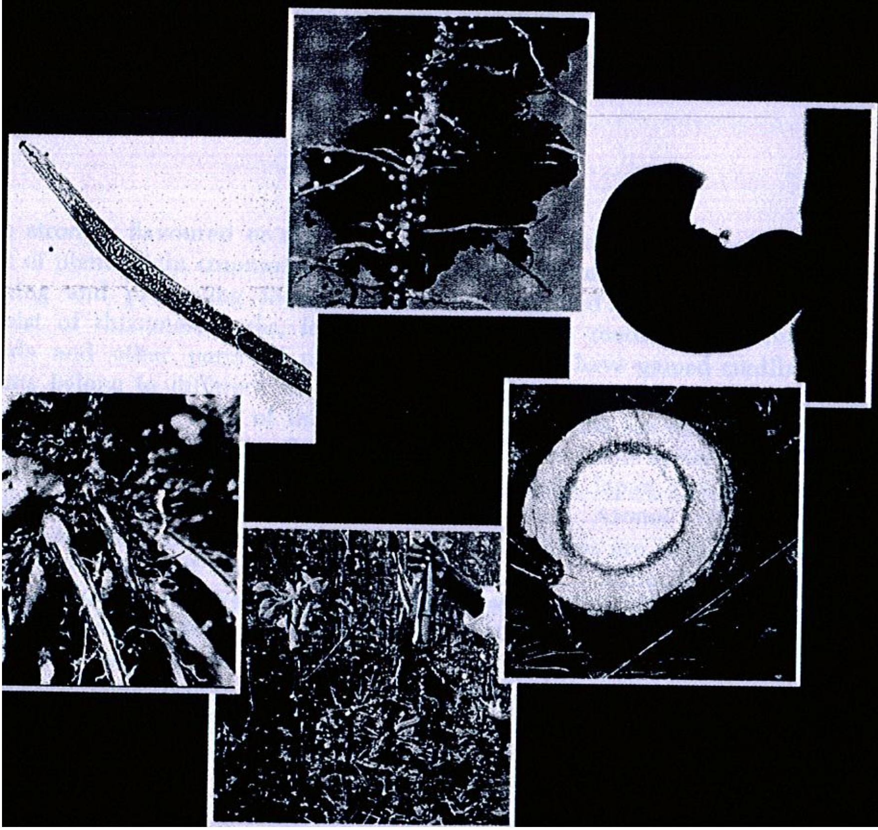
ANT PARASITIC NEMATODES IN SUBTROPICAL AND TROPICAL AGRICULTURE

SECOND EDITION



21 Nematode Parasites of Spices, Condiments and Medicinal Plants*

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Spices are strongly flavoured or aromatic substances of plant origin commonly used for seasoning and preserving foodstuffs. They consist of rhizomes, barks, leaves, fruits, seeds and other parts of plants. These plants belong to different families, genera and species. The bulk of the dry matter of their products consists of carbohydrates, volatile oils, fixed oils, proteins, tannins, resins, pigments and mineral elements. These constituents differ in their composition and content in different spices. Most of the spices are crops of the humid tropical regions. India is considered as the home of spices from ancient times and produces a large proportion of all spices. There are innumerable biotic and abiotic problems on spice crops that adversely affect production, including plant parasitic nematodes which can cause considerable damage to some of these crops. Nematode problems of chilli and garlic, which, depending on use, can be considered spices, are not included in this chapter as they are discussed under vegetables. Nematode problems of betel vine (*Piper betle*) and kava (*Piper methysticum*) are also included in this chapter.

Traditional medicines derived from plant sources have gained credibility and have become an important aspect of herbal medicine systems for human health care. The herbal medicine system is widespread in China, India, Japan, Pakistan, Sri Lanka and Thailand. Aroma compounds from botanical sources are increasingly used in cosmeceutical, nutraceutical and the processed food industry due to growing public awareness of the risks involved in the use of synthetic additives. The plant retail for herbs and medicinal plants in the USA is estimated to have a turnover of approximately US$1.6 billion annually. In Europe, about 400,000 t of medicinal plant material is imported from Asia and Africa yearly. The average market value of this plant material is estimated at US$1 billion. Many of the raw materials used in the pharmaceutical industry come from medicinal plants produced on a global scale.

* A revision of the chapter by P.K. Koshy and J. Bridge.

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Black Pepper

Black pepper (*Piper nigrum* L.) is a branching and climbing perennial shrub belonging to the family Piperaceae and is cultivated in the hot and humid parts of the world. India, Indonesia, Vietnam and Brazil, contributing 34, 20, 14 and 10%, respectively, are the major pepper-producing countries in the world today. World production of pepper during 1999 was 219,840 t and covered an area of 466,070 ha (Selvan, 2002). Its origin is considered to be in the hills of south-western India where it is known as the 'king of spices'. It is used in culinary seasonings, as a preservative for meat and other perishable foods, and in medicine. Piperine, the bite factor of pepper, is used to impart a pungent taste to brandy. Pepper oil is used in perfumery. The pepper vine can be propagated either vegetatively or by seed. Raising plants through cuttings is universally adopted. Two pepper vines entwined about a teak wood or concrete post, set in the field, is known as a 'pepper tree'. In India, live trees are used as supports (standards) for climbing pepper.

