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4. Root-Knot Disease Complex in Vegetable Plant: An Interaction Perspective with Other Microorganisms

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Abstract:

The production of horticulture has showed potential improvement over the past few decades in natural and protected cultivation. In horticulture crop cultivation, especially in vegetable crops root knot nematode Meloidogyne incognita is an emerging problem. Through the creation of many root galls on host plants, this nematode can induce chlorosis, stunting and reduces yields. By generating specialized feeding cells, or large cells in vascular tissue, the root-knot nematode severely damages the root system of the plant. In order to combat root knot nematodes, integrated nematode management strategies have been developed and have been used with success in past. These strategies include soil solarisation, biological control, organic amendment, crop rotation, field sanitation and fumigants. This chapter, we discuss biology, the life cycle of root-knot nematode species, control measures and suggested future plans to enhance Meloidogyne incognita management. Also, will discuss biotic and abiotic factors influencing the interaction between phytophagous nematodes and soilborne disease, along with the processes underlying these interactions.

Keywords:

Root-knot nematode, Meloidogyne incognita, Integrated Disease Management (IDM), nematode-microorganism's interactions

4.1 Introduction:

Root knot nematodes are microscopic, soil-dwelling roundworms that belong to the family Meloidogyne. They are considered to be one of the most damaging plant parasitic nematodes worldwide. These parasites are widely distributed in temperate and tropical regions, and they infect a broad range of plant species, including both monocotyledons and dicotyledons. The name "root knot" comes from the characteristic galls or knots that form on the roots of infected plants, which can result in stunted growth, reduced yield, and in severe cases, plant death. The ability of root knot nematodes to cause significant damage to crops has led to extensive research efforts aimed at developing effective management strategies for these pests. The extent of yield loss due to root-knot nematodes varies depending on the crop, nematode species, and severity of infestation. For instance, in tomato crops, root-knot nematodes can cause yield losses of up to 60%, as reported by Davies et al. (2011). Similarly, in carrot crops, yield losses of up to 40% have been reported (Brito et al., 2012), whereas in cucumber crops, root-knot nematodes can cause yield losses of up to 50% (Sánchez-Moreno et al., 2014). In eggplant crops, yield losses of up to 90% have been reported (Sikora et al., 2018), and in pepper crops, root-knot nematodes can cause yield losses of up to 70% (Aelami et al., 2016). Root-knot nematodes (Meloidogyne spp.) often form a disease complex with various microorganisms such as fungi, bacteria, and viruses, leading to even more severe damage to plants (Sikora et al., 2004). Fusarium wilt, caused by the fungus *Fusarium oxysporum*, is a common disease that frequently accompanies root-knot nematode infestations (Jatala and Kalburtji, 1987). This is because nematodes damage the root system, allowing the fungus to easily infect the plant (Sikora et al., 2004). Similarly, bacterial wilt, caused by the bacterium *Ralstonia solanacearum*, can also occur in plants that have been weakened by root-knot nematodes (Sikora et al., 2004). Additionally, certain viruses can infect plants that have been damaged by nematodes, resulting in stunted growth and reduced yields (Sikora et al., 2004). For example, tomato spotted wilt virus (TSWV) and Tobacco ringspot virus (TRSV) have been reported to infect plants that have been damaged by root-knot nematodes (Sikora et al., 2004). Therefore, it is important to consider the disease complex that can arise from root-knot nematode infestations when developing management strategies for controlling these pests. Integrated pest management (IPM) strategies that combine cultural, biological, and chemical control methods can effectively manage root-knot nematode populations and reduce the occurrence of disease complexes (Sikora et al., 2004).

4.2 Nematodes and Their Role in Complex Diseases:

Root-knot nematodes (RKNs) are known to be important plant parasitic nematodes that cause significant damage to a wide range of vegetable crops worldwide. Recent research has shown that RKNs can also play a role in the development of complex diseases in vegetable crops. For example, in tomatoes, infection with RKNs has been linked to an increased incidence of bacterial wilt caused by the pathogen *Ralstonia solanacearum* (Fatima *et al.,* 2021). This is thought to be due to the nematode's ability to alter the plant's root system, which can make it more susceptible to other pathogens. Similarly, in sweet potatoes, RKNs have been shown to increase the severity of the fungal disease black rot caused by *Ceratocystis fimbriata*. This is thought to be due to the nematode's ability to alter the plant's physiology and reduce its defense mechanisms against other pathogens (Souza et al., 2020). Overall, RKNs can have a significant impact on the health and productivity of vegetable crops, and their role in the development of complex diseases highlights the importance of effective management strategies to control their populations. These strategies may include the use of crop rotation, resistant varieties, and biological control agents (Barros et al., 2021).

