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Nematode Management in Plantation Crops and Spices

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ABSTRACT: Mixed cropping systems of Kerala involve perennial crops *viz*., coconut, arecanut, coffee, betelvine, cardamom, black pepper, ginger and turmeric in the same piece of land. Plant parasitic nematodes cause significant damage in coconut-based cropping systems leading to reduced yield and economic loss. Under '*safe to eat*' policy of the state, chemical nematicides are not allowed, because a significant quantity of the spices produced are intended for export to foreign countries and some are consumed in raw state without being processed. The application of chemical pesticides for nematode management will have an adverse effect on soil microflora and fauna, resulting in high levels of pesticide residues in harvested produce. It is, therefore, imperative to implement a bio-intensive nematode management strategy using resistant varieties, alternating crops, planting antagonistic crops, and incorporating biofortified organic manures. The selection of nematode-tolerant domesticated or wild species and the incorporation of resistance through breeding offer an eco-friendly alternative to chemical nematicides. Fungal and bacterial antagonists have been proven effective against root-knot nematodes in mixed cropping systems in Kerala. Application of organic manures, mulching and growing antagonistic crops helps to reduce nematode population and improve soil health in mixed cropping systems involving plantation crops. Integrated management programmes are to be formulated in multi-crop production systems based upon the impact of the control method on nematode population and benefit-cost ratio as the level of control varies with environmental factors, crop and targeted nematode.

Keywords: Antagonistic crops, biofortified organic manure, coconut-based cropping system, crop rotation, nematode management, varietal resistance

INTRODUCTION

Kerala accounts for a significant share in the export of spices and plantation crops, and the spice industry continues to be a key source of foreign revenue for the nation. The most popular cropping system in Kerala is coconut-based cropping system incorporating coconut, arecanut, black pepper, coffee, ginger, and turmeric. Farmers also intercrop shade-tolerant crops like betelvine and banana within coconut plantations. This approach efficiently and economically uses the space between plantation crops yielding high economic returns per unit area especially for small and marginal farmers. Growing multiple crops on the same piece of land helps in utilizing the interspaces between plantation crops more efficiently and economically. The multispecies cropping system involving coconut as the main crop is particularly effective in Kerala due to the limited land availability and high population density. This system involves growing coconut as the primary crop along with various intercrops *viz.*, vegetables, tuber crops, and pineapple; their choice is based upon the space and resource utilization capabilities. Not only does this system boost farmers' income, but also it significantly contributes to the dietary nutrition of households. This method supports biodiversity, enhances soil health, diversifies income sources, and ensures high productivity and profitability for small landholders. In the Idukki district, cardamom plantations intercropped with black pepper, arecanut, tea, and coffee are highly profitable, showing favourable benefit-cost ratios. Currently, plant parasitic nematodes are becoming one of the important limiting factors in mixed cropping systems in Kerala. Root-knot nematodes (*Meloidogyne* spp.), burrowing nematode (*Radopholus similis*), lesion nematode (*Pratylenchus coffeae*), and reniform nematode (*Rotylenchulus reniformis*) are economically important nematodes in mixed cropping system involving plantation crops in Kerala. Wounds caused by nematodes serve as infection points leading to increased incidence of diseases resulting in complete crop failure.

