Nature's Guardians: Exploring Biopesticides and the Impact of Entomopathogenic Fungi

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Abstract

Biopesticides are natural or biologically derived agents used to control pests, offering an eco-friendly alternative to chemical pesticides. They include microorganisms, plant extracts and natural toxins that target specific pests without harming non-target organisms or the environment. Among these, entomopathogenic fungi play a crucial role in pest management. These fungi infect and kill insect pests through infection, providing a biological control solution for a wide range of agricultural crops. Entomopathogenic fungi are particularly valued for their effectiveness against insect pests, their ability to target specific species and their environmental sustainability. In India, biopesticides like Entomopathogenic fungi are gaining attention as part of integrated pest management (IPM) strategies to reduce reliance on chemical pesticides, although challenges related to formulation consistency, storage and awareness still need to be addressed for wider adoption.

Keywords: Biopesticides, entomopathogenic fungi, IPM.

Biopesticides have garnered considerable attention for their eco-friendly nature and efficacy in pest management (Pretty & Bharucha, 2015). Biopesticides, derived from natural sources such as plants, microorganisms and minerals, offer an effective alternative to conventional pesticides. They harness the power of nature's own mechanisms to target and manage pests, providing a sustainable and environmentally friendly approach to pest management. Among the diverse array of biopesticides, entomopathogenic fungi have emerged as promising biocontrol agents in managing insect pests.

Entomopathogenic fungi are naturally occurring microorganisms that have evolved to infect and kill insect pests. They possess innate predatory capabilities, which they utilize to invade the bodies of target pests, ultimately leading to their demise. This natural mode of action makes entomopathogenic fungi highly effective in controlling pest populations while minimizing harm to non-target organisms and the environment. The utilization of entomopathogenic fungi in pest management represents a significant advancement in the field of biopesticides. Their ability to provide targeted control of specific pest species, along with their minimal environmental impact and compatibility with integrated pest management strategies, makes them an attractive option for sustainable agriculture. (Butt et al., 2016).

Types of biopesticides (Isman, 2006):

A. Microbial pesticides: These are based on microorganisms such as bacteria, viruses, fungi, and protozoa that infect or otherwise interfere with the physiology of pests.

B. Plant-incorporated protectants (PIPs): These are pesticidal substances that plants produce from genetic material that has been added to the plant. They can protect the plant from pests or enhance its resistance to diseases.

C. Biochemical pesticides: These are naturally occurring substances that control pests by non-toxic mechanisms, such as pheromones, plant extracts, or insect growth regulators.

D. Botanical pesticides: These are pesticides derived from plants or plant extracts that have pesticidal properties, such as neem oil, pyrethrum, or garlic extract.

Advantages of Biopesticides (Kumar *et al.*, 2018):

A. Biopesticides are typically less toxic to non-target organisms, including humans, beneficial insects and wildlife. They also degrade more rapidly in the environment, reducing their impact on ecosystems.

B. Many biopesticides have narrow target ranges by minimizing harm to beneficial organisms and reducing the risk of pest resistance.

C. Biopesticides leave little to no harmful residues on crops or in the environment, reducing the risk of pesticide contamination in food and water sources.

D. Biopesticides are compatible with integrated pest management (IPM) approaches, which emphasize the use of multiple pest control methods to minimize reliance on chemical pesticides and promote long-term sustainability.

Entomopathogenic fungi

Entomopathogenic fungi are microorganisms capable of infecting and killing arthropods, making them an eco-friendly option for pest control. These fungi are extensively utilized as biopesticides, especially in ecological farming, where they serve as a sustainable substitute for harmful chemical insecticides (Lovett & Leger, 2017). Entomopathogenic fungi are found amongst the families of Zygomycota and Ascomycota and in the class of Hyphomycetes in Deuteromycota. They are natural biological control agents for many insects and other arthropods and frequently behave as epizootics that significantly decrease host populations (McCoy, 1990).

