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# Plant-parasitic nematodes of paddy in India with special reference to Bihar: Diversity, distribution and management perspectives

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## ABSTRACT

Rice (*Oryza sativa* L.) is a staple crop underpinning food security and rural livelihoods across India, particularly in agriculturally dependent states such as Bihar. However, rice productivity is significantly constrained by plant-parasitic nematodes, which cause substantial yield losses and often remain undetected due to their hidden mode of infection. India supports a diverse community of nematodes associated with paddy ecosystems, including economically important species such as *Meloidogyne graminicola, Aphelenchoides besseyi, Hirschmanniella oryzae,* and *Ditylenchus angustus*. Among these, *M. graminicola* is recognized as the most destructive, particularly in upland and rainfed conditions. Despite the agricultural importance of Bihar, systematic studies on nematode diversity and distribution in the region remain limited. This review synthesizes current knowledge on the diversity, biology, distribution, and economic importance of paddy nematodes in India, with special emphasis on Bihar. It also examines advances in diagnostic approaches and highlights sustainable management strategies, including cultural, biological, and integrated pest management practices. The study identifies key research gaps and emphasizes the need for region-specific investigations to support effective nematode management and enhance rice productivity.

**Key Words -** Paddy, Nematodes, *Meloidogyne graminicola*, Integrated Pest Management

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## INTRODUCTION

Rice (*Oryza sativa* L.) remains the backbone of food security in India, sustaining more than half of the population as a primary dietary staple. In agriculturally intensive states such as Bihar, rice cultivation is not merely an agronomic activity but a central pillar of rural livelihoods, employment, and economic stability. The state's fertile alluvial soils, abundant monsoonal rainfall, and favorable agro-climatic conditions make it highly suitable for rice production across diverse ecosystems, including irrigated, rainfed lowland, and upland systems. Despite this natural advantage, productivity often falls short of its potential due to multiple biotic and abiotic constraints (Jones *et al.,* 2013; Coyne *et al.,* 2018).

Among the biotic stresses, plant-parasitic nematodes represent an often underestimated yet highly destructive group of pathogens. Nematodes are microscopic, worm-like organisms inhabiting soil and plant tissues, many of which have evolved specialized parasitic relationships with crops (Mantelin *et al.,* 2017). In rice ecosystems, a diverse assemblage of nematode species has been reported, including root-knot nematodes

(*Meloidogyne* spp.), root nematodes (*Hirschmanniella* spp.), stem nematodes (*Ditylenchus angustus*), and white tip nematodes (*Aphelenchoides besseyi*) (Coyne *et al.,* 2018). These nematodes attack different parts of the rice plant roots, stems, and leaves causing symptoms such as root galls, lesions, stunted growth, chlorosis, and malformed grains. Their damage is often insidious and easily confused with nutrient deficiencies or other stresses, which complicates diagnosis and management.

The diversity of nematodes in rice fields reflects the complexity of agroecosystems, where factors such as soil type, water regime, cropping patterns, and climate influence species composition and population dynamics (Mantelin *et al.,* 2017). In flooded rice systems, for example, certain nematodes like *Hirschmanniella* spp. thrive under anaerobic conditions, while others dominate in upland or intermittently flooded fields. This ecological adaptability makes nematodes persistent and difficult to control, particularly in regions like Bihar where smallholder farming and limited access to diagnostic facilities constrain effective management (Bridge & Starr, 2007).

Economically, nematode infestations can have devastating consequences. Yield losses in rice due to nematodes have been reported to range widely depending on species, environmental conditions, and management practices, with severe cases reaching up to 90% (Baqri & Das, 1990; Coyne *et al.,* 2018). Such losses are especially critical in Bihar, where a large proportion of the population depends on agriculture for subsistence and income. Even moderate infestations can significantly reduce grain quality and market value, compounding economic hardship for farmers.