Nematodes on Black Pepper

Many nematodes have been reported on black pepper (Table 21.1), but the only two known to cause serious damage to the crop are *Radopholus similis* and *Meloidogyne* spp.

Radopholus similis

Association of the burrowing nematode *R. similis* with the yellows disease of pepper was first reported in 1936 and later by Van der Vecht (1950), who made extensive field studies and also demonstrated its pathogenicity under laboratory conditions. The nematode is notorious for being associated with the loss of 22 million pepper vines within 20 years in Bangka Island, Indonesia due to 'yellows disease' (Christie, 1957, 1959). Subsequently, *R. similis* was reported from black pepper from India (D'Souza *et al.*, 1970; Kumar *et al.*, 1971; Venkitesan, 1972; Koshy *et al.*, 1978; Mohandas and Ramana, 1987c; Ramana *et al.*, 1987a; Ramana and Mohandas, 1989), Malaysia, Thailand (Sher *et al.*, 1969; Reddy, 1977) and Sri Lanka (Gnanapragasam *et al.*, 1985). The nematode is also involved in 'slow wilt' disease of black pepper in India, which is almost identical to pepper yellows in Indonesia (Van der Vecht, 1950; Mohandas and Ramana, 1987b) hence, they are dealt with together. Intensive surveys carried out on the role of plant parasitic nematodes in the slow wilt disease complex of black pepper in India showed that high populations of *R. similis* occurred more frequently in slow wilt disease-affected plants than in healthy plants. Discriminate analysis indicated the involvement of *R. similis* in slow wilt disease (Ramana *et al.*, 1987a).

Black pepper was introduced to Indonesia from Kerala, India (Nambiar, 1977) and it is quite likely that the burrowing nematode was also introduced along with the rooted cuttings of black pepper.

Symptoms of damage

The primary symptom of the yellows (slow wilt) disease is the appearance of pale yellow or whitish yellow drooping leaves on the vines. The number of such leaves increases gradually until large numbers of leaves or even the entire foliage becomes yellow (Plate 22A). Yellowing is followed by shedding of leaves, cessation of growth and dieback symptoms (Fig. 21.1). The symptoms are very pronounced when soil moisture is depleted. In the very early stage of the disease in India, the symptoms may disappear with the onset of the south-west monsoon, resulting in an apparently healthy appearance of such plants in the following years because of new leaf growth and shedding of yellowed leaves. This has often given a mistaken impression of the disease being caused by soil moisture stress rather than nematodes. However, within 3–5 years of initiation of yellowing, all the leaves are shed and death of the

Table 21.1. Plant parasitic nematodes associated with spice crops.

Nematode species	Black pepper	Cardamom	Ginger	Turmeric	Fennel	Fenugreek	Coriander	Cumin	Celery	Dill	Vanilla
Aphelenchoides fragariae									•		
A. ritzemabosi									•		
Belonolaimus longicaudatus									•		
Criconema cardamomi		•									
Criconemoides brevistylus						•					
C. onoensis	•										
C. ornatus	•		•	•			•		•		
C. sphaerocephalus				•							
C. xenoplax					•	•					
Discocriconemella limitanea	•										
Ditylenchus destructor									•		
D. dipsaci					•				•		
Dolichodorus sp.	•										
Helicotylenchus abunaami	•		•	•							
H. dihystera	•	•	•	•		•					
H. erythrinae	•		•								
H. indicus						•	•				
H. multicinctus		•		•			•				
H. pseudorobustus	•		•	•							
H. variocaudatus	•										
Hemicriconemoides cocophillus			•	•		•					
H. gaddi	•	•									
H. mangiferae	•										
Hemicycliophora arenaria						•					
Heterodera avenae						•	•				
H. schachtii										•	
Hirschmanniella mucronata							•				
H. oryzae							•				
Hoplolaimus columbus	•			•							
H. indicus	•		•	•		•	•				
H. seinhorsti	•		•								
Longidorus apulus									•	•	
Meloidogyne arenaria		•	•		•	•					

Continued

Table 21.1. *Continued.*

Nematode species	Black pepper	Cardamom	Ginger	Turmeric	Fennel	Fenugreek	Coriander	Cumin	Celery	Dill	Vanilla
M. hapla			•		•		•		•	•	
M. incognita	•	•	•	•	•	•	•	•	•		
M. javanica	•	•	•	•	•	•	•	•	•	•	
M. piperi	•										
Paralongidorus maximus	•										
Paratrichodorus christiei										•	
P. mirzai						•	•				
Pratylenchus brachyurus			•								
P. coffeae	•	•	•	•					•	•	
P. exilis							•				
P. indicus			•								
P. penetrans					•				•		
P. pratensis			•								
P. thornei						•	•				
P. zeae			•			•	•				
Radopholus similis	•	•	•	•							
Rotylenchulus reniformis	•	•	•	•		•	•	•			
Rotylenchus sp.	•	•		•							
Scutellonema siamense	•										
Trichodorus minor		•									
T. primitivus							•		•		
Trophotylenchulus piperis	•										
Tylenchorhynchus mashhoodi	•					•					
T. vulgaris					•						
Tylenchulus semipenetrans	•				•						
Xiphinema americanum			•							•	
X. basiri			•	•			•				
X. brevicollum											•
X. diversicaudatum							•			•	
X. elongatum	•										
X. index			•								
X. insigne			•	•							
X. radicicola	•										

Fig. 21.1. Yellowing and defoliation in black pepper vines affected with yellows or slow decline disease caused by *Radopholus similis*. (Photo: V.K. Sosamma.)

