



# Endophytic fungi - a promising approach for integrated pest management

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Insect pests and plant pathogens represent significant problems to agriculture, while reliance on chemical pesticides poses environmental and health hazards. Endophytic microbes, particularly fungi like *Beauveria bassiana* and *Metarhizium anisopliae*, colonize plant tissues without causing harm while increasing resistance to pests and diseases. They affect pests directly by infecting them and creating harmful metabolites, as well as indirectly by regulating plant defences and emitting volatiles that attract natural enemies. Endophytes can be spread vertically by seeds or horizontally via environmental spores and vectors, allowing for long-term colonization. Including endophytes in integrated pest management minimises pesticide use, promotes sustainable practices and strengthens agroecosystems. Despite limitations such as slower insect death, environmental sensitivity and potential effects on natural enemies, endophytes provide promising eco-friendly techniques for long-term crop protection.

**Keywords:** Endophytes, *B. bassiana*, *M. anisopliae*, Integrated Pest Management, Fungi

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## Introduction

Contemporary agricultural systems are increasingly confronted with the challenge of meeting the rising global demand for food driven by rapid population growth. To remain economically viable and competitive, it is imperative to reduce the cost of cultivation while ensuring environmentally sustainable and pollution-free agricultural practices over the long term. Plant pathogens and insect pests are responsible for an estimated 30–50% reduction in global annual crop yields, posing a significant challenge to food security for the continuously growing human population (Mousa & Raizada, 2013). To minimize these losses and meet the increasing food demand, chemical pesticides are commonly employed for the management of these pests and pathogens. Increasing concerns regarding the environmental and public health implications of these practices have created a demand for more reliable and cost-effective alternatives that emphasize environmental safety

(Panwar & Szczepaniec, 2024). One promising yet relatively underexplored approach that has recently gained considerable attention is the use of beneficial endophytes as biological control agents for crop protection (Le Cocq et al., 2017). Endophytic microorganisms are those that reside within the internal tissues of plants without causing apparent harm to their host.

These microorganisms may include bacteria, fungi, and occasionally viruses. Endophytes often establish beneficial associations with their host plants, contributing to enhanced nutrient acquisition, improved tolerance to environmental stresses and increased resistance to diseases (Turbat et al., 2020). Many of their bioactive compounds, initially associated with disease resistance or stress tolerance, are now recognized for their potential roles in plant protection and pest management (Gundel et al., 2020). The role of endophytes in managing insect pests and plant diseases through mechanisms such as antibiosis and antixenosis has been demonstrated by several researchers. Their use in plant protection can reduce reliance on chemical pesticides and promote a more stable and sustainable agroecosystem (Gunjal, 2024). This chapter focuses on the associations between endophytic microorganisms and plants, with particular emphasis on their role in insect pest management.

### **Potential of fungal endophytes for insect pest management**

Fungi are a group of eukaryotic organisms, ranging from unicellular to multicellular forms and exhibit remarkable diversity in their adaptability and survival under various environmental conditions. Entomopathogenic fungi are capable of infecting a broad range of arthropod pests and are widely distributed across most terrestrial ecosystems, where they perform diverse ecological functions (Lovett, 2017). In addition to their occurrence in soil and on the phylloplane (leaf surfaces), these fungi have also been reported as endophytes residing within plant tissues and as rhizosphere competent microorganisms associated with the root environment (Vega, 2018).

#### **Direct effects on insects**

The first research on fungal endophytes was conducted on *Phomopsis oblonga*, an endophytic fungus that protected elm trees from an insect *Physocnemum brevilineum* (Webber, 1981). Following that, numerous naturally occurring endophytic fungi were isolated from their individual host plants, including *Beauveria bassiana*, *Clonostachys rosea*, and *Isaria farinose* (Bills & Polishook, 1991; Cherry et al., 1999; Pimentel et al., 2006). In order to manage the European corn borer, *Ostrinia nubilalis* in corn, early research on introducing entomopathogenic fungi as endophytes carried out in 1990 used *B. bassiana* as an endophytic fungus (Bing & Lewis, 1991).