NEMATODE PARASITES OF COCONUT-BASED CROPPING SYSTEM IN KERALA

Coconut

Coconut, one of the major plantation crops in Kerala is grown in 765.44 thousand hectares and yields 5522.66 million nuts annually (source: Ministry of Agriculture and Farmers' Welfare, Government of India). Coconut palms cultivated in homesteads and plantation situations suffer considerable damage due to infestation of nematodes from the seedling stage. Of the 78 nematode species reported on coconut (Govindankutty and Koshy, 1979), the red ring nematode, *Bursaphelenchus cocophilus* and burrowing nematode, *Radopholus similis* are the major nematodes reported to cause significant damage on coconut palms in tropical and subtropical regions globally. The red ring disease has not been reported in India. *R. similis* is often found in crops such as coconut, arecanut, black pepper, banana, betelvine, and ginger. Koshy (1986) stated that it co-evolved with black pepper and banana in the western highlands of South India. Stunting, yellowing, a decrease in the quantity and size of leaves and leaflets, delayed flowering, button shedding, and a poorer yield are some of the symptoms. It causes a 30 per cent yield loss in coconut. The haustoria, leaf bases and plumule of coconut seedlings are damaged by *R.similis*. According to Koshy and Sosamma (1977), the coconut isolate of *R. similis* from Kerala is banana race. They do not infect *Citrus* spp. and cause small, elongated, orange-coloured lesions on tender creamy white roots of coconut. As these nematodes multiply, these lesions get bigger and merge together causing decay of root tissues. The orange-coloured semi-hard roots crack and tender roots become spongy. *R. similis* being migratory endoparasites, spend their entire life within roots. Roots have cavities in the outer cortex during early stages of infection. Later, as a result of nematode feeding and reproduction, they merge with one another. The cortex is destroyed by the formation of cavities and their coalescence, while the stelar tube remains intact. Koshy *et al.* (1975) described a method for extraction of *R. similis* from roots by peeling and longitudinally slicing the semi-hard roots (1cm diameter) into 4–8 pieces that are 3–5 cm long. These sliced root bits are kept at 20–25°C temperature in Petri dishes filled with water. It is necessary to replace the water after every 24 hrs of incubation and most nematodes are recovered within a period of 4 to 7 days.

Management: The application of nematicides for the control of burrowing nematode will result in residual toxicity in coconut water and other products of coconut. High-density multispecies cropping with susceptible crops *viz.*, banana, black pepper, arecanut, betelvine, ginger and cardamom within a coconut garden may cause contamination of produce due to nematicides.

Cultural practices: Soil application of oil cakes, farmyard manure and growing sunhemp in the basins, and incorporating it as green manure before flowering are effective strategies to prevent the reproduction of nematodes. The application of neem or marotti cake (2–4 kg/palm/year) and mulching the basins with *Gliricidia maculata* @ 50 kg/palm/year helps in controlling burrowing nematode and improving the nutritional status of the soil.

Plant resistance: Soasamma *et al.* (1986) screened 29 exotic, 15 indigenous and 15 hybrid coconut cultivars and reported that dwarf cultivars, Kenthali and Klappawangi as well as the hybrids like Java Giant x Kulasekharam Dwarf Yellow, Java x Malayan Dwarf Yellow and San

Ramon x with Gangabondam were least susceptible to nematode infestation showing lower number of lesions.

Biological: Incorporation of *Purpureocillium lilacinum*, *Pasteuria penetrans* and Arbuscular Mycorrhizal Fungi (AMF) into a potting mixture in polybags and planting pits has proved effective in managing nematodes in young coconut plants. AMF *viz.*, *Acaulospora bireticulata, Glomus fasciculatum, G. macrocarpum, G. mossae, G. versiforme, Sclerocystis rubiformis* and *Scutellospora nigra* reduced *R. similis* incidence and enhanced growth in seedlings (Sosamma, 1994).

Arecanut

Koshy *et al*. (1976) reported 22 genera of plant parasitic nematodes from the root zone of arecanut and among them, *R. similis* was the most predominant nematode and its presence was observed in 32 per cent of root samples from major arecanut-producing regions in South India. The visible symptoms include yellowing, stunted growth, reduced vigour and yield. The nematodes feed on the roots causing small orange-coloured lesions in young tender creamy white roots which eventually merge, causing root rot. The primary roots from the base of the plant show oval-shaped dark sunken lesions. Unlike in coconut palms, the ends of the tender roots turn black in colour when damaged by the nematode. Nematodes are found both within and between the cells in the cortex, yet they do not invade the stele. Due to nematode's feeding activity in the outer layer, numerous nematodes and their eggs are present in cavities.

Management: VTL-11 × VTL-17, the hybrid variety of arecanut exhibited high resistance to *R. similis.* Using resistant/tolerant cultivars of arecanut and nematode-free seedlings helps in managing nematodes in arecanut-based cropping system. Intercrops susceptible to *R. similis viz*., black pepper and banana should be avoided in affected areas. Incorporation of Gliricidia or Crotalaria (5 to 10 kg) as green manure enhances soil aeration and its capacity to retain water. Application of neem cake @ 1 kg/palm/year helps in reducing the population of nematodes and improving the soil structure. In arecanut-based farming systems, application of phorate @ 3 g a.i./ plant around the root area of arecanut, banana, and black pepper during June-July and October-November was found effective in controlling *R. similis* (Griffith *et al.*, 2005).

