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Entomopathogenic Microorganisms: Their Role in Insect Pest Management

*Alisha Ray
M.Sc. Research Scholar, Department of Entomology, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha – 751003
*Corresponding Author's email: rayalisha683@gmail.com

Agricultural pests like fungi, bacteria, viruses, nematodes, weeds, insects, mites, slugs, snails, and even some vertebrates feed on crops and cut down both their yield and quality. Experts estimate there are many different pest species worldwide, causing about 40% of potential global crop losses, even with all the hard work farmers put into managing them. Insect issues feel like an inevitable part of farming life. These losses happen because farms are simplified versions of nature think monocultures that offer pests a feast with less competition or predators around. Tilling the soil and using broad-spectrum chemicals can make conditions even better for pests while wiping out helpful microbes. That's where entomopathogens come in: natural bacteria, fungi, viruses, protozoa, and nematodes that infect and kill insects and mites. Many are grown in labs or hosts and sold as eco-friendly biopesticides for "microbial control," fitting nicely into integrated pest management (IPM) strategies.

Introduction

Globally, pest populations are estimated to comprise millions of species, collectively responsible for approximately 40% losses in potential crop yields despite intensive management practices. Insect pests, in particular, account for 10-26% of post-Green Revolution agricultural losses, equating to economic impacts exceeding $470 billion annually. While synthetic insecticides have been widely adopted for their efficacy, ease of application, and rapid action, their indiscriminate use has precipitated widespread resistance in up to 80% of major pest taxa. Consequently, entomopathogens comprising naturally occurring bacteria, fungi, viruses, protozoa, and nematodes emerge as critical biocontrol agents, regulating insect populations through host-specific pathogenesis and integrating effectively within sustainable pest management frameworks.

Entomopathogenic Fungi

Entomopathogenic fungi can infect and kill insects or other arthropods. Unlike traditional chemical pesticides, EPF infects the host through contact with the fungal spores. These diverse, heterotrophic eukaryotic microbes are unicellular or filamentous and reproduce sexually, asexually, or both, producing infectious spores whose field success depends on UV light, temperature, and humidity. They're mainly in orders like Hypocreales, Onygenales (Ascosphaera), Entomophthorales, and Neozygitales (Entomophthoromycota). Fossils date back to scale insects with Ophiocordyceps-like fungi, termites with Entomophthora, and ants with Beauveria. Key genera include Metarhizium, Beauveria, Verticillium, Nomuraea, Entomophthora, &Neozygites, spanning Zygomycota, Ascomycota, Deuteromycota, & more.

Mechanism of Action: Entomopathogenic fungi produce conidia and blastospores that adhere to the insect cuticle via a mucus layer of proteins and glucans, often forming specialized appressoria. Germination follows, with germ tubes penetrating the cuticle through combined mechanical pressure and hydrolytic enzymes, including lipases, proteases, and chitinases. Hyphae then colonize the hemocoel, leading to vegetative growth. Insect death results from mycelial proliferation (causing mummification via mechanical disruption) or toxin secretion—e.g., destruxins from *Beauveria* and *Metarhizium*, bassianolide from *Beauveria*, and peptins from *Tolypocladium*. Post-mortem, the fungus produces and disperses thousands of new spores from the cadaver to infect additional hosts. Entomopathogenic fungi can attack insects from different orders: Lepidoptera, Coleoptera, Hemiptera, Diptera, Orthoptera, Hymenoptera. Some species of fungi (belongs to the Hypocreales) have a very wide spectrum of potential victims and Entomophthorales are pathogens only one particular species of insect. They are reported to infect a very wide range of insect pest and mite species including lepidopterous larvae, aphids and thrips which are of great concern in agriculture worldwide .

Entomopathogenic bacteria

The majority of bacterial pathogens of insects occur in the family Bacillaceae, Pseudomonadaceae, Enterobacteriaceae, Streptococcaceae, and Micrococcaceae. Most of these bacteria are weak pathogens that infect insects subject to environmental stress, but a minority are highly virulent. Most attention has been given to the Bacillaceae. *Bacillus popillae* causes milky disease in scarbaeids, while *Bacillus sphaericus* is a lethal pathogen of mosquitoes. *Bacillus thuringiensis* (Bt) is widespread in soil and most widely used entomopathogenic agent and control of caterpillars, beetles. Bt is a spore forming bacterium. Sporulation is usually associated with the synthesis of proteinaceous protoxin crystal that has insecticidal activities. Ingested crystals dissolve within the gut and cleaved by host proteases to form an active toxin, termed the δ-endotoxin. This bacterium is the production of parasporal bodies(crystals) containing specific insecticidal endotoxins (Cry proteins) acting by ingestions through a pore-forming mechanism of action detrimental for the insect gut epithelium. Bacillus pumilus strain 15.1 has recently been shown to be poisonous to larvae of the Mediterranean fruit fly, *Ceratitis capitata*, one of the most devastating pests to fruits and vegetables globally. During sporulation, this strain produces parasporal crystals that resemble those formed by Bacillus thuringiensis cry proteins. Several genes in the B. pumilus15.1 genome encode well-known entomopathogenic factors such chitinases, metalloproteases, and cytolysins .