Endophytic colonization of banana (*Musa* spp.) by *B. bassiana* significantly reduced larval survivorship and plant damage caused by *Cosmopolites sordidus*, with substantial larval mortality associated with fungal mycosis compared to untreated controls (Akello et al., 2007). Field studies showed that *Metarhizium* and *B. bassiana* effectively controlled diamondback moth, (*Plutella xylostella*) and significantly increased cauliflower yield, with *M. anisopliae* being the most effective (Bathina & Bonam, 2020). These fungi have been demonstrated to suppress pest reproduction in addition to decreasing pest survival, probably as a result of their detrimental effects on insect growth and nutrition. The endophytic fungus *B. bassiana* and *Lecanicillium lecanii* (Zimmermann) reduced cotton aphid reproduction by 61% and 57%, respectively, when compared to untreated leaves (Gurulingappa et al., 2010). Reduced larval growth in *Agrotis ipsilon* on *Metarhizium robertsii* inoculated plants shows that endophytic fungus can inhibit insect growth and reproduction without necessarily resulting in mortality (Ahmad et al., 2020).

### **Indirect effects on insects**

By activating or augmenting plant defence systems, endophytic fungi can also indirectly increase plant resilience against herbivores. In *Phoenix dactylifera*, endophytic colonization by entomopathogenic fungi like *B. bassiana* and *Lecanicillium dimorphum* improves defence priming and metabolic control by increasing plant defence and stress-related protein production (Gómez et al., 2009). Through the production of secondary compounds by fungi within the plant, fungal endophytes may also have an indirect effect on insect herbivores. Endophytic colonization by *B. bassiana* leads to *in-planta* production of beauvercin in crops such as *Vigna unguiculata*, which can directly impair herbivores and cause high mortality, thereby enhancing plant defence (Pachoute & de Souza, 2024). Destruxin A produced by *M. robertsii* can cause up to 100 per cent mortality in *Anastrepha obliqua*, demonstrating that endophytic fungal metabolites directly enhance plant defence by reducing insect fitness (Golo et al., 2014). Increased recruitment of parasitoids and predators in crops colonized by fungi like *B. bassiana* and *Trichoderma* spp. also provides evidence that endophytic fungi can improve plant resistance by changing volatile emissions, thereby attracting natural enemies and enhancing pest suppression (González et al., 2021).

### **Mechanisms underlying insect pest control by endophytic fungi**

The ability of endophytic fungi to discourage insects, decrease feeding, hinder growth and development and increase pest mortality has been primarily attributed to toxin production. Conidial adhesion to the insect cuticle is the first stage of entomopathogenic fungal infection, which is followed by germination, appressoria formation, and enzymatic penetration. This results in hyphal invasion of the hemocoel, where blastospores multiply and release insecticidal metabolites like beauvericin and destruxins that quickly kill the host. Moreover, species like *M. robertsii* can colonize plants endophytically, improving plant growth and protection while using insect cadavers as a source of nutrients (Ahmad et al., 2022). Several reports suggest that these fungi can make host plants unpalatable to a variety of herbivorous pests. For instance, Ullah, (2023) showed in that endophytic fungi produced toxic secondary metabolites that protected Canadian fir from spruce budworms. Patterson et al. (1991) found that the production of alkaloids by *Acremonium* prevented the Japanese beetle *Popilla japonica* from attacking *Lolium* and *Festuca*. Endophytic fungi are a valuable source of insecticidal toxins, according to surveys conducted to find novel bioactive compounds. For instance, an unidentified endophytic fungus linked to wintergreen, *Gaultheria procumbens*, was found to contain two active chemicals that were effective against the spruce budworm, *Choristoneura fumiferana* (Findlay et al., 1997).

### **Metabolic modulation of host plants by endophytic entomopathogenic fungi**

When entomopathogenic fungi colonize host plants, they can alter the nutrient composition and defence chemicals of the plant, making it less suitable as a food source for herbivores or enhancing their repellence. The production of secondary metabolites, including phenolics, terpenes, flavonoids, alkaloids and volatile organic compounds, as well as plant hormones that boost resistance against herbivores and stimulate plant development, is frequently linked to these negative consequences (Hendra et al., 2026).