The pathogenesis of complex diseases caused by root-knot nematodes (RKNs) involves a multifaceted interaction between the nematode, the plant, and other pathogens. Upon infection, RKNs penetrate the plant roots and establish a feeding site, known as a giant cell, where they feed and reproduce (Abad et al., 2008). The feeding activity of RKNs can lead to the formation of galls, which can interfere with the normal functioning of the root system and reduce the plant's ability to absorb nutrients and water (Jones et al., 2013). In addition to the direct damage caused by RKN feeding, these nematodes can also alter the plant's physiology and immune response, making it more susceptible to other pathogens. For example, RKNs have been shown to suppress the expression of plant defense genes and induce the expression of genes associated with stress responses and cell wall modifications (Mitchum*et al*., 2013). These changes can create a more favorable environment for other pathogens to establish and cause disease. Furthermore, RKNs can interact with other soilborne pathogens and influence their pathogenicity. For instance, RKNs have been shown to increase the severity of bacterial wilt caused by Ralstonia solanacearum in tomatoes (Fatima et al., 2021). The feeding activity of RKNs can weaken the plant's immune response and alter its root system, creating entry points for the bacteria to infect and spread.

4.3 Fungal Interaction with Nematodes:

Plant-parasitic nematodes, including root-knot nematodes, can cause significant damage to crops by feeding on plant roots, leading to reduced growth, yield, and quality. In some cases, nematodes can interact with soil-borne fungi to cause complex diseases that are even more damaging to crops. The interaction between root-knot nematodes and various fungi, including Fusarium oxysporum, Macrophominaphaseolina, Verticillium dahliae, and Pythium aphanidermatum, can result in diseases such as Fusarium wilt complex, Macrophomina root rot complex, Verticillium wilt complex, and Pythium root rot complex, respectively.

In the case of Fusarium wilt complex, root-knot nematodes damage the roots, creating entry points for the soil-borne fungus Fusarium oxysporum to colonize and block the xylem vessels of the plant, leading to wilting and eventual death. Similarly, in Macrophomina root rot complex, the nematodes damage the roots, creating entry points for the fungus Macrophomina phaseolina to colonize and cause rotting of the roots and lower stem. The interaction between root-knot nematodes and Verticillium dahliae in Verticillium wilt complex also results in wilting and death of the plant, as the fungus colonizes and blocks the xylem vessels of the plant. In Pythium root rot complex, the nematodes damage the roots, allowing the fungus Pythium aphanidermatum to colonize and cause rotting of the roots and lower stem.

4.4 Interaction Between Root Knot Nematode and *Fusarium*spp:

Fusarium species are soil-borne fungal pathogens that cause wilt, root rot, and other diseases in various vegetable crops. The interaction between Fusarium and root-knot nematodes (Meloidogyne spp.) can exacerbate the disease symptoms in plants. Root-knot nematodes create feeding sites in the roots of plants that can serve as entry points for Fusarium infection. *Fusarium oxysporum* has been found to interact with root-knot nematodes and exacerbate Fusarium wilt disease symptoms in tomato plants (Li et al., 2021). In addition, a study by Zhang et al. (2018) found that root-knot nematode infection can enhance the virulence of *Fusarium oxysporum* in watermelon plants. The interaction between Fusarium and root-knot nematodes can also affect plant defense responses. A study by Zhang et al. (2019) found that the presence of root-knot nematodes can reduce the expression of defense-related genes in tomato plants infected with *Fusarium oxysporum*. Root-knot nematodes induce the formation of specialized feeding sites, known as giant cells, within the roots of their host plants. These sites are also targeted by other plant pathogens, such as *Fusarium* spp., which cause severe root rot and wilt diseases. The interaction between RKNs and *Fusarium* spp. involves multiple molecular signaling pathways in both the plant and the pathogens, making it a complex process. Research has revealed that RKNs affect plant defense responses to Fusarium spp. infection through several pathways. One important pathway involves the plant hormone jasmonic acid (JA), which plays a key role in the defense against herbivores and necrotrophic pathogens like Fusarium spp. RKNs have been shown to suppress JA signaling in infected plants, which can enhance their susceptibility to Fusarium spp. infection (Ali et al., 2019).

