Chapter

Nematodes Diseases of Fruits and Vegetables Crops in India

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Abstract

Nematodes are the most plentiful animals on earth, commonly found in soil or water, including oceans. Some species of nematodes are parasites of plants and animals. Plant-parasitic nematodes are non-segmented microscopic, eel-like round worms, obligate parasite possess stylets that live in soil causing damage to plants by feeding on roots or plant tissues. Plant-parasitic nematodes feed on roots, either within the root, some nematodes feed leaves. These nematodes cause breakdown of resistance to fungal diseases in fruit crops. Plant-parasitic nematodes living host tissue to feed on to grow and reproduce. Nematode life cycle consists of an egg, 4 pre-adult stages (juveniles) and an adult, life cycle depending on the species and the temperature. Nematodes do not move long distances (less than 6 inches per year). They are usually transported over long distances on machinery, in nursery stock, transplants, seeds, or by animals, moves soil, water and wind. They acquire nutrients from plant tissues by needle-like feeding structure (stylet/spear). Nematodes can be classified into three groups depending on feed on the plants such as ecto-parasitic nematodes are always remaining outside the plant root tissues. Migratory endoparasitic nematodes move through root tissues sedentary endoparasitic nematodes penetrate young roots at or near the growing tip. They steal nutrients, disrupt water and mineral transport, and provide excellent sites for secondary pathogens (fungus and bactria) to invade the roots and decay. Several nematode species that cause problems in fruit orchards that are major limiting factors in fruit crop production cause extensive root necrosis resulting in serious economic losses. The root-knot nematode (*Meloidogyne* spp.), burrowing nematode (*Radopholus similis*) and citrus nematode (*Tylenchulus semipentrans*) are the major nematode pests that infect fruit crops. Parasitic nematodes that can damage tree fruit roots. Many kinds of nematodes have been reported in and around the roots of various fruit crops, only few are cause serious damage, including Root-knot nematodes (*Meloidogyne* spp.), Lesion nematodes (*Pratylenchus* species), Ring nematodes (*Mesocriconema* spp) are cigar-shaped that are strictly ectoparasitic, Dagger nematodes (*Xiphinema* spp) are relatively large ectoparasites that feed near root tips, Sting nematodes (*Belonolaimus* species) are ectoparasitic, Citrus nematodes *(Tylenchulus semipenetrans)* are sedentary semi-endoparasites. Nematodes reduce yield without the production of any noticeable above ground symptoms. Typical above ground symptoms of nematode infections stunting, yellowing and wilting. Major nematodes associated in large number of vegetables crops in India such as root-knot nematodes (*Meloidogyne* spp.), cyst nematodes (*Heterodera* spp.), lesion nematodes (*Pratylenchus* sp.), reniform nematodes (*Rotylenchulus* sp.) lance nematodes (*Hoplolaimus* spp.), stem and bulb nematode (*Ditylenchus* spp.) etc. Root-knot nematodes are important pests of vegetables belonging to solanaceous (brinjal, tomato, chili), cucurbitaceous (biter ground, cucumber, pumpkin, bottle gourd) leguminous (cowpea, bean,

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pea), cruciferous cauliflower, cabbage, broccoli, brussels, sprout), okra and several other root and bulb crops (onion, garlic, lettuce, celery, carrot, radish). Four species (*M. incognita, M. javanica, M. arenaria and M. hapla*) are more than 95% of the root-knot nematode population worldwide distribution. Stem and Bulb nematode (*Ditylenchus* spp.) commonly attacks onion, garlic, potato, pea and carrot etc. The nematodes spread from one area to another mainly through infested planting materials, water drains from infested areas into irrigation system, soil that adheres to implements, tyres of motor vehicles and shoes of plantation workers. Management recommendation through bio-pesticides, cultural practices, enrichment of FYM, Neem cake and other organic amendments.