The scientific understanding of nematodes has evolved considerably over time. Early pioneers such as Nathan Augustus Cobb highlighted the immense abundance and ecological significance of nematodes. Similarly, Ernst A. Bessey made foundational contributions to the study of plant-parasitic nematodes (Bessey, 1911). These contributions laid the groundwork for modern nematology, which now integrates molecular tools, advanced diagnostics, and ecological approaches (Subbotin & Moens, 2021).

Despite global advances in nematode research, region-specific studies in Bihar remain sparse and fragmented. There is a clear need for comprehensive documentation of nematode diversity, distribution, and impact in local rice ecosystems (Singh *et al.,* 2020; Kumar *et al.,* 2021).

## DIVERSITY OF PADDY NEMATODES IN INDIA

India harbors a remarkably rich diversity of nematodes associated with rice-based agro ecosystems, reflecting the country's wide range of climatic zones, soil types, and cropping systems. From irrigated lowlands and deep-water rice fields to upland and rainfed ecosystems, each production environment supports a distinct assemblage of plant-parasitic nematodes (Coyne *et al.,* 2018). Early systematic surveys estimated that nearly 35 nematode species are associated with paddy cultivation in India (Baqri & Das, 1990), though subsequent regional studies suggest that this number may be even higher due to improved diagnostic techniques and expanded sampling.

This diversity is shaped by ecological conditions such as soil moisture, temperature, and cropping intensity (Mantelin *et al.,* 2017). Flooded conditions typical of lowland rice favor migratory endo parasites like *Hirschmanniella* spp., while upland and rainfed systems provide ideal conditions for sedentary endoparasites such as *Meloidogyne* spp.

### *Major Nematode Species*

Among the diverse nematode fauna, a few species have emerged as economically significant due to their widespread distribution and destructive potential:

- *Meloidogyne graminicola*
- *Aphelenchoides besseyi*
- *Hirschmanniella oryzae*
- *Ditylenchus angustus*
- *Heterodera oryzicola*

Each of these species exhibits distinct modes of parasitism and symptom expression. For instance, *Hirschmanniella oryzae* is a migratory endoparasite that causes root lesions and decay under submerged conditions, whereas *Aphelenchoides besseyi* is primarily seed-borne and responsible for the characteristic “white tip” symptom on rice leaves. *Ditylenchus angustus*, the causal agent of “ufra disease,” attacks stems and panicles, leading to severe yield reductions in deep-water rice ecosystems. Meanwhile, *Heterodera oryzicola* forms cysts on roots, enabling long-term survival in soil and complicating management strategies.

Among these, *Meloidogyne graminicola* is widely regarded as the most damaging nematode species in Indian rice systems (Kyndt *et al.,* 2014; Mantelin *et al.,* 2017). It induces the formation of characteristic root galls, disrupting water and nutrient uptake and resulting in stunted growth and poor tillering. Its significance is particularly pronounced in upland and rainfed ecosystems, where intermittent soil moisture and aerobic conditions favor rapid reproduction and population buildup. Under such conditions, infestations can escalate quickly, leading to substantial yield losses (Prasad *et al.,* 2005).

The widespread occurrence and adaptability of these nematodes underscore the need for region-specific monitoring and management. Their diversity not only reflects ecological complexity but also highlights the challenge of developing universal control measures. A deeper understanding of species distribution, host interactions, and environmental preferences is therefore essential for designing effective and sustainable nematode management strategies in Indian rice cultivation systems.

## STATUS OF NEMATODE FAUNA IN BIHAR

The state of Bihar remains relatively underexplored in terms of nematode biodiversity, despite its strong agricultural base and extensive rice cultivation. At the national level, India is known to harbor an impressive diversity of nematodes, with approximately 1600 species documented across various ecosystems. However, only a small fraction estimated at around 7% has been reported from Bihar (Baqri & Kankans, 2000). This disparity does not necessarily reflect low nematode diversity in the state, but rather indicates limited systematic surveys, insufficient taxonomic studies, and gaps in regional documentation (Singh *et al.,* 2020; Kumar *et al.,* 2021).