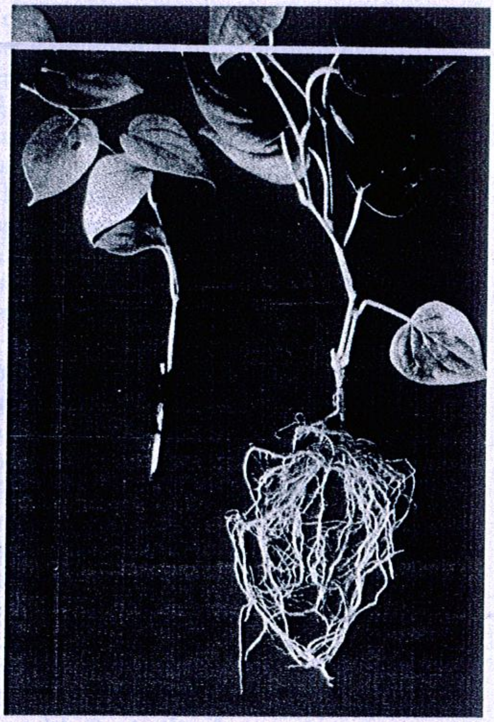

Fig. 21.2. Damage to black pepper cutting (left) caused by *Radopholus similis*. (Photo: V.K. Sosamma.)

vine takes place, and hence the name 'slow wilt' disease. In bearing vines, shedding of spikes (inflorescences) is a major symptom. Large numbers of shed spikes are seen at the base of affected vines. In large plantations, affected patches become conspicuous initially as yellowed plants, and later with large numbers of barren standards that have lost the vines (Plate 22B), or standards supporting dead vines without any leaves. Young and old plants are affected and the replanted vines normally die within 2 years.

The tender thin, white, feeding roots show typical orange to purple coloured lesions. Lesions are not clearly seen on older roots, being brown in colour. The root system exhibits extensive rotting, and the main roots are devoid of fine feeder roots that rot quickly. Extensive necrosis of larger lateral roots develops over time (Fig. 21.2).

Biology and life cycle

The nematode penetrates roots within 24 h of inoculation and the cells around the site of penetration become brown (Venkitesan and Setty, 1977). Nematodes do not enter the stelar portions of the root, but plugging of xylem vessels with a gum-like substance has been reported (Freire and Bridge, 1985a). *R. similis* completes its life cycle within 25 days, in a temperature range of 25–28°C (Geetha, 1991). The black pepper isolate of the nematode is easily cultured on carrot discs at 25°C (Koshy, 1986b). The *R. similis* populations in Indonesia and Kerala (India) have a haploid number (n = 4) of four chromosomes and belong to the 'banana race' (Huettel *et al.*, 1984; Koshy, 1986b; Jasy, 1991; Ramana, 1992).

In India, the maximum nematode population in roots of pepper occurs between September and October and the minimum density between April and May (Ramana, 1986; Mohandas and Ramana, 1988). Low soil temperatures coupled with adequate soil moisture and availability of young tender roots help in the build-up of the population during September–October.

Other hosts

A large number of tree species such as coconut (*Cocos nucifera*), arecanut (*Areca catechu*), jack fruit (*Artocarpus integrifolia*), mango (*Mangifera indica*), gliricidia (*Gliricidia maculata*), dadap (*Erythrina indica*), garuga (*Garuga pinnata*) and Vatta (*Macaranga indica*) are used as live standards. Among these, coconut and arecanut are good hosts of *R. similis*. Crops such as banana, ginger and turmeric that are susceptible to *R. similis* are also intercropped with pepper.

Disease complexes

It has been speculated that yellows disease in Indonesia is caused by a nematode–fungus complex (Hubert, 1957; Bridge, 1978) involving *R. similis*, *Fusarium* spp. and possibly other fungi. There is little direct evidence to support the hypothesis. However, Freire (1982) showed that an Indonesian isolate of *R. similis* predisposed black pepper seedlings to attack by a weakly pathogenic isolate of *Fusarium solani*, causing severe root damage. In addition, Mustika (1992a,b) has clearly demonstrated that *R. similis* alone caused growth reduction and yellow leaves with a stiff droop, but damage was more obvious when *R. similis* acted together with *F. solani*. Studies under simulated field conditions showed that *R. similis* and *Phytophthora capsici* alone or in association resulted in root rotting, leading to slow decline disease (Ramana *et al.*, 1992; Anandaraj *et al.*, 1996a,b).

Economic importance and population damage threshold levels

The slow wilt disease was first reported from the Wynad area in Kerala as early as 1902, and Krishna Menon (1949) reported mortality of up to 10% of the vines due to the disease. Reduction in plant growth has been reported in sterile soil when 55-day-old rooted cuttings of black pepper in pots are inoculated with 2300 nematodes.