Novel applications of entomopathogenic fungi

- **Encapsulation:** Microencapsulation and nanoencapsulation involve enclosing entomopathogenic fungi within tiny polymer capsules, providing protection against environmental challenges like UV radiation and desiccation. Production of nano and microcapsules incorporating entomopathogenic fungi like *Metarhizium anisopliae* (Metchnikoff) Sorokin *and Beauveria bassiana* (Bals.-Criv.) Vuill. is predominantly achieved using alginate (Shah *et al.,* 2023). Additionally, starch and chitosan have been utilized for developing capsules containing *Beauveria* (Fernando *et al.,* 2020). Numerous patents have been registered for alginate-based formulations used as bioinsecticides. For example, US Patent 9808768B2 outlines an alginate-based formulation incorporating entomopathogenic fungi for managing agricultural pests. Algibio is the commercially available alginate-based formulation which has been used for the control of various insect pests, such as the citrus blackfly (*Aleurocanthus woglumi* Ashby) and the coffee berry borer (*Hypothenemus hampei* Ferrari).

- **Secondary metabolites:** *Beauveria* spp. possess more than 10 metabolites with insecticidal activity, including beauvericin, allobeauvericin, isariin, isoisariin, isarfelin, cyclosporine and bassianolide. Efrapeptins are the peptides found in *Tolypocladium spp.* (W. Gams)., target mitochondrial ATP synthase in insects, leading to energy depletion and mortality. They infest a wide range of pests, including root-feeding insects (Niu *et al*., 2024). Cordycepin is ubiquitous among *Cordyceps* spp. (Fr.) It exhibits immunosuppressive action against *G. mellonella* and can cause high mortality .
- **Endophytes:** Endophytic insect pathogenic fungi (EIPF) play a vital role in enhancing plant resilience to various stresses and promoting soil nutrient distribution. *Beauveria bassiana* and *Metarhizium anisopliae* have emerged as promising endophytic fungi, capable of colonizing internal plant tissues asymptomatically. As endophytes, these fungi exhibit dual functionality by directly suppressing insect pests and indirectly benefiting plants through enhanced growth, improved tolerance to abiotic stress, and increased resistance to pathogens (Dara, 2021).

Mode of action of Entomopathogenic fungi:

Entomopathogenic fungi employ a multi-stage mode of action to target and control insect pests effectively. Initially, specialized structures such as spores or conidia attach to the cuticle, the outer surface of the insect (Figure 1).

Table 1: Different Entomopathogenic fungi and their target pests

Fungal strain	Target insect pests	Mode of action	Application	Reference
Beauveria bassiana	Whiteflies, aphids, root grubs, caterpillars	Penetrates cuticle, produces toxins and kills	*Helicoverpa armigera* in cotton and *Spodoptera litura* in vegetables.	Sharma & Gupta, 2018
Metarhizium anisopliae	Termites, root grubs, locusts	Germinates on insect cuticle, releasing toxins	Fall armyworm (*Spodoptera frugiperda*) in maize.	Gurung & Prakash, 2021
Lecanicillium lecanii (R. Zare & W. Gams)	Aphids, whiteflies, thrips	Infects insect surface and sporulates inside host	Greenhouse whitefly (*Trialeurodes vaporariorum*) and aphids in vegetable crops.	Inglis *et al*., 2001
Hirsutella thompsonii (Pat)	Mites	Enzymatic degradation of mite exoskeleton	Effective against coconut eriophyid mite (*Aceria guerreronis*), reducing damage in South India.	Mishra *et al*., 2015
Cordyceps militaris	Caterpillars, grasshoppers	Produces bioactive compounds to kill insects	Proven potential against tea mosquito bug (*Helopeltis* spp.) in tea plantations.	Charnley & Collins, 2007
Isaria fumosorosea (Wize)	Whiteflies, aphids	Spores attach to and germinate on insect surface	Controlled *Bemisia tabaci* (whitefly) in cotton and vegetables, mitigating viral disease spread.	Manisegaran & Babu, 2019
Paecilomyces lilacinus (Bainier)	Nematodes, root-infesting pests	Parasitizes eggs and juvenile stages of nematodes	Widely used to control root-knot nematodes (*Meloidogyne spp.*) in vegetable and fruit crops.	Gurung & Prakash, 2021

Subsequently, enzymes and toxins are produced to aid in penetrating the insect's cuticle, facilitating the fungi's entry into the insect's body. Once inside, the fungi colonize and proliferate, utilizing the insect's internal tissues as a nutrient source. During this stage, they may also secrete secondary metabolites that weaken or kill the insect. As the fungi continue to grow, they eventually produce spores or conidia, which are released into the environment to infect other susceptible insects, completing the lifecycle. Overall, entomopathogenic fungi employ a combination of mechanical penetration and biochemical degradation to effectively target and control insect pests (Ma *et al,* 2024).