Black pepper

Black pepper (*Piper nigrum*), popularly known as "Black Gold" or "King of Spices" is one of the world's most precious and highly valued spices. Black pepper is prominently cultivated in humid tropics with abundant rainfall. The tropical forest in the Western Ghats of South India is recognized as the center of origin and is the key source of diversity for multiple *Piper* spp. India, globally renowned as the home of spices, grows more than 75 cultivars of black pepper. It is cultivated in an estimated area of 2,88,118 ha, with annual production reaching around 60,000 t in the year 2021–22 (Indian Spice Board, 2022). Black pepper is mostly grown in Kerala, Karnataka, Tamil Nadu, Goa, Puducherry, and some northeastern states. Karnataka and Kerala are the primary black pepper-producing states in India. Kerala is the leading producer, contributing to over 50 per cent of the country's total black pepper production, followed by Karnataka and Tamil Nadu.

Plant parasitic nematodes have a crucial role among the biotic factors, causing yield losses that range from 30 to 65 per cent (Ramana, 1991). Although numerous plant parasitic nematodes have been identified in black pepper, root-knot, and burrowing nematodes cause more economic damage. Butler discovered root-knot nematodes (RKN) infecting black pepper from Wayanad, Kerala, in 1906. In Kerala, among the endoparasites associated with black pepper, *M. incognita* was the most common and notorious species (Jacob and Kuriyan, 1979a). *Meloidogyne* spp. are obligate endoparasites that mainly infect root tissues and establish biotrophic interactions with susceptible host plants. RKN juveniles infect the plant roots behind the root tip region and migrate intercellularly into the root tissue causing enlargement of epidermal, cortical and stelar cells resulting in cortical hypertrophy. This invasion results in the formation of specialized multinucleated feeding cells, known as giant cells, within the vascular parenchymatic cells. The giant cells serve as the nutritive source for all stages of the nematodes, hindering the root's ability to absorb and transport water and nutrients from the soil. The giant cells exhibit elevated levels of DNA, RNA, and photosynthates, particularly three to four weeks after inoculation. As the infestation progresses, the roots develop significant swelling, and mature female nematodes with their egg masses can be seen embedded in the roots. The galls with egg masses give a rough, pitted appearance on the surface of the roots in most cultivars (Fig. 1). The above-ground symptoms of nematode infestation in black pepper include yellowing, severe shedding of spikes, stunted growth, and dieback leading to a substantial reduction in yield (Fig. 1) (Ramana, 1992).

Fig.1. Symptoms of nematode infestation in black pepper (Top left - yellowing; Top middle - drying of immature berries; Top right - root galling; Bottom left - egg masses; Bottom middle - root-knot females in a gall; Bottom right - lesions)

The most damaging nematode in black pepper is *R. similis* which causes consistent yellowing of leaves, leaf drop, stunted growth, and dieback. When soil moisture is depleted, these symptoms are well pronounced. Within three to five years of symptom onset, the plants die. This condition is termed as *slow decline* or *slow wilt* disease. A typical sign of nematode infestation in bearing vines is spike shedding and irregular berry formation. Nematode infested areas are initially conspicuous by yellow patches which eventually lead to barren standards devoid of vines or holding dead vines. The young slender feeding roots develop orange or purple-coloured lesions (Fig.1) and in older roots, the lesions are not clearly seen because of the brown colour of the roots. The root system decays and feeder roots rot quickly. The large lateral roots undergo severe necrosis. The use of coconut and arecanut as living standards for growing black pepper is common among farmers of Kerala. However, this practice exacerbated the damage caused by *R. similis* as these plants are very good hosts of the nematode.

Another nematode of wide occurrence in black pepper tracts in Kerala and Karnataka is *Trophotylenchulus piperis* (Ramana and Mohandas, 1987). The parasitic females are slightly swollen, spirally coiled and found attached to roots. Sahoo *et al.* (2000) identified *M. piperi* from black pepper plants in Kerala. Nisha *et al.* (2019) reported the occurrence of *M. incognita*, *Rotylenchulus reniformis, R. similis, Helicotylenchus dihystera* and *Tylenchorhynchus* sp. in the rhizosphere of black pepper plants grown in Thiruvananthapuram, Kollam, and Idukki districts.

