



Entomopathogenic Nematodes: Tiny Warriors for Crop Protection

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Agriculture forms the backbone of India's economy. Insect infestations substantially reduce agricultural crop productivity. Meeting the food demands of growing populations in India and other developing nations requires sustainable agricultural production systems for future generations. This article examines the current status of entomopathogens in the agricultural sector. Synthetic chemical pesticides remain routinely employed for insect pest management, yet they adversely impact environmental health and non-target beneficial organisms, including humans. Entomopathogens serve as safe, natural, and cost-effective biopesticides that can replace hazardous chemical alternatives. Due to limited research innovations and policy support in India, few entomopathogenic formulations currently reach commercial markets, proving insufficient to satisfy farmer requirements. Production and utilization of entomopathogens remain minimal compared to synthetic chemical pesticides. This article advocates for enhanced technology-focused research and increased production of entomopathogenic biopesticide formulations to achieve environmentally responsible agricultural productivity.

Keywords: Entomopathogenic nematodes, *Heterorhabditis indica*, *Steinernema carpocapsae*, mode of action, biological control

Introduction

The term "entomopathogenic nematodes" (EPNs) derives from Greek roots: *entomos* (insect), *pathê* (disease), and *genos* (producing), referring to nematodes capable of causing disease in insects by suppressing their immune systems. Entomopathogenic nematodes were first identified during the 1920s, with commercialization beginning in the 1980s. These beneficial nematodes attack soil-borne insect pests while remaining harmless to humans, animals, plants, and earthworms, making them suitable biological control agents. Nematodes constitute worm-like, unsegmented invertebrates distributed worldwide across diverse habitats including soil, freshwater, saltwater, plants, and animals. Entomopathogenic nematodes are microscopic worms possessing insect-killing capabilities. They belong to the order Rhabditida and families Heterorhabditidae and Steinernematidae, occurring naturally in soil habitats where they locate hosts through chemical and physical signal responses (Shapiro-Ilan et al., 2012). Both families contain species successfully commercialized as bio-insecticides in pest management programs. Rao and Manjunath (1966) first demonstrated the DD-136 strain of *Steinernema carpocapsae* in India for managing lepidopteran pests affecting apple, rice, and sugarcane. Farmers in developed countries utilize species-specific EPN-based products including Biovector, Sanoplant, Helix, Magnet, and Entonem. India developed two formulations, "Green Commandos" and "Soil Commandos," using foreign EPN species; however, these nematodes

demonstrated limited effectiveness against target insects, likely due to poor adaptation to Indian climatic conditions. Currently, Multiplex Biotech Pvt. Ltd. markets formulations named Soldier (containing *Heterorhabditis indica*) and Bouncer (containing *Steinernema carpocapsae*), though farmer adoption remains limited. *Steinernema carpocapsae*, *S. feltiae*, *S. kraussei*, *S. glaseri*, *S. riobrave*, *Heterorhabditis bacteriophora*, and *H. megidis* represent the most commonly utilized and successfully applied nematodes due to their ease of production in liquid culture (Abate et al., 2017).

Indiscriminate chemical pesticide application for insect control across various agro-ecosystems has generated numerous environmental concerns including groundwater contamination, food residues, resistance development, soil pollution, air pollution, secondary pest outbreaks, and pest resurgence. Entomopathogenic nematodes have gained popularity as pesticide alternatives due to their environmentally favorable characteristics. Most cases require no specialized application equipment, as nematode species remain compatible with pressurized, mist, electrostatic, fan, and aerial sprayers. Watering cans, hose-end sprayers, and pump sprayers serve as excellent applicators. Nematodes can also be applied to agricultural fields through irrigation systems during crop growing seasons. Prasad et al. (2007), Shapiro-Ilan and Gaugler (2010), and Gozel and Gozel (2016) documented commercial EPN applications against various insect pests, as presented in Tables 1, 2, and 3.