Impact of climate change on the effectiveness of entomopathogenic fungi

- Rising temperatures can exceed the thermal tolerance of many fungal strains, reducing their viability and effectiveness.
- Changes in rainfall patterns and prolonged dry spells negatively impact fungal spore germination and infection processes.
- Climate-induced changes in pest distribution may expose fungi to pests for which they are less effective, requiring the development of new strains.
- Existing fungal formulations may not perform reliably under fluctuating climatic conditions, necessitating improved stabilization techniques.
- Changes in soil properties, host-plant dynamics, and microbial communities due to climate change can further affect fungal performance.
- Enhanced genetic and biotechnological tools are required to develop strains that can withstand extreme environmental conditions.

Incorporation of entomopathogenic fungi into Integrated Pest Management (IPM) practices (Chandler et al., 2011):

- Monitoring pest populations and setting action thresholds, entomopathogenic fungi can be strategically applied when pest levels exceed tolerable limits.
- Cultural practices such as crop rotation and habitat manipulation can create favorable conditions for these fungi to thrive, complementing biological control efforts.
- Selective use of chemical pesticides that are compatible with entomopathogenic fungi further enhances pest management outcomes.

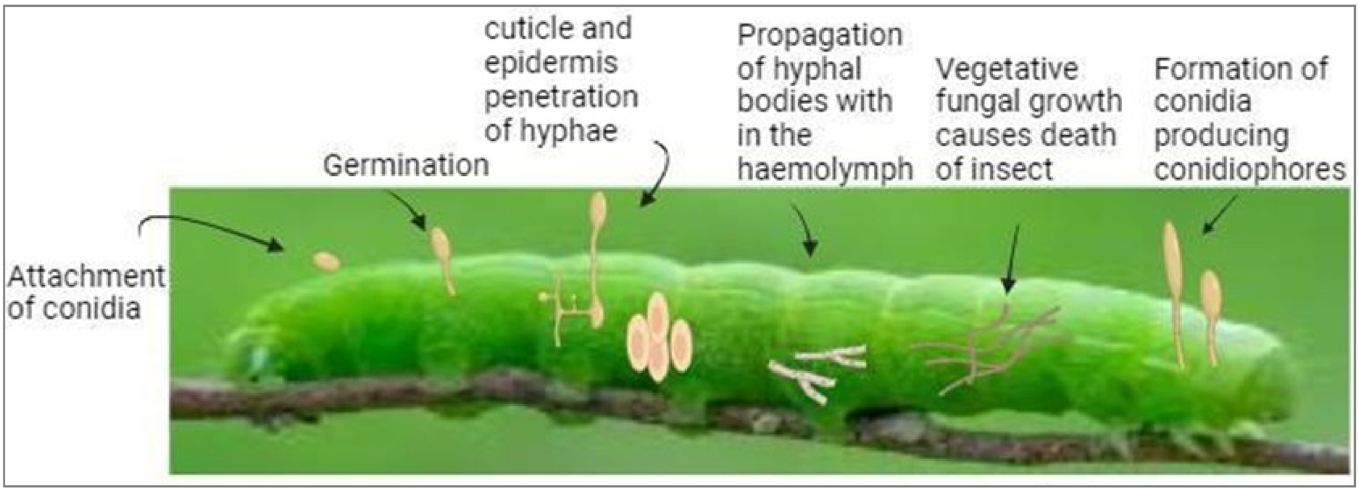

Figure 1: Mode of action of Entomopathogenic Fungi (Senthil-Nathan, 2014)

- Optimal application techniques, resistance management strategies, and ongoing education and training ensure the effective utilization of entomopathogenic fungi within IPM programs.

Case studies: Success stories of entomopathogenic fungi in pest control

In a study conducted in Karnataka, India, researchers evaluated the field efficacy and safety of indigenous strains of *Beauveria bassiana* against the pink bollworm (*Pectinophora gossypiella,* Busck), a major pest of Bt cotton crops. Using different formulations of *B. bassiana* applied via standard spraying techniques, the researchers observed significant reductions in pink bollworm populations in treated plots compared to untreated ones. Moreover, *B. bassiana*-treated plots showed lower levels of pest infestation and damage to cotton bolls, with the efficacy of *B. bassiana* biopesticides comparable to synthetic chemical pesticides commonly used for pink bollworm control. Importantly, the study found that the use of *B. bassiana* biopesticides was safe for beneficial insects and non-target organisms, highlighting its potential as an environmentally friendly pest management strategy in Bt cotton cultivation (Prasannakumar *et al.,* 2016).

