# Advances in Research of the Growth-Promoting Effects of Entomopathogenic Fungi on Host Plants

Xiaolei JI[1], Ting LI[2], Tongrui YANG[3], Gongping HU[1 *], Yun LIU[1], Jing PENG[1], Jian TANG[1]

1. Guizhou Light Industry Polytechnic University, Guiyang 550025, China; 2. Guizhou Qiannan College of Science and Technology, Qiannan 550600, China; 3. Xihang University, Xi'an 710077, China

**Abstract** Entomopathogenic fungi are valuable beneficial microorganisms that display dual roles as insect pathogens and plant growth promoters in agriculture. This review presents recent advances in understanding the biological foundations of their growth-promoting effects and the molecular mechanisms underlying plant-fungus interactions. We further provide a comprehensive overview of the field performance of these fungi on major crops and the pathways for translating research into practice. Moreover, the review assesses the integrated value from ecological, economic, and social perspectives, aiming to offer theoretical guidance and practical insights for the deep development and broad application of entomopathogenic fungi in sustainable agriculture.

**Key words** Entomopathogenic fungi, Endophytic colonization, Growth-promoting effect, Molecular mechanism, Sustainable agriculture

## 0 Introduction

Entomopathogenic fungi are filamentous fungi commonly found in soil and plant rhizosphere ecosystems. They serve as biocontrol agents against a wide range of agricultural pests by penetrating the insect cuticle, overcoming cuticular defenses, and proliferating in the hemocoel, ultimately leading to host death. Recent studies have revealed that these fungi can also colonize plants internally or the rhizosphere in a non-pathogenic manner, establishing mutualistic endophytic or rhizosphere associations. These interactions significantly enhance host plant growth and development, increase nutrient uptake efficiency, induce systemic resistance, and improve tolerance to both biotic and abiotic stresses[1]. By virtue of these attributes, entomopathogenic fungi occupy a distinct functional niche within agroecosystems, acting as a critical node in the soil-plant-insect food web. Understanding the molecular basis of their interactions with plants and harnessing their growth-promoting capacity are therefore essential for improving ecosystem services in agriculture and advancing the shift toward sustainable farming. In this paper, we provide a systematic overview of entomopathogenic fungi, covering strain diversity and functional traits, underlying mechanisms of plant growth promotion, molecular plant-fungus interactions, as well as practical applications and pathways for technology transfer. The review is intended to serve as a comprehensive scholarly resource and practical guide to support further research and the translation of these fungi into industrial applications.

## 1 Biological foundations of the growth-promoting effects of entomopathogenic fungi

Entomopathogenic fungi are taxonomically placed within the order Hypocreales (Ascomycota). Genera known for their plant growth-promoting effects include *Beauveria*, *Metarhizium*, *Lecanicillium*, *Cordyceps*, and *Paecilomyces*. The functional performance of these fungi is shaped by a combination of factors, such as host plant genotype, soil physicochemical properties, climatic conditions, and agricultural management practices[2]. It should be noted that the location and pattern of fungal colonization within plant tissues directly determine the expression of their beneficial functions. Additionally, secondary metabolite profiles are highly strain-specific, with marked variation in the spectrum and concentration of phytohormone analogues, antibiotics, and volatile organic compounds. Such metabolic divergence directly translates into differential regulation of plant growth promotion and stress resistance.

The growth-promoting effects of entomopathogenic fungi on plants arise from a complex, multi-factorial biological process that operates through multiple pathways and at multiple levels. These mechanisms can be broadly divided into direct and indirect modes of action. Direct growth promotion occurs when fungal metabolic activities directly influence plant physiology, including the production of phytohormones, the transfer of nutrients, and the mobilization of soil nutrients. Indirect promotion, on the other hand, is achieved when the fungi shape a favorable biological environment for plant growth, for instance, by restructuring the rhizosphere microbial community, suppressing soilborne pathogens, or eliciting induced systemic resistance in the host plant.

Numerous studies have established that entomopathogenic fungi can synthesize a wide array of plant growth regulators. For instance, volatile organic compounds emitted by *Beauveria bassiana* have been shown to markedly enhance shoot and root fresh weight, plant height, and primary root length in sorghum seedlings, with the growth promotion closely linked to elevated levels of indole-3-acetic acid (IAA)[3]. Beyond auxins, these fungi also

Received: April 3, 2026 Accepted: June 2, 2026
Supported by SPGY2025-YB040 Project (Qian Jiao He KY[2016]332).
Xiaolei JI, bachelor's degree, research fields: agronomy. * Corresponding author. Gongping HU, master's degree, research fields: microbial ecology.