The primary cause of losses in black pepper production is due to diseases, which are mainly caused by soil-borne fungi and nematodes. Black pepper plants are known to be affected by 17 diseases (Sarma *et al.,* 1991) and the primary incitants of slow decline are *M. incognita* and *R. similis.* Sheela and Venkitesan (1990) studied the interaction between *M. incognita* and the fungus, *Fusarium* sp. in hybrid variety, Panniyur-1 under pot culture conditions and found that inoculating the nematode and fungus together significantly reduced the plant growth more than the fungus alone. Plants inoculated first with nematode followed by the fungus exhibited a higher degree of fungal infection in the stem portion (83%) compared to those inoculated simultaneously (66%), or with the fungus preceding the nematode. Root-knot and burrowing nematodes in association with the fungal pathogen, *Phytophthora capsici* aggravated wilt symptoms in black pepper as the wounds caused by the nematode serve as entry points of the pathogen (Anandaraj *et al*., 1996).

Management: Live standards used to trail vines being perennial, nematode management in black pepper is difficult. Management practices like fallowing and crop rotation are impractical. Being export-oriented crop, eco-friendly management without using chemicals is more desirable.

Phytosanitation: Diseased plants in the garden should be destroyed along with root mass. The galled roots including underground plant parts should be burnt, and the affected should not be used for replanting for many years (Ridley, 1912).

Use of nematode-free planting materials: Raising nematode-free rooted cuttings using soilless media or solarized potting mixture is also the best option for nematode management in black pepper. Mother vines for raising nurseries should be collected from selected healthy vines and nematode-free gardens. The rooted cuttings can be raised in soilless media with coir pith or vermiculite. Soil used for preparing the potting mixture should be sterilized using solar heat, steam or soil fumigants (formaldehyde or hydrogen peroxide). In summer, denematization of soil in a potting mixture can be achieved by solarization using transparent polythene sheets for 2 to 3 months. Solarized potting mixture supplemented with nematophagous fungal biocontrol agents (*P. lilacinum* and *Pochonia chlamydosporia*), AMF and *Trichoderma* spp. helps in production of nematode-free rooted cuttings.

Organic amendments and mulches: Mulching with Gliricidia leaves @10 g/kg soil was found to be effective in reducing the population of *R. similis* and promoting the growth of black pepper vines. Soil amendment with neem cake @ 2 kg/vine two times annually proved effective in reducing the population of root-knot nematodes. Addition of organic amendments and mulches not only boosts the ability of the soil to retain moisture but also improves its fertility and the activity of beneficial soil microbes.

Cultivation practices: Black pepper is trailed in live standards *viz*., coconut, arecanut, *Erythrina indica* which are good hosts of nematodes. These plants harbour high populations of nematodes so the control measures are to be repeated every year. It is observed that *Garuga pinnata, Macaranga indica* and *G. sepium* are less prone to root-knot nematode infestation which can be used as alternative live standards instead of coconut, arecanut and *E. indica*. In newly established plantations, non-living standards or nematode-resistant plant species can be used to trail the vines. The nematode-susceptible intercrops *viz*., banana, ginger, turmeric, cardamom, arecanut *etc*. should be avoided in black pepper gardens. Additionally, weeds also harbour root-knot nematodes, so regular weeding can be recommended in black pepper gardens.

Resistance and Tolerance: Nematode-resistant rootstocks are one of the best methods to raise nematode-free seedlings. To identify nematode-resistant rootstocks, several black pepper germplasms were screened for nematode resistance by several workers. Koshy and Sundararaju (1979) reported that among the seven popular cultivars of black pepper *viz*., Panniyur I, Karimunda, Kuthiravalli, Kalluvalli, Kottanadan, Narayakodi, and Valiakaniakadan, the hybrid Panniyur 1 exhibited highest susceptibility to *M. incognita,* while Valiakaniakadan was least susceptible. Jacob and Kuriyan (1979b) evaluated eight black pepper cultivars for their resistance to *M. incognita* and found that cultivars *viz*., Kalluvalli, Balancotta, Karimunda, Narayakodi, and Padapan exhibited lower number of galls compared to Panniyur 1, Cheriyakaniakadan, and Kottanadan. Ravindran *et al*. (1992) evaluated the resistance of Coll. 812, Karimunda and Panniyur 1 against *M. incognita*, and found that Coll. 812 is resistant with a gall index of 2. This cultivar was named ‘Pournami’ and is used for cultivation in areas with high population of root-knot nematodes. Eapen *et al*. (2011) screened 525 black pepper germplasms (wild-100, cultivated-213, and hybrids-212), against *R. similis* and found 24 accessions resistant. Chinnapappa *et al*. (2018) screened *Piper colubrinum*, *P. argyrophyllum* and cultivated varieties of *P. nigrum viz*., IISR Sakthi, IISR Thevam, Panniyur-1, and Karimunda against *M. incognita* and the results after 30 days of nematode inoculation indicated that IISR Sakthi is highly resistant, while *P. colubrinum*, IISR Thevam, and Karimunda were resistant indicating their potential as valuable sources of resistance. Grafting scions of nematode susceptible high yielding varieties of black pepper with varieties having high yield potential and oleoresin content to nematode-resistant rootstocks will help in producing seedlings with nematode resistance.

