Host Parasite Relationship in Nematode Infestation

Deepak Singh, Nishant Gaurav, Akash Kumar, Deepak, Kshitij and S.K. Biswas
Chandra Shekhar Azad University of Agriculture and Technology, Kanpur- 208 002, U.P., INDIA
Email: alokjadaun0708@gmail.com

The host-parasite relationship in nematode infestations is a critical aspect of agricultural ecosystems, influencing crop productivity and sustainability. Nematodes, being abundant and diverse organisms, exhibit varied biological attributes that shape their interactions with host plants. Predatory nematodes offer potential as biological control agents against plant-parasitic nematodes, but challenges in mass production and storage hinder their widespread use. Plant-parasitic nematodes, on the other hand, establish complex interactions with host plants, triggering defence mechanisms and affecting crop yields. Despite challenges, ongoing research efforts offer promising opportunities for sustainable nematode management through the development of resilient crop cultivars, integrated pest management strategies, and innovative approaches to biological control. Collaboration among researchers, farmers, and policymakers is essential for navigating the complexities of nematode infestations and ensuring agricultural resilience in the face of these challenges.

Introduction

Ensuring food security and meeting the needs of a growing global population will pose a major challenge in the coming years. This challenge will be particularly pressing in resource-poor regions, notably in Africa, where populations are expanding rapidly. While a 35% increase in population is projected by 2050, the demand for food is expected to rise by approximately 75% due to economic development and shifts in food preferences. To address this, significant improvements in resource use efficiency are imperative.

While precise data may vary from year to year and by region, nematode infestations have been documented to lead to yield losses ranging from 10% to 50%, depending on factors such as crop type, nematode species, and management practice. For instance, in states like Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, and Uttar Pradesh, where agriculture plays a vital role in the economy, nematodes have been reported to cause significant damage to crops such as potatoes, tomatoes, cotton, sugarcane, and bananas. In some cases, nematode-induced losses have been estimated to cost farmers billions of rupees annually.

Efforts to enhance agricultural productivity must be prioritized, especially in regions experiencing rapid population growth. Achieving optimal pest and disease management will be crucial in maximizing crop yields and moving towards an efficiency frontier. It's important to acknowledge the evolving nature of agricultural production, with some commodities experiencing shifts in proportional production over time.

Nematodes represent the most abundant group of multicellular animals on Earth in terms of sheer numbers. Despite the identification of over 4,100 species of plant-parasitic nematodes, ongoing discoveries continually add to this count, with some previously benign species emerging as pests due to changes in cropping practices. However, economically significant plant-parasitic nematodes generally belong to specific, specialized groups that directly damage their host plants or serve as vectors for viruses.

In a square meter of moderately fertile soil to a depth of 30 cm, an astonishing 50 million nematodes can be found. These nematodes exhibit diverse ecological roles, with roughly half of all species inhabiting marine environments, 25% living as free-living soil inhabitants, 15% parasitizing animals and humans, and the remaining 10% infesting plants.

According to recent research, there are approximately 4100 species of plant parasitic nematodes (PPN) known today, posing a significant threat to global food security. The World Bank projected in 2008 that with economic development and changing food preferences, the world population could increase by 35% by 2050, resulting in a corresponding 75% rise in food demand. This projection underscores the urgent need for sustainable approaches to optimize resource utilization, a concern shared by stakeholders worldwide.

Amidst these considerations, nematode constraints are often overlooked but must be addressed comprehensively. Nematodes can significantly limit crop production, and their management should be integrated into broader agricultural strategies to ensure sustainable food production and mitigate yield losses. By recognizing and addressing the full spectrum of crop production limitations, including nematode constraints, we can work towards enhancing agricultural productivity and achieving food security for all.

Nematode behavior feeding and host parasite interaction

Plant parasitic nematodes exhibit a diverse array of interactions with their host plants, categorized as ecto or endo parasites depending on the plant tissues they target. Some nematodes are migratory, moving easily from soil to plant tissues, while others are sedentary, with adult females remaining immobile and attached to plant roots. Sedentary endo parasites rely on specialized cells around the female head for feeding. Most plant parasitic nematodes possess a stylet, a needle-like protractible oral structure used to puncture plant tissues. They release enzymes into the tissues to partially digest plant cells, facilitating ingestion into the nematode gut.