Mode of Action

Only the third-stage infective juvenile (IJ) of both *Steinernema* and *Heterorhabditis* nematodes possesses infective and pathogenic capabilities. *Xenorhabdus* and *Photorhabdus* represent entomopathogenic bacteria vectored by *Steinernema* and *Heterorhabditis* genera, respectively. Infective juveniles constitute the sole free-living stage of EPNs, while other developmental stages occur exclusively inside infected insect hosts. Infective juveniles enter the host insect's hemocoel through natural openings including spiracles, mouth, and anus, or in certain species through inter-segmental cuticular membranes. Additionally, *Heterorhabditis* species can penetrate the insect host by abrading the cuticle. Upon entering the epidermis, infective juveniles release symbiotic bacterial cells from their alimentary canal into the hemocoel. Bacteria proliferate within the insect hemolymph, producing toxins and specific immune suppressors that disable the insect's immune system, resulting in death within 24-48 hours. *Photorhabdus* and *Xenorhabdus*, the well-known bacterial symbionts of EPNs, not only prove toxic to insect fauna but also inhibit opportunistic bacteria and fungi from utilizing the nutrient-rich cadaver, effectively preserving it for nematode reproduction.

Table 1: EPN formulations developed and tested in India

SN	EPN Species	Formulation/Tested/Products name
1.	<i>Heterorhabditis indica</i>	Spray formulations talk-based, Soldier,
2.	<i>Steinernema carpocapsae</i>	Spray formulations talk-based, Bouncer, Alginate capsule, Wheat bran pellets, Pearl (Sodium alginate- based), Vermiculite-based
3.	<i>Steinernema abbasi</i>	Talk based
4.	<i>Steinernema bicornutum</i>	Bait as alginate capsule
5.	<i>Steinernema riobrave</i>	Spray adjuvants
6.	<i>Steinernema abbasi</i>	Hydrogel

Table 2: EPN formulations developed by different countries

SN	EPN Species	Formulation/Products name	Country
1.	<i>Heterorhabditis bacteriophora</i>	E-Nema Gmbh	Germany
		Otinem	USA, Switzerland
		Soil commondos	India
		Nemopak HB	Italy
2.	<i>Steinernema carpocapsae</i>	ORTHO Biosafe, Biovector, X-GNAT, Ecomask, Heteromask	USA
		Biovector	Columbia
		Green commonda, Bouncer	India
		Helix	Canada
		CAPSANEM	Netherland
		Mioplant	Austria
		Sanoplant	Switzerland
3.	<i>Steinernema feltiae</i>	Nemastar	Italy
		Magnet	USA
		Entoname	Netherland
		Nemasys, Stealth	U. K.
4.	<i>Steinernema kushidai</i>	Exhibit	Switzerland
		Agrifutur	Italy
5.	<i>Steinernema riobrave</i>	SDS Biotech	Japan
6.	<i>Heterorhabditis indica</i>	Vector MG, Biovector	USA
		Biovector	Columbia
7.	<i>Heterorhabditis megidis</i>	Soldier	India
		Nemasya	UK
		Larvanem	Netherland
8.	<i>Steinernema scapterisci</i>	NovoNem	Germany
		Proactant Ss	USA
9.	<i>Phasmarhabditis hermaphrodita</i>	Nemaslug	UK

Table 3: Globally commercial use of EPN against some insect-pests as bio-control agents

Pests/Common Name	Scientific name	Crops/Targeted	Effective nematode species
Artichoke plume moth	<i>Platyptilia carduidactyla</i>	Artichokes	<i>Steinernema carpocapsae</i>
Black cutworm	<i>Agrotis ipsilon</i>	Turf, vegetables	<i>Steinernema carpocapsae</i>
Rice moth	<i>Corcyra cephalonica</i>	Rice	<i>Steinernema carpocapsae</i> , <i>S. glaseri</i> , <i>S. thermophilum</i> , <i>S. seemae</i> , <i>S. masoodi</i>
Gram pod borer	<i>Helicoverpa armigera</i>	Chickpea, Pigeon pea, Tomato, Field pea	<i>Steinernema carpocapsae</i> , <i>S. glaseri</i> , <i>S. thermophilum</i> , <i>S. seemae</i> , <i>S. masoodi</i>
Greater wax moth	<i>Galleria mellonella</i>	Worker honey bee	<i>Steinernema carpocapsae</i> , <i>S. glaseri</i> , <i>S. thermophilum</i> , <i>S. seemae</i> , <i>S. masoodi</i>
White grub	<i>Holotrichia consanguinea</i>	Potato, Sugarcane, Groundnut	<i>Steinernema carpocapsae</i> , <i>S. glaseri</i>
Blue butterfly	<i>Lampides boeticus</i>	Black and Green	<i>Steinernema carpocapsae</i> , <i>S.</i>

