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Biological Control of Plant-Parasitic Nematodes: Prospects and Challenges

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Eco-friendly nematode control uses beneficial microbes and antagonistic plants to reduce nematode populations naturally. In India bio-agents such as *Paecilomyces lilacinus*, *Pochonia chlamydosporia* and *Pasteuria penetrans* have shown strong effectiveness against major nematode pests. Their integration with cultural and physical practices enhances long-term suppression and improve soil health. Recent advances in microbial formulations enhanced the shelf life, field stability and effectiveness of biocontrol agents strengthening their role in sustainable nematode management.

Introduction

Biological management of nematodes involves the use of living organism such as fungi, bacteria, predator and antagonistic plants to plant parasitic population these biological agent act through mechanism such as parasitism, predation, antibiotics and competition, thereby reducing nematode reproduction and survival in the soil with increasing concern over environmental safety and the negative impact of chemical nematicides, biological control has gained importance as a sustainable and eco-friendly alternative (Stirling, 2014). In India the use of bio agents like *Paecilomyces lilacinus*, *Pochonia chlamydosporia* and *Pasteuria penetrans* as soon promising result against root knot and cyst nematode in vegetables and plantation crops (Rao *et.al.*, 2016).

Integration with other management practices

Biological methods are most effective when integrated with cultural, physical and botanical practices. Organic amendment, such as neem cakes, farmyard, manure and compost enhance the activity and establishment of beneficial organism in the soil for example application of the bio control fungi along with organic matter improves soil microbial diversity and increases nematode suppression (Tomar *et.al.*, 2025). Similarly, combining biological agent with physical methods like soil solarisation or hot water treatment reduces initial nematode population allowing bio agents to establish more effectively. Crop rotation and resistant varieties further complement biological control by lowering nematode pressure such integration forms the foundation of integrated nematode management (INM) which aims to achieve long-term nematode suppression while maintaining soil health and ecological balance.

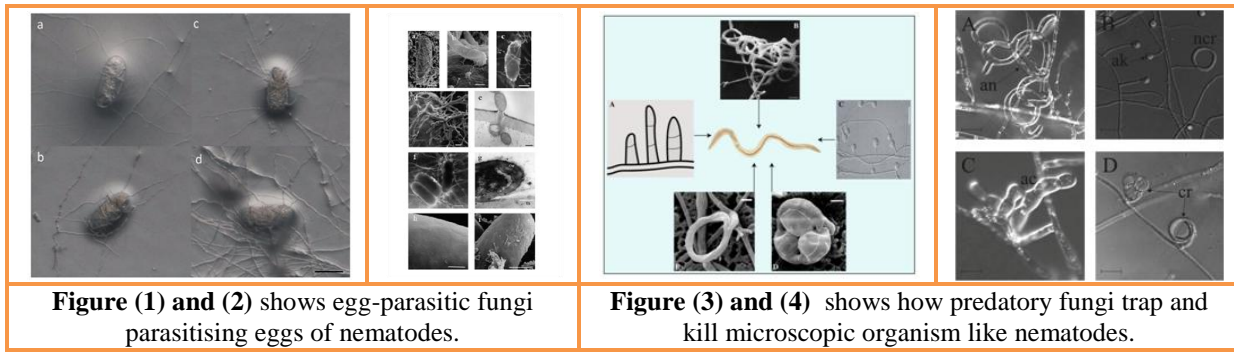
Biological methods of nematode control

Bio control agents include nematophagous fungi, antagonistic bacteria and beneficial soil microorganism. Egg parasitic fungi such as *Pochonia chlamydosporia* attack nematode eggs while predatory fungi, like *Arthrobotrys* species trap and kill juvenile (Lily *et.al.*, 2025). Bacterial agents such as *Pasteuria penetrans* parasitise initially reducing their reproduction

plant-based biological approaches including the use of trap crops and antagonistic plant like marigold also helps suppress nematode population by producing toxic exudates these methods are particularly suitable for sustainable and organic farming system.

Biological methods of nematode control

Biological Agent	Target Nematode Stage	Mode of Action	Example/Crops	References
Egg- parasitic fungi	Eggs	Penetration & destruction of egg shells	<i>Pochonia chlamyosporia</i> against cysts and root-knot nematodes	(Lily et.al., 2025)
Predatory fungi	Juveniles	Formation of trapping structures (nets/rings)	<i>Arthrobotrys</i> spp. in vegetables crops	(Ramatsitsi et.al., 2025)
Bacterial parasites	Juveniles & adults	Internal parasitism and sterilisation	<i>Pasteuria penetrans</i> against <i>Meloidogyne</i> spp.	(Poornima & Walia, 2025)
Antagonistics bacteria	Juveniles	Antibiosis and competition	<i>Bacillus</i> , <i>Pseudomonas</i> spp.	(Ratnakala et.al., 2023)
Antagonistics plants	Juveniles and eggs	Toxic root exudates and trap cropping	Tagetes spp. (Marigold)	(Khan, 2023)
Mycorrhizal fungi	Indirect suppression	Improved plant resistance and root health	<i>Glomus</i> spp. In horticultural crops	(Patel et.al., 2022)
<i>Pseudomonas fluorescens</i>	Juveniles and eggs	Produces antibiotics & lytic enzymes	Tomato, Chilli, Brinjal, okra, Carrot	GOI, MA, FW & CIBRIC (2025)
<i>Trichoderma harzianum</i>	Eggs and Juveniles	Parasitized nematode eggs	Tomato, chilli, Brinjal, Cucumber, Papaya, Banana, Potato, Cotton, Gerbera, Carnation, Tuberos, Acid lime	GOI, MA, FW & CIBRIC (2025)
<i>Trichoderma viride</i>	Eggs and Juveniles	Egg parasitism	Tomato, Chilli, Brinjal, Cucumber, Banana, Potato, Sugarcane & Ornamental crops.	GOI, MA, FW & CIBRIC (2025)
<i>Verticillium chlamyosporium</i>	Eggs	Egg parasitism	Tomato, Chilli, Brinjal, okra, Carrot	GOI, MA, FW & CIBRIC (2025)
<i>Paecilomyces lilacinus</i>	Eggs	Parasitised nematode eggs	Tomato, Brinjal	GOI, MA, FW & CIBRIC (2025)



Advantage and limitations

Biological management offer several advantages including environmental safety, long-term sustainability and minimal risk of resistant development these methods improve soil held by enhancing beneficial microbial activity and maintaining ecological balance. Biological agents are generally safe to non-target organism and contribute to sustainable crop production however their effectiveness can be influenced by soil type, temperature, moisture and farming practises. Biological control agent act slowly compared to chemical nematicides and may require repeated application for consistent result (Jaiswal *et.al.*, 2022). In addition availability, quality and self life of bio agents can limit their adoption by farmers therefore biological method alone may not provide complete control but are highly effective when used as part of an integrated approach.

Future prospects and Conclusion

Advantage in microbial biotechnology and formulation techniques are expected to enhance the efficacy and reliability of biological nematode management development of multi-strain and consortium based bio products, improve carrier materials and longer self life formulation will increase field performance (Raypuriya *et.al.*, 2025). Molecular tools and precision agriculture can aid in the selection of effective bio agent suited to specific soil and crop conditions with strengthening extension services, farming, training, and awareness program will play a crucial role in promoting large-scale adoption of biological nematode management growing emphasis on sustainable agriculture biological control is expected to become a key component of future management strategies (Yadav *et.al.*, 2025). Overall biological nematode management offers a long-term solution for suppressing plant-parasitic nematodes when integrated with different management practices which helps to maintain ecological balance and reduce reliance on chemical nematicides.

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