produce gibberellins (GA), cytokinins (CTK), abscisic acid (ABA), and ethylene (ET), along with their biosynthetic precursors. Acting through intricate hormonal signaling networks, these compounds collectively orchestrate fundamental physiological processes such as cell division, differentiation, and elongation, root and xylem development, seed germination, and photosynthesis[4]. Nutrient transfer represents another key mechanism, wherein entomopathogenic fungi mediate the movement of insect-derived nitrogen to host plants through a tripartite "insect-fungus-plant" pathway, effectively adding a supplementary branch to the soil nitrogen cycle. Behie & Bidochka[5] showed that Metarhizium robertsii transfers nitrogen acquired from Galleria mellonella larvae into plant tissues, significantly boosting the productivity of crops such as soybean, wheat, mung bean, and switchgrass. This establishes a resource-based mutualism in which plants provide carbon derived from photosynthesis to the fungi, and in return, the fungi supply insect-derived nitrogen. Beyond nitrogen transfer, entomopathogenic fungi that colonize roots also enhance soil nutrient availability by secreting organic acids and siderophores, which solubilize recalcitrant phosphates and improve the bioavailability of micronutrients like iron and zinc. Moreover, the hydrolytic enzymes released by these fungi contribute to the decomposition of soil organic matter, accelerating nutrient cycling and the flow of materials through the soil ecosystem.

## 2 Molecular mechanisms of plant-fungi interaction

The interaction between entomopathogenic fungi and plants is initiated by the recognition and adhesion of fungal spores to the root surface, and proceeds through rhizosphere colonization, root surface proliferation, tissue penetration, and systemic colonization. As with insect infection, these plant colonization processes are governed by an array of cell surface proteins and precisely regulated signaling molecules. During spore attachment, various surface proteins mediate specific recognition and firm adhesion to plant tissues, while hydrophobins assemble into a hydrophobic coat that protects spores against environmental stress. Plant hormones act as master regulators of growth, development, and stress adaptation. By modulating host hormone biosynthesis, transport, and signal transduction networks, entomopathogenic fungi are able to precisely tune the balance between plant growth and defense. Following root colonization, the cell wall constituents and secreted effector proteins of entomopathogenic fungi are perceived by plant pattern recognition receptors as microbe-associated molecular patterns (MAMPs). This recognition initiates primary immune signaling and, through systemic signal propagation, primes aboveground tissues for enhanced defense. Cachapa *et al.*[6] uncovered the molecular basis of defense induction by root-associated entomopathogenic fungi, demonstrating that colonization by *Metarhizium* and *Beauveria* species stimulates the production of diverse defense-related secondary metabolites. These secondary metabolites not only exert direct inhibitory effects on plant pathogens but also participate in multiple defense processes, including plant cell wall reinforcement, reactive oxygen species homeostasis regulation, and the modulation of hypersensitive responses. Endophytic fungi, with their remarkable tolerance to extreme conditions such as high osmotic stress, elevated temperatures, and broad pH ranges, represent ideal candidates for improving crop resilience to abiotic stress. A notable example is the entomopathogenic fungus Metarhizium anisopliae, which, through the regulation of ion homeostasis, osmolyte accumulation, and antioxidant defense systems, enables rice plants to sustain relatively high growth rates and yields even under salt stress[7].

## 3 Practical application and technology transformation path

In recent years, entomopathogenic fungal products have become an important component of the biopesticide market. However, the field application efficacy of entomopathogenic fungi is complexly affected by multiple factors, including strain characteristics, inoculation methods, application dosage, environmental conditions, and crop species, and requires coordinated breakthroughs at multiple levels, such as strain improvement, fermentation technology, formulation innovation, and extension strategies. In terms of strain improvement, targeted strain modification based on gene editing technologies such as CRISPR-Cas9 is expected to yield engineered strains with stronger colonization competitiveness, higher growth-promoting efficiency, and broader environmental adaptability. Furthermore, bioprospecting for wild strains with unique stress resistance gene resources from extreme habitats is also an important approach for strain improvement.

In terms of fermentation technology, the production of entomopathogenic fungal preparations mainly includes two technical routes: solid-state fermentation and submerged liquid fermentation. Solid-state fermentation technology is widely applied in developing countries due to its simple equipment, low investment, and low technical threshold, while submerged liquid fermentation technology has attracted increasing attention in recent years for its advantages of short production cycles, high automation, controllable product quality, and ease of scaling up. In terms of formulation innovation, novel formulation technologies such as microencapsulation, nanocarriers, and smart release systems have significantly improved the environmental stability and field persistence of entomopathogenic fungal products, and biopolymers have become ideal coating materials due to their biodegradability and environmental safety. In terms of market promotion, the commercialization of entomopathogenic fungal products still faces challenges such as low farmer awareness, poor efficacy stability, high technical requirements for application, and insufficient competitiveness compared with chemical pesticides. The sustainable development of the entomopathogenic fungal industry in the future requires strong support from government policies, deep integration of industry, academia, and research, as well as the establishment of farmer training and technical service systems.

