



Harnessing Entomopathogenic Nematodes for Sustainable Insect Pests Management

*Tejpal Tetarwal, Rahul Nodal and Sachin Yadav

Ph.D. Scholar, Department of Entomology, Rajasthan College of Agriculture,
MPUAT, Udaipur, Rajasthan-313001, India

*Corresponding Author's email: tejpalteetarwal2001@gmail.com

Entomopathogenic nematodes (EPNs) represent a promising and environmentally sustainable alternative to chemical pesticides for managing insect pests in agricultural systems. Belonging primarily to the families Steinernematidae and Heterorhabditidae, these soil dwelling nematodes form symbiotic associations with specific bacteria (*Xenorhabdus* and *Photorhabdus* genera, respectively) that are lethal to a wide range of insect hosts. EPNs actively seek out or ambush insect larvae, penetrate through natural body openings and release their symbiotic bacteria into the host hemocoel, causing septicemia and death within 24-48 hours. This review discusses the biology, life cycle, mode of action, advantages, limitations and application strategies of EPNs in integrated pest management (IPM) programs. EPNs offer significant advantages including host specificity, safety to non target organisms, compatibility with chemical pesticides and the ability to be mass produced commercially. Despite challenges such as sensitivity to environmental conditions and storage limitations, EPNs continue to gain importance as a key component of sustainable agriculture and biological pest control strategies worldwide.

Keywords: Entomopathogenic nematodes, biological control, Steinernema, Heterorhabditis, symbiotic bacteria, IPM

Introduction

Insect pests cause substantial economic losses to agricultural crops worldwide with estimates suggesting that pests destroy approximately 20-40% of global crop production annually. Traditionally, synthetic chemical insecticides have been the primary method for pest control. However, excessive and indiscriminate use of these chemicals has led to several problems, including the development of insecticide resistance in pest populations, harmful effects on non-target organisms (including beneficial insects like pollinators and natural enemies), environmental pollution and residual toxicity in food products posing risks to human health (Lacey *et al.*, 2015). These growing concerns have prompted researchers and farmers to seek eco-friendly, sustainable alternatives for pest management. Biological control, which utilizes natural enemies to regulate pest populations, has emerged as a viable solution. Among the various biological control agents including parasitoids, predators and entomopathogens (fungi, bacteria and viruses) entomopathogenic nematodes (EPNs) have gained considerable attention due to their unique biological characteristics and effectiveness (Kaya and Gaugler, 1993). EPNs are microscopic, soil-inhabiting roundworms that parasitize and kill insects. They were first discovered in the early 20th century, but their potential as biological control agents was fully recognized only in the latter half of the century (Kaya and Gaugler, 1993). Unlike many other biocontrol agents, EPNs possess the unique ability to actively search for and kill their insect hosts rapidly, often within one to two days of infection. Their mutualistic relationship with pathogenic bacteria makes them doubly effective acting as both a vector and a lethal agent (Grewal *et al.*, 2005).

Taxonomy and Classification

Entomopathogenic nematodes belong to the phylum Nematoda and are primarily classified into two major families used in biological control:

1. **Steinernematidae** (Genus: *Steinernema*): associated with bacteria of the genus *Xenorhabdus*
2. **Heterorhabditidae** (Genus: *Heterorhabditis*): associated with bacteria of the genus *Photobacterium*. Common species used commercially include *Steinernema carpocapsae*, *Steinernema feltiae*, *Steinernema riobrave*, *Heterorhabditis bacteriophora* and *Heterorhabditis indica* (Grewal et al., 2005).

Life Cycle and Biology

The EPN life cycle consists of four juvenile stages (J1-J4) followed by the adult stage. The infective juvenile (IJ) also called the 'Dauer stage', is the only free-living stage found in soil. This non-feeding, developmentally arrested stage is specifically adapted for host-seeking and survival in adverse environmental conditions (Kaya and Gaugler, 1993).

The life cycle proceeds as follows:

1. **Host-seeking:** Infective juveniles locate potential insect hosts using carbon dioxide gradients, vibrations and other chemical cues released by the host (Grewal et al., 2005).
2. **Penetration:** IJs enter the hosts body through natural openings-mouth, anus, spiracles or in the case of *Heterorhabditis* species, directly through the insect cuticle using a specialized tooth like structure.
3. **Bacterial release:** Once inside the hosts hemocoel (body cavity) the nematode releases its symbiotic bacteria.
4. **Septicemia and host death:** The bacteria multiply rapidly, producing toxins that cause septicemia, leading to insect death typically within 24-48 hours (Lacey et al., 2015).
5. **Nematode reproduction:** The nematodes feed on the bacteria and degraded host tissues, moult through juvenile stages to become adults and reproduce within the insect cadaver.
6. **Emergence:** After 1-3 generations (depending on resource availability), hundreds of thousands of new infective juveniles emerge from the depleted cadaver, dispersing into the soil to seek new hosts (Kaya and Gaugler, 1993).

Mode of Action and Host Range

EPNs exhibit two distinct host-finding strategies:

- **Ambushers** (e.g., *S. carpocapsae*): Wait near the soil surface and attach to passing hosts, suitable for highly mobile surface-dwelling insects.
- **Cruisers** (e.g., *H. bacteriophora*): Actively move through soil searching for sedentary or soil dwelling hosts (Grewal et al., 2005).

