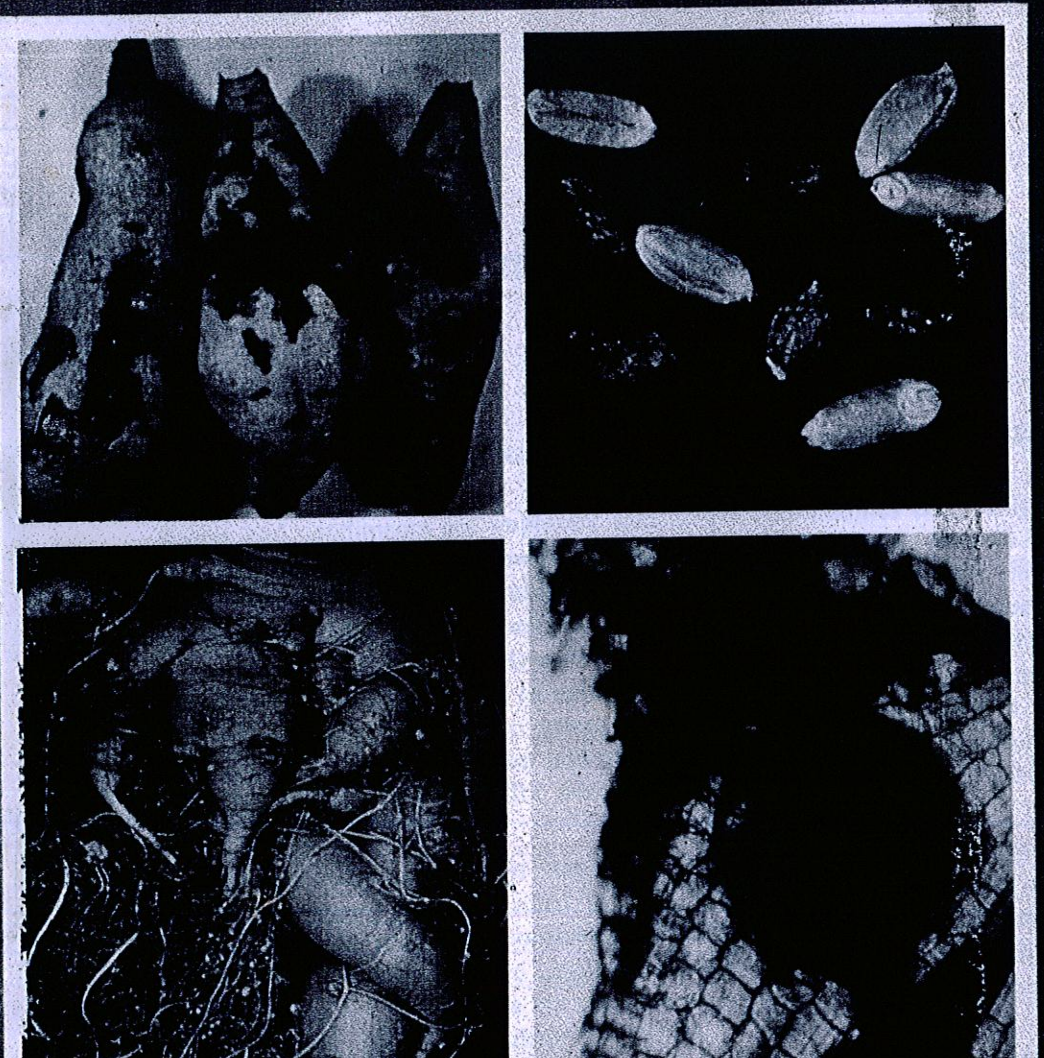
Nematode Diseases in Plants



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Plant Parasitic Nematodes Associated with Spices and Condiments

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Spices and condiments are important agricultural commodities commonly used for seasoning and preserving food and are also indispensable in the culinary. Spices are also widely used in cosmetics, perfumes, confectionery, medicines etc. Spices, the aromatic dried roots, rhizomes, bark, buds, seeds, berries, other plant parts get their characteristic odor from volatile constituents in the plant materials. There is no clear-cut distinction between spices and condiments. Under the Indian Spices Act, 52 plant species are denoted as spice crops. Spices are mostly grown in tropical and subtropical regions. In India, an array of spices are grown and therefore India is known as the 'Home of Spices'. It is a major producer and exporter of various spices and value added products. During 1993-94, India earned about Rs. 540 crores through export of 175,532 MT of different spices and spice products.

Several biotic and abiotic factors affect production and productivity of spices crops. Among the biotic factors, diseases caused by fungi and nematodes and disease complexes involving both these pathogens are major constraints. Plant parasitic nematodes, besides feeding and damaging the host root system, are also responsible for rendering the plants susceptible to attack by several fungal pathogens. Nematodes are also known to break the resistance to fungal/bacterial pathogens in many spice crops particularly in chillies.

In spices cultivation, root knot nematodes (*Meloidogyne* spp.) occupy a unique place since these nematodes infest almost all spice crops. The burrowing nematode (*Radopholus similis*) is another important nematode pathogen, a severe constraint in the production of spices, particularly black pepper. *Ditylenchus* spp. are important on garlic. However, nematological investigations are mostly concentrated on major spice crops like black pepper, cardamom, ginger, turmeric, chillies, garlic etc. and to a lesser extent on seed spices like cumin, coriander, fenugreek and fennel.

Nematological problems in spices and condiments have been reviewed recently (Koshy and Bridge, 1990; Koshy and Geetha, 1992; Ramana and Eapen, 1995). In this review an attempt is made to update the information already available on all the important spice crops, except chillies as it is covered under vegetable crops.

BLACK PEPPER

Black pepper (*Piper nigrum* L.), a perennial climber belonging to Piperaceae family, originated in the Western Ghats of India, is a major spice crop of India. It is mostly grown in the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Indonesia, Malaysia, Brazil, Sri Lanka, Vietnam, Thailand etc. are other black pepper producing countries where it is cultivated on a commercial scale. Among the spice crops, black pepper occupies first position in foreign exchange earnings of India. During 1993-94 India exported 46,650 MT and earned Rs. 17,967 lakh foreign exchange.

Production and productivity of black pepper are seriously affected by two major diseases in all pepper growing countries. These are *Phytophthora* foot rot caused by the fungus *Phytophthora capsici* and slow decline (slow wilt/pepper yellows), mainly due to plant parasitic nematodes, *Meloidogyne incognita* and *Radopholus similis*. Nematode problems in black pepper were reviewed recently (Ramana, 1991; Ramana et al., 1993; 1994).

Nematodes associated with black pepper

Plant parasitic nematodes belonging to 30 genera and 54 species were reported in association with black pepper in various countries (Table 13.1). *M. incognita, R. similis, Helicotylenchus* sp., *Rotylenchulus reniformis* and a new semi endoparasitic nematode, *Trophotylenchulus piperis* are the major nematodes associated with the crop in India Kumar et al., 1971; Venkitesan, 1972; Jacob and Kuriyan, 1979; Sundararaju et al., 1979; Ramana and Mohandas, 1987; 1989). Sher and others (1969) reported *Tylenchulus semipenetrans* on black pepper in Thailand and also mentioned that *Meloidogyne* spp., *T. semipenetrans* and *R. reniformis* were more prevalent than *R. similis* on black pepper in Thailand. *M. incognita, Xiphinema* sp., *Helicotylenchus* sp. and *Macroposthonia onoensis* were the most common nematodes on black pepper in Para, Brazil (Freire and Monteiro, 1978).

Table 13.1. Plant parasitic nematodes associated with black pepper, *Piper nigrum* L

Sl.No.	*Nematode species*	*Reference**
1.	*Acontylus* sp.	39
2.	*Aglenchus* sp.	24
3	*Aphelenchoides* sp.	17, 24, 30
4.	*A. dactylocerus*	38
5.	*Aphelenchus* sp.	30, 39
6.	*Aphelenchus avenae*	30
7.	*Aphelenchus isomerus*	38
8.	*Basirolaimus columbus* (= *Hoplolaimus columbus*)	24
9.	*B. indicus* (= *Hoplolaimus indicus*)	36
10.	*B. seinhorsti* (= *H. seinhorsti*)	24
11.	*Criconemoides* sp.	24, 39
12.	*Diphtherophora* sp.	24, 30
13.	*Discocriconemella limitanea*	17
14.	*Ditylenchus* sp.	24, 30
15.	*Dolichodorus* sp.	17
16.	*Helicotylenchus* sp.	15, 27, 24, 27, 28, 30, 39
17.	*H. abunaamai*	32, 36
18.	*H. dihystera*	17, 36

(Contd.)