Early nematological investigations in Bihar laid the groundwork for understanding the presence of economically important plant-parasitic nematodes. Pioneering work by M. R. Siddiqi (2000) in the 1960s documented key root-knot nematodes such as *Meloidogyne incognita* and *Meloidogyne javanica* in agricultural soils of the region. These species are highly polyphagous and known for causing root galling, which interferes with nutrient and water uptake, ultimately reducing crop productivity.

Subsequent studies expanded the list of nematode fauna associated with rice and other crops in Bihar. Notably, species such as *Hirschmanniella oryzae*, a dominant parasite in flooded rice systems, and *Hoplolaimus indicus*, a migratory ecto-endoparasite affecting a wide range of crops, were reported (Siddiqi, 1965; Khan *et al.,* 1967). These findings highlighted the presence of both specialized rice nematodes and generalist species capable of persisting across different cropping systems.

Despite these early contributions, the overall understanding of nematode diversity in Bihar remains fragmentary. Several important taxonomic groups, including members of the suborder Criconematina and the family Longidoridae, are poorly studied or entirely unreported in the region. These groups are of particular interest due to their ecological roles and, in some cases, their ability to act as vectors of plant viruses, which can further exacerbate crop losses (Subbotin & Moens, 2021).

The lack of comprehensive surveys, modern diagnostic tools, and updated taxonomic revisions has limited the accurate assessment of nematode fauna in Bihar. Given the state’s diverse agroecological zones and intensive cropping practices, it is highly likely that many species remain undocumented. Recent studies from eastern India further support the assumption that nematode diversity is underestimated due to limited sampling intensity and methodological constraints (Kumar *et al.,* 2021).

This knowledge gap underscores the urgent need for systematic, large-scale nematological surveys incorporating both classical taxonomy and molecular approaches (Singh *et al.,* 2020; Subbotin & Moens, 2021). Strengthening research efforts in this area would not only enhance biodiversity inventories but also support the development of targeted nematode management strategies tailored to local conditions. Improved understanding of species composition, distribution patterns, and host associations is essential for mitigating crop losses and ensuring sustainable agricultural productivity in Bihar.

## BIOLOGY & PATHOGENICITY OF MAJOR SPECIES

Understanding the biology and pathogenic mechanisms of key nematode species is essential for developing effective management strategies in rice ecosystems. The major nematodes affecting rice differ significantly in their life cycles, feeding behavior, and modes of infection, which in turn influence the type and severity of damage they cause. These nematodes exhibit diverse survival strategies and ecological adaptations that enable them to persist under varying environmental conditions and exploit different niches within the rice plant system (Mantelin *et al.,* 2017; Coyne *et al.,* 2018).

### Root-Knot Nematode

*Meloidogyne graminicola* is one of the most destructive nematodes in rice, particularly in upland and rainfed conditions. It is a sedentary endo parasite, meaning that after infecting the root, it establishes a permanent feeding site within plant tissues. The infective second-stage juveniles (J2) penetrate young roots and migrate to the vascular region, where they induce the formation of specialized feeding cells known as giant cells. This results in the development of characteristic root galls, which interfere with normal root function and physiology.

The life cycle of *M. graminicola* is relatively rapid, typically completed within 2–3 weeks under favorable temperature and moisture conditions (Narasimhamurthy, 2016). This short generation time allows for multiple overlapping generations within a single cropping season, leading to rapid population buildup (Mantelin *et al.,* 2017). The nematode thrives particularly well in aerobic or intermittently flooded soils, making upland and rainfed rice systems highly vulnerable (Kyndt *et al.,* 2014).

Severe infestations disrupt root architecture and significantly impair water and nutrient absorption, ultimately leading to substantial yield losses. In addition, damaged roots become more susceptible to secondary infections by soil-borne pathogens, further aggravating plant stress.