### **Variations in plant volatile profiles**

Microbes play a crucial role in the synthesis and release of these bioactive compounds, and *B. bassiana* colonization modifies plant volatile profiles, affecting the attraction of natural enemies and deterrence of herbivores. Endophytic colonization by entomopathogenic fungi can change the dynamics of insect populations at higher trophic levels (Quesada-Moraga et al., 2022). By changing plant volatile emissions,

endophytic colonization by entomopathogenic fungi can modify herbivore interactions and increase the attraction of natural enemies, which in turn can affect insect population dynamics at higher trophic levels (Aravinthraju, et al., 2024.) Endophytic colonization by *B. bassiana* increases the emission of herbivore-induced volatile compounds, such as 6-methyl-octadecane in melon and 4-methyl-octane,  $\alpha$ -caryophyllene, and (E)-hex-2-en-1-ol in cotton. These compounds may attract natural enemies or deter pests, while also suppressing insect immune responses and increasing their susceptibility to predation (Reddy & Guerrero, 2004; Shrivastava et al., 2015).

### **Impact on secondary metabolite production**

Plant secondary metabolites, in addition to volatile compounds, play an important role in pest defence and their modulation by endophytic colonization can enhance resistance, as evidenced by reduced *O. nubilalis* infestation on maize colonized by *B. bassiana*, which is most likely due to fungal metabolites mediating deterrence or antibiosis (Lacava & Azevedo, 2014). Endophytic colonization by entomopathogenic fungi stimulates the production of a variety of plant defence compounds, including, root exudates and strigolactones while fungi use detoxifying enzymes to counteract inhibitory plant metabolites (Rojas et al., 2026). Fungal metabolites also play important roles in plant-insect-microbe interactions, stress tolerance and communication, with root exudates promoting *Metarhizium* colonization.

### **Effects on plant hormones and enzymatic activity**

Plant hormones and enzymes, though less directly involved in defence, play a crucial role in plant growth. Endophytic entomopathogenic fungi enhance growth by producing phytohormones such as indole-3-acetic acid and cytokinins, as well as by improving nutrient uptake, particularly nitrogen and phosphorus (Malinowski & Belesky, 1999; Luo et al., 2023; Tang et al., 2022).

### **Increased production of antimicrobial compounds**

Despite altering plant metabolites and volatile organic compounds, endophytic colonization can increase the synthesis of antimicrobial compounds. This is because plants react to the presence of microorganisms by producing more antifungal and antibacterial compounds, such as benzaldehyde and (2Z,13E)-octadeca-2,13-dien-1-ol, which help them become resistant to pests and diseases (Aravinthraju, et al., 2024).

### **Endophyte transmission pathways**

Endophytic fungi come from a variety of sources within the plant environment, such as airborne fungal spores, rhizosphere-associated microorganisms, and vectors like insects and other animals whose feeding habits help them spread and colonize host plant tissues (Sasse et al., 2018). Endophytic fungi are transferred in two ways: horizontally and vertically. Vertical transmission involves the direct transfer of endophytes from mother plants to progeny via seeds as shown in Figure.1 (Salamon et al., 2025). Endophyte transmission can occur vertically through seeds, allowing them to remain throughout the plant's life cycle, as is common in grasses, where a single endophyte species with a uniform genotype is usually maintained (Sharon et al., 2023). Endophytes can also be spread horizontally through environmental spores, with seedlings initially free of colonization becoming gradually infected via air, rain, or vectors such as insects and mammals, resulting in increased colonization over the growth season as in Figure.1 (Helander et al., 2007). Symbiotic interactions between plants and a diverse community of soil microbes can aid in the establishment of fungal endophytes, as these fungi use the rhizosphere as an entry point, adhere to root surfaces and develop specialized structures such as appressoria to penetrate and colonize internal plant tissues, resulting in stable endophytic associations

(Peng, et al., 2026). Crop plant microbiome modification can involve both vertical and horizontal transmission, as achieved through approaches such as maternal plant inoculation to produce endophyte-colonized seeds, as well as seed treatments, soil amendments and foliar applications, with a better understanding of endophyte transmission and life cycles assisting in the development of more effective inoculation strategies and application techniques (Quesada-Moraga et al., 2014).