Sl.No.	Nematode species	Reference*
19.	*H. erythrinae*	10, 24
20.	*H. paracanalis* (= *H. trivandranus*)	19
21.	*H. pseudorobustus*	36
22.	*Hemicriconemoides gaddi*	14
23.	*H. mangiferae*	24
24.	*Hemicycliophora* sp.	15, 30
25.	*Heterodera* sp.	15
26.	*H. marioni*	24
27.	*Hoplolaimus* sp.	15, 24, 30, 39
28.	*Longidorus* sp.	30, 39
29.	*Macroposthonia onoensis*	27
30.	*M. ornata*	24
31.	*Meloidogyne* sp.	1, 2, 11, 12, 23, 24, 37
32.	*M. incognita*	9, 14, 15, 17, 18, 27, 28, 30, 31, 36, 39, 40
33.	*M. javanica*	8, 14, 16, 31
34.	*Neolobocriconema braziliense* (= *Merocriconema braziliense*)	21
35.	*Paratylenchus* sp.	30
36.	*P. leptos*	20
37.	*Pratylenchus* sp.	12, 14, 24, 39
38.	*P. coffeae*	12, 13, 14, 32
39.	*Radopholus similis*	3, 4, 5, 6, 11, 12, 14, 15, 22, 24, 25, 26, 28, 35, 39, 40
40.	*Rotylenchoides variocaudatus*	7
41.	*Rotylenchulus reniformis*	11, 14, 15, 17, 24, 30, 36, 39
42.	*Rotylenchus* sp.	30
43.	*Scutellonema* sp.	24, 39
44.	*S. siamens*	30
45.	*Trichodorus* sp.	17
46.	*Trophotylenchulus piperis*	33, 34, 39, 40
47.	*Tylenchulus semipenetrans*	11
48.	*Tylenchorhynchus* sp.	24, 39
49.	*T. clarus*	36
50.	*T. mashhoodi*	36
51.	*Xiphinema* sp.	23, 24, 30, 39
52.	*X. elongatus*	24
53.	*X. radicicola*	24
54.	*X. vulgare*	17, 29, 36

* 1. Delacroix, 1902; 2. Butler, 1906; 3. Goodey, 1936; 4. Van der Vecht, 1950; 5. Christie, 1957; 6. Hubert, 1957; 7. Luc, 1960; 8. Holliday and Mowat, 1963; 9. Nadackal, 1964; 10. Goodey et al, 1965; 11. Sher et al., 1969; 12. D'Souza et al., 1970; 13, 14. Kumar et al., 1971a & B; 15. Venkitesan, 1972; 16. Winoto, 1972; 17. Sharma and Loof, 1974; 18. Ichinohe, 1975; 19. Mohandas, 1975; 20. Raski, 1975; 21. Raski and Pinochet, 1975; 22. Koshy and Sosamma, 1975; 23. Ting, 1975; 24. Reddy, 1977; 25. Koshy et al., 1978; 26. Bridge, 1978; 27. Freire and Monteiro, 1978; 28. Jacob and Kuriyan, 1979b; 29. Loof and Sharma, 1979; 30. Sundararaju et al., 1979a; 31. Razak, 1981; 32. Routaray and Das, 1982; 33. Mohandas and Ramana, 1982; 34. Mohandas et al., 1985; 35. Gnanapragasam et al., 1985; 36. Ray and Das, 1985; 37. Leong, 1986; 38. Rashid et al., 1986; 39 and 40. Ramanna and Mohandas, 1987; 1989a.

A. Root knot nematode (*Meloidogyne* spp.)

The root knot nematode (*Meloidogyne* sp.) was the first nematode recorded on black pepper (Delacroix, 1902). In India its association with black pepper in Waynad, Kerala was first reported by Butler (1906) and later by Ayyar (1926) as *Heterodera radicicola*. The occurrence of this nematode on black pepper was also reported from other pepper growing countries like Malaysia (Holiday and Mowat, 1963; Winoto, 1972; Ting, 1975; Razak, 1981), Brazil (Sharma and Loof, 1974; Ichinohe, 1975), Indonesia (Ichinohe, 1976), Thailand (Sher et al., 1969), Fiji (Swaine, 1971) and Guyana (Biessar, 1969). Out of three species of *Meloidogyne* (*M. incognita, M. javanica and M. arenaria*) reported on black pepper in Malaysia (Kueh, 1975), *M. incognita* is the predominant species (Siti Hajijah, 1993). *M. incognita* population in black pepper gardens reaches maximum during December/January (Ramana, 1992).

B. Burrowing nematode (*Radopholus similis*)

Black pepper was first recorded as a host of *R. similis* (*Anguillulina oryzae*) by Goodey (1936). Association of this nematode with yellow disease of black pepper was first reported in Bangka Islands, Indonesia (Van der Vecht, 1950). In India this nematode was first recorded on black pepper by D'Souza and others (1970). Subsequently its wide spread occurrence in black pepper plantations was reported from India (Kumar et al., 1971; Venkitesan, 1972; Koshy et al., 1978; Jacob and Kuriyan, 1979; Ramana and Mohandas, 1987; 1989), Thailand (Sher et al., 1969), Malaysia (Reddy, 1977) and Sri Lanka (Gnanapragasam et al., 1985).

R. similis completes its life cycle within 25 days at a temperature range of 25-28°C (Geetha, 1991). The two morphologically indistinguishable races of *R. similis,* viz. 'banana race' infecting banana but not citrus and 'citrus race' infecting citrus and banana, were proved as sibling species. The 'citrus race' has been elevated to a new species, *R. citrophilus* based on morphological, cytological and host range differences (Huettal et al., 1984). *R. similis* populations of black pepper in India have chromosome number $n = 4$ and belong to the 'banana race' (Koshy, 1986; Jasy, 1991; Ramana, 1992). *R. similis* population is low during summer months (April/May) and starts building up from June/July and reaches the peak during September/October. These population fluctuations are positively correlated with rainfall and negatively correlated with soil temperature (Mohandas and Ramana, 1988).

C. Pepper nematode (*Trophotylenchulus piperis*)

This nematode, a semiendoparasite is wide spread in all major black pepper growing areas in Kerala (Ramana and Mohandas, 1987) and Karnataka (Ramana and Mohandas, 1989). It was initially identified as *Trophotylenchulus floridensis* (Mohandas and Ramana, 1982) and was subsequently raised to a new species, *Trophotylenchulus piperis* (Mohandas et al., 1985). Necrosis and general drying of the root tissues are observed at regions where *T. piperis* females are found attached to pepper roots. Further studies to understand the nature of damage and nematode-host interaction on black pepper are in progress at National Research Centre for Spices, Calicut, India.

Nature of damage

Gradual decline and foliar yellowing are the predominant symptoms of root knot nematode infestation. Leaves exhibit dense yellowish discolouration of the interveinal areas (interveinal chlorosis) (Ramana, 1991; Ramana et al., 1994). In addition, Kueh (1979; 1990) observed that leaves were held inward and upward and wound fall commencing from older leaves resulting in a vine with few climbing stems and a few discoloured leaves. Roots of infested plants show varying degrees of galling. Typical galls or knots are seen on secondary and fibrous roots and as elongated swelling on thick primary roots. Adult females with egg masses are generally enclosed deep within the roots (Ramana, 1992; Ramana et al., 1994). Histopathological studies showed that *M. incognita* occupied the stelar portion of the roots. Two weeks after inoculation, the fourth stage juveniles were found to feed on the giant cells. One month after inoculation the giant cell occupied almost the entire portion of the stele and vascular system was damaged (Mustika, 1990).

Accumulation of high concentration of total phenols in plants inoculated with *M. incognita* was reported though no resistance to nematode was exhibited by these plants (Ferraz et al., 1984). Further, Ferraz and others (1988) found significant reduction in absorption and translocation rates of P, K, Zn, Mn, Cu with accumulation of Ca and Mg, but showed no differences in Fe levels in the leaves of pepper plants inoculated with *M. incognita*. They also found that the total chlorophyll content of leaves was significantly reduced in plants inoculated with *M. incognita* implying less growth of infected plants. Plants showing signs of nutrient exhaustion dropped part of leaves as a mechanism to ensure food supply for the remaining leaves and therefore to survive. The possible changes in host physiology and nutrition and leaf senescence are factors that could account for reduced chlorophyll content in diseased plants. Further, senescence itself could be caused by growth regulator imbalance and host nutritional deficiency (Ferraz et al., 1989). Freire and Bridge (1985b) observed several changes in the levels of aminoacids, organic acids and sugars in the plants infected with *M. incognita*.

R. similis penetrates roots through root tips and cortical cells surrounding the nematode turn necrotic and some xylem vessels were plugged with gum like substances. Nematodes take feeding position intercellularly and intracellularly making tunnels in the cortical tissues (Venkitesan, 1976; Venkitesan and Setty, 1977; Freire and Bridge, 1985a). Necrotic lesions are more visible on white feeder roots. Subsequently the lesions merge and encircle the root cortex leading to disintegration of distal portion of the roots. Occasionally the nematode infects the underground portion of the stem, particularly the rooted cuttings in the nursery (Ramana et al., 1994). Damage caused to the roots directly affects vigour and productivity of the vines. Foliar yellowing and defoliation are the main above ground symptoms expressed by the vines infected with *R. similis*. Ichinohe (1976) observed that in vines infected with *R. similis*, the leaves were pale yellow, whitish and the hanging leaves curled inwards. Venkitesan and Setty (1977) reported that black pepper plants inoculated with *R. similis* @ 1000 and 10,000 showed wilt symptoms after 90 days and all succumbed within 118 days of inoculation. Mohandas and Ramana (1991) reported foliar yellowing and defoliation were severe in the vines inoculated with *R. similis* alone or in combination with *M. incognita* and these symptoms were more pronounced in summer months.