### White Tip Nematode

*Aphelenchoides besseyi* is primarily an ectoparasitic and seed-borne nematode that colonizes the aerial parts of the rice plant. Unlike root-infecting nematodes, it survives in a quiescent state within dry seeds and becomes active when conditions become favorable, particularly under high humidity and warm temperatures.

After germination, the nematodes migrate to growing points and leaf tissues, feeding externally on epidermal cells. Their life cycle is closely synchronized with the host plant's development, enabling efficient colonization and spread within the crop canopy. This synchronization allows the nematode to persist across cropping cycles through infected seed material (Coyne *et al.,* 2018).

Because of its seed-borne nature, *A. besseyi* can be easily disseminated over long distances through infected planting material, making it a significant concern for disease spread and quarantine management. Yield losses are often associated with reduced grain quality and incomplete grain development.

### Rice Root Nematode

*Hirschmanniella oryzae* is a migratory endoparasite commonly associated with flooded and lowland rice systems. Unlike sedentary nematodes, it continuously moves within root tissues, feeding and causing mechanical damage as it migrates. This mobility enables the nematode to exploit multiple feeding sites within a single host root.

The nematode penetrates roots and feeds on cortical cells, creating lesions and cavities. This feeding activity not only damages root tissues directly but also predisposes plants to secondary infections by fungi and bacteria, thereby compounding the overall impact on plant health (Bridge & Starr, 2007).

Infested plants often exhibit reduced vigor, poor growth, and lower yield potential. Due to its ability to survive in flooded soils and persist in crop residues, *H. oryzae* remains a chronic problem in intensively cultivated rice fields, particularly in lowland ecosystems.

**SYNTHESIS OF PATHOGENIC STRATEGIES**

Collectively, these nematodes exhibit diverse biological strategies sedentary (*Meloidogyne*), migratory (*Hirschmanniella*), and ectoparasitic/ seed-borne (*Aphelenchoides*) that enable them to exploit different ecological niches within the rice plant. Their pathogenicity not only results in direct tissue damage but also indirectly affects plant health by interfering with physiological processes, reducing nutrient uptake efficiency, and facilitating secondary infections (Mantelin *et al.,* 2017; Coyne *et al.,* 2018). Understanding these mechanisms is crucial for designing integrated nematode management approaches tailored to specific rice ecosystems and production conditions.

**ECONOMIC IMPORTANCE**

Plant-parasitic nematodes impose a substantial economic burden on rice cultivation by directly reducing yield and indirectly affecting grain quality, nutrient use efficiency, and overall crop productivity. Among the various nematodes associated with rice, *Meloidogyne graminicola* has emerged as one of the most significant constraints in Indian rice systems, particularly under upland and rainfed conditions. Infestation by this nematode leads to the formation of characteristic root galls, which disrupt normal root architecture and impair the plant's ability to absorb water and essential nutrients. As a result, affected plants exhibit stunted growth, chlorosis, reduced tillering, and poor grain filling.

Empirical studies conducted under Indian conditions have reported yield reductions ranging from 16% to 32%, depending on factors such as nematode population density, soil type, crop variety, and management practices (Prasad *et al.,* 2005; Coyne *et al.,* 2018). In severe infestations, particularly when nematode damage is compounded by abiotic stresses such as drought or nutrient deficiency, yield losses may exceed these estimates and become economically devastating. In addition to yield reduction, nematode infestation often leads to inferior grain quality, which reduces market value and farmer profitability.

Globally, plant-parasitic nematodes are recognized as major contributors to crop losses across a wide range of agricultural systems, with annual losses estimated in billions of dollars (Jones *et al.,* 2013). Their economic impact is further amplified by their hidden, soil-borne nature, which makes early detection difficult and often results in delayed or inappropriate management interventions.