Keywords: fruits, vegetables, nematodes, symptoms, management

1. Introduction

Nematodes are microscopic roundworms live in soil, marine, freshwater. Plant parasitic nematodes cause economic damage to cultivated crops in the tropics and subtropics areas, estimated about 10 percent of world crop production is lost due to nematode [1]. More than 4100 species of plant-parasitic nematode of global food security [2] and damage caused by plant nematodes has been estimated at $US80 billion per year [3]. Presently 25 genera of plant parasitic nematodes, include species that are economic pests of crop plants. Ten most important nematode genera are significance at global level *viz., Meloidogyne, Pratylenchus, Heterodera, Ditylenchus, Globodera, Tylenchulus, Xiphinema, Radopholus, Rotylenchulus and Helicotylenchus* [4]. The root-knot nematode (*Meloidogyne* spp.) include over 100 species, with *Meloidogyne incognita, Meloidogyne javanica*, *Meloidogyne arenaria*, and *M*eloidogyne hapla, are the most destructive to agricultural crop [5]. Root knot nematodes develop primary feeding site of the giant cell [6]. Multi-nucleated giant cell -induced within the host cell in the absence of cytokinesis. Cysts nematodes (*Heterodera* and *Globodera* spp.) eggs in cyst body of the female releases larvae (J_2) infect the host and develop into adult stages within host tissue. Cyst nematodes enter root tips and induce specialized feeding structures syncytia. [7, 8]. Root-lesion nematodes (*Pratylenchus* spp.) are distributed worldwide and wide host range of plant species [9]. Lesion nematodes are migratory endoprasite, feeding mainly in the root cortex. Typically symptoms are lesion formation on roots and aboveground chlorosis of leaf [10]. *Radopholus similis (*burrowing nematode) is a migratory plant parasitic nematode causes severe economic losses in yields and quarantine plant pest worldwide [11]. considered the most important phytopathogenic nematode in banana-growing areas and also damages the crop banana, citrus, pepper, coffee [12].

Plant Parasitic nematodes are associated in agricultural crop in global food security. Agriculturally important root-knot nematodes and identified by Berkeley [13] (1855) who observed galls on cucumber roots. Plant-parasitic nematodes have a stylet, which is used for penetration of host plant tissue and release proteinaceous secretions from the glands to the host cell. These glandular secretions induce cellular metabolically active feeding cell [14]. Cellulose is the primary component of plant cell walls, cellulases (β-1,4-endoglucanases) are secreted to degrade the cell wall which allows nematode entry into host tissue. On the basis of their feeding habits, they are migratory ectoparasites, endoparasites, semi-endoparasitic. Ectoparasitic nematodes in the soil, feed at the root surface and Endoparasitic nematodes feed within the root. Endoparasitic nematodes are further divided into migratory and sedentary groups. Migratory endoparasitic nematodes include *Pratylenchus* spp. (lesion nematode), *Radopholus* spp. (burrowing nematodes) and

Hirschmanniella (rice root nematode). Nematodes associated with cultivated crops that are considered economically important. Viz., cyst nematodes (*Heterodera* spp.), lesion nematodes (*Pratylenchus* spp.); root knot nematodes (*Meloidogyne* spp.); and stem nematode (*Ditylenchus dipsaci)*. Plant parasitic nematodes feed underground plant tissues, such as roots, rhizomes, tubers, bulbs and symptoms appears on the aerial parts and often confused with those from abiotic stress, such as lack of nitrogen and water deficit. Some nematode species feed stems, leaves, flowers, fruits and seeds. *Some Plant parasitic nematodes are highly polyphagous in nature, such as Meloidogyne spp. and Pratylenchus spp.,* which can infect many species of plants [15].

The most economically important nematodes, the root-knot and cyst nematodes are wide range of species [16]. The potato (*Solanum tuberosum*) crops suffering root-knot nematodes (*Meloidogyne* spp.), stem nematode *Ditylenchus destructor* and cyst nematodes are cause losses in yields. Root-knot nematode (*Meloidogyne chitwoodii*) is considered the most important species [17]. *Globodera rostochiensis* and *Globodera pallida* originate from S. America are known pests [18]. In sweet potato (*Ipomoea* batatas L. Lam) *Ditylenchus destructor* is a major pest cause up to 100% yield losses in China [19, 20]. Lamberti [21] (1979) reported 50–60% losses in tomato and eggplant by RKN. Bhatti and Jain [22] estimated a loss of 46.2% in tomato due to *M. incognita.* Alam and Jairajpuri [23] estimated that nematodes are responsible for causing up to 70–90% yield losses in tomato and brinjal.

