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Biotechnological Approaches: A New Era in Root Knot Nematode (*Meloidogyne*) Management

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Abstract

Root-knot nematodes (RKN), belonging to the genus *Meloidogyne*, are devastating plant parasites that cause significant global agricultural crop losses. Traditional control strategies like chemical nematicides and crop rotation have limited efficacy and environmental sustainability. In recent years, biotechnological tools have emerged as promising alternatives. Techniques such as RNA interference (RNAi), host-induced gene silencing, molecular marker-assisted selection, and transgenic strategies offer novel and eco-friendly management options for plant parasitic nematodes. This article explores the mechanisms and potential applications of these biotechnological interventions, highlighting their effectiveness and future prospects in integrated pest management (IPM) systems.

Keywords: Root-knot nematode, RNA interference, transgenic plants, proteinase inhibitors, biocontrol, molecular markers

Introduction

Nematodes, derived from the Greek word “nema” meaning thread, are thread-like roundworms found in various ecosystems (Li *et al.*, 2017). Among them, plant-parasitic nematodes (PPNs), especially root-knot nematodes (*Meloidogyne* spp.), are the most economically damaging and cause annual crop losses worth billions globally (Elling, 2013). RKNs induce gall formation in plant roots by manipulating host cell physiology through the secretion of enzymatic and hormonal signals, leading to hypertrophy and hyperplasia.

Conventional management strategies, particularly chemical nematicides, often have adverse environmental and health effects. With the rise of pesticide resistance and regulatory restrictions, biotechnological interventions offer a sustainable alternative for effective nematode control.

Biotechnological Tools in RKN Management

1. RNA Interference (RNAi)

RNAi is a gene-silencing mechanism triggered by double-stranded RNA (dsRNA), leading to the degradation of specific mRNA sequences (Rahman *et al.*, 2008). This method allows targeted silencing of nematode pathogenic genes.

Mechanism:

- dsRNA is processed into small interfering RNAs (siRNAs) by the enzyme Dicer.
- These siRNAs are incorporated into RNA-induced silencing complexes (RISC), guiding the degradation of complementary mRNA in nematodes.

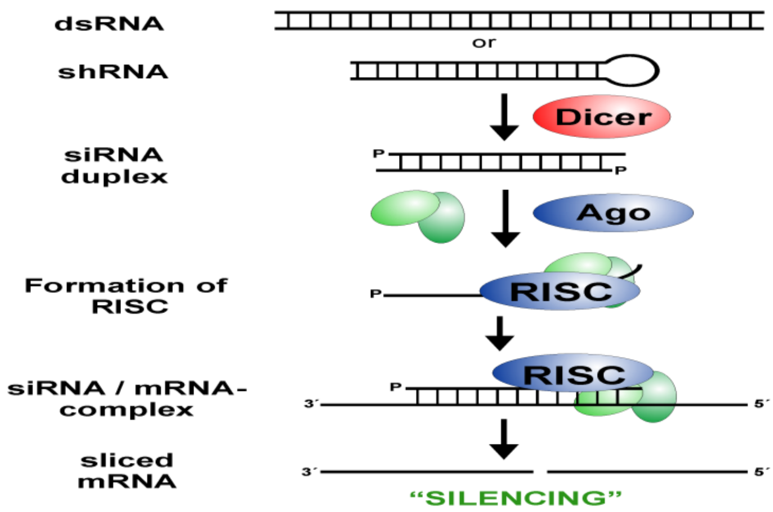

Fig: RNA interference mechanism (Goel, 2023)

Applications:

- *In vitro* soaking of nematodes in dsRNA solutions has shown temporary but significant gene silencing.
- Host-generated RNAi, where plants are engineered to produce dsRNA targeting nematode genes, offers a more stable and practical solution.

Notable Successes:

- Targeting genes like *Mi-gsts-1* and *Mi-crt* in *Meloidogyne incognita* has led to reduced transcript levels and nematode infection.

2. Host-Induced Gene Silencing (HIGS)

HIGS involves transgenic plants expressing dsRNA or siRNA targeting nematode genes. Upon feeding, the nematodes ingest these RNA molecules, leading to gene silencing.