In regions such as Bihar, where agriculture is predominantly smallholder-based and resource-limited, the impact of nematodes is particularly severe. Farmers often remain unaware of nematode infestations due to the absence of visible above-ground symptoms during early stages, leading to misdiagnosis as nutrient deficiency or other stress factors. This not only results in direct yield losses but also contributes to inefficient use of agricultural inputs such as fertilizers and irrigation, thereby increasing production costs without corresponding yield benefits.

Given that rice is a cornerstone of food security and rural livelihoods in Bihar, the unchecked proliferation of plant-parasitic nematodes poses serious socioeconomic challenges. Therefore, understanding the economic significance of these pests is crucial for prioritizing research, improving diagnostic capabilities, and implementing effective, sustainable management strategies aimed at minimizing losses and enhancing productivity.

## ADVANCES IN TAXONOMY AND IDENTIFICATION

The identification and classification of plant-parasitic nematodes have traditionally relied on detailed morphological and morphometric analyses, including characteristics such as body length, stylet structure, esophageal features, tail morphology, and reproductive anatomy. Classical taxonomic frameworks, such as those developed by M. R. Siddiqi (2000), have provided a strong foundation for distinguishing major nematode genera and species associated with crop plants. While these approaches remain fundamental to nematology, they often present limitations due to overlapping morphological features, phenotypic plasticity, and intraspecific variability, which can complicate accurate identification, particularly among closely related or cryptic species.

To address these challenges, modern nematology has increasingly incorporated advanced diagnostic tools that complement traditional taxonomy. Biochemical methods, such as isozyme analysis, have been used to differentiate species based on enzyme activity patterns, offering improved resolution in certain cases. The most significant advancements have come from molecular techniques, which provide high levels of specificity, sensitivity, and reproducibility.

Molecular diagnostic approaches, including Polymerase Chain Reaction based identification, DNA barcoding, and sequencing of ribosomal RNA (rRNA) genes, have revolutionized the field of nematode taxonomy (Janssen *et al.,* 2016; Subbotin & Moens, 2021). These techniques enable rapid and accurate identification of nematode species, even from minute or mixed samples, and are particularly valuable for detecting cryptic species and early-stage infestations. DNA barcoding using conserved genomic regions, such as ITS (Internal Transcribed Spacer) and 18S rRNA sequences, has become a widely adopted tool for species-level identification and phylogenetic analysis.

Advancements in genomic and bioinformatics tools have facilitated deeper insights into nematode evolution, population genetics, and host–parasite interactions (Abad *et al.,* 2008). These developments have significant implications for quarantine regulation, pest surveillance, and the design of targeted management strategies.

The integration of classical taxonomy with molecular and biochemical approaches has thus greatly enhanced the accuracy and reliability of nematode identification. Such integrative diagnostics are essential for effective monitoring, timely intervention, and the development of sustainable nematode management programs, particularly in regions like Bihar where diagnostic infrastructure is still developing.

## MANAGEMENT STRATEGIES

### Chemical Control

Chemical nematicides have historically played a significant role in managing plant-parasitic nematodes in rice ecosystems by providing rapid and often effective suppression of nematode populations. Compounds such as carbofuran and phorate were widely used in intensive rice cultivation systems to control major species like *Meloidogyne graminicola* and *Hirschmanniella oryzae*. These chemicals act by disrupting nematode nervous systems or metabolic pathways, thereby reducing their population density in soil. However, the use of chemical nematicides has declined considerably in recent years due to increasing concerns over environmental pollution, toxicity to non-target organisms, and potential risks to human health. Additionally, the persistence of chemical residues in soil and water bodies, along with their high cost, has limited their adoption, particularly among smallholder farmers. Regulatory restrictions and growing emphasis on sustainable agriculture have further accelerated the shift away from chemical control toward safer alternatives (D'Addabbo *et al.,* 2019; Coyne *et al.,* 2018).

