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Biology, Symptomatology and Cultural Management of Root-Knot Nematodes (Meloidogyne spp) associated with Tomato

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Abstract

Root-knot nematodes (Meloidogyne spp.) are among the most important biotic constrains to tomato production in Kenya and the rest of the world. The main species of root-knot nematodes associated with tomato are M. incognita, M. hapla and M. javanica. The presence of Root-knot nematodes in tomato fields remains a major problem due to their potential to cause huge agriculture losses. This review provides a concise discussion of their reproduction, adaptation to survival, mechanism of infestation, distinct symptomatic manifestations on tomato crop and easy-to-apply cultural management options which are affordable and environmentally safe to smallholder resource poor tomato farmers.

Keywords: Biology; Management; Meloidogyne Spp; Symptomatology; Tomato

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Introduction

Many pests significantly contribute to poor yields of tomato in terms of quality and quantity. Key among them are the plant parasitic nematodes. Due to their devastation of tomato [1], and a wide alternative host-range, this category of nematodes is a major setback to the delivery of global food security. On a global scale, nematodes of the Meloidogyne spp remain the most widespread and economically devastating plant-parasitic nematodes that attack tomato [2].

Root knot nematodes have a vast host range; thus, limiting growers' options for crop rotation. Reports indicate that an average of 10% reduction in yield is attributed to root knot nematodes [3], but this could even be much higher depending on the species, race, population density, crop susceptibility, and environmental factors. Such low figures are attributed to the ignorance of many rural based resource-poor smallholder farmers about the existence and threat of these pests [3]. Consequently, plant parasitic nematodes still rank among the major constrains to sustainable availability of food across Africa and Asia [4-

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6]. According to the most destructive Meloidogyne species are; *Meloidogyne incognita, M. javanica, M. arenaria and M. hapla*, including *M. enterolobii* and *M. chitwoodi* which have been reported in recent studies. Several studies have been undertaken on the classification of Meloidogyne species, their damage impact across different vegetable crops including tomato, and various management options have been suggested. The study of Meloidogyne spp. on tomato has continued to attracted more interest from crop protection experts since methyl bromide was phased out. On the contrary, findings from these studies have not been properly disseminated to farmers as the main target group in the value chain. The choice of *M. incognita* for this review is informed by its dominance of Kenyan soils and severity as a major biotic constrain to tomato production. Consequently, this review provides an insight into the biology, symptomatology, economic impact and sustainable cultural options for management of Meloidogyne spp.

Biology of Meloidogyne spp

i. Life cycle and Adaptation to Survival:

Root-knot nematodes have simple life cycle which begins from the egg, four larval stages, and ends with the adult male or female. Females remain sedentary and produce large egg masses while males migrate from the plant into the soil [7]. A single female of the root-knot nematode species produces an upwards of 2000 eggs. The eggs are usually deposited into a gelatinous matrix that protects and holds them together. This matrix may hold from 300-1,000 eggs that usually protrude from the “butt” end of the nematode and protrude to the surface of the root [8]. Under ideal environmental conditions, the life cycle is complete within 4 to 8 weeks with a possibility of 5 to 8 generations in one growing season [9]. Nematode development is generally most rapid within an optimal soil temperature range of 70°F to 80°F.The first stage larvae develop in the egg where the first molt also occurs. Eggs then hatch and the second stage larvae emerge to locate and infest plant root or foliar tissues. Movement of the juveniles in the soil to locate hosts is aided by surface films of water around rhizosphere soil particles or root surfaces. Most feeding occurs when the young larval stages invade root tissues and establish permanent feeding sites. As a result of intense feeding and development of internal body tissues, the second stage larvae undergo three molts to eventually become adult male or female.