Experiments conducted under artificial inoculation with *M. incognita* showed varying degrees of reduction in the growth of pepper vines. An initial inoculum of 10 second stage juveniles of *M. incognita* was found to reduce growth by 16% while at the level of 100,000 nematodes 50% reduction in the growth of rooted seedlings was observed over a period of one year (Koshy et al., 1979). This nematode was reported highly pathogenic at 100-10,000 per seedling (Freire and Bridge, 1985c). In Indonesia, 'yellows' symptoms appeared in plants having a population level 47/100 g soil and 350/10 g roots of *M. incognita* (Mustika, 1978). Adult vines grown under stimulated field condition showed significant reduction in height (5.44 to 20.34%), number of primary shoots (13.43 to 22.2%), and dry weights of shoot (12.21 to 52.26%), leaf (2.48 to 32.35%) and root (14.54 to 32.8%) and yield (12.82 to 46.9%) with the initial inoculum levels ranging from 100 to 100,000 nematodes/plant (Mohandas and Ramana, 1991). Further, foliage yellowing and defoliation were maximum in vines inoculated with higher inoculum levels (> 10,000 nematode/plant). Similar reduction in the growth of pepper vines due to root knot nematodes were reported by others also (Winoto, 1972; Jacob and Kuriyan, 1979c). In Sri Lanka, Lamberti and others (Lamberti et al., 1983) reported that *Hoplolaimus seinhorstii, Xiphinema ifaeolum, M. arenaria, M. incognita* and *M. javanica* caused significant reduction in the growth of black pepper vines.

Pathogenicity tests with *R. similis* on black pepper vines grown in microplots under simulated field conditions showed that the nematode is highly pathogenic to black pepper and caused significant reduction in the growth and yield of the vines with initial population (Pi) 100 to 10,000 nematodes (height 0.21 to 19.63%, number of primary shoots 13.23 to 56.61%, dry weights of shoot 24.74 to 60.83%, leaf 25.34 to 77.12%, root 34.37 to 81.86%, yield 0.30 to 59.47%) (Mohandas and Ramana, 1991).

The onset of yellows diseases in Sumatra, Indonesia is correlated with *R. similis* population of 2/100 g soil and 25/10 g roots (Mustika, 1978). In India a minimum population of 250 nematodes/g roots was consistently recorded with slow decline affected pepper vines. Black pepper vines at all stages of growth and susceptible to the nematode infestation (Ramana, 1992). *R. similis* infestation restricted the development and multiplication of *M. incognita* (Sheela and Venkitesan, 1981; Mohandas and Ramana, 1991).

Economic importance

Nematode infestations often assume alarming proportion leading to 'slow decline', a debilitating disease in black pepper plantations. Mild to moderate foliar yellowing at different regions of the affected vine is the initial aerial symptom of slow decline disease. With the advancement of the disease, the infected vines show defoliation and die back leading to loss of vigour, yield and finally death of the vine. Vines in the early stages of the disease look apparently normal with the onset of monsoon, but foliar yellowing becomes more pronounced with the depletion of soil moisture in summer season (Mohandas and Ramana, 1987; 1991; Ramana et al., 1994). This disease was first reported by Van der Vecht (1950) as 'pepper yellows' on the islands of Bangka, Indonesia and *R. similis* was reported as responsible for the disease. Later Christie (1957) reported this nematode was responsible for the death of 20 million pepper vines. Further, Sitepu and Kasim (1991) reported that this disease causes upto 32% loss in Indonesia. In Para, Brazil, about 90 per cent of black pepper vines were infected with root knot nematodes, mostly *M. incognita* (Ichinohe, 1975). In Guyana, about 30% vines were destroyed by similar disease (Biessar, 1969). Experimental evidence showed that black pepper yields could be increased by 50% by controllong nematode infestation through nematicidal applications (Kueh, 1978; Davide, 1985). Though exact crop losses in India are not available, this disease is prevalent in all major black pepper growing areas and the nematodes, *M. incognita* and *R. similis* are associated with the disease vines (Ramana et al., 1987a; 1994; Ramana, 1991). Yield losses ranged from 38.5 to 64.6% when pepper vines were inoculated with *R. similis, M. incognita* alone or in combinations under simulated field conditions (Mohandas and Ramana, 1991).

Interaction with other organisms

Though slow decline is primarily attributed to infestation by *R. similis* and *M. incognita* (Van der Vecht, 1950; Christie, 1957; Hubert, 1957; Ting, 1975; Ichinohe, 1976; Nambiar and Sarma, 1977; Venkitesan and Setty, 1977; Mustika, 1978; Ramana et al., 19787a; Mohandas and Ramana, 1991). other microorganisms particularly fungi were reported in association of the disease. Hubert (1957) and Bridge (1978) opined that though *R. similis* is primarily responsible for the disease, in association with fungus like *Fusarium* sp. is necessary to cause 'yellows' disease. Winoto (1972) also observed that plants infested with root knot nematodes were more susceptible to *Phytophthora* infections. However, Holiday and Mowat (1963) could not find any relation between *M. javanica* infestation and foot rot caused by *Phytophthora palmivora* in pepper plantations in Sarawak, Malaysia.

Several attempts were made to assess the role of *Fusarium* spp. in association with nematodes in causing slow decline disease in black pepper. An Indonesian isolate of *R. similis* predisposed black pepper seedlings to attack by a weak pathogenic isolate of *Fusarium solani* resulting in severe root damage (Freire, 1982). A synergistic effect with root knot nematode, *R. similis* and *Fusarium* sp. on reduction in growth of pepper vines and increase in severity of foliar yellowing was observed (Lopes and Lordello, 1979; Hamada et al., 1985; Sheela and Venkitesan, 1990; Mustika, 1990, 1992). The fungus also showed antagonistic effect on the multiplication and production of root galls by *M. incognita* (Sheela and Venkitesan, 1990; Mustika, 1992). Varughese and Anuar (1992) also reported the association of *Pythium* sp. and *Fusarium* sp. with the roots of slow decline affected vines in Malaysia. In India, presence of *Fusarium* sp., *Rhizoctonia bataticola* and *Pythium* sp. in the roots of slow decline affected vines was reported by Nambiar and Sarma (1977). However, the possible role of *Fusarium* sp. in the slow decline disease complex could not be established in India (Ramana et al., 1992).

Experiments conducted in microplots under simulated field conditions to assess the role of *M. incognita, R. similis* and *P. capsici* in slow decline disease showed that *R. similis* and *P. capsici* alone or in association and *M. incognita* in association with either *R. similis* or *P. capsici* or both resulted in root rotting leading to typical slow decline disease (Anandaraj et al., 1991).

Besides biotic factors, abiotic factors such as nutrients, soil moisture, etc. are also reported to enhance the severity of the disease. Nambiar and Sarma (1977) opined that the disease is complex involving nematode - fungal interaction coupled with nutrient deficiency and soil moisture stress. de Waard (1979) considered this disease was mostly due to nutrient deficiency and nematodes are of secondary importance causing the death of physiologically weakened vines and the disease could be controlled by application of fertilizers consisting N, P, K, Ca and Mg along with mulch. Wahid and others (1982) also stated that foliar yellowing and necrosis of distal ends of leaf margins in slow decline affected vines were due to N and K deficiency respectively.

Ferraz and Sharma (1979) found *M. incognita* alone and in combination with *Rotylenchulus reniformis* had a highly pathogenic effect on the growth of rooted cuttings of black pepper and *R. reniformis* had an inhibitory effect on the multiplication of *M. incognita.* Sheela and Venkitesan (1981) reported that simultaneous inoculation of *R. similis* and *M. incognita* suppressed the plant growth to the maximum extent. Root knot nematode population buildup was adversely affected under combined inoculation.

Nematode management

Since plant parasitic nematodes cause extensive damage to feeder roots, leading to slow decline either independently or in association with certain fungi, nematode management in black pepper acclaims a prime place. Since nematodes cannot be eliminated in a perennial crop like black pepper, the general goal is to keep the nematode populations as low as possible. Efficient management requires carefully integrated combination of several practices.

A. Use of nematode free planting materials

Pepper rooted cuttings are more susceptible to nematode infestation and planting infested cutting gradually increases the nematode population in the plantation and leads to the incidence of slow decline disease. Nurseries are more ideal sites for adoption of any nematode management measures and therefore production of healthy, nematode-free planting materials should be given high priority (Sarma et al., 1987). For large scale production of nematode free planting materials, nursery soil mixture should be sterilized with solar heat, steam or soil fumigants (Ramana et al., 1994).