The onset of yellows disease in Sumatra, Indonesia is correlated with *R. similis* populations of 2 nematodes/100 g of soil and 25 nematodes/10 g of roots, and *Meloidogyne* spp. populations of 47 nematodes/100 g of soil and 305 nematodes/10 g of roots (Mustika, 1978). Bridge (1978), however, stated that a low population of less than 310 nematodes/10 g of roots may not alone cause the disease. A population level of 250 nematodes/g of roots was constantly recorded with slow-wilt-affected pepper vines in Kerala (Ramana, 1986). In pathogenicity tests, *R. similis* caused significant reduction in the growth and yield of black pepper (Mohandas and Ramana, 1991). Black pepper vines of any age group are susceptible to this nematode (Ramana, 1992). Inoculation with *R. similis* alone reduced growth rate of different cultivars of black pepper (Mustika, 1991).

Management measures

At present, there are no effective control measures for slow wilt or pepper yellows. The price of black pepper is known to fluctuate greatly and, with a fall in prices, the farmer often loses interest in the crop and tends to neglect adoption of even standard agronomic practices. Control methods need to be adopted every year for black pepper, which is a perennial crop, especially under Indian conditions where live standards are used. The perennial multicropping systems involving coconut, arecanut, black pepper, betel vine, banana, ginger, turmeric, etc. that have developed over many years on the west coast of South India are ideal situations where the burrowing nematode multiplies and causes extensive damage to all the susceptible crops. Black pepper, betel vine and banana are crops that succumb to nematode attack early. In later years, the farmers abandon pepper cultivation in arecanut-based farming systems where arecanut is the live standard. Although application of phorate at 3 g a.i./vine twice a year has been found to control *R. similis*, the high density multispecies cropping pattern does not permit use of nematicides, as most of the crops are export oriented and some products are consumed without any processing or cooking, such as banana, betel leaves, etc. This situation is complicated further because arecanut and coconut that are used as live standards are also very good hosts of *R. similis*, which warrants higher dosages and more frequent use of nematicides, especially under irrigated conditions.

CULTURAL. Symptoms of slow wilt and pepper yellows are known to be ameliorated with mulching. Pasril (1976) has recorded an 18% reduction in disease incidence on Bangka Island, Indonesia, after mulching. He also observed a reduction in disease symptoms after application of nematicide with a corresponding increase of yield in the first year of treatment. Addition of chopped leaves of *Glyricidia maculata* (10 g/kg of soil) as green manure reduced populations of *R. similis* and increased plant growth (Jasy and Koshy, 1992).

De Waard (1979) suggested application of fertilizers at a per hectare dose of 400 kg N, 180 kg P, 480 kg K, 425 kg Ca and 112 kg Mg in combination with a mulch for effective control of yellows disease in Bangka, Indonesia. Mustika *et al.* (1984) also reported remission of disease severity when fertilizers were applied to infected vines. Furthermore, foliar yellowing and necrosis of distal ends of laminae of slow wilt-affected vines in Kerala, India were attributed to N and K deficiencies (Wahid *et al.*, 1982).

RESISTANCE AND TOLERANCE. A number of black pepper germplasm accessions, including wild types, were screened against *R. similis* by several workers (Venkitesan and Setty, 1978; Jacob and Kuriyan, 1979a; Koshy and Sundararaju, 1979; Leong, 1986; Paulus *et al.*, 1993). The wild collection Vittal No. 430, *Piper hymenophyllum* and *P. attenuatum*, recorded less than 30% root reduction and a 1.5-fold nematode population increase. The hybrid pepper variety Panniyur-I recorded 91.4% root reduction and a 7.6-fold nematode increase (Venkitesan and Setty, 1978). However, a local cultivar at Peringamala in Kerala, India was not invaded by *R. similis* (Jacob and Kuriyan, 1979b). In Sri Lanka, a black pepper variety, PW 14, was immune to *R. similis* (Gnanapragasam, 1989). No resistance or tolerance was found on screening cultivated and wild germplasm, intercultivar hybrids or open pollinated seedlings, except for *P. colubrinum*, which is now widely used as a rootstock to graft cultivated pepper plants (Ramana *et al.*, 1987b; Ramana, 1992).

CHEMICAL. A number of pesticides have been found effective in reducing *R. similis* populations on black pepper in pot trials as well as in field trials. Aldicarb sulphone at 8 kg a.i./ha was most effective for control of *R. similis* on pepper in pot trials (Venkitesan, 1976; Venkitesan and Setty, 1979). DD, Vapam, Nemagon, Temik, Furadan, Nemacur, Mocap, Hostathione, Dasanit and Dasudin were found to reduce populations of *Meloidogyne* spp. and *R. similis* on *P. nigrum* in greenhouse trials (Mustika and Zainuddin, 1978). Under Indian conditions, aldicarb/carbofuran/phorate at 3 g a.i./vine applied in May/June and again in September/October results in the remission of foliar yellowing and reduction in nematode populations. Among the above three nematicides, phorate is superior (Ramana, 1986; Mohandas and Ramana, 1987a; Lokesh and Gangadharappa, 1995; Sundararaju and Sudha, 1998). The chances of rehabilitating severely affected vines by application of nematicides are low because of heavy damage already caused to the root system and the inability of such plants to put out new roots for quick rejuvenation. Although chemicals have been reported to reduce the nematode population and ameliorate slow wilt symptoms, the cost:benefit ratio has not been calculated.