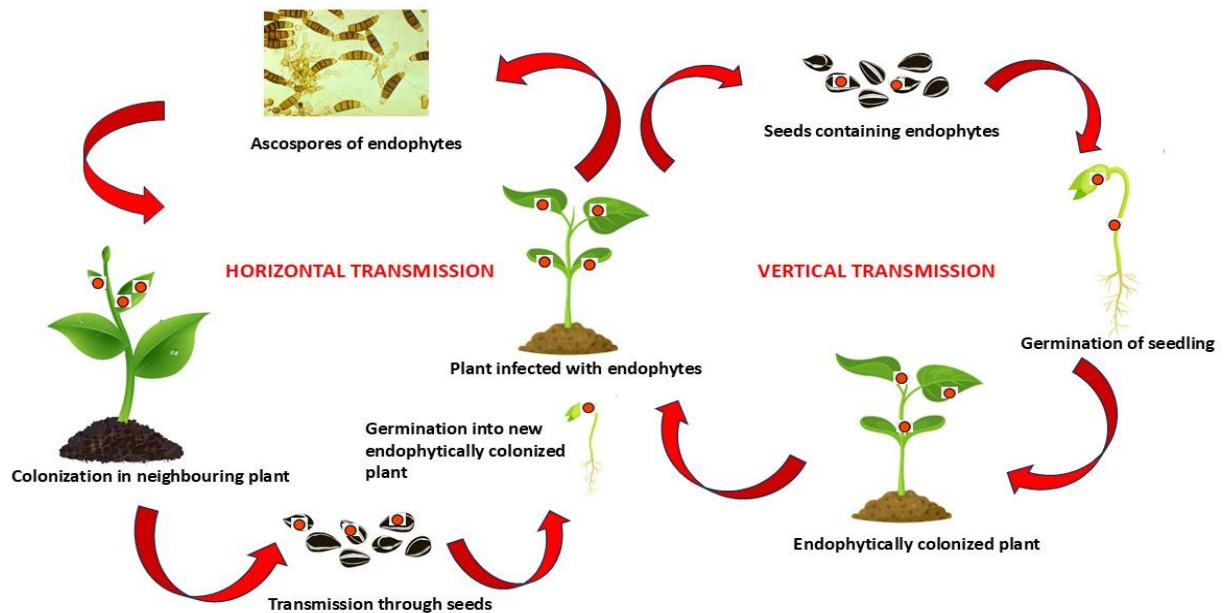
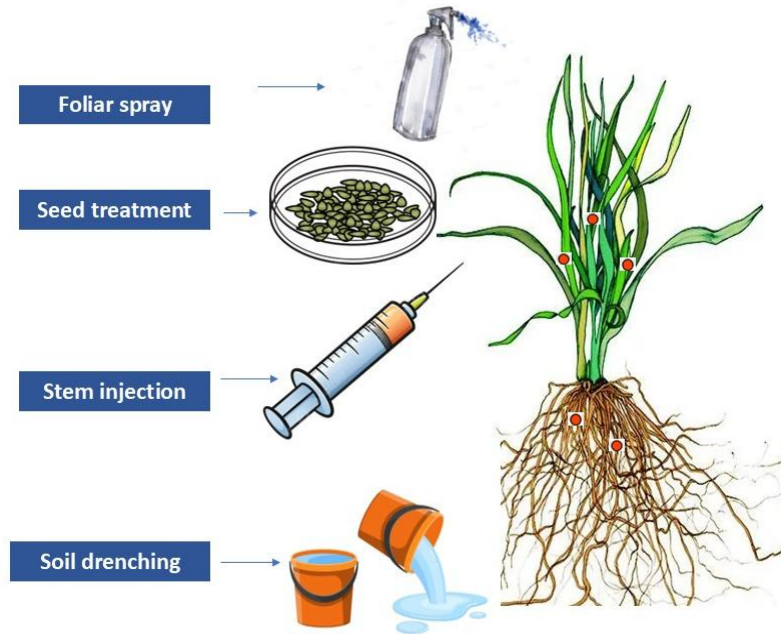