Another pathway involves the plant hormone salicylic acid (SA), which is essential for defense against biotrophic pathogens like RKNs. RKNs have been found to induce SA signaling in infected plants, which can interfere with JA signaling and increase their susceptibility to Fusarium spp. infection (Castañeda et al., 2018). Moreover, RKNs can modulate the expression of genes involved in plant defense responses to Fusarium spp. infection. For instance, RKNs have been shown to downregulate the expression of genes involved in lignin biosynthesis, which can make the plant cell walls more vulnerable to degradation by Fusarium spp. (Kumar et al., 2021).

4.5 Interaction with *Rhizoctonia solani*:

The interaction between RKNs and *Rhizoctonia solani* involves multiple mechanisms. RKNs enhance the severity of *Rhizoctonia solani* infection in vegetable crops by altering the plant root architecture and physiology. RKNs induce the formation of galls or root knots, which provide a favorable environment for the growth and proliferation of *Rhizoctonia solani* (Zhang et al., 2018). Moreover, RKNs can suppress plant defense responses against *Rhizoctonia solani* infection. RKNs have been found to suppress the production of plant hormones, such as jasmonic acid (JA), which play a key role in plant defense against necrotrophic pathogens like Rhizoctonia solani. RKNs can also induce the production of plant hormones, such as auxins, which promote the growth and development of Rhizoctonia solani (Liu et al., 2019). Furthermore, RKNs can alter the expression of genes involved in plant defense responses against *Rhizoctonia solani* infection. For example, RKNs have been shown to downregulate the expression of genes involved in lignin biosynthesis, which can make the plant cell walls more susceptible to degradation by *Rhizoctonia solani* (Kumar et al., 2021). Managing the interaction between Fusarium and root-knot nematodes in vegetable crops requires an integrated approach that considers both pathogens.

Crop rotation, use of resistant cultivars, and application of biological control agents have been suggested as potential strategies for managing both Fusarium and root-knot nematode infections in vegetable crops.

4.6 Bacterial Interaction:

Root knot nematode (RKN) disease is a widespread issue in vegetable production, caused by parasitic nematodes of the genus Meloidogyne. These nematodes infect plant roots and induce the formation of galls or knots, which can restrict the uptake of water and nutrients, leading to stunted growth and reduced yields (Sasser and Freckman, 1987). RKN, bacterial pathogens also cause significant losses in vegetable crops by inducing diseases such as bacterial wilt, soft rot, and leaf spot (Hirano and Upper, 2000). When bacterial pathogens infect plants that are already weakened by RKN infestation, it can lead to a complex disease situation that is difficult to manage (Chellemi et al., 2001). Combination of RKN *Meloidogyneincognita* and the bacterial pathogen *Ralstonia solanacearum* can cause severe damage to tomato crops. *M. incognita* can cause significant damage to the tomato roots, while R. solanacearum causes bacterial wilt, a devastating disease that can cause complete crop loss (Buddenhagen and Kelman, 1964; Chellemi et al., 2001).

When both pathogens are present, they can synergistically affect plant growth and lead to even greater yield losses (Chellemi et al., 2001). Management of RKN disease complex with bacteria in vegetable crops involves an integrated approach, including cultural practices, such as crop rotation, sanitation, and soil management, as well as chemical control measures (Hirano and Upper, 2000). It is crucial to use a combination of strategies as relying solely on one method may not be effective. Additionally, the use of resistant cultivars may be effective in reducing the impact of RKN and bacterial pathogens in vegetable crops (Chellemi et al., 2001).

4.7 *Bacillussubtilis* and Root Knot Nematode:

The interaction between root knot nematodes (RKNs) and *Bacillus subtilis* in vegetable crops has been the subject of numerous studies in recent years. Root knot nematodes are known to cause significant damage to vegetable crops by feeding on the plant roots, which can lead to reduced nutrient uptake and stunted growth. On the other hand, Bacillus subtilis is a beneficial microorganism that can colonize the plant roots and provide protection against pathogens through the production of antimicrobial compounds and stimulation of plant defense responses. Several studies have investigated the potential of Bacillus subtilis in suppressing the population of RKNs in the soil and reducing the incidence of root knot disease in vegetable crops. For example, a study by Kumar et al. (2012) found that the application of Bacillus subtilis significantly reduced the number of galls caused by RKNs and increased plant growth in tomato plants compared to non-treated plants. Similarly, a study by Karimi et al. (2018) showed that the application of *Bacillus subtilis* to cucumber plants reduced the severity of root knot disease and improved plant growth compared to non-treated plants. The mode of action of Bacillus subtilis in suppressing RKNs is not fully understood, but several studies have suggested that it involves the production of secondary metabolites and extracellular enzymes that can degrade the nematode cuticle and inhibit nematode egg hatching. For example, a study by Zhang et al. (2017) found that Bacillus subtilis produced extracellular proteases that could degrade the cuticle of RKNs and inhibit nematode egg hatching. Interaction between RKNs and Bacillus subtilis in vegetable crops can have both positive and negative effects on plant growth and disease development. The application of Bacillus subtilis can suppress the population of RKNs in the soil and reduce the incidence of root knot disease in vegetable crops, but the mode of action of Bacillus subtilis in suppressing RKNs is not fully understood. Further research is needed to elucidate the mechanisms involved in this interaction and develop more effective strategies for managing root knot disease in vegetable crops.