In a study conducted in the southern United States, particularly Louisiana and Mississippi, researchers investigated the efficacy of *Metarhizium anisopliae* in controlling the southern pine beetle (*Dendroctonus frontalis,* Zimmermann), a destructive pest of pine forests. Laboratory experiments demonstrated high mortality rates of southern pine beetles exposed to *M. anisopliae* spores, indicating the pathogenicity of the fungus to the target pest. Field trials further confirmed the effectiveness of *M. anisopliae* formulations in reducing southern pine beetle populations, with beetle mortality rates increasing with higher concentrations of fungal spores. The successful suppression of southern pine beetle populations by *M. anisopliae* in both laboratory and field trials highlights the potential of this indigenous fungus as a biocontrol agent for managing forest pests in the southern United States (Goble *et al.,* 2007).

Limited popularity of entomopathogenic fungi in the Indian market:

The adoption of entomopathogenic fungi in India has been limited, despite their eco-friendly nature and potential to reduce chemical pesticide use. One of the primary challenges is the inconsistency in product quality. Many commercially available formulations suffer from low spore viability, inadequate concentrations, and contamination with non-target microorganisms. These issues often stem from poorly regulated manufacturing processes and a lack of adherence to quality control standards. Additionally, fungal biopesticides are sensitive to environmental conditions, and improper storage during distribution reduces their effectiveness. Farmer awareness is another significant barrier. Most farmers are unfamiliar with EPF products or lack trust in their efficacy due to previous experiences with substandard products. The limited availability of extension services to educate farmers about proper application techniques and the benefits of EPF further hinders their acceptance.

Education and awareness: Farmers and consumers:

- Education and awareness efforts play a crucial role in facilitating the adoption of entomopathogenic fungi by farmers and consumers. Farmers and agricultural stakeholders require access to accurate, science-based information regarding the benefits, efficacy, and application methods of these fungi.

Dissemination of knowledge through extension services, training programs, and outreach initiatives is essential to build capacity among end-users. Furthermore, on-farm demonstration trials and case studies showcasing the effectiveness of entomopathogenic fungi can increase confidence and trust among farmers, motivating adoption and encouraging sustainable pest management practices. Additionally, raising consumer awareness of the environmental and health benefits of biopesticides is vital for driving demand for sustainably produced food products. Marketing campaigns, eco-labeling initiatives, and consumer education programs can effectively raise awareness and promote the adoption of biopesticide-treated crops in the marketplace.

Strategies to Strengthen the Value Chain for Entomopathogenic Fungi

- A comprehensive approach involving policy, research, and market support is essential.
- Regulatory frameworks must enforce stringent quality control standards for production, ensuring formulations meet minimum spore viability, purity, and efficacy benchmarks.
- Subsidies and tax incentives for manufacturers adhering to these standards could encourage compliance.
- Investments in research and development should focus on creating resilient fungal strains that are effective under diverse agro-climatic conditions, along with user-friendly formulations.
- Government-backed training programs and extension services are needed to educate farmers about the benefits and proper application techniques of EPF.
- To streamline distribution, public-private partnerships can establish cold chain networks to maintain product integrity during storage and transportation.
- Financial support schemes such as micro loans for smallholder farmers to adopt biopesticides, coupled with awareness campaigns, can boost market demand.

Conclusion

Entomopathogenic fungi represent a promising solution for sustainable pest management, offering numerous advantages over conventional pesticides. Their targeted control of specific pest species minimizes harm to non-target organisms and reduces the risk of pesticide resistance. Their biodegradability and minimal impact on humans, animals, and beneficial insects make them environmentally friendly options. With their efficacy and versatility, entomopathogenic fungi can be utilized across various agricultural settings, integrating seamlessly with integrated pest management strategies. Moreover, by preserving natural enemies of pests and reducing reliance on chemical pesticides, they contribute to biodiversity conservation and ecosystem health. To realize the full potential of biopesticides like entomopathogenic fungi, collaboration and investment in research, regulatory support, education, and awareness are essential. By embracing biopesticides, we can pave the way for a healthier and more sustainable future in agriculture, ensuring the well-being of both current and future generations.

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