Figure 1. Vertical and horizontal transmission of endophytic fungi

### Isolation and inoculation of endophytes

In order to isolate endophytes, usually plant tissues are first surface sterilized, then the internal tissue segments are aseptically dissected and cultured on appropriate growth conditions (Hallmann et al., 2001). The selection of fresh, healthy plant tissues provides the foundation for endophyte isolation. Sequential surface sterilization is a commonly used technique in which tissues are first treated with 70% ethanol, then sodium hypochlorite (0.5–3.5% for 1–3 min), briefly rinsed again in 70% ethanol, and finally washed with sterile distilled water to remove any remaining sterilants and external contaminants before isolation (Batool et al., 2024). Sterilized tissue segments are aseptically placed on appropriate media and incubated, and emerging growth is subcultured to obtain pure endophytic isolates.

Several methods and protocols have been developed in order to artificially inoculate entomopathogenic fungi as endophytes in different crop plants. These techniques include spraying leaves with a conidial suspension, soaking seeds in a conidial suspension, injecting fungal inoculum into the stem, dipping seedling roots in a conidial suspension and saturating soil with a conidial suspension (Figure 2). The most popular technique, foliar spray, has demonstrated encouraging outcomes in a number of crops (Francis et al., 2022). Additionally, stem injection has been used as an endophytic fungal inoculation technique with subsequent research showing that *Helicoverpa armigera* can be effectively controlled in tomato plants using this method (Silva et al., 2023). In rice, seedling root dip method has been shown to be an efficient inoculation strategy, although its efficacy varies when compared to foliar spray and is heavily dependent on plant variety (Arun et al., 2023).



**Figure 2. Artificial inoculation methods of endophytes**

### Endophytes in Integrated Pest Management (IPM)

Endophytes have sparked renewed attention in integrated pest management due to their function in increasing plant resistance and supplementing existing control measures. Endophytes act as natural antagonists to plant pests, facilitating biological control. Some create secondary metabolites that are harmful or repellent to herbivorous insects. For example, grass-associated Clavicipitaceae fungi produce alkaloids that deter herbivores and may influence predators or parasitoids used in biological control (Schardl et al., 2013). Incorporating endophytes into IPM can minimise dependency on chemical pesticides, encouraging more sustainable and environmentally friendly pest management.

### Challenges and future prospects

Fungal biocontrol agents have a minimal market share since they act slowly than chemical pesticides and require a large inoculum. Their field performance is frequently uneven because fungal infections are susceptible to environmental stress. Even highly virulent strains often kill the host within 2-5 days, allowing pests to cause major agricultural damage (Wang et al., 2024). While they have potential as biocontrol agents, they may harm natural adversaries. The fungus *Acremonium coenophialum* inhibited the growth and survival of parasitoids *Euplectrus comstockii* via endophyte-inoculated autumn armyworm hosts (Bultman et al., 1997). These findings imply that endophytes can influence food web dynamics, potentially restricting natural enemy potency. Thus, assessing non-target consequences and mitigation techniques is critical to their successful incorporation into IPM.

### Conclusion

The widespread use of chemical pesticides for pest and disease control poses considerable problems to modern agriculture. In this context, biocontrol agents have received attention for their ability to promote sustainable and environmentally stable behaviours. Endophytes play an important function in plant disease

suppression and insect pest management. Expanding endophyte research provides intriguing solutions for promoting healthy, resilient ecosystems and sustainable agriculture for future generations.

### Conflict of interest statements

The authors declare no conflicts of interest.

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