Most economically important Root-knot nematode species such as M. javanica, M. incognita, M. arenaria, and some populations of M. hapla [10] reproduce parthogenically (without fertilization), and males are usually very few. Certain races however, reproduce amphimictically (females are fertilized by the males). Suboptimal conditions and high population densities may activate sex reversal on early juvenile stages resulting to increase in the population of males [11-13]. Species of Root-knot nematodes are sexually dimorphic, with mature females being sedentary and pyriform (pear) or saccate (pouch-like) shaped. Mature males are vermiform (worm-shaped) but do not actively feed, hence exist in the soil for a short while and eventually die. Because they are obligate parasites, Root-knot nematodes’ survival depends on the availability of suitable host plants, without which their populations naturally decline and eventually disappear. Most ideal hosts are the susceptible crop host but in the absence of such hosts, these plant parasites can still survive on weed hosts. This implies that conditions which promote healthy growth of plants equally favor the multiplication of Root-knot nematodes. For instance, the optimum moisture levels for hatching of M. incognita eggs and survival of juveniles slightly exceeds the field capacity.

Consequently, the absence of potential host plants during the emergence triggers juveniles to exhaust their energy reserves and eventually die. Although the Root-knot nematode

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populations rapidly decrease under such conditions, perpetuation of the species is insured by a significant portion of eggs that undergo diapause. The egg like seed in higher plants is less sensitive to extreme conditions compared to the other stages in the life cycle of plant parasitic nematodes. Most Root-knot nematodes remain within the senescing plant host tissue and this provides a physical barrier to slow evaporative water loss. They also migrate to escape unfavorable environmental stress. For instance, when moisture levels on the surface soils go down, the nematodes migrate to deeper moist soil layers. A mass movement of Root-knot nematodes from old plants to younger plants may also occur. Under the practice of fallowing, Root-knot nematodes can survive longer in cooler climates. M. hapla, also known as the northern root-knot nematode, is favored by moderate to cool weather while M. incognita prefers a more temperate environment [14,15].

ii. Mechanism of Infestation:

Root-knot nematodes are biotrophic parasites with very complex strategies for successful infestation across a diversity of plant species. They attack by producing cell wall degrading enzymes; a mechanism of attack which is reportedly similar to that of the pathogenic bacteria and fungi. Root tissue infestation begins with the injection of enzymatic secretions [16]. The second-stage juveniles then hatch within the root elongation zones which have rapidly dividing cells and actively invade the host. They then migrate along the intercellular tissues to the root tips and settle within the vascular cylinder as permanent feeding sites where they develop into adults.

Symptomatology of Meloidogyne spp

Root-knot nematodes (Meloidogyne spp.) pose a major threat to achievement of high tomato yields due to malformation of the root system which is key to growth and development of plants. The three most common and widely distributed root-knot nematode species of significance to tomato production are *M. javanica, M. incognita, and M. hapla*. Meloidogyne has been reported as having a wide range of hosts among cultivated crops and broadleaf species of weeds. The main symptoms associated with Meloidogyne spp inversion are broadly classified into two namely; above-ground and below-ground symptoms.

i. Above ground symptoms:

The above ground symptoms are mainly observed in the canopy and generally manifest as nutrient deficiency symptoms. These include stunting, leaf chlorosis, premature wilting and slow response to improved soil fertility and moisture status. Meloidogyne spp attack in tomato crop is closely linked to accelerated secretion of ethylene which enhances the manifestation of symptoms mainly gall formation. Plants expressing symptoms of root knot-nematode attack usually appear as patches of irregular growth instead of a general decline of the entire crop. The appearance of severe symptoms especially injuries to plant tissues is attributed to Meloidogyne spp population density, susceptibility of the tomato plant and the prevailing abiotic conditions.

For instance, severe nematode attack results in stunted growth or death of transplants thus presenting a poor crop stand with irregular patches [17,18], with lighter-textured soils around affected roots. Foliage symptoms on tomato crop under the severe attack of Root-knot nematodes include stunting, premature wilting, and slow recovery after irrigation or rainfall and leaf chlorosis. Fruits tend to mature early but without uniformity. When the population density of root knot nematodes is low, several reproductive cycles are required to build a population that can initiate a severe attack. Consequently, severe symptoms such as malformed root systems may only manifest on crops towards the end of the cropping season.