BIOLOGICAL. There have been few successful attempts to control *R. similis* by using any of the fungal biological control agents, probably due to the migratory endoparasitic nature of this nematode (Geetha, 1991; Ramana, 1994). The mycorrhizal fungus, *Glomus fasciculatum*, suppressed burrowing nematode infestation (Anandaraj *et al.*, 1996c). Recently, rhizobacteria that suppressed *R. similis* infesting black pepper were identified in greenhouse studies (Beena *et al.*, 2003).

Summary of management measures

Integrated methods of nematode management that can be suggested are:

- Planting of nematode-free rooted cuttings raised in nursery mixture sterilized with steam, solar heat or fumigants.
- Uprooting of affected vines and replanting after a period of 9–12 months.
- Use of non-living supports or standards.
- Exclusion of *R. similis*-susceptible trees as standards for trailing black pepper vines, and exclusion of susceptible intercrops such as banana, ginger and turmeric.
- Application of phorate at 3 g a.i./vine with the onset of the monsoon and again after 3 months. The nematicide may be applied after removing the top soil without causing damage to the roots, followed by replacement of the soil. The susceptible intercrops, e.g. banana, may also be treated with nematicides.
- Application of organic amendments, such as 200 g of neem oil cake (*Azadirachta indica*), green foliage (3–5 kg) or farmyard manure (1 kg) per vine.
- Earthing-up after application of nematicides, NPK fertilizers and organic amendments in September/October.

Methods of diagnosis

The presence of nematodes and their association with the disease can be diagnosed by soil sampling at a distance of 25–50 cm from the base of the vine at a depth of 20–30 cm. A soil sample of 200 cm^3 and root sample of 0.5–1.0 g of thin, tender, feeder roots should be taken to obtain maximum nematode population estimates (Koshy, 1986b, 1987a, 1988). Infested roots, showing lesions and rotting, may be split longitudinally and cut to a length of 1–2 cm. When such roots are submerged in water contained in Petri dishes or shallow pans and incubated at 20–25°C, 50% of nematodes are released in 72 h.

Meloidogyne

The root knot nematode, *Meloidogyne* sp., was the first nematode to be recorded on black pepper (Delacroix, 1902) in Cochin, China. In 1906, Butler reported root knot nematodes from black pepper in Wynad, Kerala (India). *M. javanica* and *M. incognita* have been reported from India, Brazil, Sarawak, Borneo, Cochin China, Malaysia, Brunei, Kampuchea, Indonesia, the Philippines, Thailand and Vietnam (Winoto, 1972; Castillo, 1974; Lordello and Silva, 1974; Ichinohe, 1975; Reddy, 1977; Freire and Monteiro, 1978; Kueh and Teo, 1978; Sundararaju *et al.*, 1979a; Ramana and Mohandas, 1983) and *M. arenaria* from Sri Lanka (Lamberti *et al.*, 1983). A new species, *M. piperi*, has been described recently from Kerala, India (Sahoo *et al.*, 2000).

Symptoms of damage

A gradual decline characterized by unthrifty growth and yellowing of leaves are the prominent symptoms. Leaves of vines infested with *Meloidogyne* spp. exhibit dense yellowish discoloration of the interveinal areas, making the leaf veins quite prominent with a deep green colour, whereas leaves of the vines infested with *R. similis* show uniform pale yellow or whitish discoloration and typical drooping (Ramana *et al.*, 1994). Kueh (1990) observed that leaves of root knot nematode-infested vines were held inward and upward and then would drop. *M. incognita* infestation reduced the uptake of nutrients such as P, K, Zn, Mn and Cu (Ferraz *et al.*, 1988). Total chlorophyll content of the leaves was significantly reduced by root knot nematodes, leading to the senescence of leaves (Ferraz and Lordello, 1989). Root systems become heavily galled and the adult females with egg masses are generally enclosed deep within the root tissue (Ramana, 1992; Ramana *et al.*, 1994). In the cv. Panniyur I, the galls are smooth and larger in size compared with the small galls with exposed egg masses, giving a pitted rough appearance to roots of cv. Karimunda.

Other hosts

Among the commercially used standards, *Oroxylum indicum* Vent., *Erythrina lithosperma* Blume, *Ceiba pentandra* (L.) Gaerth. and *Bombax malabaricum* DC. are highly susceptible to root knot nematodes, whereas *Garuga pinnata* Roxb. and *Macaranga indica* Wight are not susceptible. The popular live standards, *Erythrina indica* Lank. and *Gliricidia sepium* (Jacq.) Walp., are less susceptible (Koshy *et al.*, 1977). Large numbers of weeds that are found in pepper gardens have been recorded as hosts of the root knot nematodes (Ramana, 1986).

