



Neem Products and Essential Oils Suitable for Management of Plant-Parasitic Nematodes: A Sustainable Approach

*Ankita Senapati

M.Sc. Scholar, Department of Nematology, College of Agriculture, OUAT,
Bhubaneswar, Odisha, India – 751003

*Corresponding Author's email: ankitasenapati342@gmail.com

Plant-parasitic nematodes (PPNs) are serious soil-borne pests responsible for major crop losses in vegetables, fruits, and field crops worldwide. Excessive use of synthetic nematicides has created environmental hazards and health concerns, necessitating the development of sustainable alternatives. Neem-based products and plant-derived essential oils have emerged as effective botanical tools for nematode management due to their nematicidal, repellent, and growth-inhibitory properties. Neem derivatives such as neem cake, neem oil, and neem seed kernel extract contain bioactive compounds like azadirachtin, nimbin, and salannin that suppress nematode reproduction and survival. Essential oils extracted from plants such as eucalyptus, clove, garlic, and lemongrass exhibit strong toxicity against nematodes by disrupting their physiological and metabolic activities. These botanicals not only reduce nematode populations but also improve soil health and microbial diversity. Integration of neem products and essential oils into Integrated Nematode Management (INM) offers an eco-friendly and sustainable alternative to chemical nematicides.

Keywords: Neem products, Essential oils, Plant-parasitic nematodes, Botanical nematicides, Integrated nematode management, Sustainable agriculture

Introduction

Plant-parasitic nematodes are microscopic roundworms that attack plant roots and interfere with water and nutrient uptake, resulting in stunted growth, chlorosis, root galling, and yield losses. Among them, root-knot nematodes (*Meloidogyne* spp.), lesion nematodes (*Pratylenchus* spp.), and cyst nematodes are economically important pests affecting crop productivity worldwide. Global yield losses caused by nematodes are estimated to exceed 12–15% annually, making them a major agricultural constraint (Chitwood, 2021). Chemical nematicides have been widely used for nematode management; however, their prolonged use has led to environmental contamination, destruction of beneficial soil organisms, and increased resistance in nematode populations. Botanical nematicides derived from plant sources have gained significant attention due to their biodegradable nature, safety to non-target organisms, and compatibility with sustainable agricultural practices (Oka et al., 2022; Isman, 2020).

Neem Products in Nematode Management

Neem (*Azadirachta indica* A. Juss.) is one of the most widely studied botanical plants known for its pesticidal and medicinal properties. Various neem-based products have been successfully used for nematode control.

Neem Cake

Neem cake is the residual material obtained after oil extraction from neem seeds and is widely used as an organic soil amendment. During decomposition, neem cake releases toxic compounds that suppress nematode populations. It also enhances soil organic matter,

improves microbial activity, and increases plant resistance against nematode infection. Application of neem cake has shown significant reduction in root-knot nematode infestation in crops such as tomato, brinjal, and okra (Akhtar & Malik, 2020).

Neem Oil

Neem oil contains several bioactive compounds, particularly azadirachtin, which interferes with nematode feeding behavior, growth, and reproduction. Soil treatment and seed treatment with neem oil reduce egg hatching and juvenile survival of nematodes while improving plant vigor (Rani et al., 2024).

Neem Seed Kernel Extract (NSKE)

Neem seed kernel extract is prepared by crushing neem seeds and extracting active compounds using water or organic solvents. NSKE has been reported to inhibit nematode egg hatching, reduce larval mobility, and suppress nematode multiplication in soil (Chitwood, 2021).

Mode of Action of Neem Products

Neem-based products control nematodes through multiple mechanisms including inhibition of egg hatching, repellent action, interference with nematode growth and reproduction, induction of plant defense mechanisms, and enhancement of beneficial soil microorganisms (Isman, 2020; Rani et al., 2024).

Essential Oils in Nematode Management

Essential oils are volatile plant extracts rich in secondary metabolites such as terpenoids, phenolics, and aldehydes. These compounds possess strong nematicidal properties and have been widely investigated for sustainable nematode control.

Eucalyptus Oil

Eucalyptus oil contains eucalyptol, which exhibits toxic and repellent effects against root-knot nematodes. Soil application of eucalyptus oil reduces nematode population density and root gall formation (Oka et al., 2022).

Clove Oil

Clove oil contains eugenol, a powerful phenolic compound that disrupts nematode nervous systems and metabolic pathways. It significantly reduces nematode reproduction and survival (Singh et al., 2023).

Garlic Oil

Garlic oil contains sulfur-containing compounds such as allicin, which exhibit strong nematicidal activity by inhibiting egg hatching and juvenile mobility.

Lemongrass and Citronella Oils

These oils contain citral and citronellal, which act as strong repellents and toxins against nematodes. Their soil application has shown promising results in reducing nematode infestation (Oka et al., 2022).

Advantages of Botanical Nematicides

Neem products and essential oils provide several advantages over chemical nematicides. They are environmentally safe, biodegradable, and exhibit low toxicity to humans and beneficial organisms. They also improve soil fertility and microbial diversity while reducing pesticide residues and enhancing compatibility with biological control agents.

Role in Integrated Nematode Management

Botanical nematicides play a crucial role in Integrated Nematode Management systems. Neem products and essential oils can be combined with crop rotation, organic amendments, resistant crop varieties, and biological control agents such as *Trichoderma* spp. and *Purpureocillium lilacinum*. Integration of these practices enhances nematode suppression, improves plant growth, and promotes sustainable agriculture (Singh et al., 2023; Rani et al., 2024).

Conclusion

Neem-based products and plant essential oils have emerged as effective, eco-friendly, and sustainable alternatives for managing plant-parasitic nematodes. Their multi-target mode of action, environmental safety, and soil health improvement make them valuable components of integrated nematode management strategies. Increased farmer awareness and further research on formulation and application techniques will enhance the large-scale adoption of botanical nematicides in modern agriculture .

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