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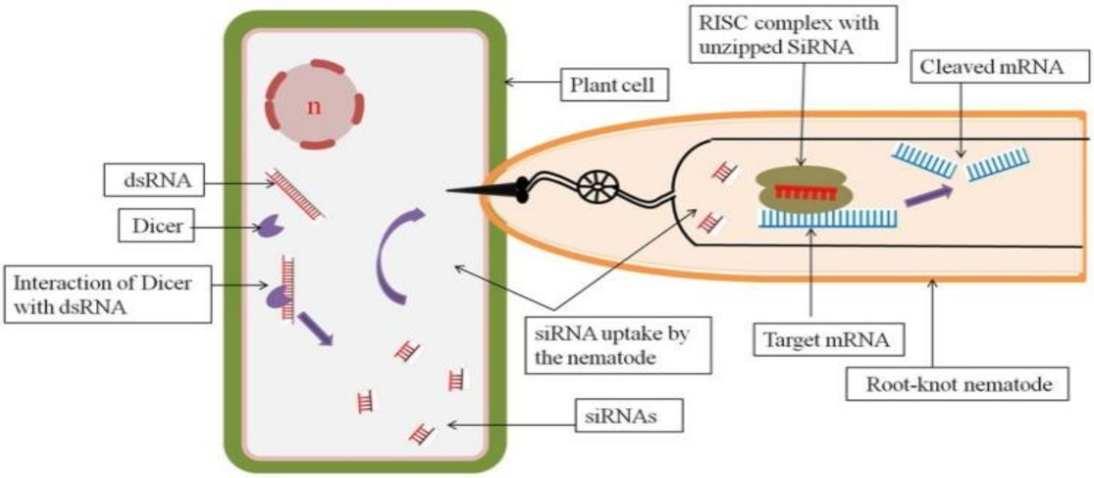

Fig: Host generated RNAi (Banerjee *et al*., 2017)

Examples:

- Transgenic tobacco expressing RNAi constructs against *integrase* and *splicing factor* genes of *M. incognita* showed over 90% reduction in nematode numbers.
- Arabidopsis expressing dsRNA against the *16D10* effector gene displayed significant reductions in gall formation.

3. Transgenic Approaches Using Resistance Genes

Some plant species possess natural resistance genes (Mi genes) effective against *Meloidogyne*. These genes trigger immune responses upon nematode attack.

Key Genes:

- Mi-1: Triggers a hypersensitive response, preventing giant cell formation.
- Mi-3 and Mi-5: Provide heat-stable resistance.

Mechanism:

- Recognition of nematode effectors activates plant immune pathways via PAMP-triggered immunity and effector-triggered immunity, resulting in localized cell death and nematode arrest.

4. Proteinase Inhibitor-Based Resistance

Proteinase inhibitors (PIs) interfere with nematode digestive enzymes. Transgenic expression of these proteins in plants can disrupt nematode development and reproduction.

Examples:

- Cystatin (Oc-IΔ86) from rice expressed in Arabidopsis reduced *M. incognita* development.

- Taro-derived CePI in tomato interfered with sex determination and gall formation.

5. Use of Nematicidal Proteins

Certain proteins possess inherent anti-nematode properties:

- **Lectins:** Bind to nematode gut glycoproteins, impairing digestion (e.g., snowdrop lectin GNA).
- **Bt Cry Proteins:** Proteins like Cry5B and Cry6A from *Bacillus thuringiensis* have nematicidal effects, disrupting nematode feeding and development.

6. Molecular Marker-Assisted Selection (MAS)

MAS accelerates the development of nematode-resistant crop varieties by identifying and tracking resistance genes using molecular markers like RAPD, AFLP, and SCAR.

Notable Applications:

- *Mi-3* gene tracking in tomato using RAPD.
- *Mj* gene mapping in cucumber with AFLP.
- Multiple resistance loci have been identified in peanut, cotton, and other crops.

Future Prospects

Biotechnology has immense potential to revolutionize nematode management. Some future directions include:

- Developing new transgenic lines with stacked resistance genes.
- Expanding RNAi targets to combat nematode resistance.
- Integrating biotechnology into IPM systems for sustainable agriculture.
- Field testing and commercial deployment of biotech solutions.

Conclusion

Biotechnological innovations provide targeted, eco-friendly, and sustainable solutions to manage root-knot nematodes. While the laboratory results are promising, real-world applications require further validation and regulatory approvals. With proper research and investment, these approaches can significantly reduce agricultural losses and dependence on chemical nematicides, ushering in a new era in nematode management.

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