Disease complexes

Meloidogyne spp. do not significantly enhance the susceptibility of pepper vines to foot rot (Holliday and Mowat, 1963). *M. incognita* and *F. solani* were found associated with black pepper vines in Paraba State, Brazil. Infested plants showed wilting, yellowing of leaves, rotting of stems and roots and cracking of stems; cracked stems 5–10 cm above the soil surface were heavily infected. Joint attack by *R. similis*, *M. incognita* and *Fusarium* sp. caused severe necrosis in the stelar part and resulted in the formation of tyloses that blocked the xylem (Mustika, 1984). Both organisms together were also found to do more harm than either of them alone in other countries (Lopes and Lordello, 1979; Sheela and Venkitesan, 1990; Mustika, 1991, 1992a,b; Zhou and Chi, 1993). Winoto (1972) reported increased susceptibility of *M. incognita*- and *M. javanica*-infested pepper cv. Kuching to *Phytophthora* infection in Malaysia. In India, black pepper plants also showed wilting symptoms quicker when root knot and burrowing nematodes were inoculated first followed by *Phytophthora capsici* (Ramana *et al.*, 1992; Anandaraj *et al.*, 1996a,b). *Rotylenchulus reniformis* was found to inhibit the multiplication of *M. incognita* and the resultant damage on black pepper in autoclaved soil in pots under greenhouse conditions in Brazil (Ferraz and Sharma, 1979). The root gall development and population build-up of *M. incognita* were suppressed in black pepper on inoculation with *R. similis* in succession in sterile soil under pot conditions (Sheela and Venkitesan, 1981).

Economic importance and population damage threshold levels

As much as 91% root knot nematode infestation was reported from Para, Brazil (Ichinohe, 1975) and Kerala, India (Ramana and Mohandas, 1987b; Ramana *et al.*, 1987a). An initial population of ten juveniles per rooted cutting reduces growth by 16%, while a maximum of 50% reduction is observed at an inoculum level of 100,000 over a period of 1 year in sterile soil under potted conditions (Koshy *et al.*, 1979b). *M. incognita* was found highly pathogenic at 100–10,000 juveniles/seedling (Freire and Bridge, 1985c; Mohandas and Ramana, 1991). In Indonesia, yellow symptoms appeared on plants with *Meloidogyne* spp. at population levels of 47 nematodes/100 g of soil and 305 nematodes/10 g of roots (Mustika, 1978).

Management measures

Root knot infestation in black pepper nurseries has been a serious problem in several government nurseries in Kerala, India. Fumigation of nursery potting mixture with methyl bromide is effective in checking the infestation (Koshy, 1974, 1986a; Mohandas and Ramana, 1987a).

CULTURAL. Growing of the non-host cover plant siratro (*Macroptilium atropurpureus*) in the interspace and mulching with Guatemala grass (*Imperata cylindrica*) are recommended to reduce populations of *M. incognita* on black pepper in the Amazonian region (Ichinohe, 1980, 1984). Mulching the basins with *Gliricidia* leaves reduced root knot nematodes in Sri Lanka (Ratnasoma *et al.*, 1991). Application of botanicals such as neem oil cake also can reduce root knot nematodes (Ramana *et al.*, 1992).

RESISTANCE AND TOLERANCE. Among the seven popular cultivars screened, the hybrid cultivar, Panniyur-I was the most susceptible and the cv. Valiakaniakadan was the least susceptible (Koshy and Sundararaju, 1979). The intensity of *M. incognita* damage was less in cultivar Karimunda compared with that of Panniyur-I (Mohandas and Ramana, 1983). Of eight cultivars screened against *M. incognita*, Kalluvalli, Balancotta, Karimunda, Narayakodi and Padapan had fewer galls than Panniyur-I, Cheriyakaniakadan and Kottanadan (Jacob and Kuriyan, 1979a). A total of 101 cultivars, 74 accessions of wild *Piper* sp. and 140 intercultivar hybrids were screened against *M. incognita*, of which one cultivar, CLT-P-812, was found resistant (Ramana and Mohandas, 1986, 1987b; Koshy, 1987b). This cultivar was released as 'Pournami' for cultivation in root knot-infested areas (Ravindran *et al.*, 1992). Some of the wild related species of *Piper* are resistant to root knot nematodes (Ramana, 1992; Paulus *et al.*, 1993).

Infection by nematodes is known to cause biochemical changes in plants (Eapen *et al.*, 1999a). The cv. Cingapura recorded high concentrations of total phenols on inoculation with 6000 *M. incognita* juveniles/pot 95 days after planting, although no resistance was shown (Ferraz *et al.*, 1984). Changes in levels of amino acids, organic acids and sugars in *M. incognita*-inoculated plants compared with uninfected plants were reported by Freire and Bridge (1985b).

CHEMICAL. Most nematicides have been found effective in reducing root knot nematode populations on black pepper, but information on their practical use is limited. Under conditions where a live standard is used, the dosage has to be different depending upon the susceptible/resistant reaction of the standard to the root knot populations. Thus, generalizations on the dosage of nematicides are not possible, and recommendations have to be location specific depending upon the standard, variety of black pepper, rainfall pattern, flowering and harvesting period of black pepper. Green berry yields can be doubled by four applications of carbofuran incorporated into mound soil at 114 g/vine per application in black pepper fields infested with *M. incognita* and *M. javanica* in Malaysia (Kueh and Teo, 1978). Application of Temik 10G at 12.5 g/plant or Furadan 5 G at 50 g/plant twice a year, including at planting around cuttings, reduced populations of *M. incognita* on black pepper in the Amazonian region (Ichinohe, 1980, 1984). Phenamiphos at 1% a.i./vine followed by carbofuran and ethoprophos was effective in controlling nematodes in Malaysia (Leong, 1986) and in Sri Lanka (Ratnasoma *et al.*, 1991).