Pratylenchus coffeae in an area of about 1,000 ha in Karnataka was estimated to be Rs. 25 million is assessed in coffee. *G. rostochiensis* in Nilgiris, about 3000 ha area is infested with this nematode and total crop failure. *Meloidogyne* spp. attack more than 3000 crop plants, include vegetables, tuber crops, pulses, number of fruits, ornamental crops, tobacco etc. In India, the nematodes that cause most severe damage to horticultural crops *viz., Meloidogyne* and *Rotylenchulus reniformis* in vegetables, *Radopholus similis* in banana, black pepper and coconut (toppling disease of banana, slow wilt of pepper and coconut), *Pratylenchus coffeae* in coffee, *Tylenchulus semipenetrans* in citrus (Citrus decline/Slow decline of citrus). Root-knot nematode (*Meloidogyne* spp.) ranks first damage at global level and worldwide distribution, wide host range, destructive nature caused disease complexes. Plant parasitic nematodes often interact with fungal, bacterial and viral pathogens to cause disease complexes. Solanaceous vegetables yield losses by root-knot nematode have been assessed in various parts of the country. Developing countries suffer a crop loss of 14.6% compared to 8.8% in developed countries.

Fruits are the most important rich in Vitamins A and C and minerals like Calcium and Iron, low caloric values and low in fats. The plant parasitic nematodes are economic importance in fruit production. Fruit crops are perennial in nature, harbor and build-up of nematode population. Roots damaged by the nematodes lose efficiency in the utilization of available soil moisture and nutrients and easy prey to many fungi and bacteria which cause root decay. Symptoms of nematode attack often include reduced growth, chlorosis, wilting and death of plants. These resulted in reduced yields and poor fruit quality of fruits viz., citrus, banana, grapevine, pineapple, pomegranate and papaya. Nematode management is important for high yields and quality of fruits production. The integrated Nematode Management is population reduction of plant parasitic nematodes and development of resistant varieties of crops.

1.1 Root-knot nematodes (*Meloidogyne* spp.)

Root-knot nematodes (*Meloidogyne* spp.) are obligate parasites and are a major economic importance distributed world-wide. Root-knot nematodes (*Meloidogyne* spp.) attack in tropical and subtropical areas of crops by *M. incognita*, *M. javanica* and *M. arenaria* are known [24]. *Meloidogyne* females almost spherical in shape, deposit eggs in an egg sac, galling of the roots is common. Eggs are broken by temperature increasing after a cool period [25]. The *Meloidogyne* life cycle consists of six developmental stages; egg, four larval stages (juvenile) and adult, taking approximately 25 days for completion. Second larval stage (J2) able to penetrate and parasite the host cells [26, 27]. Lifecycle involves four developmental stages, larval stage (J_1) within the egg, larval stage (J_2) migratory, larval stage (J_3) sedentary, larval stage (J_4) sedentary and adult stage (sedentary). Females are characteristic "apple" shape Greek nomenclature *Meloidogyne*. Infective second-stage juveniles (J2s) are often attracted to root exudates and migrate to root tips behind the root cap at the elongation zone. The Meloidogyne genus well recognized species, *M. incognita, M. javanica, M. arenaria,* and *M. hapla* are the most important ones [28]. Root-knot nematodes are major pests of horticultural crops and infect more than 50 horticultural plant species. Meloidogyne is cosmopolitan genus, and distribued in temperate, subtropical, and tropical areas [29]. In warmer regions on volunteer grass hosts, more than one generation per season is possible [30]. Plant parasitic nematodes present some of the most difficult pest problems evaluated in our agricultural economy, because nematode damage is often overlooked due to mostly non specific symptoms. Mature females lay eggs in a protective gelatinous matrix which forms an egg mass. *Meloidogyne* species have a broad host range and, in general, hatching is dependent solely on suitable temperature and moisture conditions, with no stimulus from host plants being required. After embryogenesis, the infective second-stage juvenile (J_2), hatches from the egg. J_2 usually penetrate the roots directly behind the root cap, combination of physical damage through thrusting of the stylet and breakdown of the cell wall by cellulolytic and pectolytic enzymes. The J2 initiates a permanent feeding site, consists of several giant cells. These cells function as specialized sinks, supplying nutrients to J2. The head is embedded in the periphery of the vascular tissue. Symptoms in patches of poorly growing, yellowing plants few square metres to larger areas. Typical symptoms include stunted growth, wilting, leaf discoloration and deformation of the roots. The increased metabolic activity in giant cells mobilizes photosynthetic products from shoots to roots [31]. The damage by some *Meloidogyne* species has been given by Wesemael *et al.* [32]. Disease complexes with *Fusarium* wilt, *Rhizoctonia solani* and *Thielaviopsis basicola,* have been reported (Manzanilla-López and Starr, 2009). Many vegetable crops are susceptible to *Meloidogyne* spp., such as potato, tomato, carrot, lettuce, okra, cucumber and gourds. The root-knot damage in potato can be recognized by plants withering even in moist soil and yellowed leaves and stunting growth [33]. *Meloidogyne hapla* causes more root gall proliferation in potato.