EPNs are effective against a broad range of insect pests including:

- Lepidopteran larvae (cutworms, armyworms, borers)
- Coleopteran pests (white grubs, weevils, beetles)
- Dipteran pests (fungus gnats, fruit flies)
- Orthopteran pests (mole crickets)

However, EPNs have limited efficacy against sap sucking insects (aphids, whiteflies) since these pests lack suitable entry points or hemocoel accessibility (Lacey et al., 2015).

Advantages of EPNs

1. **Environmental Safety:** Non-toxic to humans, plants and most non-target organisms including beneficial insects, birds and mammals (Lacey et al., 2015).
2. **Host Specificity:** While having a broad host range, EPNs generally do not harm beneficial insects like pollinators when applied correctly.
3. **Self-Perpetuating:** Can establish in soil and provide extended control through reproduction within killed hosts.
4. **Compatibility:** Can be combined with chemical pesticides, fertilizers and other IPM components without antagonistic effects (Koppenhöfer and Grewal, 2005).

5. **No Resistance Development:** Due to their complex mode of action involving multiple bacterial toxins and pest resistance development is rare.
6. **Exempt from Pesticide Registration:** In many countries, EPNs are not subject to the same stringent regulatory processes as chemical pesticides, facilitating faster commercialization (Ehlers, 2001).
7. **Mass Production Feasibility:** Can be produced using both in vivo (insect based) and in vitro (liquid fermentation) techniques for commercial scale application (Shapiro-Ilan *et al.*, 2012; Ehlers, 2001).

Limitations and Challenges

Despite their advantages EPNs face several constraints:

1. **Environmental Sensitivity:** Susceptible to desiccation, UV radiation and extreme temperatures, limiting their effectiveness in foliar applications and open field conditions (Shapiro-Ilan *et al.*, 2012).
2. **Soil Moisture Requirement:** Require adequate soil moisture for movement and survival, making them less effective in arid conditions without irrigation support.
3. **Storage and Shelf Life:** Live organisms have limited shelf life compared to chemical formulations, requiring specific storage conditions (cool temperatures) (Ehlers, 2001).
4. **Cost:** Production and application costs can be higher than conventional chemical pesticides, though this is improving with advances in mass production technology (Shapiro-Ilan *et al.*, 2012).
5. **Limited Efficacy Against Certain Pests:** Less effective against pests that live in protected habitats or lack natural openings accessible to nematodes.

Application Methods

EPNs can be applied using conventional agricultural equipment with modifications to prevent damage to the nematodes (Shapiro-Ilan *et al.*, 2012):

- **Soil drenching:** Direct application to soil for below-ground pests
- **Foliar spraying:** For above-ground pests, typically applied during evening hours to avoid UV damage and desiccation
- **Irrigation systems:** Incorporation into drip or sprinkler irrigation systems
- **Granular formulations:** Combined with carriers for easier handling and application

Best practices include application during cooler parts of the day, ensuring adequate soil/leaf moisture and compatibility checks with other pesticides being used simultaneously (Koppenhöfer and Grewal, 2005).

Commercial Status and Future Prospects

Several EPN-based biopesticides are commercially available worldwide, including products like Nemasys, BioSafe and Capinem (Ehlers, 2001). Research continues to improve formulation technology, enhance environmental tolerance through genetic selection and develop novel application techniques to overcome current limitations (Shapiro-Ilan *et al.*, 2012). Advances in genetic engineering and strain improvement programs aim to enhance EPN virulence, environmental tolerance and host-specificity, further expanding their applicability in diverse agro-climatic conditions (Lacey *et al.*, 2015).

Summary

Entomopathogenic nematodes represent a highly effective and environmentally sustainable biological control tool for managing insect pests in agricultural systems. Their unique symbiotic relationship with pathogenic bacteria enables rapid and lethal action against a wide range of insect pests while remaining safe for humans, beneficial organisms and the environment. The dual benefits of immediate pest control and self-sustaining population establishment make EPNs an attractive component of integrated pest management programs. While challenges related to environmental sensitivity, storage and application costs remain, ongoing research and technological advancements continue to improve the practicality and efficiency of EPN-based biopesticides. As global agriculture moves toward more sustainable

practices, EPNs are poised to play an increasingly significant role in reducing dependence on chemical pesticides, protecting biodiversity and ensuring long-term agricultural productivity. Successful implementation requires proper application techniques, environmental management and integration with other pest control strategies to maximize their effectiveness in diverse cropping systems.

References

1. Ehlers, R.U. (2001). Mass production of entomopathogenic nematodes for plant protection. *Applied Microbiology and Biotechnology*, 56(5-6): 623-633.
2. Grewal, P.S., Ehlers, R.U. and Shapiro-Ilan, D.I. (2005). *Nematodes as Biocontrol Agents*. CABI Publishing, Wallingford, UK.
3. Kaya, H.K., and Gaugler, R. (1993). Entomopathogenic nematodes. *Annual Review of Entomology*, 38(1): 181-206.
4. Koppenhöfer, A.M. and Grewal, P.S. (2005). Compatibility of entomopathogenic nematodes with other biological control agents. In *Nematodes as Biocontrol Agents*, CABI Publishing, 363-381.
5. Lacey, L.A., Grzywacz, D., Shapiro-Ilan, D.I., Frutos, R., Brownbridge, M. and Goettel, M.S. (2015). Insect pathogens as biological control agents: Back to the future. *Journal of Invertebrate Pathology*, 132: 1-41.
6. Shapiro-Ilan, D.I., Han, R., and Dolinski, C. (2012). Entomopathogenic nematode production and application technology. *Journal of Nematology*, 44(2): 206-217.