Promising isolates of biocontrol agents like vesicular arbuscular mycorrhizae viz., *Glomus mossae, G. fasciculatum, Acaulospora laevis, Gigaspora margarita,* which are suppressive of nematodes on black pepper (Anonymous, 1991; Anandaraj et al., 1991) can be incorporated with the nursery soil mixture for better establishment and production of nematode free planting materials. Besides, use of nematicides like phorate 10 G (1g/plant) or carbofuran 3 G (3 g/plant) is also recommended to bring down the nematode population in the nursery (Mohandas and Ramana, 1987).

B. Cultural

Ichinohe (1985) suggested a combination of nematicide treatment (Temik 12.5 g or Furadan 50 g per cutting), mulching with Guatemala grass (*Imperata cylindrica*) around the pepper cuttings at planting and also growing non host cover plants such as 'Siratro' (*Macroptilium atropurpureus*) with occasional trimming for better growth in black pepper plantations infested with *M. incognita.*

C. Host resistance

Developing genetically resistant to tolerant black pepper varieties is the best alternative for effective nematode management. Attempts were made to identify resistant/tolerant genotypes of black pepper to nematodes (Venkitesan and Setty, 1978; Koshy and Sundararaju, 1979; Jacob and Kuriyan, 1979a; Leong, 1986; Paulus et al., 1993). Standardised methodologies were developed for screening of black pepper germplasm against nematodes (Ramana and Mohandas, 1989b). Ramana and Mohandas (1986) identified a black pepper cultivar resistant to *M. incognita* that has good yield potential (Ravindran et al., 1992), but no cultivar was found resistant/tolerant to *R. similis* in India (Venkitesan and Setty, 1978; Ramana et al., 1987b). One variety PW14 was reported as totally immune to *R. similis* in Sri Lanka (Gnanapragasam, 1989).

A wild related species, *P. colubrinum* is resistant to both *M. incognita* and *R. similis* (Ramana et al., 1994). Efforts should be made to identify gene(s) responsible for resistance to these nematodes in *P. colubrinum* and transfer them to high yielding cultivars using modern biotechnology tools.

In India, a variety of plant species are used as live standards for trailing black pepper vines. Susceptibility of these live standards to nematodes is also important as susceptible plant species contribute to nematode build up in the plantations. *Ailanthus malabaricus, Artocarpus heterophyllus, A. hirsutus, Mesopsis emini, Peltophorum pterocarpum, Swietenia macrophylla, Tamarindus indica* (Ramana, 1986), *Garuga pinnata, Macaranga indica* are resistant/non hosts of *M. incognita. Erythrina indica, Garuga pinnata* and *Macranga indica* are comparatively less susceptible to *M. incognita* and can be used as standards for black pepper (Koshy et al., 1977). Almost all the plant species cited were susceptible to *R. similis.* Coconut (*Cocos nucifera*) and Arecanut (*Areca catechu*) that are commonly used for trailing black pepper vines in India are known hosts of both *M. incognita* and *R. similis.*

Associated crops grown in black pepper gardens also influence the nematode population in the fields. In India, black pepper is mostly grown as mixed crop. Ginger, turmeric, elephant - foot yam and banana are some of the crops grown in pepper gardens which are very good hosts of *M. incognita* and *R. similis.* These crop combinations are ideal for population build up of the nematodes and black pepper may become more vulnerable to nematodes in such crop combinations. This aspect is more important in management of nematodes in black pepper.

D. Biological

Efficiency of biological control agents as the sole means of nematode management is still debatable. The present consensus is that it should form an integral part of a complete management approach with other methods. A variety of microorganisms inhibit rhizosphere along with plant parasitic nematodes and some of these are known to parasitize or predate on nematodes. Manjunath and

Bagyaraj (1982) reported the occurrence of vesicular arbuscular mycorrhizae (VAM) on black pepper roots. The beneficial effects of VAM on black pepper were also reported (Shivashanker and Rohini, 1988; Bopaiah and Khader, 1989). Anandaraj and others (1991) found significant increase in growth of pepper vines and reduction in root-knot nematode (*M. incognita*) infestation and multiplication when the plants were challenged by VAM fungi viz. *Glomus mossae, G. fasciculatum, Acaulospora laevis* and *Gigaspora margarita*. *G. fasciculatum* was also found to suppress the infestation by *R. similis* and the pathogenic fungus *P. capsici* on black pepper (Anonymous, 1991).

Similarly inoculation of pepper rooted cuttings with *Glomus fasciculatum* or *G. etunicatum* reduced root knot nematode (*M. incognita*) population in the root and rhizosphere soils (Sivaprasad et al., 1990; 1992).

Ramana and Sarma (1994) found *Paecilomyces lilacinus* suppressed nematode infestation in black pepper and increased the production of root mass. Freire and Bridge (1985) found high infestation of eggs of *M. incognita* by *P. lilacinus* and *Verticillium chlamydosporium* under artificial inoculation but to a lesser extent in the egg mass from the roots of black pepper inoculated with the fungi. *Nectria haematococca* f.sp. *piperis* and *Phytophthora palmivora* also infected a few eggs.

Bacillus pumilis, B. macerans and *B. circulans* significantly reduced *M. incognita* population and improved the growth of black pepper plants (Sheela et al., 1993).

Application of neem cake @ 2 kg/vine was highly effective against *M. incognita* than *R. similis* Ramana et al., 1992). Jasy and Koshy (1992) reported that leaf extracts of *Glyricidia maculata, Ricinus communis* and *Crotalaria juncea* were lethal to *R. similis* at dilution of 1:5 within 24 hours. Addition of chopped leaves of *G. maculata* (10 g/kg soil) as green manure reduced population of *R. similis* and increased growth of black pepper in pot culture studies (Jasy and Kosby, 1992). Aqueous leaf extracts of *Chromolaena odoratum, Piper colubrinum,* all spice, etc. were also reported to exhibit nematicidal properties against *M. incognita* population of black pepper (Anonymous, 1993; 1994).

E. Chemical

Nematicides are important and reliable means of controlling nematodes. Various nematicides like phenamiphos @ 20 g/vine (Nambiar and Sarma, 1977), aldicarb sulphone @ 8 kg/ha (Venkitesan and Setty, 1979). Phorate, carbofuran and aldicarb @ 3 g a.i./vine (Venkitesan and Charles, 1979; Venkitesan and Jacob, 1985; Mohandas and Ramana, 1987; Ramana, 1992) are effective in controlling nematodes infecting black pepper in India. In Malaysia, carbofuran @ 114 g/vine (Kueh and Teo, 1978) and phenamiphos and oxamyl (Kueh, 1979) were effective for the control of root-knot nematodes. Leong (1986) reported that fenamiphos @ 1% a.i. was most effective in controlling root-knot nematodes followed by carbofuran and ethoprophos in Sarawak, Malaysia. Similarly, in Indonesia nematicides like Shell DD, Vapam EC, Nemagon 75 EC, Temik 10 G, Furadan 3G, Nemacur 5G, Mocap 10G, Hostathion 5G, Dasanit 5G and Basudin 60 EC were all effective to control nematodes of black pepper (Mustika and Zainuddin, 1978), In Brazil, Ichinohe (1980) found application of Temik 10G @ 12.5 G or Furadan 5G @ 50 g/plant twice a year reduced nematode population and improved the growth. Mustika and others (1984) stated that the severity of pepper yellows was reduced by application of fertilizer (NPK 15:15:15) at 250 g/plant/year and either with aldicarb (50 g/plant) of mancozeb (12 g/plant) or both since the disease can be caused by a multiple attack by nematodes (*M. incognita* and *R. similis*) and *Fusarium oxysporum*.

In view of the inseparable nature of plant parasitic nematodes and *P. capsici* under field conditions, particularly in India, a combination of a nematicide and a fungicide is recommended for a better control of the disease complex in black pepper (Anonymous, 1991).

CARDAMOM

Cardamom (*Elettaria cardamomum* Maton), the 'Queen of spices' is cultivated in an area of about 71,000 ha in the western ghats of India. Plant parasitic nematodes are recognized as an important problem in cardamom plantations and nurseries.