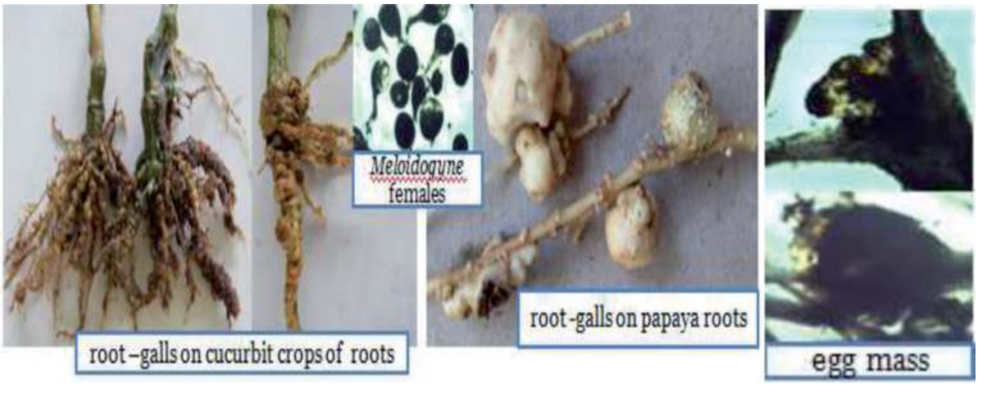

Figure 1.
Root-knot of infected roots, Meloidogyne females and egg mass.

Root-knot infection symptoms in ginger formation of gall characterized on rhizome showing brown to black lesions with accumulated fluid [34, 35]. In carrots, infection results in excessive root growth, forking formations and galls around the lateral roots and galls can be easily observed in okra and pumpkin roots [34, 36]. Among the fruits the root-knot nematodes hosts of banana (*Musa* spp.), grapevine (*Vitis vinifera*), and papaya (*Carica papaya*) **Figure 1**.

1.2 Cyst nematodes (*Heterodera* spp.)

Cyst nematodes (*Heterodera* spp.) attack wide range of pulses, grains, and vegetables including carrots, beans and peas cause huge economic losses for farmers. Vegetables *viz*., carrots, beans, peas, beetroot, cyst nematodes cause significant losses to agricultural crops. The beet cyst nematode (*Heterodera schachtii*) can cause yield loss in vegetable crops such as cabbages, Chinese cabbages, cauliflowers, Brussels sprouts, broccoli, turnip, radish beets and spinach, damaging root especially during summer. Nematodes feed on plant roots, reducing the ability of plants to take up nutrients and water. The above-ground symptoms look like nutrient deficiency, poor growth, stunting, yellowing and wilting. The sign of beet cyst nematode is the appearance of glistening white-yellow bodies about the size of a pin head attached to the fibrous roots. These mature and harden to produce a light-brown to reddish-brown cyst. Cyst nematodes (*Heterodera* spp.) are one of the most important groups of plant-parasitic nematodes worldwide. The most economic importance on cereals cyst nematode (*Heterodera avenae)*, detected in India [37, 38]. *Heterodera avenae* has polymorphous with many pathotypes [39, 40]. *H. avenae* is sexual dimorphism, female lemon-shaped and eggs are retained within body, after the female died, body wall hardens resistant brown cyst, which protects the eggs and juveniles. The eggs within the cyst remain viable for several years [30] (**Figure 2**).

Figure 2.
Cyst of Heterodera sp. and cyst attached with the roots.

1.3 Lesion nematodes (*Pratylenchus* spp.)

The genus *Pratylenchus* is a large group of species affecting both monocots and dicots, polyphagous migratory endoparasites. Lesion nematodes (*Pratylenchus* spp.) are most common genus and have a very wide host range crops such as vegetables, and tree fruits. In fruit orchards, this nematode can be a major cause of orchard replant failures. It major problem causing damage in apple, peach, cherry, grape and potato. Eggs are lay inside root tissues and emerging juveniles enter in the roots and cause root injury, and allow other soil microorganisms to enter the root tissues and contribute to root rot and decay. Root lesion nematodes are migratory and capable of repeatedly entering and exiting from root tissue, several generations occur inside the roots. Nematodes cause small brown lesions on the white lateral roots and kill the fine feeder roots. Affected plants lose all feeder roots, its serious problem in orchard replant. The infected tree often exhibits stunting, chlorosis, and twig dieback with a decline in vigor, especially in peach and cherry orchards. The nematode invades the tissues of the plant root, migrating and feeding inside the root causing characteristic dark brown or black lesions on the root surface.