4.8 Interaction with Pseudomonas fluorescens:

Although *Pseudomonas fluorescens* has been shown to have a beneficial effect on the growth and health of vegetable crops, some studies have suggested that its interaction with root knot nematodes (RKN) may be complex and not always positive. For example, one study reported that co-inoculation of *P. fluorescens* and RKN on eggplant plants resulted in increased gall formation and nematode population compared to plants inoculated with RKN alone (1). This may be due to the ability of P. fluorescens to stimulate root growth, providing more sites for nematode infection. Another study showed that the application of P. fluorescens to tomato plants infected with RKN and the fungus *Fusarium oxysporum* resulted in reduced plant growth and yield compared to plants treated with RKN and *F. oxysporum*alone (2). The researchers suggested that *P. fluorescens* may have interfered with the plant's defense mechanisms against the nematode and the fungus. *P. fluorescens* has been shown to have a positive effect on the growth and health of vegetable crops, its interaction with root knot nematodes may be complex and context-dependent. Further studies are needed to fully understand the mechanisms underlying this interaction and to optimize the application *of P. fluorescens* in agricultural practices.

4.9 Interaction with Plant Virus:

Meloidogyne is a genus of parasitic nematodes that commonly infect the roots of plants, causing significant damage to crops. The interaction between Meloidogyne and plant viruses is complex and can have varying effects on the host plant.

One possible scenario is that *Meloidogyne* infection can increase the susceptibility of the host plant to viral infection. This is because the nematode can alter the root structure and physiology of the plant, making it more susceptible to viral infection. In addition, Meloidogyne can also suppress the host plant's immune system, further weakening its ability to resist viral infection (Alam et al., 1990).

On the other hand, there are also reports that suggest that the presence of plant viruses can actually reduce the damage caused by Meloidogyne infection. This is because some viruses can induce systemic acquired resistance (SAR) in the host plant, which can enhance the plant's defense mechanisms against nematode infection. Overall, the interaction between Meloidogyne and plant viruses can be complex and highly dependent on various factors such as the specific nematode and virus species, as well as the host plant.

There is limited research on the specific interaction between Meloidogyne and cucumber mosaic virus (CMV). However, some studies have investigated the effect of CMV on plant-parasitic nematodes in general, and the results suggest that the interaction can be complex and depend on various factors. One study found that CMV infection in tomato plants can suppress the reproduction of the root-knot nematode, which is another species of plant-parasitic nematode similar to Meloidogyne. The researchers proposed that this may be due to the induction of systemic acquired resistance (SAR) in the host plant, which can enhance the plant's defense mechanisms against nematode infection. However, another study found that the reproduction and damage caused by the root-lesion nematode in pea plants was actually increased in the presence of CMV. The researchers suggested that this may be due to the suppression of the host plant's immune response by the virus, which can also make it more susceptible to nematode infection (Senesi et al.,2022).

Therefore, it is difficult to predict the exact nature of the interaction between Meloidogyne and CMV without further research. The interaction may vary depending on the specific nematode and virus strains, as well as the host plant.

4.10 Conclusion:

Understanding the interactions between Meloidogyne, or root-knot nematodes, and microorganisms is important for several reasons. Meloidogyne can cause significant damage to plant roots, leading to reduced growth and yield. Understanding how microorganisms can affect Meloidogyne populations and plant health can help identify potential strategies for controlling these nematodes.

Meloidogyne can be managed through the use of chemical nematicides, but these can have negative impacts on the environment and human health. Developing sustainable, non-chemical methods for controlling Meloidogyne, such as through the use of beneficial microorganisms, can help reduce the reliance on chemical inputs.

The interactions between Meloidogyne and microorganisms can also affect soil health. For example, the use of certain microorganisms can enhance soil fertility and structure, which can benefit both plant growth and overall soil health. Future research: Understanding the interactions between Meloidogyne and microorganisms can also inform future research on nematode biology and ecology. This can help identify new targets for nematode control and provide insights into the broader functioning of soil ecosystems.

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