Nematodes associated with cardamom

Plant parasitic nematodes belonging to 20 genera are reported on cardamom (Table 13.2). Among these, the most important and more widely distributed are the root knot nematodes, *Meloidogyne* spp. *Pratylenchus* spp. is commonly seen in cardamom + coffee mixed plantations while *Radopholus similis* is prevalent in cardamom + areca mixed gardens. Among the three root knot nematode species observed in cardamom plantations and nurseries, *M. incognita* is the predominant species (Koshy et al., 1976; Ali and Koshy, 1982b; Ali, 1984; 1986a). The root knot nematode population

Table 13.2. Plant parasitic nematodes associated with cardamom, *Elettaria cardamomum* Maton

Sl.No.	Nematode species	Reference*
1.	*Aphelenchoides* sp.	9
2.	*Criconema cardamomi* (= *Nothocriconema cardamomi*)	5
3.	*C. coorgi* (= *N. coorgi*)	5
4.	*Criconemella cardamomi*	14
5.	*Discocriconemella elettaria*	14, 15
6.	*Helicotylenchus* sp.	9
7.	*H. dihystera*	6
8.	*H. multicinctus*	6
9.	*Hemicriconemoides gaddi*	6
10.	*Hemicycliphora* sp.	17
11.	*H. argiensis*	5
12.	*Hoplolaimus* sp.	9
13.	*Meloidogyne* sp.	1, 15
14.	*M. arenaria*	11
15.	*M. incognita*	3, 6, 8, 9, 10, 11, 12, 13
16.	*M. javanica*	3, 10, 16
17.	*Ogma taylata* (= *Homogma taylata* and *Crossonema taylata*)	7
18.	*Paratrichodorus* sp.	15
19.	*Pratylenchus* sp.	6, 9, 15
20.	*P. coffeae*	1, 2, 3, 4, 6
21.	*Radopholus similis*	1, 3, 6
22.	*Rotylenchus* sp.	6
23.	*Rotylenchulus reniformis*	3, 6
24.	*Scutellonema* sp.	16
25.	*Trichodorus minor*	6
26.	*Tylenchorhynchus* sp.	6
27.	*Xiphinema* sp.	6

* 1. D'Souza et al., 1970; 2 and 3, 14. Kumar et al., 1971a & b; 4. Kumar and Vishwanathan, 1972; 5. Khan and Nanjappa, 1972; 6. Vishwanathan et al., 1974; 7. Khan et al., 1975; 8. Koshy et al., 1976; 9. Sundararaju et al., 1979a; 10. Ali and Koshy, 1982b; 11 and 12. Ali, 1984, 1986a; 13. Raut and Pande, 1986; 14. Sharma and Edward, 1986; 15. Agnihothrudu, 1987; 16. Lopez and Salazar, 1988; 17. Koshy and Bridge, 1990.

in cardamom plantations showed typical population fluctuation patterns. In roots their level is highest during the post monsoon period (November-January), while in soil maximum of second stage juveniles are seen during March-April month (Eapen, 1993).

Nature of damage and economic importance

The general symptoms of nematode attack in cardamom nurseries and main fields are patches of stunted and weak plants. The leaves show varying degrees of chlorosis, narrowing and drying at leaf tips and margins. Tillering and capsule production are severely hampe d. Root knot nematode infestation in nurseries causes more than 50 per cent reduction in germination (Ali and Koshy, 1982a). About 40 per cent of such seedlings fail to establish in secondary nurseries (Koshy and Bridge, 1990). Root system of infested plants shows varying degrees of root galling. It is observed that young seedlings are more susceptible to root knot nematode attack than mature plants (Eapen, 1992). Microplot studies under simulated field conditions showed 46.6% yield loss at an initial inoculum level of 4 nematodes/100 cm^3 soil (Eapen, 1994).

Interaction with other organisms

M. incognita is the predisposing factor to *Rhizoctonia solani* infection, causing damping off and rhizome rot, prevalent in cardamom nurseries (Ali and Venugopal, 1992; 1993). Cardamom plants infected with "Katte" disease (a virus disease) supported 5-10 times more *M. incognita* population, which may further reduce their economic life span (Ali, 1989).

Nematode management

A. Cultural

In view of the wide spread prevalence of root knot nematodes in cardamom nurseries, use of nematode-free planting materials is very much essential in cardamom cultivation. Soil fumigation or soil solarization of nursery sites and random rotation of nursery sites are found highly effective (Ali and Koshy, 1982a; Anonymous, 1993; 1994). Nursery sanitation also should be given high priority.

B. Host resistance

The popular cardamon types, Malabar, Mysore and Vazhuka are susceptible to root knot nematodes. Several accessions of cardamom have been screened against root knot nematode using standardized techniques (Eapen, 1990). None of them were found resistant or tolerant to root knot nematodes (Anonymous, 1993; 1994; Hedge et al., 1993).

C. Biological

Paecilomyces lilacinus and *Trichoderma* spp. were effective in suppressing root knot nematodes in both pot studies and field trials (Anonymous, 1993; 1994; Eapen and Venugopal, 1995). Vesicular arbuscular mycorrhizae (VAM) viz., *Gigaspora margarita* and *Glomus fasciculatum* suppressed *M. incognita* and improved the growth and vigour of cardamom seedlings (Thomas et al., 1989).

D. Chemical

Frequent application of nematicides has to be followed in nematode infested cardamom nurseries and 'sick patches' of plantations. Aldicarb, carbofuran, fenamiphos and phorate @ 5-10 kg a.i./ ha were found to reduce the root knot nematode population and improved the growth and vigour of cardamom seedlings (Koshy et al., 1979b; Jacob and Chandrasekharan, 1982; Ali, 1986b; 1987b).

In plantations, application of phorate @ 2.5-5.0 g a.i./plant reduced the nematode incidence and increased the yield by more than 40% (Ali, 1987a; Anonymous, 1993).

GINGER

Ginger of commerce is the dried underground stem or rhizome of the zingiberous, herbaceous plant, *Zingiber officinale* Rosc. In India, it is cultivated in an area of 58,000 ha. During 1993-94 India earned Rs. 2158 lakhs through export of 17,150 MT of ginger.

Nematodes associated with ginger

Several plant parasitic nematodes have been recorded from ginger (Table 13.3). However, the most important nematode pests are root knot and burrowing nematodes. Root knot nematode infestation in ginger was first reported by Nagakura (1930) while Hart (1956) reported parasitism by *Radopholus similis*. Occurrence of *R. similis* along with *M. incognita, Pratylenchus* sp. and *Helicotylenchus* sp. has also been reported from India (Charles, 1978; Charles and Kuriyan, 1979; Anonymous, 1993).

Nature of damage and economic importance

Stunting, chlorosis, poor tillering and necrosis of leaves are the common symptoms of nematode infestation. The affected plants mature and dry faster than healthy ones, resulting in a poor crop stand. Root knot nematodes cause galling and rotting of roots and underground rhizomes. Fresh roots are invaded along the entire length, while in fibrous roots it is in the area of differentiation. Infested rhizomes have brown, water soaked areas in the outer tissues (Huang, 1966; Cheng and Tu, 1979). *Radopholus similis* produce small, shallow, sunken, water soaked lesions on roots (Vilsoni et al., 1976; Sundararaju et al., 1979b). *Pratylenchus coffeae* infestation caused yellowing of leaves (Kaur and Sharma, 1990). Rhizomes with dry rot symptoms yielded *Pratylenchus* sp. also.

Abnormal xylem and parenchyma with thickened cell walls are observed in all root knot nematode infested tissues except in rhizome meristems (Routaray et al., 1987a). *M. incognita* entered the cortex and stelar regions forming giant cells (Lanjewar and Shukla, 1988). These giant cells showed karyotic nuclear divisions and had thickened cell walls. Corky wounds are found at infection sites in differentiated rhizomes and fresh roots (Huang, 1966; Shah and Raju, 1977). The burrowing nematodes migrate intracellularly producing large infection channels or galleries within the rhizomes (Vilsoni et al., 1976).

M. incognita is widely distributed in ginger fields and causes a loss of 46.4% (Charles, 1979) and 74% reduction in rhizome weight under artificial inoculation studies (Parihar, 1985; Sudha and Sundararaju, 1986). The economic threshold levels of root knot nematode in ginger have been reported as one infective juvenile of *M. incognita* per 30 g soil (Sudha and Sundararaju, 1986), 50 larvae of *M. incognita* and *M. hapla* per 100 ml soil (Kaur, 1987) and two nematodes per gram soil (Parihar and Yadav, 1986; Routaray et al., 1987a)to cause significant reduction in growth and yield. *M. arenaria* is also highly pathogenic to ginger (Kaur and Sharma, 1988). An initial level of 10 *R. similis* caused 39.8% reduction in rhizome weight (Sundararaju et al., 1979b). *P. coffeae* is reported to cause 'ginger yellows' disease (Kaur and Sharma, 1990). Their highly pathogenic nature and reports of interaction with other microorganisms in causing disease complexes make them important pests of ginger.