Pratylenchus pratensis was first described in 1880 [9]. Currently, the genus *Pratylenchus* is found worldwide, with more than 75 species described [41]. Lesion nematodes an important group of root migratory ecto-endoparasites in a variety of hosts. The damage caused by lesion nematodes in roots and tubers. *Pratylenchus* attack host tissues due to their free movement through the root and feeding in the plant cortex, resulting in dark spots or lesions. Members of the *Pratylenchus* genus may be sexual or asexual depending on the species. *Pratylenchus neglectus, P. thornei* and *P. brachyurus* reproduce by parthenogenesis, while *P. penetrans* must mate before producing fertile eggs. *Pratylenchus thornei* is considered the most economically important species. *Pratylenchus* females lay an average of one egg per day, the life cycles range from 45 to 65 days [42, 43]. All stages are capable of infecting and feeding from plant roots. Lesion nematode damage in plant roots is generally evidenced by necrosis and death of plants. The most economically important species in potato and tubers worldwide are *P. penetrans* and *P. scribneri* [34]. Root lesion nematodes get inside tubers using lenticels and surrounding tissue causing variable-sized circular lesions [44]. These lesions are usually superficial and decrease the marketable quality [9]. The symptoms of root lesion nematode infection in yam are more severe, and infection is characterized by a dehydrated, cracked skin, and softness of the tuber. *Pratylenchus* attack in broadleaf plants, especially lettuce, results in a reduction in growth, yellowing, and small head formation [36] **Figure 3**.

Figure 3.
Lesions on roots caused by Pratylenchus sp.

1.4 Burrowing nematodes (*Radopholus* spp.)

Radopholus genus is known as burrowing nematode, species are migratory endoparasitic. The *Radopholus* genus has a relatively wide host range and the most important species for horticulture crops. *Radopholus citri* and *Radopholus similis* infect citrus and banana respectively. Burrowing nematode causes damage worldwide and found especially in tropical and subtropical areas [45]. *Radopholus* genus similar behavior and life cycles as *Pratylenchus* spp. Burrowing nematode highly infective and complete their life cycles within the host root cortical cells, causing root cell death and necrosis. *Radopholus* reproduces sexually; 2 to 5 eggs are laid per day in the root tissues, and life cycle completed in 3 weeks under favorable conditions [46]. The most characteristic symptoms of infected plants are lesions, burrows in the roots and malnutrition [34]. The disease caused by *Radopholus similis* in banana is known as 'blackhead' due to feeding on the root cortex, cause internal necrosis, symptoms on above ground parts of banana are stunted growth, yellowing leaves, small bunches and uprooting [47]. *Radopholus similis* has already been recorded as the cause of 100% losses in Cavendish banana [48]. *Radopholus similis* is also a problem for ginger, and the symptoms are similar to those seen in *Meloidogyne* infection. *Radopholus citri* and *Radopholus similis* are serious problems for citrus, causing stunted growth and reducing fruit in terms of quantity and quality **Figure 4**.

Figure 4.
Infected banana plan and lesion on roots.

1.5 Citrus nematode *(Tylenchulus semipenetrans)*

The citrus nematode was first discovered in California, later described as a new species, *Tylenchulus semipenetrans*, and causal agent of slow decline in citrus Cobb [49]. Citrus nematode (*Tylenchulus* sp.) is a semi-endoparasitic nematode cause's slow decline in citrus crops, it's also problem in grapes and apple. Second stage juveniles (J_2) are infective; partly invade roots and exposed part of female body becoming enlarged on the surface of the roots. The highest numbers of nematodes are found in late spring and late autumn. Infected plants show aerial symptoms similar to nutrient deficiencies. Damage root system of fruit trees in all soil types and. Having high pH. *Tylenchulus semipenetrans* reported in every citrus growing areas of the world [50]. *Tylenchulus semipenetrans* disseminated in citrus growing areas by infected preparative plant material. Higher populations are found in orchards in sandy soils with high organic matter [51]. Mature females are attached to roots covered by soil particles stick to the gelatinous matrix. *Tylenchulus semipenetrans* is a dimorphic species at both the juvenile and adult stage. The female juveniles feeding on the epidermis and superficial layers of the cortical parenchyma of the roots. The immature female penetrates into the deep cortical layers. It becomes sedentary and establishes a permanent feeding site consisting of specialized cells (nurse cells). The posterior portion of body swells and protrudes from the root surface while its elongate neck and head remains embedded into the cortex. Mature females produce eggs that are embedded in a gelatinous matrix secreted through the excretory pore. The length of the female life cycle from egg to egg ranges from four to eight weeks [52]. *Tylenchulus semipenetrans* is a sexually reproducing species, occasionally reproduce by facultative parthenogenesis. Nematod has a restricted host range, includes citrus, trifoliate orange, grapevines, persimmon, and olive [53–55]. Currently, three biotypes are accepted, citrus, poncirus and mediterranean [55, 56]. Slow decline