		gram	<i>seemae</i> , <i>S. masoodi</i>
Diamond black moth	<i>Plutella xylostella</i>	Cabbage	<i>Steinernema carpocapsae</i>
Tobacco caterpillar	<i>Spodoptera litura</i>	Tobacco	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i> , <i>S. abbasi</i> , <i>Heterorhabditis indica</i>
Armyworm	<i>Spodoptera frugiperda</i>	Vegetables	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i> , <i>S. riobrave</i>
Banana root borer	<i>Cosmopolites sordidus</i>	Bananas	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i> , <i>S. glaseri</i>
Banana moth	<i>Opogona sacchari</i>	Ornamentals, Banana	<i>Steinernema carpocapsae</i> , <i>Heterorhabditis bacteriophora</i>
Plum curculio	<i>Conotrachelus nenuphar</i>	Fruit trees	<i>S. riobrave</i>
Sweet potato weevil	<i>Cylasformic arius</i>	Sweet potato	<i>Steinernema carpocapsae</i> , <i>Heterorhabditis bacteriophora</i> , <i>S. feltiae</i>
Root weevil	<i>Otiorhynchus ovatus</i>	Berries strawberry	<i>Heterorhabditis marelata</i>
Leaf miner	<i>Liriomyza</i> spp. (dip: Agromyzidae)	Vegetables, Ornamentals	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i>
Mole cricket	<i>Scapteriscus</i> spp.	Turf	<i>Steinernema carpocapsae</i> , <i>S. riobrave</i>
Grape root borer	<i>Vitace apolistiformis</i>	Grapes	<i>Heterorhabditis bacteriophora</i> , <i>H. zealandica</i>
Corn rootworm	<i>Diabrotica</i> spp.	Vegetables	<i>Steinernema carpocapsae</i> , <i>Heterorhabditis bacteriophora</i>
Corn earworm	<i>Helicoverpa zea</i>	Vegetables	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i> , <i>S. riobrave</i>
Citrus root weevil	<i>Pachnaeus</i> spp.	Citrus, Ornamentals	<i>Heterorhabditis bacteriophora</i> , <i>S. riobrave</i>
Shore fly	<i>Scatella</i> spp.	Ornamentals	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i>
Black vine weevil	<i>Otiorhynchus sulcatus</i>	Berries, Ornamentals	<i>Heterorhabditis bacteriophora</i> , <i>H. downesi</i> , <i>H. morelata</i> , <i>H. megidis</i> , <i>Steinernema carpocapsae</i> , <i>S. glaseri</i>
Navel orange worm	<i>Amyeloistran sitella</i>	Nut and fruit trees	<i>Steinernema carpocapsae</i>
Small hive beetle	<i>Aethina tumida</i>	Bee hives	<i>Heterorhabditis indica</i> , <i>S. riobrave</i>
Plum curculio	<i>Conotrachelus nenuphar</i>	Fruit trees	<i>S. riobrave</i>
Iris borer	<i>Macronoctua onusta</i>	Iris	<i>Heterorhabditis bacteriophora</i> , <i>Steinernema carpocapsae</i>
Fungus gnat	Dip: Sciaridae	Mushrooms	<i>Heterorhabditis bacteriophora</i> , <i>S. feltiae</i>