When aldicarb at 1 g a.i./vine applied twice a year (May/June and October/November) is integrated with fertilizers (N = 100 g, P = 40 g, K = 140 g/vine) in two equal split doses, plus earthing up to 50 cm radius at the base of the vines and mulching the vine base with leaves, there is a reduction in foliar yellowing of 83% and of *M. incognita* juvenile populations by 33–88% (Venkitesan and Jacob, 1985).

BIOLOGICAL. Nematode-free cuttings could be raised by incorporating a biological control agent in the potting mixture. A number of organisms have been tested and found effective in reducing root knot nematodes. Promising among these are *Paecilomyces lilacinus* (Freire and Bridge, 1985d; Ramana, 1994; Sosamma and Koshy, 1997), *Pochonia chlamydosporium* (syn. *Verticillium chlamydosporium*) (Freire and Bridge, 1985d; Sreeja *et al.*, . 1996), *Pasteuria penetrans* (Ratnasoma *et al.*, 1991; Sosamma and Koshy, 1997), *Bacillus* spp. (Sheela *et al.*, 1993) and *Pseudomonas fluorescens* (Eapen *et al.*, 1997). A number of rhizobacteria that are antagonistic to root knot nematodes have been isolated recently (Beena *et al.*, 2001). Black pepper plants pre-inoculated with arbuscular mycorrhizal fungi such as *Glomus fasciculatum*, *G. etunicatum*, *G. mossae* and *Gigaspora margarita* recorded a significant increase in growth even in the presence of root knot nematodes (Sivaprasad *et al.*, 1990, 1992; Anandaraj *et al.*, 1991).

Other nematodes of black pepper

The other nematodes that have been found associated with black pepper (Table 21.1) in various countries are considered to be of minor economic importance (Timm, 1965; Sher *et al.*, 1969; Castillo, 1974; Sharma and Loof, 1974; Ichinohe, 1975; Reddy, 1977; Bridge, 1978; Sundararaju *et al.*, 1979b; Dasgupta and Rama, 1987; Rama, 1987; Ramana and Mohandas, 1987a). *Trophotylenchulus piperis* has been reported as a widespread parasite of black pepper roots in South India (Mohandas and Ramana, 1982; Mohandas *et al.*, 1985; Ramana and Mohandas, 1987a, 1989; Sundararaju *et al.*, 1997). *T. piperis* completed its life cycle on black pepper roots within 55 days at a room temperature of 24–32°C (Sundararaju *et al.*, 1995). Feeding of this nematode on black pepper roots caused drying and shrinkage of cells in the vicinity of infection (Ramana and Eapen, 1997).

Future prospects

Incorporation of crop rotation systems designed to reduce root knot densities in soil, avoiding susceptible live supports or standards and using resistant cultivars where present, in an integrated nematode management system with minimum or no nematicide application, should be the main thrust of research to increase black pepper yield in areas infested with damaging nematodes.

Cardamom

Cardamom is a fruit (capsule) of the plant *Elettaria cardamomum* Maton, belonging to the family Zingiberaceae. It is a perennial plant having an underground stem (rhizome) with aerial shoots. A mature cardamom plant may measure about 2–4 m in height. Flowers are borne on panicles which emerge directly from the swollen base of the aerial shoot. The fruits are small, trilocular capsules containing 15–20 seeds. Cardamom, known as the 'queen of spices', has its origin in the evergreen rainforests of South India and is basically a shade-loving plant. India and Guatemala are the main producers and exporters of cardamom. Tanzania, Sri Lanka, El Salvador, Vietnam, Laos, Kampuchea and Papua New Guinea are also cardamom growers. The area under cardamom cultivation in India during 1999–2000 was 62,700 ha and the total production was 7800 t (Selvan, 2002). Cardamom is used for flavouring various food preparations, confectionery, beverages, liquors and medicines. Cardamom can be propagated through seedlings as well as suckers. Suckers are better suited for gap filling and multiplication of selected high yielding types.

Nematodes of Cardamom

Nematological investigations on this crop have been undertaken in India, where a number of plant parasitic nematodes have been found (Table 21.1). The most important nematode problem is caused by the root knot nematodes, *Meloidogyne* spp., although the lesion nematode *Pratylenchus coffeae* and the burrowing nematode *R. similis* are also known to cause root rotting (D'Souza *et al.*, 1970; Kumar *et al.*, 1971; Khan and Nanjappa, 1972; Viswanathan *et al.*, 1974; Sundararaju *et al.*, 1979b). Reniform nematode, *R. reniformis*, was also recorded on cardamom (Eapen, 1995a).

Meloidogyne

Widespread occurrence of root knot nematodes *M. incognita* and *M. javanica* has been reported in cardamom nurseries and plantations in India (Kumar *et al.*, 1971; Koshy *et al.*, 1976; Ali and Koshy, 1982a; Ali, 1985, 1986a; Raut and Pande, 1986).