Biological control: Several bioagents *viz*., plant growth promoting rhizobacteria, arbuscular mycorrhizal fungi, and egg parasitic fungi proved effective in reducing nematode population. *Bacillus, Pseudomonas* and *Pasteuria* predominantly act as nematophagous bacteria in the soil. They adversely affect nematodes through parasitism, toxin, antibiotic or enzyme production, disruption of host recognition, competition for nutrients, enhancement of plant resistance and plant health (Siddiqui and Mahmood, 1999). Sheela (1991) reported that *B. pumilus, B. subtilis, B. coagulans, B. circulans, B. macerans* and *B. licheniformis* have ovicidal and larvicidal effects. *Bacillus* spp. interrupt the life cycle of nematodes by releasing toxic substances that inhibit hatching of eggs and the movement of juveniles (Kavitha *et al.*, 2007). *B. subtilis* possesses diverse mechanisms *viz*., phytohormone production, mineral solubilization, reduction in activity of egg hatching factors, altering root exudate production and inhibiting nematode penetration (Karanja *et al.*, 2008). Kavitha *et al*. (2012) reported that crude extracts of *B. subtilis* strain Bs 5 carrying *surfactin* and *iturin* genes exhibited the highest juvenile mortality (92.3%) of *M. incognita* at 100 per cent concentration after 72 hr of exposure. Plant growth-promoting rhizobacteria, *P. fluorescens* colonize the roots and produce compounds toxic to nematodes. Senthil Kumar and Ananthan (2018) reported that black pepper cuttings treated with *P. fluorescens* (Pf bv 22) exhibited a 60.1 and 38.1 per cent reduction in nematode population in soil and root, respectively. Pre-inoculation of black pepper plants with *G. fasciculatum*, *G. etunicatum*, *G. mossae* and *Gigaspora margarita* showed a substantial reduction in population of root-knot nematodes and improved plant growth parameters (Anandaraj *et al.,* 1991; Sivaprasad *et al*., 1992). Combined application of neem cake @ 200 g/plant and talc-based formulation of *P. fluorescens* @ 20 g/plant during the months of May-June and October-November suppressed nematode population and increased yield in established plantations (Anon., 2020).

Cardamom

Elettaria cardamomum, commonly referred as small cardamom or the "Queen of spices" plays a vital role in earning foreign exchange. The natural habitat of cardamom in India is the evergreen forests of the Western Ghats also known as the Cardamom Hills. The cultivation of the crop spans 70,410 ha, out of which Kerala occupies 60 per cent, followed by Karnataka (30 per cent) and Tamil Nadu (10 per cent). While India has the largest cardamom cultivation area in the world, its yield is quite low when compared to other leading producers. The productivity of cardamom has shown a declining trend in Kerala during the last few years and one of the reasons is damage by plant parasitic nematodes.

Plant parasitic nematodes belonging to 19 genera and 28 species are reported in cardamom. Among them, the most important and widely distributed is *Meloidogyne* spp. The predominant species is *M. incognita*, while *M. javanica* and *M. arenaria* have restricted distributions. Other nematodes of common occurrence are *Helicotylenchus* spp. and *R. reniformis. R. similis* and *P. coffeae* are other two important nematodes generally observed in mixed plantations of cardamom with arecanut and coffee, respectively. Due to the damage of these nematodes, more than a 50 per cent reduction in seed germination was observed in cardamom nurseries and the infested seedlings failed to establish after being transplanted. Root-knot nematodes pose a greater threat to young cardamom plants than to the older ones. The infected seedlings exhibit stunted growth, yellowing, sparse tillering, drying out of the tips and edges of leaves, and heavy galling in roots. Patches of stunted and weak plants in cardamom plantations are common symptoms of nematode infestation. In mature plants, severe infestation leads to reduced growth and tillering, yellowing of leaves, early drying of leaf tips and edges, leaf blade narrowing, delayed flowering, premature fruit shedding and decline in yield. Though in cardamom plants, the galling of roots being not very prominent, the infested roots often develop an abnormal pattern of excessive branching similar to a "*witches' broom*" (Fig. 2). *M. incognita* infestation predisposes plants to *Rhizoctonia solani* infection leading to rhizome rot and damping off prevalent in cardamom nurseries. Cardamom plants infected with the viral disease "Katte" supported 5–10 times more *M. incognita* population (Ali, 1989).