Codling moth	<i>Cydia pomonella</i>	Pome fruit	<i>Steinernema carpocapsae</i> , <i>S. feltiae</i>
Cranberry girdler	<i>Chrysoteuchia topiaria</i>	Cranberries	<i>Steinernema carpocapsae</i>
Billbug	<i>Sphenophorus</i> spp. (Col: Curculionidae)	Turf	<i>Heterorhabditis bacteriophora</i> , <i>Steinernema carpocapsae</i>
Cat flea	<i>Ctenocephalides felis</i>	Home yard, turf	<i>Steinernema carpocapsae</i>

Application Technology

EPN application in soil and on plants requires careful handling to minimize environmental adverse effects and ensure efficient performance. Poor post-application survival reduces EPN effectiveness. Several methods address this challenge, including desiccated cadavers, capsules, and baits. EPNs can be delivered alongside pesticides or fertilizers and through irrigation systems. Small pressurized sprayers, mist blowers, and fan sprayers serve as suitable application equipment. Spray tank pressure should remain moderate to prevent nematode damage, as EPNs tolerate pressures up to 300 pounds per square inch and remain compatible with all standard nozzle types featuring openings as small as 50 microns in diameter.

1. Soil Application

Sandy loam soil generally supports better nematode migration and survival compared to clay soil. Soil temperature significantly influences EPN efficacy. When soil temperature exceeds 28°C, light pre-irrigation helps reduce temperature. Light irrigation following EPN application facilitates nematode movement deeper into soil for efficient action (Prasad et al., 2007). Effective control typically requires minimum application rates of 2.5×10^9 IJs/ha ($\approx 25/\text{cm}^2$) or higher. Irrigate fields 2-3 days before EPN application to maintain soil moisture, or apply directly if adequate moisture already exists. During field preparation, mix 2-5 kg/acre EPN culture (powder formulation) with 20-50 kg well-decomposed farm yard manure, vermicompost, cocopeat, or sand. For plantation and fruit crops, apply 5-25 g EPN per plant.

2. Soil Drenching

Maintain soil moisture and mix 10 g EPN per liter of clean water. Thoroughly mix the suspension. Remove the knapsack pump nozzle before drenching and apply EPN solution to root zone areas.

3. Foliar Application/Stem Borer Management

Spraying on standing crops represents one of the most common EPN application methods. Nozzle type, droplet size, and spray distribution mechanisms influence EPN deposition on plant surfaces. Adjuvant addition enhances EPN deposition on foliage. Adjuvants help overcome high temperature and UV radiation challenges. Adding fluorescent brighteners such as Tinopal, Ujala, or Ranipal (@ 0.01%) or glycerine @ 1% provides effective protection against environmental influences (Prasad et al., 2007). Apply 1000 IJs per plant (equivalent to 125 million IJs/ha) or @ 1×10^6 IJs/ml or 3×10^9 IJs/ha as a prophylactic control measure.

For stem borer, pseudostem weevil, or banana stem weevil (*Odoiporus longicollis*) management, observe holes with frass material or jelly-like exudations on pseudostems. Inject 20 ml of active infective juveniles @ 1000 IJs/ml into the holes as a curative measure.

Compatibility with Pesticides

EPNs tolerate most agrochemicals including fungicides, insecticides, herbicides, and acaricides, allowing tank mixing. Many toxic compounds produce only temperature-related effects, as nematodes recover rapidly following exposure. Short exposures permit simultaneous nematode application with pesticides and fertilizers. *S. glaseri* demonstrates compatibility with carbofuran and quinalphos, while *S. carpocapsae* remains compatible with

dimethoate, endosulfan, mancozeb, malathion, and zineb. Mancozeb and neem prove safe for most nematode populations except *H. indica*. Neem products including Achook and Neem Gold remain compatible with *S. carpocapsae* (Prasad et al., 2007).

Advantages

1. EPNs exhibit high toxicity to economically important insect pests while minimizing off-target effects.
2. They demonstrate remarkable safety for humans and the environment, requiring no safety equipment, producing no residual effects, avoiding groundwater contamination, and protecting pollinator populations.
3. EPNs kill target insects within 24-48 hours of infection.
4. Mass production proves straightforward, and application utilizes standard agrochemical equipment and irrigation systems.

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