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ii. Below ground symptoms:

Symptoms induced by Root-knot nematodes include root dysfunction and formation of large galls or "knots" in the entire root system. Attack by M. hapla results in small galls which concentrate on the apical meristems of the primary roots thus affects only a smaller portion of the root system. However, M. incognita and M. javanica are associated with formation of large galls that affect the entire root system [19]. Roots develop abnormal swellings called galls which result from multiple infestation by root knot nematodes. These swellings are commonly spherical in shape and vary in size. They can easily be observed as elongated, convoluted, tumorous swellings. Root galling is commonly considered as positive diagnostic confirmation of nematode infestation or presence and potential for crop damage. Decline in yield is often directly associated with pre-existing nematode populations in the soil prior to planting and other environmental stress factors that affect plants during growth. Generally, the slightest presence of root-knot nematodes in the soil indicates a potentially serious challenge, especially when soil temperatures favor intensive feeding and high multiplication rates.

The susceptibility of tomato cultivars to Meloidogyne spp is widely varied. Previous studies on root knot nematode related damage and yield loss have revealed considerable variations in the level of susceptibility across tomato cultivars. In addition, wide variations in the pathogenicity of specific populations within same Meloidogyne species against a specific tomato cultivar have been reported. For instance, a tomato variety that is considered susceptible to one population may exhibit moderate tolerance to another population within the same species. Related studies across the globe have also reported the potential of different species of Root knot nematodes to cause damage across a wide germplasm of tomato cultivars under pot and field experiments.

Among the common factors affecting the development of nematode populations include soil type and variations in levels of tolerance across different tomato varieties and cultivars, tomato cropping systems, pre-existing densities of nematode species [20,21]. A commonly reported average yield loss occasioned by root knot nematodes is 10 percent [22]. However, much higher figures have been reported from different locations as influenced by population levels, genus, and frequency of attack and crop species. For instance, M. incognita has been associated with 22-30% losses in tomato yield [23]. Meloidogyne spp. have caused up to 80% yield losses in processing tomato-growing areas [23]. Reported that an initial population density in soil of 4750 juveniles of M. javanica caused a 61% yield reduction in tomato cropped in summer plastic houses

Cultural Management Practices

i. Solarization:

[25] Reported that soil solarization is effective in the management of Root-knot nematodes. It is best applied in dry spell when long hours of solar radiations are experienced. The soil surface is covered using a plastic film for a minimum period of 2 weeks. This concentrates heat in the superficial soil layers, killing the eggs of Root-knot nematodes, thus reducing the population. According to [17], soil solarization works best in loamy and clay soils compared to sandy soils. This is because soils with good moisture holding capacities enhance heat transfer to deeper soil layers thus exposing a larger population of Root-knot nematodes to heat.

ii. Trap Cropping:

This is a Root-knot nematode management method which has been studied and practiced for centuries. The technique works by the principle of luring Root-knot nematodes to be induced to attack and establish a permanent

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feeding site on a specific host. Due to their sedentary nature, the mature female nematodes remains on the trap crop which is destroyed after two weeks along with the entire nematode population within the rhizosphere. Common examples of trap crops are beans and carrots. This method may not be very effective as the use of nematicides since some populations may not enter the trap crop roots. Besides, it may be costly to large scale farmers due to the extra cost of establishing a trap crop besides the main crop. However, for the home or kitchen gardeners, this method is relatively less hazardous both to the environment and households.

iii. Quarantine:

