Integrated Management of *Meloidogyne incognita*: A Review of Biocontrol Agents and Organic Amendments

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Abstract - The agricultural crops across the globe are under a significant threat from Meloidogyne, which is a genus of root-knot nematodes. The present analysis centres on the comprehensive management of Meloidogyne incognita. The present study assesses the efficacy of biocontrol agents and organic amendments in mitigating nematode populations. Several biological control agents, such as nematophagous fungi (e.g. Pochonia chlamydosporia) and filamentous fungi (e.g. Syncephalastrum racemosum), as well as bacterial agents (e.g. Bacillus and Pseudomonas species), have exhibited potential in mitigating nematode infestation. Bioagents utilize various mechanisms including antibiosis, competition, mycoparasitism, and induction of plant resistance. In addition, the utilization of organic amendments can aid in the reduction of nematode infestation and improvement of plant growth by means of their nematotoxic characteristics and facilitation of advantageous microorganisms. The process of decomposing organic amendments results in the release of substances that impede the penetration of nematodes and hinder their infective activity. Furthermore, these amendments promote the proliferation of microorganisms that exhibit antagonistic behaviour towards nematodes, thereby hindering their reproduction. Organic amendments present a promising strategy for controlling Meloidogyne incognita through the improvement of soil properties, release of nematotoxic substances, and enhancement of plant resistance. Additional investigation is required to enhance the efficacy of organic amendments in the context of nematode management approaches, and to evaluate their enduring impacts on soil well-being and sustainability.

Keywords - Meloidogyne incognita, control, Biocontrol agents, Organic amendments.

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INTRODUCTION

Reduced crop yield is a major agricultural concern due to the susceptibility of vegetables to pathogen-induced illnesses. Exposure to microorganisms, which thrive in favourable climatic conditions, can significantly increase one's susceptibility to disease. The presence of plant-parasitic nematodes is one of the many difficulties associated with growing vegetables. Parasites and other insects present additional challenges in this area. Vegetable crops of all kinds are at risk from these nematodes because of how susceptible they become to infestation and how much their output decreases as a result.

Meloidogyne, a genus of phytonematodes, is considered to be a highly destructive and significant group in the field of agriculture. Specifically, the root-knot nematodes fall under this classification. The aforementioned nematodes are classified as sedentary obligate endoparasites, and have the ability to infect a vast majority of higher plant species. Whilst their distribution is global, their prevalence is highest in regions characterised by tropical or subtropical climates. Production losses caused by nematodes are typically greater in developing countries in these locations than in industrialised countries. For instance, research has found that in tropical and subtropical regions, developing countries experienced 14.6% larger production losses from nematodes compared to losses in industrialised countries (8.8%). This demonstrates the substantial monetary influence that nematodes have on agricultural systems. Major phytonematodes cause significant economic losses, especially in India. It is estimated that these nematodes cause a yearly loss of Rs. 242.1 billion in agricultural value in India (Jain et al., 2007). The root-gall nematodes of the genus *Meloidogyne* are the most common and damaging species of phytonematodes found in agricultural settings.

The genus *Meloidogyne* comprises approximately one hundred distinct species worldwide, as reported by Elling in 2013. The majority of instances, specifically over 95 percent, are attributed to the species *M. incognita, M. arenaria, M. javanica, M. chitwoodi, M. hapla,* and *M. fallax*. These particular species possess the most extensive range and are prevalent in numerous locations. According to Khan et al. (2014), a total of fourteen discrete species of root-knot nematodes have been identified in India. *M. javanica* and *M. incognita* are the most frequently encountered species and exhibit the most extensive range throughout the country. The species *M. hapla* is exclusively distributed in regions characterised by temperate mountainous terrain.

These organisms frequently engage in reproduction and feeding activities within the plant roots, leading to the development of root galls and knots that can vary in size from minuscule to substantial. The gelatinous egg sacs that encapsulate the eggs of the root-knot nematode are observable on the surface of galled roots. The egg sacs are discernible to the unaided eye. Occasionally, they are detected within the root galls. Following embryogenesis, the egg undergoes its initial ecdysis, leading to the emergence of the second-stage juvenile (J2). The hatching of *Meloidogyne spp.* eggs is contingent upon temperature, and it is not reliant upon any form of stimulation from plant roots. Conversely, it is possible for eggs to hatch due to root diffusates on certain occasions. In certain instances, the age of the host plant may serve as a determining factor in the necessity of a hatching stimulus emanating from stated plant.

The purpose of this review paper is to synthesise the research on the integrated control of *Meloidogyne incognita*. It will investigate the effectiveness of biocontrol agents and organic materials in reducing nematode populations and protecting crops.

BIOLOGICAL CONTROL AGENTS FOR *M. INCOGNITA*

Biological control, which employs non-toxic methods, is increasingly being seen as a practical method for dealing with a variety of phytopathogens, such as plant-parasitic nematodes. Many phytopathogens can be managed with the help of biological control (Zhang et al., 2016; Aballay et al., 2011). Nematode illnesses can be efficiently reduced by using bioagents for their antagonistic potential in a number of ways. Antibiosis, competition, mycoparasitism, cell membrane breakdown, inductive resistance, plant growth promotion, and rhizosphere colonisation capacity are all examples of such mechanisms. Predatory nematodes, nematophagous fungus, nematophagous bacteria, mites, plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), and arbuscular mycorrhizal fungi (AMF) are also possible sources for these bioagents (Askary & Martinelli, 2015).