Fig. 2. Symptoms of root-knot nematode infestation in cardamom (Left - yellowing; Middle - witches' broom type branching; Right - galling in roots)

Management: Nematode problems in nurseries and plantations are to be tackled differently. The main objective of nematode management in plantations is to reduce the nematode population to a non-injurious level, while eradication should be the goal in nurseries. Fallowing, summer ploughing, and shifting of the nursery are methods for mitigating nematode problems in cardamom nurseries. Soil solarization and application of organic manure enriched with biocontrol agents *viz*., *P. lilacinum* and *P. chlamydosporia* proved to be effective in suppressing root-knot nematodes in cardamom nurseries. For established plantations, it is beneficial to use healthy, nematode-free planting materials, avoid planting nematode susceptible shade trees like *Erythrina* sp., maintain regular weeding, mulch wild sunflower (*Tithonia diversifolia*) leaves @ 5 kg around the base of the plants and use talc-based *P. lilacinum* @ 50 g/plant during May-June. Combined application of neem cake @ 500 g/plant along with *P. lilacinum* @ 30 g/plant and mulching with Gliricidia leaves @ 2 kg/plant proved effective in suppressing nematode population and increasing yield (Anon., 2020).

Ginger

India stands as the largest producer and exporter of ginger, supplying it to more than 50 countries and contributing to more than 50 per cent of global production. Kerala is renowned for producing the finest quality ginger which is grown in 3218 ha. Sundararaju *et al*. (1979a) identified plant parasitic nematodes from 17 different genera affecting ginger. In Kerala, *M. incognita*, *R. similis* and *P. coffeae* are the predominant nematodes found in the ginger rhizosphere. Other nematodes observed were *Rotylenchulus reniformis, Helicotylenchus multicinctus, Tylenchorhynchus* spp., *Hoplolaimus indicus*, *Criconemoides* spp., and *Xiphinema* spp. Sheela *et al.* (1995) reported an avoidable yield loss of 43 per cent at an initial inoculum level of 166 *M. incognita* juveniles/250 cc soil. Higher inoculum levels of *R.similis* (10000 nematodes/plant) caused a 74 per cent reduction in rhizome weight (Sundararaju *et al*., 1979b). The intensity of rhizome rot in ginger caused by *Pythium aphanidermatum* increased when rhizomes were infected with nematodes. Nematode feeding leads to hypertrophy and hyperplasia of parenchymatous cells resulting in the formation of galls in roots and rhizomes (Fig. 3). The nematodes invade both fleshy and fibrous roots. They also attack the rhizomes leading to water-soaked patches in outer tissues, which may turn into necrotic spots subsequently. Nematodes continue to develop after the maturity of the crop, multiply during storage and cause deterioration of seed rhizomes. Plants with heavy nematode infestation exhibit stunted growth, poor tillering, and foliar yellowing. The affected plants tend to dry out and die more prematurely than healthy ones resulting in a poor crop stand at the time of harvest.

Fig. 3. Galling in roots of ginger

Infected rhizomes serve as a source of nematode inoculum during storage.