## 4 Conclusions and prospects

Entomopathogenic fungi are now widely acknowledged as multifunctional microbial agents that combine insect pathogenicity with plant growth promotion, offering considerable ecological value and application potential in agroecosystems. This review provides a systematic overview of recent advances in understanding their growth-promoting effects. The principal findings are summarized below. (i) Entomopathogenic fungi display extensive strain diversity and functional versatility. Representative species such as *Beauveria bassiana* and *Metarhizium* spp. stimulate crop growth through diverse mechanisms, including phytohormone production, nutrient transfer, nutrient mobilization, and emission of volatile signals. (ii) The plant-fungus interaction is underpinned by an intricate network of molecular events, notably MAMP perception, effector secretion, hormonal signal modulation, and the induction of systemic resistance. (iii) Field trials confirm that entomopathogenic fungi deliver dual benefits (enhanced growth and yield alongside effective pest suppression) in staple food and cash crops, with recorded yield increments of 15% – 46%. (iv) The benefits of entomopathogenic fungi span environmental, economic, and social dimensions, positioning them as a key technological choice for driving the green transformation and long-term sustainability of agriculture.

As interdisciplinary research continues to advance and technology innovation systems steadily improve, entomopathogenic fungi are expected to play an ever more significant role in sustainable agriculture throughout the 21st century. They will contribute substantially to global food security, environmental protection, and the long-term sustainability of agricultural systems.

## References


[1] HENDRA Y, ULPAH S, TRIZELIA T, *et al.* Triple functional roles of endophytic fungi in pest management: A systematic review[J]. Egyptian Journal of Biological Pest Control, 2026, 36: 1.

[2] SADIA A, MUNSHI AR, KATAOKA R. Harnessing endophytic fungi for sustainable agriculture: Interactions with soil microbiome and soil health in arable ecosystems[J]. Sustainability, 2026, 18(2): 872.

[3] ADAME-GARNICA SG, RAMÍREZ-ORDORICA A, MONTEJANO-RAMÍREZ V, *et al.* Volatiles emitted by the entomopathogenic fungus *Beauveria bassiana* elicit growth and defense in sorghum plants[J]. Frontiers in Fungal Biology, 2025, 6: 1725103.

[4] AHSAN SM, INJAMUM-UL-HOQUE M, DAS AK, *et al.* Plant-entomopathogenic fungi interaction: Recent progress and future prospects on endophytism-mediated growth promotion and biocontrol [J]. Plants, 2024, 13(10): 1420.

[5] BEHIE SW, BIDOCHKA MJ. Ubiquity of insect-derived nitrogen transfer to plants by endophytic insect-pathogenic fungi: An additional branch of the soil nitrogen cycle [J]. Applied and Environmental Microbiology, 2014, 80(5): 1553 – 1560.

[6] CACHAPA JC, MEYLING NV, BUROW M, *et al.* Induction and priming of plant defense by root-associated insect-pathogenic fungi[J]. Journal of Chemical Ecology, 2021, 47: 112 – 122.

[7] CHOWDHURY MZH, MOSTOFA MG, MIM MF, *et al.* The fungal endophyte Metarhizium anisopliae (MetA1) coordinates salt tolerance mechanisms of rice to enhance growth and yield[J]. Plant Physiology and Biochemistry, 2024, 207: 108328.


(From page 29)


[4] MATSUI Y, SUGIYAMA K, KAMEI M, *et al.* Extract of passion fruit (*Passiflora edulis*) seed containing high amounts of piceatannol inhibits melanogenesis and promotes collagen synthesis[J]. Journal of Agricultural and Food Chemistry, 2010, 58(20): 11112 – 11118.

[5] WANG KJ, ZHANG WQ, LIU JJ, *et al.* Piceatannol protects against cerebral ischemia/reperfusion-induced apoptosis and oxidative stress via the Sirt1/FoxO1 signaling pathway [J]. Molecular Medicine Reports, 2020, 22(6): 5399 – 5411.

[6] ZHANG SS, LIU GL, ZHOU HX. The effects of piceatannol on proliferation, apoptosis and autophagy of liver cancer HepG2 cells were investigated based on ULK1/Atg13 signaling pathway[J]. Chinese Hepatology, 2025, 30(1): 61 – 64, 77. (in Chinese).

[7] LIU Q, ZHENG J, GAO LL, *et al.* The effect of piceatannol on inflammatory response in hepatitis B virus infected rats by regulating Notch signaling pathway [J]. Chinese Journal of Infection and Chemotherapy, 2025, 25(4): 418 – 424. (in Chinese).

[8] CHENG YJ, LIU GW, LU EQ, *et al.* Protective effect of piceatannol on liver injury induced by deoxynivalenol in mice[J]. China Animal Husbandry & Veterinary Medicine, 2025, 52(3): 1447 – 1454. (in Chinese).

[9] WU QR, YANG QS, WANG YL, *et al.* Through inhibition of HMGB1/TLR4/NF-κB signaling pathway, piceatannol attenuates the damage caused to H9c2 cardiomyocytes by doxorubicin[J]. Chinese Journal of Modern Applied Pharmacy, 2025, 42(5): 735 – 742. (in Chinese).

[10] WANG YL, WU QR, LI B. Protective effects of piceatannol on hydrogen peroxide-induced damage to human corneal epithelial cells [J]. Chinese Journal of Modern Applied Pharmacy, 2026, 43 (2): 223 – 232. (in Chinese).

[11] YUAN Y, QIAN YP, YANG SY, *et al.* Anti-rotavirus effect of piceatannol *in vitro* [J]. Central South Pharmacy, 2024, 22 (10): 2656 – 2662. (in Chinese).