➢ Nematophagus Fungus as Biocontrol Agent

Pochonia chlamydosporia var. chlamydosporia, a nematophagous fungus, has been studied as a possible biological control agent for *Globodera, Heterodera, Meloidogyne, Nacobbus*, and *Rotylenchulus,* all of which are phytoparasitic nematodes (Manzanilla-Lopez et al., 2013). The nematode-parasitic fungus *P. chlamydosporia* (Goddard) Zare and Gams is well-known and found all over the world.

The presence of a large number of dictyochlamydospores, the development of the conidia in chains or heads, and the conidial position and form can all be used to identify a *P. chlamydosporia* population (Zare and Gams, 2004). It is a common parasite in the wild, feeding on phytoparasitic nematode females, cysts, and eggs (Manzanilla-Lopez et al., 2013; Lopez-Llorca et al., 2008). If neither the plant nor the nematode is present, this fungus can survive as a saprophyte in the soil. Endophytic colonisation of host plant roots inside the rhizosphere by this fungus provides numerous benefits to the host plant in the form of resistance to soil-borne pests (Maciá-Vicente et al., 2009a, b). *P. chlamydia*'s biocontrol ability against phytoparasitic nematodes has been the subject of extensive study (Kerry and Hirsch, 2011; Manzanilla-Lopez et al., 2013). To accomplish this, it promotes aspersoria at the fungal hyphae's lateral tip, which causes the hyphae to strongly adhere to the eggshell's surface and, ultimately, to pierce the eggshell via an infection peg. This procedure results in the infection of nematode eggs (Holland et al., 1999). Mycelia expand inside nematode eggs after an infection, killing off the nematode and its offspring (Esteves et al., 2009a; Tikhonov et al., 2002). Eggshell and juvenile cuticle breakdown has been linked to *P. chlamydosporia*'s enzymatic activity and released toxic compounds (Khan et al., 2004). Significant structural changes, such as the breakdown of lipid and vitelline layers, occur within nematode eggs as a result of *P. chlamydosporia* production of serine, protease, and chitinase. *P. chlamydosporia* produces these three enzymes. All of these characteristics make *P. chlamydia* a powerful bio agent (Esteves et al., 2009b; Rumbos et al., 2006; Van Damme et al., 2005).

➢ Filamentous Fungus as Biocontrol Agent

When used as a biological control agent, the filamentous fungus *Syncephalastrum racemosum* has been found to be effective against a variety of phytoparasitic nematodes (Sun et al., 1999, 2008). Root-knot nematode populations have been shown to diminish when *S. racemosum* is present in the soil and on plant roots (Sun et al., 2008; Huang et al., 2014). The reduction in nematode infestation caused by the application of *S. racemosum* has been attributed to either direct parasitism of nematodes by

S. racemosum or the release of secondary metabolites in the soil (Sahebani and Hadavi, 2008; Hashem and Abo-Elyousr, 2011). Greenhouse studies showed that *S. racemosum* significantly decreased nematode multiplication rates in the soil and the root-gall index in cucumber by 94.7 and 53.5%, respectively (Sun et al., 2005).

- **Bacterial Agents and their effectiveness against *M. incognita***

Additionally, many bacterial spore treatments were tested for their efficacy against phytoparasitic nematodes. Among the many varieties of bacteria utilised as bioagents in the fight against nematodes, *Bacillus* and *Pseudomonas* species are among the most common. *Bacillus* spp., when exposed to adverse conditions, can spread to form enormous, irregularly shaped colonies that range in colour from grey to white and are covered in endospores (Dawar et al., 2008). Biocontrol of *Meloidogyne* spp has been linked to the release of lytic enzymes, cyclic lipopeptides, and other secondary metabolites from *Bacillus* spp (Grey et al., 2006; Lanna Filho et al., 2010; Machado et al., 2012). *Bacillus cereus* may produce several different types of lytic enzymes, such as chitinase and glucanase (Csuzi 1978). Wepuhkhulu et al. (2011) found that these lytic enzymes are toxic to *M. javanica. Bacillus subtilis*' cyclic peptides surfactin and iturin were more effective at preventing *M. incognita* egg hatching and played a significant role in increasing the percentage of juveniles who perished (Kavitha et al., 2012). The density of nematodes and the number of galls were both decreased with the application of *B. subtilis* (Prakob et al., 2009). Certain strains of *Bacillus subtilis* have been demonstrated to have an influence on the proliferation of root-knot nematodes in a variety of agricultural crops (Abbasi et al., 2017; Hussain et al., 2020; Bavaresco et al., 2021). Rao et al. (2014) discovered that *B. subtilis* effectively suppressed *M. incognita* development in okra crops, which had a beneficial influence on yields overall. *Bacillus subtilis* forms protective biofilms around plant roots, which may fend off parasitic microorganisms like fungi and nematodes. Moreover, the plant's systemic resistance, which develops in response to *B. subtilis*, and the release of antimicrobial compounds contribute to this defense (Vlamakis et al., 2013).

