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Sustainable Agriculture: The Protective Role of Endophytic Fungi

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Abstract

Insect pests cause up to 26% of annual crop losses globally. Overuse of chemical insecticides has led to widespread resistance, necessitating alternative solutions. Integrated Pest Management (IPM) combines various methods, including the use of entomopathogenic fungi (EPF) such as *Beauveria*, *Metarhizium*, and *Lecanicillium*, which are effective, environmentally friendly, and promote biodiversity. These fungi infect and kill pests and can also colonize plants as endophytes, enhancing plant growth and pest resistance. Endophytic fungi live inside plant tissues without causing harm and form mutualistic associations. They can be classified by reproduction, transmission, nutrition, infection expression, and plant part colonized. Endophytic fungi use mechanisms like antibiosis, induced plant defences, herbivore-induced plant volatiles, and altering plant volatiles to protect plants. Despite their potential, challenges like product efficacy and environmental compatibility must be addressed for successful commercialization. Ongoing research and effective farmer communication are crucial to advancing sustainable agricultural practices.

Introduction

Insect pests are responsible for significant agricultural losses, causing 18-26% of annual crop production losses globally. Field losses before harvest can reach up to 16%, and post-harvest pests can result in up to 60% of stored grain losses. Overreliance on chemical insecticides has led to resistance in over 500 arthropod species. Developing new insecticides is both costly and time-consuming, with costs exceeding $250 million and taking 8-12 years for a single compound to be approved. Integrated Pest Management (IPM) offers a sustainable alternative, combining techniques like sanitation, resistant crop varieties, cultural practices, and biological control, with chemical use as a last resort. Among biological controls, entomopathogenic fungi (EPF) are particularly effective. They are cost-effective, environmentally friendly, and promote biodiversity. Common EPF genera include *Beauveria*, *Metarhizium*, *Isaria*, *Lecanicillium*, and *Hirsutella*, which infect insects by penetrating their bodies, growing inside them, and eventually killing them to produce new spores. EPF have been discovered to infect around 750 insect and mite species. They exhibit high reproductive rates, target specificity, and longevity, which ensure their survival even in the absence of a host. However, field efficacy of fungal entomopathogens is limited by factors like UV light sensitivity, low moisture, and application challenges. Interest is growing in using these fungi as endophytes to understand their effects on pests, plant pathogens, and plants themselves. Many EPF species can also colonize plant tissues, acting as endophytes, which can enhance plant growth and reduce pest infestations. Endophytes are fungi that live inside plant tissues without causing harm, forming mutualistic associations that often enhance plant growth and defence against pests. They are common in the Ascomycota phylum but can also be found in

Basidiomycota, Glomeromycota, and Zygomycota. Establishing EPF colonization can be achieved through foliar sprays, soil drenching, seed soaking, and injections. Endophytic EPF can survive throughout an entire growing season and are found in crops like wheat, bananas, soybeans, and tomatoes, acting as plant growth promoters and microbial control agents. Further research is needed to optimize the mechanisms of endophytism and understand plant and pest responses to colonization.

Classification of Fungal Endophytes

Fungal endophytes, though diverse, have only a few species isolated, identified, and characterized so far. They can be broadly classified into two major groups: clavicipitaceous and non-clavicipitaceous. Clavicipitaceous endophytes are common in grasses, whereas non-clavicipitaceous endophytes are predominant in vascular and non-vascular plants.

- **Based on reproduction:** Endophytes can be classified as sexual or asexual. *Epichloë* endophytes reproduce sexually, while *Neotyphodium* reproduces asexually.
- **Based on transmission:** Endophytes can be vertically transmitted (from parent to offspring through seeds) or horizontally transmitted (between different individuals in a population). True endophytes, like *Neotyphodium*, are mostly seed-transmitted. *Epichloë* endophytes and *Beauveria bassiana* in opium poppy are examples of vertically transmitted endophytes. Horizontally transmitted endophytes spread via airborne spores or vegetative propagules and are common in woody and herbaceous plants.
- **Based on source of nutrition:** Biotrophs derive nutrients from living host tissues, while necrotrophs grow on dead tissues after killing host cells. These fungi-plant interactions involve endophytes obtaining carbon from their hosts in exchange for providing benefits to the plant. Endophytes can switch between biotrophic and necrotrophic lifestyles due to environmental changes, as seen with *Leptosphaeria maculans* in stressed *Arabidopsis thaliana*.
- **Based on the expression of infection:** Endophytes can be symptomatic (causing symptoms) or asymptomatic (symptomless). Many endophytes infect above-ground plant tissues without showing symptoms, such as *Fusarium* spp. in banana roots. Environmental conditions can cause asymptomatic endophytes to become pathogenic.
- **Based on the plant part they colonize:** Root endophytes (e.g., *Fusarium* spp., *Metarhizium* spp., *Piriformospora indica*, *Glomus* spp.) infect plant tissues from the rhizosphere, while foliar endophytes invade stems and leaves (e.g., *Beauveria bassiana*, *Pochonia chlamydosporia*, *Metarhizium* spp.).

Different Mechanisms Used by Endophytic Fungi Against Herbivores

- **Antibiosis and Feeding Deterrence:** *Metarhizium* spp. are known to produce destruxins, which have insecticidal properties. These metabolites can be detected in plants colonized by Metarhizium, such as cowpea and potato plants. Destruxins interfere with insect physiology, contributing to reduced insect fitness and survival.
- **Induced Plant Defences:** *Beauveria bassiana* colonizing tomato plants induces the production of terpenoids like δ-2-carene and α-humulene. These compounds enhance plant resistance against herbivores such as beet armyworm (*Spodoptera exigua*), resulting in reduced insect feeding and growth rates compared to non-colonized plants.
- **Herbivore-Induced Plant Volatiles (HIPVs):** *Lecanicillium lecanii* benefits from HIPVs induced by aphid feeding on tobacco plants. The presence of HIPVs enhances the germination and pathogenicity of *L. lecanii* conidia, potentially increasing its effectiveness as a biocontrol agent against aphids.
- **Direct Ingestion of Fungal Hyphae:** *Helicoverpa zea* larvae fed on diets containing *Beauveria bassiana* mycelia powder exhibited varied responses. High concentrations of

mycelial powder led to increased larval mortality and developmental delays, likely due to the ingestion of fungal metabolites or deterrence of feeding.

- **Altered Plant Volatiles and Kairomones:** Endophytic fungi like *Hypocrea lixii* can alter the volatile profiles emitted by plants, influencing insect behaviour. *Thrips tabaci* showed a preference for plants without *H. lixii*, suggesting a repellent effect of fungal colonization on insects.

Conclusion

Endophytes present promising alternatives to chemical pesticides for enhancing agricultural crop performance through biocontrol. However, successful commercialization hinges on addressing key challenges such as product efficacy, viability during storage, and compatibility with varying environmental conditions. Effective communication and education are crucial to foster confidence and demand among farmers. Continued research, encompassing both controlled experiments and field trials, is essential to develop robust biocontrol agents tailored to diverse crops and environments. Integration of molecular technologies and ecological insights will further advance the commercialization of these agents, contributing to sustainable agricultural practices globally. Future investigations should prioritize understanding the physiological mechanisms of endophyte-plant interactions and optimizing deployment strategies for enhanced efficacy in integrated pest management programs.

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