Mechanism of action: Entomopathogenic bacteria primarily infect insects via oral ingestion, utilizing specialized mechanisms to traverse the midgut epithelium, suppress humoral and cellular immunity, secrete insecticidal toxins, and induce systemic septicaemia culminating in host mortality. These pathogens are categorized into spore-forming (e.g., Firmicutes like *Bacillus thuringiensis* [Bt], *Lysinibacillus sphaericus*, *Clostridium bifermentans*) and non-spore-forming (e.g., Serratia, Pseudomonas) genera. (Mampallilet al., 2017). Spore-formers produce resilient endospores that persist ex vivo; upon ingestion, they germinate in the alkaline midgut (pH 8–11). Crystalliferous species like Bt additionally form parasporal crystals (δ-endotoxins, primarily Cry and Cyt proteins) within sporangia. In Bt pathogenesis:

(1) δ-endotoxin solubilizes and protoxins are cleaved by midgut proteases into ~60–70 kDa toxins

(2) activated toxins bind specific cadherin-like receptors (e.g., BtR175) on epithelial microvilli, oligomerizing into ~250 kDa pores

(3) this triggers cytolysis via colloid osmosis, ion efflux (K^+, H^+), midgut paralysis, and cessation of feeding within minutes

(4) epithelial lysis (~2–6 h post-ingestion) releases gut contents into the hemolymph and hemocoel, disrupting pH homeostasis (ΔpH ~2–3 units), enabling bacterial translocation, toxin dissemination, and proliferative septicaemia

Entomopathogenic viruses

Entomopathogenic viruses that are harmful to insect and have emerging recent years. A great variety of viruses attack and kill many insects. These viruses are called entomopathogenic viruses and have been found in many insect orders. Some insect pests are also susceptible to viral infections and hence, these viruses can be used as biological 5 control agents. Insect viruses may be double or single-stranded DNA (dsDNA and ssDNA) or RNA(dsRNA and ssRNA). Entomopathogenic viruses act as obligate intracellular parasites, incapable of replication *in vitro* without host cells, and are classified into 12 families by the International Committee on Taxonomy of Viruses (ICTV). Highly host-specific, they can decimate target populations; three families—Baculoviridae, Polydnaviridae, and Ascoviridae. They are arthropod-exclusive, with Baculoviridae (double-stranded DNA viruses) standing out as safe biocontrol alternatives to chemical pesticides due to their narrow host range, safety for non-targets (beneficial insects, mammals), and efficacy against lepidopteran crop pests. Baculoviruses split into nucleopolyhedroviruses (NPVs) and granuloviruses (GVs), both featuring circular dsDNA genomes (~80–180 kbp) occluded in protein matrices (virions in polyhedral or granular bodies). Widely used for recombinant protein production in insect cell lines (e.g., Sf9 cells), they infect via midgut epithelium post-ingestion: larvae slow, cease feeding, and halt growth as initial symptoms, progressing to viral replication, tissue liquefaction, melanization, and host rupture for dispersal.

Mechanism of Action: Entomopathogenic viruses infect insects mainly by ingestion: virions bind to specific receptors on midgut epithelial cells, enter via endocytosis or membrane fusion, and initiate primary replication in gut tissues.

Systemic Spread: In Baculoviridae, budded virus (BV) forms emerge from midgut cells, entering the hemocoel to infect fat bodies, tracheae, and organs; occlusion-derived virus (ODV) embeds in protein matrices for oral transmission. Acute infection kills hosts in 5–14 days, marked by lethargy, feeding cessation, fat body hypertrophy (causing whitish translucence through thinning integument), and pre-death ascent to inverted "V" postures on foliage.

Host Death and Dispersal: Integument ruptures, releasing liquefied cadavers laden with billions of occlusion bodies (OBs)—protected virions ensuring field persistence and rain/UV dispersal to new hosts.

Practical Efficacy: Narrow host range (e.g., family-specific in Lepidoptera) enables safe biocontrol: *Spodoptera exigua* NPV, *Helicoverpa* NPVs on cotton; CpGV against codling moth (*Cydia pomonella*) on apples. *In vivo* mass production in larvae is viable for larger lepidopterans.

Entomopathogenic Nematodes

Entomopathogenic nematodes (EPNs) are microscopic roundworms (*Steinernema* and *Heterorhabditis* spp.) that parasitize and kill soil-dwelling insect pests, partnering with symbiotic bacteria (*Xenorhabdus* or *Photorhabdus*) for lethal efficiency.

EPNs exist as infective juveniles (IJs)—the durable, free-living stage that survives soil stresses (UV, desiccation). Steinernematids "cruise-and-wait"; heterorhabditids actively hunt, penetrating hosts via natural openings (mouth, anus, spiracles) or cuticle (heterorhabditids).

Mechanism of Action

1. **Entry & Release**: IJs enter hemocoel, regurgitate bacteria.
2. **Septicemia**: Bacteria multiply, secrete toxins/exoenzymes, liquefy tissues (~48 h kill).
3. **Reproduction**: Nematodes feed, develop 1–3 generations; new IJs (~10,000–250,000 per cadaver) exit to reinfect.

Conclusion

Chemical insecticides, while widely used in crop protection, have spurred widespread insect resistance, prompting a shift toward natural enemies like entomopathogenic microorganisms (fungi, bacteria, viruses, nematodes). These pathogens offer eco-friendly biocontrol alternatives, infecting and killing pests to suppress populations below economic damage thresholds, enhancing agroecosystem sustainability through biological rather than chemical means.

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