Figure 5.
Infected roots by Tylemchulus semipenetrans and female.

depend on age of trees and time of infection, reduced leaf and fruit size, most conspicuous symptoms of slow decline [50]. Yield losses due to *T. semipenetrans* range between 10–30% depending on the level of infection **Figure 5**.

1.6 Reniform nematode (*Rotylenchulus* sp.)

Reniform nematodes (*Rotylenchulus spp*) are a semi-endoparasitic species, females penetrate the root cortex and establish a permanent-feeding site in the stele region and become sedentary. The head region embedded in the root and tail region protrudes from the root surface and swells to form kidney-shaped. Genus *Rotylenchulus* have ten species; *Rotylenchulus reniformis* is the most economically important species [57] and called the reniform (kidney-shaped) nematode. *Rotylenchulus reniformis* is largely distributed in tropical, subtropical [58]. *Rotylenchulus reniformis,* has a wide host range on cultivated and noncultivated plants. First reported as a parasite of cotton in Georgia and tomato in Florida, and on cowpea roots in Hawaii [59]. Its associated with several kinds of tropical fruit trees [60–62]. Eggs hatch one to two weeks after laid. The second-stage juvenile (J_2) that emerges from the egg. *Rotylenchulus reniformis* is sexually dimorphic, males and females population are usually equal. Some populations of reniform nematodes reproduce parthenogenetically. Females produce eggs and deposited into a gelatinous matrix about 60 to 200 egg. The life cycle usually three weeks depends on soil temperature. It can survive two years in the absence of a host through anhydrobiosis [63] *R. reniformis* parasitizes a large number of plants and fruit trees. *R. reniformis* is a tropical nematode, thus soil temperature is not important factor [64]. Nematode causes root rotting and reduced uptake of water and soil nutrients. *R. reniformis* is pathogenic to sweet potato first time reported by Martin [65]. The reniform nematode causes root necrosis, dwarfing of plants, yellowing and wilting. The immature female formed C-shaped when killed by heat. The life cycle from egg to egg is from 22 to 29 days in susceptible host. Management recommendation by crop rotation with resistant plant species is recommended. These include mustard (*Brassica nigra*), oats, onion, sugarcane, and sun hemp [57, 66]. Sugarcane, Sorghum, maize and soybeans are recommended as rotation crops [67]. Managenet through crop rotation, non-host crops, resistant crops can be planted trap and antagonistic crops and use of organic mendments. Planting *Tagetes erecta* and *Crotolaria spectabilis* in nematode infested soil. *Paecilomyces lilacinus*, fungal egg parasite and effective against the reniform nematode **Figure 6**.

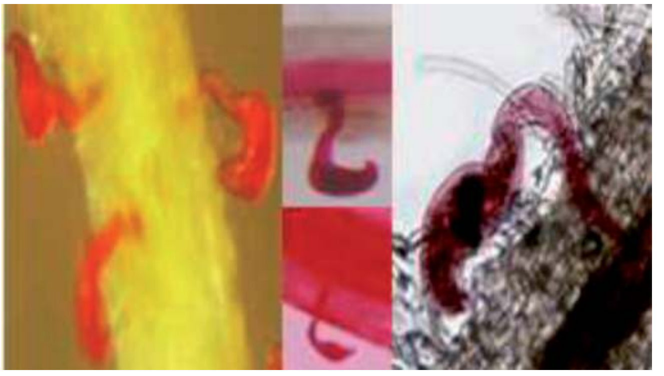

Figure 6.
Infected roots by Rotylenchulus sp.