Interaction with other organisms

Rhizome rot incidence in ginger is reported to be severe when rhizomes are infested with nematodes like *M. incognita* or *P. coffeae* (Dohroo et al., 1987). However no interaction has been observed

Table 13.3. Plant parasitic nematodes associated with gingers, *Zingiber officinale* Rosc

Sl No	Nematode species	Reference*
1.	*Aphelenchoides tenuicaudatus*	2
2.	*Aphelenchus avenae*	21
3.	*Basirolainus indicus* (= *Hoplolaimus indicus*)	25, 26
4.	*B. seinhorsti* (= *H. seinhorsti*)	25
5.	*Bitylenchus vulgaris* (= *Tylenchorhynchus vulgaris*)	12
6.	*Caloosia* sp.	13
7.	*C. exilis*	26
8.	*Helicotylenchus* sp.	22, 23, 24, 31
9.	*H. abunaamai*	25, 26
10.	*H. dihystera*	21, 26
11.	*H. erythrinae*	21
12.	*H. pseudorobustus*	26
13.	*H. serenus*	25
14.	*Hemicrinonemoides cocophilus*	26
15.	*Hemicycliphora* sp.	24
16.	*Longidorus* sp.	31
17.	*Macroposthonia ornata*	26
18.	*Meloidogyne* sp.	1, 11, 21, 31
19.	*M. acrita* (= *M. incognita acrita*)	7, 21
20.	*M. arenaria*	7, 27
21.	*M. hapla*	30
22.	*M. incognita*	4, 6, 8, 13, 14, 15, 22, 23, 24
23.	*M. javanica*	5, 7
24.	*Pratylenchus* sp.	22
25.	*P. brachyurus*	25
26.	*P. coffeae*	22, 25, 28
27.	*P. indicus*	30
28.	*P. pratensis*	7
29.	*P. zeae*	29
30.	*Radopholus similis*	3, 17, 18, 19, 20, 21, 22, 23
31.	*Rotylenchulus reniformis*	9, 25, 26, 31
32.	*Tylenchorhynchus* sp.	24, 31
33.	*Tylenchulus* sp.	21
34.	*Xiphinema* sp.	31
35.	*X. americanum*	25
36.	*X. basiri*	10, 15
37.	*X. index*	25
38.	*X. insigne*	26

* 1. Nagakura, 1930; 2. Steiner and Buhrer, 1933; 3. Hart, 1956; 4, 5. Colbran, 1958; 1962; 6. Nadakal, 1963; 7. Goodey et al., 1965; 8. Huang, 1966; 9. Swarup et al., 1967; 10. Yadav and Verma, 1967; 11. Kulkarni and Jain, 1969; 12. Upadhyay and Swarup, 1972; 13. Haynes et al., 1973; 14. Mammen, 1973; 15. Roy, 1973; 16. Pegg et al., 1974; 17. Vilsoni, 1974; 18. Butler and Vilsoni, 1975; 19. Vilsoni et al., 1976; 20. Koshy and Sosamma, 1975; 21. Reddy, 1977; 22. Charles, 1978; 23. Charles and Kuriyan, 1979; 24. Sundararaju et al., 1979a; 25. Rama and Dasgupta, 1985; 26. Ray and Das, 1985; 27, 28. Kaur and Sharma, 1988; 1990; 29. Kaur et al., 1989; 30. Koshy and Bridge, 1990; 31. Anonymous, 1993.

with *M. incognita* and *Pythium aphanidermatum* (Doshi and Mathur, 1987), *M. incognita* and *Pythium myriotylum* (Lanjewar and Shukla, 1985). Basal sheath rot, a new disease of ginger is suspected to be caused by the combined infection of *Aphelenchus* spp. and *Fusarium* sp. (Magar and Mayee, 1988). Bacterial wilt of ginger, caused by *Pseudomonas solanacearum* is also influenced by *M. incognita* (Samuel and Mathew, 1983).

Nematode management

A. Physical

Hot water treatment of ginger seed material at 50°C for 10 minutes is found to reduce the nematode incidence (Colbran and Davis, 1969; Anonymous, 1971). Soil solarization was successful in ginger fields for the control of diseases (Balakrishnan et al., 1993). This technology is useful against nematodes also.

B. Cultural

Transmission and spread of nematodes are mainly through infested vegetative seeds (Kulkarni and Jain, 1969). All care should be taken to use nematode-free planting materials. Soil fumigation and planting nematode-free ginger increased the yields (Milne et al., 1979). In South Africa *in vitro* ginger plantlets are used to get rid of root-knot nematode problem (Nel, 1985). Mulching with sawdust (Colbran, 1974) or applying well-decomposed cattle manure or poultry manure or compost or neem cake and mulching with green leaves reduces nematode built up (Kaur, 1987; Sterling, 1989). In Fiji, use of clean seed and a ginger - dalo - fallow rotation are recommended for the control of nematodes (Haynes et al., 1973). Application of neem cake @ 1t/ha before planting increased the yield of ginger in India (Mohanty et al., 1992).

C. Host resistance

No resistant/tolerant lines are identified against any nematode pests of ginger (Charles and Kuriyan, 1982; Routaray and Mohapatra, 1988).

D. Chemical

Soil fumigation (Colbran, 1961; 1962; 1968; Pegg et al., 1974; Milne, 1979) or application of granular nematicides like fenamiphos (Colbran, 1972; Willers, 1985; Kaur, 1987) or dip treatment with fenamiphos (Willers, 1991) also reduced the nematode incidence and increased the yield.

TURMERIC

Turmeric (*Curcuma longa* L) is an important and ancient spice of India. It is cultivated in an area of 128,600 ha mostly concentrated in Andhra Pradesh, Tamil Nadu and Kerala. The annual production of turmeric in India was about 397,400 MT during 1992-93. The export of turmeric during the same period was 25,250 MT worth Rs. 5200 lakhs.

Nematodes associated with turmeric

Among the 35 nematode species associated with turmeric, *Meloidogyne* spp., *Radopholus similis* and *Pratylenchus coffeae* are of economic importance (Table 13.4). Root knot nematode on turmeric was first reported by Ayyar (1926) and is the only nematode that received maximum attention in the past.

Table 13.4. Plant parasitic nematodes associated with turmeric, *Curcuma longa* L

Sl.No.	Nematode species	Reference*
1.	*Aphelenchus* sp.	13
2.	*Aphelenchus avenae*	12
3.	*Basirolaimus columbus* (= *Hoplolaimus columbus*)	17
4.	*B. indicus* (= *H. indicus*)	10, 12, 17
5.	*Bitylenchus brevilineatus*	20
6.	*Criconemella* sp.	18
7.	*Caloosia* sp.	13
8.	*Helicotylenchus* sp.	13, 18, 20
9.	*H. abunaamai*	12, 17
10.	*H. dihystera*	10
11.	*H. multicinctus*	18
12.	*H. pseudorobustus*	10
13.	*Hemicriconemoides cocophillus*	10
14.	*H. mehdii*	16
15.	*Hemicycliophora ulkali*	10
16.	*Hoplolaimus* sp.	8, 13, 22
17.	*Longidorus* sp.	18, 22
18.	*Macroposthonia ornata*	9, 10, 17
19.	*M. sphaerocephala* (= *Criconemella sphaerocephala*)	16
20.	*Meloidogyne* sp.	1, 22
21.	*M. incognita*	3, 8, 11, 13, 14, 17, 20, 21
22.	*M. javanica*	2
23.	*Paratrichodorus* sp.	20
24.	*Pratylenchus* sp.	4, 13, 22
25.	*P. coffeae*	15
26.	*Radopholus similis*	5, 6, 7, 8, 13
27.	*Rotylenchus* sp.	18
28.	*Rotylenchulus reniformis*	10, 13, 17, 20, 21, 22
29.	*Tylenchorhynchus* sp.	13
30.	*Tylenchus* sp.	13
31.	*Xiphinema* sp.	18
32.	*X. basiri*	19
33.	*X. insigne*	17

* 1. Ayyar, 1926; 2. Nirula and Kumar, 1963; 3. Nadakal and Thomas, 1964; 4. Sarma et al., 1974; 5. Koshy and Sosamma, 1975; 6. Vilsoni et al., 1976; 7. Sosamma et al., 1979; 8. Sundararaju et al., 1979a; 9, 10. Ray and Das, 1980; 1985; 11. Patel et al., 1982; 12. Routaray and Das, 1982; 13. Venkitesan and Charles, 1982; 14. Chen et al., 1986; 15. Das and Das, 1986; 16. Muthukrishnan, 1987; 17. Routaray et al., 1987b; 18. Koshy and Bridge, 1990; 19. Rajeswari and Muthukrishnan, 1990; 20. Mani and Sri Hari, 1989; 21. Mani and Prakash, 1992; 22. Anonymous, 1994.

Nature of damage and economic importance

Nematode affected turmeric plants have stunted growth, yellowing, marginal and tip drying of leaves and reduced tillering. Infested plants age, dry faster and die prematurely, leaving a poor crop stand at harvest. Infested rhizomes lose their bright yellow colour (Mani et al., 1987). Root knot nematodes cause galling and rotting of roots. Roots damaged by *R. similis* become rotten and most of these decayed roots retain only the epidermis lacking cortex and stelar portions. Shallow water soaked, brownish areas are seen on the surface of rhizomes. An initial inoculum level of 10 *R. similis* caused 35-46 per cent reduction of rhizome weight (Sosamma et al., 1979).

Significant reduction in growth and yield of turmeric were noticed in plants inoculated with >1000 root knot nematode juveniles/plant (Sudha et al., 1989). Four varieties viz. Suvarna, Suguna, Sudarshana and Alleppey were tested against *M. incognita*. Maximum reduction of fresh rhizome weight (18%) was observed in Suvarna at a Pi = 2 juveniles/g soil (Anonymous, 1993). *Xiphinema basiri* was also found to be pathogenic to turmeric (Rajeswari and Muthukrishnan, 1990).

Nematode management

Though the pathogenic effects of *M. incognita* and *R. similis* on turmeric were well established, not much attention was paid so far for control of these nematodes. Since the infested seed materials are the main source of nematode inoculum, planting nematode free rhizomes is of utmost importance to prevent their spread and also to avoid crop losses. Nematodes inside the rhizomes can be destroyed by dipping in hot water at 55°C for 10 min or 45°C for 50 min (Chen et al., 1986).