Economically important plant parasitic nematodes, such as root-knot (*Meloidogyne sp*.), cyst (*Globodera sp*., *Heterodera sp*.), reniform (*Rotylenchulus sp*.), and citrus (*Tylenchulus semipenetrans*) species, are biotrophic and sedentary. They lay clusters of eggs either inside their bodies or attached to their bodies. After embryogenesis, first stage juveniles (J1) molt to form second stage infective juveniles (J2), which hatch from the eggs to infect root tissues. This often results in the formation of galls or pathological nodes induced by nematode stylet punctures on the root surface.

Meloidogyne, with nearly 98 species, has a broad host range and can parasitize numerous vascular plants. Second stage juveniles employ both physical and enzymatic methods to penetrate hosts, damaging the plant cell wall with their stylets and releasing cellulolytic and pectolytic enzymes for digestion. Conversely, cyst nematodes move intercellularly within root cells, aiming for the zone of differentiation, where giant cells act as permanent feeding sites.

Mitigating damage caused by Meloidogyne species poses challenges due to their short life cycles and wide host range. These nematodes spread quickly, infecting nearby crop plants rapidly. They are well adapted to flood conditions, posing threats to both upland and lowland rice crops and capable of causing significant crop losses, with reports of up to 85% loss.

Disease complexes	Root knot Nematode spp.	Associated Pathogenic spp.	Vegetable crops	References
Damping off	*M. incognita*	*Rhizoctonia solani*	Tomato	Arya and Saxena, (1999)
Collar rot	*M. incognita*	*Sclerotium rolfsii*	Brinjal	Goswami *et al*., (1970)
Bacterial wilt	*M. incognita*	*Ralstonia (Pseudomonas) solanacearum*	Tomato	Haider *et al*., (1989)
Soft rot	*M. incognita*	*Pectobacterium carotovorum subsp. carotovorum*	Carrot	Sowmya *et al*., (2012)
Fusarium wilt	*M. incognita*	*Fusarium oxysporum f. sp. lycopersici*	Tomato	Akram and Khan, 2006
Fusarium wilt	*M. incognita*	*Fusarium oxysporum f. sp. conglutinans*	Cauliflower	Rajinikanth *et al*., 2013
Damping- off	*M. javanica*	*Pythium debaryanum*	Tomato	Ram Nath *et al*., 1984

Plant response to nematode interaction

The impact of nematode infections on plants varies depending on factors such as plant cultivar, species, temperature, soil moisture content, nematode type, soil characteristics, and crop rotations. Symptoms of nematode infection range from premature wilting, chlorosis, and nutrient deficiencies leading to stunted growth to fragile roots and swollen root areas due to gall formation. *Pratylenchus* species, for instance, cause lesions in roots, resulting in cell necrosis, browning, and root rotting due to secondary infections by soil-borne fungi and bacteria. Infected plant roots often exhibit discoloration, stubby appearance, and stunted growth, rendering them vulnerable to water stress conditions. In banana plants, certain *Radopholus* species may induce toppling disease.

A reduction in crop yield, both in terms of quality and quantity, is a common indicator of nematode infestation. The threshold level for nematode infestation can be as low as one nematode egg per 100 cm^3 of soil. Specific nematode species, such as *Ditylenchus angustus,* feed ecoparasitically on the leaves and stems of rice, causing ufra disease, while *Ditylenchus dipsaci* primarily infects onion and garlic, leading to discoloration of infected bulbs and stunted growth. *Ditylenchus dipsaci* is classified as a migratory endoparasite, whereas *Ditylenchus angustus* is categorized as a migratory ectoparasite. These diverse symptoms and impacts underscore the importance of understanding nematode biology and their interactions with host plants to develop effective management strategies.

Current management strategies and their limitations

Merely identifying nematodes and applying nematicides is not a sustainable solution for nematode management. Many chemical nematicides are costly, carcinogenic, and harmful to humans, animals, and the environment. They can contaminate groundwater and degrade soil quality over time. Additionally, unfavorable climatic conditions can render applied nematicides ineffective against nematodes. Consequently, several chemical nematicides have been banned or severely restricted worldwide due to these concerns.