Management: Ginger being export-oriented and sometimes consumed raw, ecofriendly methods are to be adopted for nematode management. Nematodes that survive in stored seed rhizomes can spread through planting materials. Using nematode-free seed rhizomes is most important for controlling or minimizing nematode damage. Rhizome solarization and immersing the rhizomes in hot water at temperatures between 50–55°C for 10 min is effective for lowering the occurrence of nematodes in ginger. Solarization of nursery beds by covering them with a 150-gauge polyethylene sheet for 15 days in summer months increases the temperature by 5 to 10°C more than the atmospheric temperature. Crop rotation practices can be tailored for areas with endemic nematode species. When ginger is grown alongside other crops, the susceptibility of the companion crop to nematodes should be considered. Ramana *et al*. (2002) isolated a variety of bacterial and fungal biocontrol agents from ginger fields. Several isolates of fungi served as egg parasites, while some strains produced toxic compounds that are detrimental to second-stage juveniles of *M. incognita* in addition to their parasitic effects. Studies indicated that five biocontrol agents *viz*., *P. chlamydosporia, P. lilacinum, Fusarium* spp., *Aspergillus nidulans* and *Scopuloriopsis* spp. were significantly effective in reducing the population of nematodes in ginger rhizosphere (Eapen *et al*., 2005). Rhizome treatment with *Trichoderma* spp./*P. lilacinum* @ 3% w/w and green leaf mulching with *G. macualta* @ 1 kg/m^2 significantly decreased the population of root-knot nematodes and boosted the yield in ginger. Combined application of *P. chlamydosporia* and *T. asperellum* @ 2.5 kg along with 2.5 t FYM/ha was found best in suppressing population of nematodes in soil (74.49%) and increasing yield (63.37%) in ginger with ICBR of 1:6.69 (Anon., 2022–2023). Application of well-decomposed cattle manure/compost/poultry manure not only lowers nematode population but also improves soil health and water retention capacity. Weeds in ginger cultivation areas often serve as hosts of root-knot nematodes. Maintaining clean fields will help in mitigating nematode problems. Application of neem cake @ 200 g/m^2 at the time of planting is recommended for the control of nematodes associated with ginger. In areas where nematodes are prevalent, an additional application of neem cake @100 g/m^2 should be carried out at 45 days after planting (Anon., 2016).

Turmeric

Meloidogyne spp., *R. similis* and *P. coffeae* are the major nematodes of economic importance in the production of turmeric. Ayyar first reported the root-knot nematodes in turmeric in 1926. Even though both *M. incognita* and *M. javanica* affect turmeric, but the major infesting species is *M. incognita*. Plants infected with *M. incognita* exhibit stunted growth, yellowing of leaves, drying of leaf margins and tips, reduced sprouting, root galling and decay of rhizomes (Fig. 4). In the fields, high inoculum levels of *M. incognita* lead to extensive yellowing, stunting, and plant withering, resulting in a weak harvest. The infected rhizomes lose their bright yellow colour. Turmeric roots damaged by *R. similis* often rot, leaving only the outer layer intact devoid of cortex and vascular tissues. These plants dry out faster than healthy ones. The rhizomes of affected plants become pale yellow instead of the golden yellow of healthy ones and develop superficial, water-soaked, brown discolourations. *R. similis* is also found in the scale leaves of the plants (Sosamma *et al.* 1979). *P. coffeae* causes discolouration and rotting of mature rhizomes with dry rot symptoms. These rhizomes exhibit dark brown necrotic lesions.

Management: High-yielding cultivars PCT 8, PCT 10, Suguna and Sudarshana were found to be unaffected by root-knot nematodes (Rao *et al.,* 1994). Immersing rhizomes in hot water at 55°C for 50 min kills *M. incognita* inside the rhizomes and soil solarization in

Fig. 4. Root-knot nematode infection in turmeric (Left - yellowing and patchy growth; Right - galling in roots)

summer months also helps in making plots free of nematodes.

CONCLUSION

Strict quarantine measures are to be enacted as the red ring disease of coconut is becoming more widespread. Recent advances in molecular diagnostic methods such as loop-mediated isothermal amplification (LAMP) of *B. cocophilus* for detection in plant and insect samples are helpful for early discovery and eradication. Ensure the availability of male-produced synthetic aggregation pheromones of black palm weevil to monitor ports of entry of potential vectors. Root-knot nematodes can be effectively managed using egg parasitic fungi, *P. lilacinum* and *P. chlamydosporia* as the egg masses are present outside the root. Since burrowing and lesion nematodes are endoparasites and lay eggs inside the roots, their management is difficult. Hence plant growth-promoting endophytes with good colonization ability and egg parasitization capacity need to be explored. In future research, thrust is to be given to the utilization of biotechnological tools for isolating and cloning nematode-resistant genes, standardization of gene editing techniques in plantation crops to knock out expression of nematode susceptible genes, identification of promising stress-tolerant strains of biocontrol agents and standardization of mass production and application techniques, isolation and characterization of biocide molecules of plant origin to develop environmentally safe and economic green nematicides.

CONFLICT OF INTEREST

None.

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