1.7 Stem and bulb nematodes (*Ditylenchus* spp.)

Stem and bulb nematodes (*Ditylenchus* spp) are migratory endoparasitic nematodes that infect plant stems and leaves feeds upon parenchymatous tissue in stems and bulbs and continues in storage. Hosts crops are beans, onion, garlic, maize, oat, pea, potato, rye, strawberry, sugar beet, tobacco, alfalfa, faba, bersem, clover, and tulip. All stages of nematodes are infective. In adverse conditions species survive in dormant structure known as 'nematode wool', which is a bundle of juveniles [68, 69]. Fourth-stage juveniles aggregate just below the surface of infested tissue form "eelworm wool" and survive under dry conditions for several years. Runoff water is very important in the spread of stem nematodes within a field and to adjacent fields. In onion crop infected seedlings by *Ditylenchus dipsaci,* plant became twisted and deformed, leaves fall, bulbs become empty and roots yellow often death of plants. In garlic crops extensive longitudinal splitting of the cotyledons and leaves short and thick and often brown or yellowish spots, swelling above the bulb in the pseudo-stem [70]. Nematodes complete life cycle about 20 days in onion at 15° C. Infections are usually swollen, distorted stems, with reddish-brown to black lesions [71]. *D. dipsaci* and *D. destructor* causing dry rot in potato crops [69]. They enter potato tubers through the lenticels and multiply rapidly and invade the whole tuber

Figure 7.
Infected garlic and onion bulb by Ditylenchu sp.

and develop within tubers in storage. *Ditylenchus distructor* can also infect tulip and peanuts. However, horticultural losses caused by *Ditylenchus* have been most associated with *Allium* production [72]. *Ditylenchus dipsaci* and *Ditylenchus destructor* are important in commercial crops. *Ditylenchus dipsaci* is economic importance in temperate zones [30]. *Ditylenchus dispaci* is a migratory endoparasite that invades the foliage and the base of the stem. Characteristic symptoms of stem basal swellings, dwarfing and twisting of stalks and leaves, shortening of internodes and an abundance of axillary buds. *Ditylenchus dipsaci* have more than 10 biological races with limited host range. The only economic effective method is the use of host resistance [73]. Crop rotation with non-hosts crops including barley and wheat **Figure 7**.

2. Common practices in nematode management

Management practices should be effective, environmentally safe, and economical and must focus on reducing nematode populations to levels below the damage threshold. The common methods of nematodes management used resistant varieties, rotating of crops, soil amendments, soil solarization and applying pesticides. Soil solarization is very effective for control of many nematodes and soil-borne pathogens. Soil solarization of field to ensure adequate moisture, cover with plastic, to make it air tight, at least 45 days during June and July. Resistant plant cultivars is limited because few nematode very specific for specific resistance, correct identification of the nematode species and race before cultivar selected. Crop resistance cultivars with crop rotation is the best management practices.

In crop rotation, crops must be select carefully because some species of nematodes viz., root-knot, reniform, and burrowing are very wide host ranges. Crop rotation and cover cropping are often practices in integrated pest management to reduce plant-parasitic nematode incidence. Soil nematode effectively decreased by rotational cultivation of non-host cultivars of wide host range of *Meloidogyne spp*. [74]. Leguminous cover crops *Mucuna pruriens* L., and *Crotalaria spectabilis* showed multiple resistance to root-knot nematodes (*Meloidogyne arenaria, M. incognita*, *M. javanica*) [75]. Flooding and bare fallowing was shown to decrease nematode soil populations and increase strawberry yields [76]. Marigold, sudan grass and *Brassica* spp. can be used as green manure crops to control plant parasitic nematodes and boost free-living nematode populations in the soil. Glucosinilate or isocthiocyanate content in many *Brassica* species is known to control many plant parasitic nematodes. Cyst nematode can efficient manage through grass-free rotations using non-host crops. Clean fallow and deep summer plowing reduce the population density of the nematode. Cultivar resistance is considered one of the best methods for nematode control and has been found to be successful in several countries. Management of root lesion nematodes, the crop rotation is limited due to the polyphagous nature of the nematode. The role of crop rotation in controlling the lesion nematodes some field and laboratory work [77–79]. Cultural methods need to be integrated with other control measures. Mulching fields with polyethylene film for six to eight weeks suppressed *populations* by 50 percent [80]. Citrus nematodes can manage by use of resistant rootstocks and certified propagative citrus plants free from nematode for preventing the damage to citrus [81].