In the management of Root-knot nematodes, quarantine is applied as a preventive approach to stop the introduction and/or further spread of economically significant nematodes into clean production areas. Phyto-sanitation has been reported as the main quarantine strategy due the convenience of its application by small holder resource poor farmers. It is built upon the creation of awareness and strict adherence to set standards and regulations. In a well-organized quarantine system, new species of Root-knot nematode must initially be intercepted by accredited quarantine or plant health inspectorate agencies, to prevent the unintended dissemination of such species to new sites). Global quarantine regulations do not focus much on the four major species of root-knot nematode namely; M. javanica M. arenaria, M. hapla and M. incognita, since they are distributed globally. However, the European Union under the directive (EC Directive 2000/29/EC) enlists the temperate species of root-knot nematodes namely; M. fallax and M. chitwoodi as quarantine pests. Simillarly, M. enterolobii is enlisted under EPPO 2014 as a quarantine pest. The latter is reportedly very aggressive and able to parasitize tomato varieties considered resistant.

iv.Plant resistance:

Presently, breeding research is frequently identifying genetically resistant varieties to root-knot nematodes. The localized tissues of genetically resistant varieties usually provide a hypersensitive response (HR) near initial feeding site thereby discouraging Root-knot nematodes from establishing permanent feeding sites. Failure to establish permanent feeding sites either lead to the death or departure of Root-knot nematodes from the roots of such plants, hence no damage. According to [24], the Mi-1.2 resistance gene in *Solanum lycopersicum* demonstrated significant levels of resistance against high Root-knot nematode pressure (200,000 eggs/plant). Other genes that have been reported to exhibit resistance against Meloidogyne are; Mi2 through Mi8 genes (all from tomato) and Me and N genes from capsicum [15].

v. Organic Amendments:

Several soil amendment options and composted materials have been used to suppress root-knot nematode populations, improve crop health and enhance yields. The common examples of organic amendments used to improve soil quality and biology are animal manures, organic mulch and cover crop residues. Certain amendments that release ammoniac nitrogen into soil are reportedly effective in suppressing nematode populations directly and promoting the rapid growth of specific microbial antagonists of Root-knot nematodes.

Generally, soil amendments improve the improve soil fertility and structure, nutrient and water holding capacity of the soil, stimulate microbial activity in the soil and reduce erosion and release specific compounds that may be nematicidal [25-26]. Enhanced microbial activities and rise in the numbers of antagonistic microbes produced by the decaying soil amendments are associated with the suppression of soil borne pathogens via the incorporation or simple mulching of composted amendments. However, [27,28] reported an increase in Root-knot nematode populations after application of the amendments. This brought forth a hypothesis that the results may have been premised on the interaction between many factors including the soil infestation level, physiological stage of plant materials incorporated as amendment, quantity of organic amendment, Carbon:Nitrogen ratio of the organic amendment, chemical properties of different materials such as presence of nematode toxic compounds, the sum duration of application and the frequency of applications., decomposition stage of organic compost, and Root-knot nematode community structures.

Conclusion

Root knot nematodes of the Meloidogyne genus are economically significant important tomato pests. None of the management options should be relied in exclusion. Rather, when practically and economically possible, each management procedure should be considered for use in conjunction with all other available measures for nematode control and used in an integrated program of nematode management. The challenge of decline in yield in tomato due to attack by Root-knot nematode in the tropics, subtropics and temperate regions. Root-knot nematodes initiate their invasion by penetrating into the tender root tissues followed by a gradual migration to the vascular cylinder, where actual root damage occurs due to intense feeding activities which culminate into root deformation and severe distortion. The result of such damage are the formation of root galls (swellings) which humper the translocation of water and dissolved minerals in plants. The severity of damage caused by Root-knot nematodes in tomatoes is influenced by the tolerance or susceptibility of the host plants. Meloidogyne spp. tend to multiply faster and cause extensive damage on highly susceptible tomato varieties. However, tolerant varieties suppress the growth of their populations and reduced their dissemination. Thus, the knowledge of how Root-knot nematodes affect tomato productivity is essential in the development of sustainable management strategies.

Data Credibility

The data supporting this review were obtained from previously reported research findings and are cited in-text.

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