### Cultural Practices

Cultural practices constitute a fundamental and eco-friendly component of nematode management in rice cultivation, focusing on modifying agronomic practices to suppress nematode populations and minimize crop damage. Crop rotation with non-host or poor-host crops is an effective strategy to break the life cycle of nematodes such as *Heterodera oryzicola*, thereby reducing soil infestation levels over time. Water management also plays a critical role; maintaining prolonged flooding in lowland rice systems can suppress aerobic nematodes like *Meloidogyne graminicola*, which thrive in well-aerated soils. Additionally, the use of resistant or tolerant rice cultivars offers a practical and cost-effective approach, as such varieties can limit nematode reproduction and reduce yield losses without requiring additional inputs. Other practices, including deep ploughing, organic amendments, and field sanitation, further contribute to reducing nematode populations. These methods are environmentally safe, economically viable, and particularly suitable for resource-limited farming systems (Sikora *et al.,* 2018; Coyne *et al.,* 2018).

**Biological Control**

Biological control has emerged as a promising and sustainable alternative to chemical nematicides, utilizing naturally occurring organisms to suppress nematode populations. A wide range of microbial antagonists, including nematophagous fungi such as *Purpureocillium lilacinum* and beneficial bacteria like *Pseudomonas fluorescens*, have demonstrated effectiveness against plant-parasitic nematodes. These organisms act through multiple mechanisms, including parasitism of nematode eggs and juveniles, production of toxic metabolites, competition for resources, and induction of systemic resistance in host plants. In addition to reducing nematode density, biological control agents improve soil health and enhance plant growth, contributing to overall crop productivity. Recent studies highlight the increasing potential of microbial consortia and bio formulations in sustainable nematode management (Khan *et al.,* 2020; Topaloviæ & Heuer, 2019).

**Integrated Pest Management (IPM)**

Integrated Pest Management (IPM) represents a holistic and sustainable approach to nematode control, combining multiple strategies to achieve effective, economically viable, and environmentally sound management. In rice ecosystems, IPM involves the integration of cultural practices such as crop rotation and water management, biological control agents, and the judicious, need-based use of safer chemical inputs. This approach emphasizes regular monitoring of nematode populations, use of resistant varieties, and adoption of site-specific interventions tailored to local agro ecological conditions. By reducing dependence on any single control method, IPM enhances system resilience, minimizes environmental impact, and delays the development of resistance in nematode populations. Increasingly, IPM is recognized as the most practical and sustainable solution for managing nematode problems in rice cultivation, particularly in developing regions where long-term productivity and ecological balance are critical (Sikora *et al.,* 2018; Coyne *et al.,* 2018).

## CONCLUSION

Plant-parasitic nematodes constitute a major yet often overlooked constraint to rice production in India, with particularly significant implications for states like Bihar where agriculture forms the backbone of rural livelihoods. The diversity of nematode species associated with paddy ecosystems, coupled with their varied biological strategies and adaptability to different agro ecological conditions, makes their management complex and challenging. Among the major species, *Meloidogyne graminicola* stands out as the most destructive, especially in upland and rainfed systems, while others such as *Hirschmanniella oryzae*, *Aphelenchoides besseyi*, and *Ditylenchus angustus* contribute to region-specific damage.

Despite early reports and scattered studies, the nematode fauna of Bihar remains inadequately documented, highlighting a critical gap in regional agricultural research. Advances in taxonomy and molecular diagnostics provide new opportunities for accurate identification and monitoring, which are essential for developing targeted management strategies. Sustainable approaches, particularly integrated pest management combining cultural practices, biological control, and minimal chemical inputs, offer the most viable pathway for long-term nematode suppression.

Future research should prioritize comprehensive surveys, molecular characterization, and the development of resistant rice cultivars tailored to local conditions. Strengthening farmer awareness, improving diagnostic infrastructure, and promoting eco-friendly management practices will be crucial for mitigating nematode-induced losses and ensuring sustainable rice production in Bihar and similar agro ecosystems.

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