Green manuring as sudangrass and corn are excellent green manure crops that provide good nematode control. The organic agriculture for environmental welfare, biological controls are great interest for crop producers. The efficacy of nematophagous bacteria and fungi in the control of cyst and root-knot nematodes has been well-documented [82, 83]. Parasitic bacteria (*Pasteuria spp.*) have been reported to infect both plant-parasitic and free-living nematodes [84]. The application of

P. penetrans for nematode control *viz*., seed, transplant, and post-plant treatments [85]. *Bacillus* spp. have shown great promise in nematode management. *B. cereus* strain S2 resulted in a mortality of 90.96% to *M. incognita* [86]. Inhibition of egg hatch and motility reported in *M. incognita*, [87]. Nematophagous fungi (*Pochonia chlamydosporia)* has potential as a biological control agent for *M. incognita* in vegetable crops. Nematophagous fungal products chitinases and their potential for the development of biopesticides. Plant extracts often contain a myriad of compounds which demonstrate nematode suppressive properties. Ethanolic extracts of *Azadirachta indica*, *Withania somnifera*, *Tagetes erecta*, and *Eucalyptus citriodora* were reported to nematicidial activity against *Meloidogyne incognita*, *Helicotylenchus multicinctus* and *Hoplolaimus* [88]. Organic matters contribute to biological activity in the soil and enhance the natural activity of organisms antagonistic to nematodes. Large populations of free-living nematodes can help control many different plant parasitic nematodes in the soil, so provide enough organic matter to increase free-living nematode populations. Natural biological control to incorporate soil amendments such as manure (poultry manure) and compost.

Most nematicides are highly toxic synthetic pesticides health risk. Limitations uses of chemical pesticides are alternative methods and great attention to nematode control. Chemical nematicides are often used in the management of root-knot nematodes, restrictions in some soil fumigants due to increased environmental toxicity expensive costs and risk to humans.

Nematode release β-1,4-endoglucanase and polygalacturonase during primary infection and feeding site and in plants growth proteins are secreted during processes to allow for cell enlargement [89]. Several root-knot resistance gene (*Mi-1*) identified in tomato [90]. In carrots, two root-knot nematode resistance genes *Mj1* [91] and *Mj2* [92] to *M. javanica*. Many specific genes involved in plant immune responses by root-knot nematodes [93]. Reactive oxygen species (ROS) accumulation is toxic to nematodes and lead to hypersensitive response during the response to root-knot nematode invasion [94]. Pathogenesis-related (PR) proteins have been identified based on their enzyme function [95]. The PR family are characterized b-1,3 glucanases, chitinases, proteinase inhibitors, defensins, ribonucleases and thionins. PR gene expression is often induced by ethylene, salicylic acid, jasmonic acid, xylanase, and systemin signaling pathways. PR transcripts accumulate in high concentrations with the long distance immune response termed systemic acquired resistance (SAR) [96]. The roles of plant developmental hormones, ethylene, jasmonic acid and salicylic acid boost up plant immunity [97]. Jasmonic acid (JA) and ethylene (ET) signaling pathways work synergistically while the salicylic acid (SA) pathway is antagonistic to JA/ET pathways [98]. Exogenous ethyhlene (ethephon) and jasmonic acid (methyl jasmonate) application triggered the induction of PR proteins and the activation of systemic defense against root-knot nematodes on rice [99]. The role of jasmonic acid in activation of systemically induced resistance, exogenous application of jasmonic acid and arachidonic acid, decreased galling on tomato roots [100]. The role of salicylic acid in host resistance against root-knot nematodes. Pathogenesis-related protein expression of salicylic acid-dependent systemic required resistance in tomatoes root-knot nematode [96]. Expression of a *NahG* which encodes for an enzyme that degrades salicylic acid to catechol, reduced *Mi-1* gene in root-knot. Nematode-resistant genes found in gene pools of a variety of plant species have been introgressed into the genomes of economically important crops through transgenic technologies [101, 102].

Management of nematodes is an integrated method of pest management system. Because of most commonly practiced methods including crop rotation, developing resistant and tolerant cultivars, using chemicals and cultural practices [24, 73]. Effective management practices are required accurate diagnosis, and proper effective management techniques.

3. Conclusion

There are several genera and species of nematodes that are of economic importance. Correct nematode diagnosis can developing management program. The nematodes must be eliminate minimize the damage to determine the appropriate method. Commonly practiced methods are including crop rotation, resistant and tolerant cultivars, cultural practices and chemicals. The ability to reduce yield losses caused by nematodes is need to understanding about pathogen biology and the application of appropriate control measures. Use of chemicals is impractical commercial and cultural methods fail to complete control. Breeding for resistance and tolerance is the major strategy for long-term and environmentally sound control. It is necessary to research particularly nematodes race and pathotype, and a great need for global collaborative research to control of these important pathogens.

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