flexibility suggests the presence of detoxification pathways and adaptive mechanisms that may confer ecological advantages under contaminated conditions. However, such responses are not universal and vary significantly among strains, highlighting the importance of intraspecific variability. studied the capacity of five DSE fungi strains to degrade three pesticides: the herbicide glyphosate, the fungicide carbendazim and the insecticide cypermethrin. For each pesticide, the treatments tried to be roughly the equivalent of the recommended agronomical dose currently used, a dose which double the recommendation and a dose 10 times higher, and their respective control. Glyphosate showed a growth inhibition from 1.25% to 47.70 % at recommended agronomical dose and 73.90 % to 85.38% at a dose 10 times higher than recommended. For their part, at recommended agronomical dose, Carbendazin increased the growth of one fungus (+0.13%) but showed a maximum growth inhibition of 86.81%, in other case. At a dose 10 times higher than recommended the growth inhibition ranged from 47.91% to 86.03%. Cypermetrim showed a growth inhibition from 8,38% to 56.42 % at recommended dose and from 71.92% to 88.72% at 10 times higher dose than recommended. Earlier pesticides were very poorly degradable, and persist in soils for years. Pesticides changed, but a anyway from a functional perspective, the inhibitory effects of current pesticides on DSE fungi may disrupt plant-fungus symbioses and, at least temporarily, potentially reducing plant resilience to environmental stress.

Effects of Oil-Derived Pollutants on DSE Fungi

Petroleum hydrocarbons and their derivatives constitute a major class of environmental pollutants, often associated with industrial activities and accidental spills. Their presence in soil can impose strong selective pressures on microbial communities [9]. studied the effects of two oil derivatives, kerosene and semi-synthetic lubricating oil, on four DSE fungi. They found that there were differences not only between the activity of the different DSE strains but also differences between strains of the same fungi species, after contamination with those oil derivatives. Fungi showed percentages between 80 and 85% of growth inhibition in kerosene, related to their respective controls. Conversely, in lube oil, a fungus showed growth induction (124%), compared to the control. These inhibitory effects are likely linked to the toxic nature of hydrocarbons, which can disrupt cell membranes and interfere with metabolic pathways. Despite these negative impacts, some DSE strains demonstrate the capacity to degrade and assimilate hydrocarbon compounds and use it as carbon source. Some fungi strains can utilize both hydrocarbons and simple sugars (e.g., glucose) as carbon sources, reflecting a high degree of metabolic versatility. The surfactant and degradant activity of these fungi against the two oil derivatives were positive, showing that most fungi can emulsify these two oil derivatives. This ability is often associated with the production of extracellular enzymes and surfactant molecules that facilitate the breakdown and emulsification of hydrophobic substrates. The coexistence of inhibitory and adaptive responses suggests that DSE fungi may play a dual role in contaminated environments: as organisms affected by pollution and as agents contributing to its transformation. This duality has important implications for ecosystem functioning and resilience, as well as their remediation.

Functional and Ecological Implications

The responses of DSE fungi to anthropogenic stressors are complex and context-dependent, encompassing both negative and adaptive outcomes. While pesticides tend to trigger more direct and pronounced inhibitory effects, oil-derived pollutants appear to elicit a broader spectrum of responses, including metabolic adaptation and biodegradation. This result differs from intuitive knowledge, possibly due to the different magnitude of what was incorporated into the soil. Generally, pesticide application is orders of magnitude smaller than an oil spill. From a physiological standpoint, these responses may involve mechanisms such as: activation of detoxification pathways, modulation of oxidative stress responses, alterations in membrane composition, and expression of degradative enzymes [10]. At the ecological level, changes in fungal growth and activity can trigger effects on plant performance and soil processes. DSE fungi are known to enhance plant tolerance to abiotic stress [11,12], improve nutrient acquisition [13], and influence root architecture [14]. Therefore, any disruption in their functionality may compromise plant health and reduce agroecosystem resilience. Conversely, the ability of some fungi to tolerate and transform contaminants suggests a potential buffering role within ecosystems. Such functional plasticity may contribute to the stabilization of microbial communities under stress, partially mitigating the negative impacts of pollution. Importantly, the variability observed among fungal strains highlights the need to consider microbial diversity at a fine scale. Functional traits related to stress tolerance and contaminant degradation may not be uniformly distributed and shifts in community composition could significantly alter ecosystem functioning.

Conclusion

Pesticides and petroleum derivatives spills exert anthropogenic significant effects on DSE fungi, predominantly through growth inhibition, but also by selecting for metabolically adaptable strains. These effects extend beyond individual organisms, potentially altering plant-fungus interactions and key ecosystem processes. The evidence suggests that fungal responses to environmental stress are governed by a balance between sensitivity and adaptability. While many fungi are negatively affected, others exhibit traits that enable them to persist and even contribute to contaminant transformation, and eventually its elimination. Understanding these dynamics is essential for predicting the long-term consequences of pollution in agroecosystems and for designing sustainable management strategies that preserve soil biological integrity. Future research should integrate physiological, ecological, and molecular approaches to better elucidate the mechanisms underlying fungal resilience to anthropogenic stress.

Conflicts of Interest:

The authors declare no conflict of interest.

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