The rhizosphere is mostly inhabited by aerobic endospore-forming bacteria, the vast majority of which are members of the genus *Pseudomonas*. Parasitic nematodes on plants can be fought off by these bacteria (Tian et al., 2007). There are rhizobacteria that are known to suppress worm populations, such as *Pseudomonas fluorescens. P. fluorescens* kills phytoparasitic nematodes by inducing systemic resistance in the plant hosts and by stimulating the production of antinemic secondary metabolites like pyoluteorin, 2,4-diacetylphloroglucinol, phenazines, hydrogen cyanide, and pyrrolnitrin. *P. fluorescens* has the capability to do this (Defago et al., 1990; Siddiqui and Shaukat, 2003; Trivedi and Malhotra, 2013).

ORGANIC AMENDMENTS FOR *M. INCOGNITA* MANAGEMENT

The utilisation of organic amendments has demonstrated significant potential in the management of *Meloidogyne incognita* through the modification of soil properties, stimulation of plant growth, and enhancement of nematode resistance. According to Oka (2010), the utilisation of organic amendments has been discovered to augment disease suppression through the enhancement of soil's physical, chemical, and biological characteristics, which ultimately leads to the promotion of plant resilience.

The nematotoxic capacity of organic amendments can be ascribed to multiple factors, such as the rise in facultative parasites caused by the organic matter content (Oka and Yermiyahu, 2002; Oka et al., 2007). Throughout the process of decomposition, organic amendments, such as agricultural wastes and plant leftovers, discharge various chemicals and by-products, including N2 and organic acids. These substances have been found to possess antimicrobial properties (Oka, 2010; Thoden et al., 2011). The organic amendments have the potential to release certain substances that can impede the proliferation and functionality of nematodes that are parasitic to plants.

Apart from exhibiting nematotoxic properties, organic amendments have the potential to enhance the occurrence of advantageous free-living nematodes and other crucial microorganisms in the rhizosphere, which can act as antagonists against plant-parasitic nematodes (Renco and Kovacik, 2012). The aforementioned practise has the potential to positively impact the rhizosphere ecosystem by mitigating nematode infestation and promoting plant well-being.

The use of organic amendments has been shown to reduce the prevalence of root-knot nematode infestation and boost plant development in numerous studies. According to Khan et al. (2016), the utilisation of sugarcane press mud has been observed to have a positive impact on the growth of plants and a reduction in the incidence of root gall disease. Studies also have demonstrated that the utilisation of organic amendments sourced from botanicals or weed plants can effectively mitigate the intensity of root-knot disease and foster plant growth, as evidenced by research conducted by Khan et al. (2019) and Hasan et al. (2021).

The process of organic matter decomposition results in the release of harmful substances that obstruct the ability of nematodes to penetrate the roots of host plants and hinder their infective activity, as noted by Oka (2010) and Thoden et al. (2011). In addition, the incorporation of organic amendments has been found to elicit a stimulatory effect on microorganisms that are pathogenic to nematodes, thereby impeding their growth and propagation (Linford et al., 1938; Stirling, 1991; Wang et al., 2002). Furthermore, the discharge of carbon dioxide by saprophytic organisms, which is triggered by organic matter, can potentially diminish the proliferation of pathogens (Papavizas and Davey, 1992).

The organic amendments present a potentially advantageous approach for the control of *Meloidogyne incognita*. Soil amendments have been found to enhance soil properties, release nematotoxic substances, promote beneficial microorganisms, and improve plant resistance. Consequently, these amendments have the potential to reduce nematode infestation and support healthier plant growth. Additional investigation is required to examine and enhance the utilisation of organic amendments in nematode control tactics and their enduring impacts on soil well-being and durability.

CONCLUSION

To sum up, *Meloidogyne incognita*, a type of nematode that causes root-knot, presents a considerable menace to agricultural produce on a global scale. The implementation of integrated management strategies that involve the use of biocontrol agents and organic amendments has exhibited potential in mitigating nematode populations and safeguarding crops. The present study conducted a thorough evaluation of the efficacy of diverse biocontrol agents, encompassing nematophagous fungi, filamentous fungi, and bacteria, for the purpose of mitigating the impact of M. incognita. Furthermore, the application of organic amendments has exhibited promising results in augmenting soil characteristics, stimulating plant development, and ameliorating nematode resilience. The mitigation of nematode infestation is facilitated by the discharge of nematotoxic agents and the stimulation of advantageous microorganisms. Nevertheless, additional investigation is required to enhance the implementation of these amalgamated management methodologies and assess their enduring impacts on soil well-being and durability. The implementation of biocontrol agents and organic amendments in nematode management practises can facilitate the adoption of sustainable and eco-friendly strategies by farmers to counteract the effects of *M. incognita* and ensure the protection of crop yields.

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