However, some chemical nematicides with reduced toxicity on non-target soil organisms have gained importance in recent years. One such product is fluensulphone, a heterocyclic fluoroalkenyl sulphone nematicide, which reportedly lacks many of the drawbacks associated with other chemical controls. Studies have demonstrated fluensulphone's efficacy against various nematode species, including *Globodera pallida, Meloidogyne javanica, M. incognita, and M. arenaria.* Nevertheless, the long-term effects of fluensulphone on the environment and human health have not been thoroughly investigated, highlighting the need for further research to validate its safety and efficacy.

Fermentation and microbial-based products

Fermentation-based products have garnered significant interest due to their sustainable and cost-effective production methods. Combining solid and liquid fermentation techniques can be particularly effective for large-scale production of fungi or other biological materials.

The efficacy of fermentation extracts against plant-parasitic nematodes (PPN). Recent research has shown that fermentation extracts of Myrothecium verrucaria exhibit high effectiveness against PPN such as Meloidogyne incognita and *Heterodera glycines*. These extracts inhibit the egg-hatching process and demonstrate lethal effects on juveniles *of Bursaphelenchus xylophilus*, *M. incognita*, and *H. glycines*.

Similarly, Hallmann and Sikora observed promising results using filtrates containing strains of *Fusarium oxysporum*, which produced toxins effective against *M. incognita*. However, it's worth noting that the organic compounds present in fermentation mediums can sometimes retard plant growth. Despite this drawback, fermentation-based products offer a promising avenue for nematode management, providing effective alternatives to traditional chemical nematicides while minimizing environmental impact.

Biocontrol of nematode

Nematophagous fungi

Research efforts focusing on the natural enemies and antagonists of plant-parasitic nematodes (PPN) have largely concentrated on predaceous (trapping) and endo parasitic fungi, which accounted for over 73-76% of total research endeavors (Bilgrami, 2008). While scientists have successfully exploited and commercially released several fungal species as biological control agents (BCAs) against PPN, including *Purpureocillium lilacinus, Pochonia chlamydosporia, Trichoderma harzianum, Aspergillus niger,* and *Arthrobotrys oligospora*, none have proven promising across all aspects (Askary, 2015).

For example, *P. lilacinus,* while effective at attacking young females and egg masses of nematodes embedded in roots, often lacks aggressive trapping mechanisms, limiting its success against mobile nematodes (Esser and El-Gholl, 1993). Moreover, *P. lilacinus* may only control one species of nematode when multiple species are present on the same host plant, leaving others unaffected. Additionally, the virulence and efficacy of fungal BCA isolates can vary considerably when introduced into soil, leading to inconsistent field performance. Antagonists of these fungi in soil further reduce their effectiveness when applied in the field.

Although the use of fungal BCAs is encouraged as an environmentally safe approach to PPN management, they may not effectively control nematodes when their inoculum levels are high in the soil. However, combining fungal BCAs with resistant cultivars or incorporating them into crop rotation as part of an integrated pest management (IPM) program can enhance their efficacy. Combined seed treatments with fungal BCAs, botanicals, and pesticides offer an economical and practical approach under field conditions, provided compatibility tests ensure no mutual suppression among components. Multi-locational field experiments involving BCAs and chemical standards can guide growers during extension services and contribute to the development of effective PPN management strategies.

Nematophagous bacteria

Numerous studies have explored the potential benefits of nematophagous bacteria as biocontrol agents against plant-parasitic nematodes (PPN), investigating various bacterial species and their mechanisms for suppressing nematode pest populations. These bacteria encompass different groups, including parasitic, opportunistic parasitic, rhizobacteria, parasporal crystal-forming, endophytic, and symbiotic bacteria of entomopathogenic nematodes. Utilization of these beneficial bacteria or their genes and products, such as metabolites, can mitigate the negative effects of PPNs and promote positive responses in infected plants.

Nematophagous bacteria offer several advantages, such as safety, biodegradability, affordability compared to chemical nematicides, and potential for reducing environmental pollution and health hazards. However, they also have limitations, including slow action, variable efficacy influenced by biotic and abiotic factors, and potential for bacterial adaptation and evolution under selective pressures. Furthermore, the unpredictable multiplication of these bacteria hampers their large-scale exploitation.

To enhance the field efficacy of nematophagous bacteria, sustainable methodologies such as integrated pest management (IPM) are recommended. Further research into the interactions among bacterial strains, soil physical and chemical factors, microbial communities, nematode targets, plants, and the environment is crucial for successfully harnessing the potential of these bacteria in PPN management across various agricultural systems.