Cultivars viz. Armoor, Duggirala, Guntur-1, Guntur-9, Rajampet, Sugandham and Uppalapadu and breeding lines viz. 5379-1-2, 5363-6-3, 5335-1-7-, 5335-27, Ca-17/1, Cli-124/6, Cli 339 were resistant to *M. incognita* (Mani et al., 1987). Cli-32/4 was found moderately resistant to *M. incognita* (Mani and SriHari, 1989). A wild related species, *Curcuma zedoaria* is more resistant to root knot nematode *M. incognita* (race 1) (Chen et al., 1986).

Application of nematicides like carbofuran resulted in 81.6% reduction in root knot nematode population (Mani et al., 1987). DBCP and phenamiphos were also effective in reducing disease symptoms in Gujarat (Patel et al., 1982).

SEED SPICES

Coriander (*Coriandrum sativum* L.), Cumin (*Cuminum cyminum* L.), Fennel (*Foeniculum vulgare* Mill), Fenugreek (*Trigonella foenum - graecum* L.), Celery (*Apium graveolens* L.), Dill (*Anethum graveolens* L.), Caraway (*Carum carvi* L.) and aniseed (*Pimpinella anisum* L.) are the important seed spices (grain spices). Based on area and production and also economic importance the first four are considered as the major seed spices.

Nematodes associated with seed spices

Several nematodes are reported on these crops (Table 13.5) and the major nematodes are root knot nematodes. No nematodes are reported on aniseed.

Nature of damage and economic importance

Meloidogyne incognita causes significant reductions in yield of coriander (52%), cumin (43%) and fennel (42%) (Midha and Trivedi, 1991). An inoculum level of 100 root knot nematodes/pot was found highly pathogenic to coriander (Midha and Trivedi, 1988a). Fenugreek is highly susceptible to root knot nematodes *M. javanica* (Paruthi et al., 1987) and *Pratylenchus zeae* (Shafshak et al., 1985). On celery, *Aphelenchoides* spp., *Aphelenchus* spp., *Paratylenchus* spp. and *Pratylenchus penetrans* are the important nematode parasites and significant economic losses are caused if the plants are infected in early stage of crop growth (Murga et al., 1990; Roan and Gonzalez, 1990; Kneuth and Schrameyer, 1991). *Ditylenchus dipsaci* caused severe losses on celery in Italy (D'Errico et al., 1991; Vovlas et al., 1993)). *M. hapla* is also an important nematode pest of celery (Starr and Mai, 1976; Bisessar et al., 1983). *Ditylenchus dipsaci* caused distortion of the petioles and swelling or blisters like areas of the epidermis of celery plants (Vovlas et al., 1993).

Table 13.5. Plant parasitic nematodes associated with seed spices

Nematode species	*Coriander*	*Cumin*	*Fennel*	*Fenugreek*	*Celery*	*Dill*	*Caraway*
Aphelenchoides sp.					28		
A. fragariae					18		
A. ritzemabosi					18		
Aphelenchus sp.					28		
Basirolaimus dubius (= Hoplolaimus dubius)				21			
B. indicus (= H. indicus)				11, 12			
Belonolaimus longicaudatus					2		
Bitylenchus brevilineatus (= *Tylenchorhynchus brevilineatus*)	1	1				34	
B. swarupi (= T. swarupi)				21			
B. vulgaris (= T. vulgaris)	9						
Ditylenchus destructor					2		
D. dipsaci					30, 33		
Filenchus filiformis (= *Tylenchus filiformis*)				21			
Helicotylenchus dihystera	15						
H. indicus				21			
Helicriconemoides cocophillus				21			
Hemicycliphora arenaria					2		
H. similis						2	
Heterodera schachtii						2	
Hirshmaniella mucronata (= *H. indica*)	15						
H. oryzae	13						
Longidorus apulus					19		
L. maximus					2	2	2
Macroposthonia ornata	15						
Malenchus bryophilus (= *Tylenchus bryophilus*)						2	
Meloidogyne sp.	2	2	2	2		2	2
M. acrita	2	32			2		
M. hapla			2		2, 20	2	
M. incognita	4, 12, 22, 25, 26	17, 26	26	4, 7, 22	20		
M. javanica	2, 3, 34	32	2	3, 24	34		
Merlinius brevidens (= *Tylenchorhynchus brevidens*)		6					
Metaphelenchus goldeni				21			
Paratrichodorus sp.				27			
P. christei					34	34	
P. mirzai				32			
Paratylenchus bukowinensis					31		

(Contd.)

Nematode spices	Coriander	Cumin	Fennel	Fenugreek	Celery	Dill	Caraway
P. hamatus					34	2	34
P. projectus					31		
Pratylenchus caffeae					34	34	
P. exilis	14						
P. penetrans			2		31		
P. zeae				23			
Quinisulcius sp.	15						
Rotylenchulus reniformis		5, 8		10, 12			
Trichodorus sp.		32			29		
T. christei		132				2	
T. primitivus					34		
Trichotylenchus falciformis	15						
Tylenchorhynchus sp.	27						
T. claytoni						2	
T. divittatus	16						
Varotylus siddiqii (= *Rotylenchus siddiqii*)	15						
Xiphinema diversicaudatum						34	
X. insigne	14						

Figures indicate the respective references.
1. Siddiqi, 1961; 2. Goodey et al., 1965; 3. Chandwani and Reddy, 1967; 4. Krishnamurthy and Elias, 1967; 5. Swarup et al., 1967; 6. Sethi and Swarup, 1968; 7. Mathur et al., 1969; 8. Verma and Prasad, 1969; 9. Upadhyay and Swarup, 1972; 10. Khan and Khan, 1973; 11. Rashid et al., 1973; 12. Sen and Dasgupta, 1977; 13. Sultana, 1978; 14. Das and Sultana, 1979; 15, 16. Ray and Das, 1980; 1983; 17. Shah and Patel, 1979; 18. Zinov'ev and Barabashova, 1980; 19. Bleve-Zacheo et al., 1982; 20. Bisessar et al., 1983; 21. Singh and Khera, 1984; 22. Pant et al., 1985; 23. Shafshak et al., 1985; 24. Paruthi et al., 1987; 25, 26. Midha and Trivedi, 1988a; 1991; 27. Koshy and Bridge, 1990; 28. Murga et al., 1990; 29. Roan and Gonzalez, 1990; 30. D'Errico et al., 1991; 31. Knuth and Schrameyer, 1991; 32. Koshy and Geetha, 1992; 33. Vovlas et al., 1993; 34. Potter and Olthof, 1994.

Coparasitism by *M. hapla* and *Pythium polymorphon* causes severe root necrosis in celery (Starr and Mai, 1976).

Meloidogyne incognita completed its life cycle in fenugreek in 42-50 days (Sharma and Trivedi, 1992b). Nematode infestation caused an increase in all metabolites especially insoluble polysaccharides and proteins in galls compared to healthy roots (Sharma and Trivedi, 1993).

Nematode management

A. Cultural

Leaf powders of *Aegle marmelos, Withania somnifer, Hibiscus rosasinensis, Murraya koenigi* and stem of *Cuscuta reflexa* significantly enhanced plant growth in fenugreek and reduced root galling caused by *M. incognita* (Sharma and Trivedi, 1992a). Crop rotations avoiding parsley and carrots but including cereals are recommended to manage nematode problems of celery (Knuth and Schrameyer, 1991).

B. Host resistance

Several attempts were made to locate resistance/tolerance to root knot nematodes in seed spices (Sharma and Trivedi, 1988; Sharma et al., 1988; 1989; Midha and Trivedi, 1988c; 1989; Patel et al., 1986; 1989). Among the seed spices, fennel is resistant to *M. javanica* while cumin and coriander are moderately resistant (Paruthi et al., 1987). Some lines of seed spices that are resistant to root knot nematodes are given in Table 13.6.

Table 13.6. Varieties/selections of seed spices resistant to root knot nematode, *Meloidogyne incognita*

Crop	*Resistant line/selection*	*Reference*
Fenugreek	VLM-112, 227, 67, 113, 24, 9	Sharma and Trivedi, 1988
	NLM, TG 2336, UM, 34, 35	Sharma et al., 1989
Coriander	CO-1, CO-2	Midha and Trivedi, 1988c
Cumin	CVT-R-S-1, CVT JC-1, CVT.JC-2 CVT.2C-3, CVT VC-43, CVT.VC-159	Midha and Trivedi, 1989

C. Biological

Paecilomyces lilacinus reduced the root knot nematode population in fenugreek (Sharma and Trivedi, 1989).

GARLIC

Garlic (*Allium sativum* L.) is an important minor spice or condiment crop, cultivated in an area of around 57,000 ha in India. Stem and bulb nematode (*Ditylenchus dipsaci*) is the major nematode problem of garlic cultivation and in storage in Western countries (Curi et al., 1984; Shubina, 1992). The potato nematode, *Ditylenchus destructor* is reported to be a serious problem of garlic in Japan (Fujimura et al., 1986). Fortunately, none of these nematodes are reported in India. Root knot nematodes (*Meloidogyne incognita*) are highly pathogenic to garlic under Indian conditions and significantly reduced shoot, root and bulb weights (Midha and Trivedi, 1988b). In Tamil Nadu, *Aphelenchoides* sp. and *Tylenchorhynchus* sp. were found associated with garlic (Sundaram et al., 1990). *Nothotylenchus alli, N. cylindricus* (Khan and Siddiqi, 1968), *Tylenchorhynchus brassicae* (Siddiqi et al., 1972), *T. vulgaris* (Upadhyay and Swarup, 1972), *Rotylenchulus reniformis* and *Hoplolaimus indicus* (Rashid et al., 1973) were also reported on garlic. However, not much is known in India about the extent of nematode damage, their nature or control measures.

TREE SPICES

Clove (*Syzygium aromaticum* Merril & Perry), nutmeg (*Myristica fragrans* Hout), cinnamon (*Cinnamomum zeylanicum* Blume) and all spice (*Pimenta dioica* Merr.) are important tree spices cultivated in India. Very little information is available on plant parasitic nematodes associated with these crops. The important nematodes are root knot nematodes (*Meloidogyne* spp.) on cinnamon, nutmeg and clove, *Pratylenchus* sp. on clove and cinnamon, *R. similis* on nutmeg and *Rotylenchulus reniformis* on clove, nutmeg and cinnamon. The role of these major nematodes should be studied in tree spice nurseries (Goodey et al., 1965; Kumar et al., 1971b; Sharma and Loof, 1974; Bridge, 1978; Sundararaju et al., 1979a; Koshy and Bridge, 1990). No nematodes are reported so far on all spice.

OTHER SPICES

Several other plants are also included in the category of spices and condiments according to the Indian Spices Act. Plant parasitic nematodes reported on some of these spices are listed in Table 13.7. Among these, root knot nematodes in basil, mustard and *Pratylenchus* spp. problem in mint are quite serious.

Table 13.7. Plant parasitic nematodes reported on some miscellaneous spices

Crop	*Nematode species*
Asafoetida (*Ferula asafoetida* L.)	*Tylenchorhynchus ancorastyletus* (Ivanova, 1983)
Basil (*Ocimum basilicum* L.)	*Meloidogyne* sp. (Goodey et al., 1965; Khan et al., 1985), *M. incognita* (Ahmed and Khan, 1960; Goodey et al., 1965; Krishnamurthy and Elias, 1967; Haseeb et al., 1988; Rhoades, 1988), *M. hapla*, *M. javanica* (Goodey et al., 1965), *Belonolaimus longicaudatus*, *Pratylenchus scribneri*, *Paratrichodorus christiei*, *Dolichodorus heterocephalus*, *Hoplolaimus galeatus* (Rhoades, 1988)
Bay leaf (*Laurus nobilis* L.)	*Xiphinema madierense* (Brown et al., 1992))
Bishop's weed (*Trachyspermum ammi* (L.) Sprague)	*Meloidogyne incognita* (Sethi et al., 1964; Haseeb and Butool, 1993), *Rotylenchulus reniformis* (Swarup et al., 1967)
Curry leaf (*Murraya koenigii* (L.) Sprengel.)	*Meloidogyne incognita* (Sundararaju et al., 1984)
Horse raddish (*Armoracia rusticana* Gaertn.)	*Aphelenchoides besseyi* (Silveira, 1990), *D. dipsaci*, *Heterodera schachtii*, *Meloidogyne* sp., *M. arenaria*, *M. javanica*, *Pratylenchus* sp., *P. penetrans* (Goodey et al., 1965)
Juniperus (*Juniperus communis* L.)	*Criconemella kralli*, *C. xenoplax* (Kataan-Gateva et al., 1991), *Hemicycliophora* sp., *Paratylenchus* sp., *Xiphinema diversicaudatum* (Goodey et al., 1965))
Mint (*Mentha piperita* L.)	*Paratylenchus macrophallus* (Goodey et al., 1965), *P. hamatus* (Goodey et al., 1965; Lisetskaya, 1985), *Pratylenchoides laticauda* (Esmenjaud et al., 1990), *Pratylenchus minyus* (Faulkner and Skotland, 1965), *P. penetrans* (Bergeson, 1963; Pinkerton, 1984), *Meloidogyne* sp. (Maqbool et al., 1985), *M. hapla* (Goodey et al., 1965)
Mustard (*Brassica juncea* (L.) Czern. & Coss.)	*Helicotylenchus abunaamai* (Padhi and Das, 1982), *Heterodera cruciferae* (Goodey et al., 1965), *H. schachtii* (Goodey et al., 1965; Zaspel and Fichtner, 1985), *H. trifoli*, *Meloidogyne* sp., *M. hapla* (Goodey et al., 1965), *M. graminis* (Kaul and Chhabra, 1988), *M. incognita* (Goodey et al., 1965; Roy, 1972; Prasad and Chawla, 1992), *M. javanica* (Dahiya et al., 1988), *Pratylenchus ranjani* (Khan and Singh, 1974), *Tylenchus microdorus* (Chawla et al., 1969)
Parsley (*Petroselinum crispum* (Mill.) Airy-Shaw)	*Aphelenchoides fragariae*, *A. ritzemabosi* (Zinov'ev and Barabashova, 1980), *Ditylenchus dipsaci* (Goodey et al., 1965; D'Errico et al., 1991), *Longidorus maximus*, *Meloidogyne* sp., *M. hapla*, *M. incognita*, *M. javanica*, *Paratylenchus hamatus* (Goodey et al., 1965), *P. bukowinensis* (Viscardi and Brzeski, 1992), *Pratylenchus penetrans* (Goodey et al., 1965)
Pomegranate (*Punica granatum* L.)	*Aphelenchus avenae*, *Helicotylenchus abunaamai* (Routaray and Das, 1982), *Basiria graminophila*, *Rotylenchulus reniformis* (Rashid et al., 1973), *Hemicaloosia delpradio* (= *Callosia delpradio*) (Ray and Das, 1980), *Ditylenchus minutus* (Husain and Khan, 1967), *H. pseudorobustus*, *Longidorus* sp. (Hashim, 1983), *Longidorus brevicaudatus*, *Xiphinema americanum* (Khan and Khan, 1972), *Macroposthonia antipoliyana* (= *M. macrolobata*) (Jairajpuri and Siddiqi, 1963), *Meloidogyne* sp. (Goodey et al., 1965; Hashim, 1983), *M. hapla* (Goodey et al., 1965), *M. incognita* (Goodey et al., 1965; Raveendran and Nadakal, 1975; Alam et al., 1976; Siddiqi and Khan, 1986), *M. javanica* (Siddiqi and Khan, 1986), *Neolobocriconema olearum* (Hashim, 1990), *Pratylenchoides crenicauda* (Jairajpuri, 1964), *Pratylenchus coffeae* (Sethi and Swarup, 1971; Routaray and Das, 1982), *P. flakkensis* (Ray and Das, 1980), *Paratylenchus lepidus* (Phukan and Sanwal, 1979), *Psilenchus hilarus* (= *P. neoformis*) (Jairajpuri and Siddiqi,

(Contd.)

Crop	*Nematode species*
	1963), *Quinisulcius punici* (Gupta and Uma, 1980), *Ogma octangularis* (= *Seriespinula punici*) (Edward et al., 1971; Khan et al., 1975), *Tylenchorhynchus clarus* (Hashim, 1983), *Xiphinema basiri*
Rosemary (*Rosemarinus officinalis* L.)	*Criconemella rosmarini* (Castillo et al., 1988), *Meloidogyne* sp. (Goodey et al., 1965)
Saffron (*Crocus sativus* L.)	*Acrotylenchus safroni* (Fotedar and Handoo, 1977), *Aphelenchus* sp. (Goodey et al., 1965)
Tamarind (*Tamarindus indica* L.)	*Helicotylenchus erythrinae*, *Basirolaimus indicus* (= *Hoplolaimus indicus*)
Vanilla (*Vanilla fragrans* (Salisbury) Ames.)	*Helicotylenchus microcephalus*, *Hemicriconemoides mangiferae*, *Meloidogyne* sp., *Radopholus williamsi*, *Rotylenchulus reniformis* (Orton)

CONCLUSION

An overview of the nematode problems of various spices and condiments reveals that plant parasitic nematodes cause serious damage to many of these plants and much attention is not paid for controlling them. Most of the nematological investigations are mere survey reports or host range studies. Very little studies have been done in India on some spices like all spice, celery, dill, garlic, vanilla, etc. eventhough they are cultivated in sizable areas. More systematic research is needed in seed spices sector. Considering the export oriented nature of spices, more emphasis should be given for developing ecofriendly nematode management practices with minimum use of pesticides. There is a very wide scope for isolating more efficient biocontrol agents useful against nematodes, in a tropical country like India. Developing resistant lines is another thrust area in spices as India possesses rich genetic resources of most of these crops. Modern biotechnology tools will be of immense use for achieving rapid successes in this field. Therefore, nematological investigations on these economically important group of crops have to be intensified and strengthened in the coming years.

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