Symptoms of damage

Heavy root knot nematode infestation in mature plants in a plantation causes stunting, reduced tillering, yellowing, premature drying of leaf tips and margins, narrowing of leaf blades, delay in flowering, immature fruit drop and reduction in yield. Unlike several other plant species, galling of roots is not a conspicuous symptom on mature plants. The infested roots, however, exhibit a 'witch's broom' type of excessive branching (Fig. 21.3).

In the primary nurseries, more than 50% of the germinating seeds do not emerge as a consequence of infection of the radicle and plumule by the second stage juveniles of the root knot nematode. The infested seedlings at the two-leaf stage show marginal yellowing and drying of leaves and severe galling of roots. On transplantation to a secondary nursery, they exhibit curling of the unopened leaves. These leaves mostly emerge after the breaking open of the pseudostem. Up to 40% of such seedlings do not establish in the secondary nursery. In secondary nurseries, the infested plants are stunted and yellowed with poor tillering, drying of leaf tips and margins, and heavy galling of root (Ali and Koshy, 1982a; Eapen, 1995b). Young seedlings are more susceptible to root knot nematode attack than mature plants, and galling is more prominent in seedlings (Eapen, 1992). Patches of stunted and weak plants with narrow leaves are a common symptom of nematode infestation in cardamom plantations (Eapen, 1994, 1995b).

Survival and means of dissemination

The heavily shaded, hot, humid atmosphere and continuous availability of soil moisture prevalent in cardamom plantations are congenial conditions for the multiplication of root knot nematodes. Root knot nematode population dynamics in cardamom plantations are influenced by rainfall, soil moisture, soil temperature and

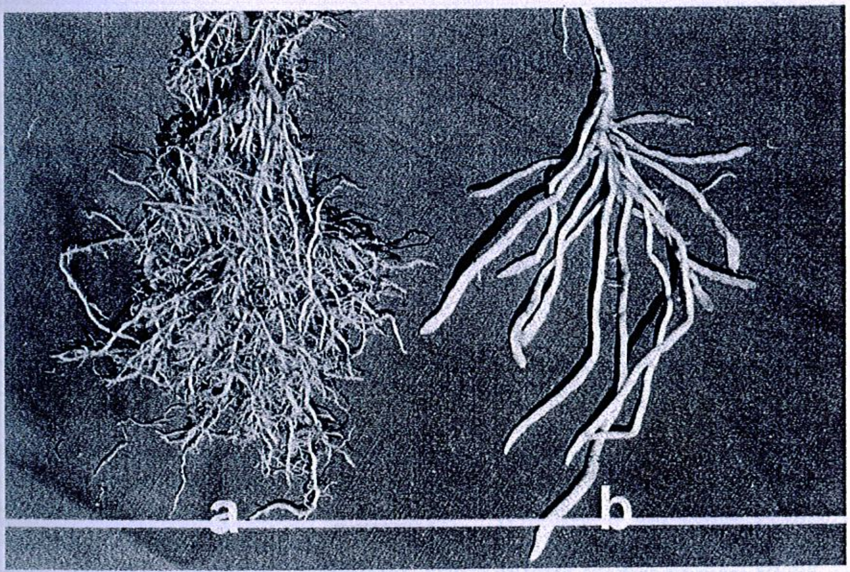

Fig. 21.3. Excessive root growth on cardamom infested with *Meloidogyne* sp. (a) compared with healthy root (b). (Photo: V.K. Sosamma.)

crop phenology. As a result, the root knot nematode population is generally high during the post-monsoon period between November and January (Eapen, 1993). The nematodes are disseminated through infested seedlings and rhizomes used for propagation. Most plantations have their own permanent nursery sites situated in areas having easy access to water sources such as forest streams.

Other hosts

A large number of annual weeds present in the cardamom plantations and the common shade trees, *Erythrina indica* and *E. lithosperma*, are hosts of root knot and help in the build-up of nematode populations (Muniappan, 1993).

Disease complexes

The incidence of rhizome rot and damping-off diseases caused by the fungus *Rhizoctonia solani* increases in the presence of *M. incognita* in the nurseries (Ali, 1986b; Eapen, 1987; Ali and Venugopal, 1992, 1993). The root knot nematode population was found to be 5–10 times higher in virus disease-affected cardamom plants than in healthy plants (Ali, 1989).

Economic importance

A yield loss of 32–47% due to root knot has been reported from the results of a nematicide experiment (Ali, 1985, 1986b). Microplot studies under simulated field conditions showed 46.6% yield loss at an initial inoculum level of 4 nematodes/100 cm^3 of soil (Eapen, 1987, 1994).

Management measures

Nematological investigations have helped in creating a general awareness among the planters as well as administrators that the root knot nematode is a major limiting factor. However, planters have not yet adopted recommended control measures. No resistance to root knot nematodes has been found, and the popular cardamom cvs Malabar, Mysore and Vazhuka are all susceptible (Hegde *et al.*, 1993; Eapen, 1995b).

It is advisable to change nursery sites every year, but this is not always practicable in view of the difficulties involved in obtaining suitable sites having facilities for irrigation. Hence, disinfestation of the nursery beds needs to be carried out every year. Disinfestation of nursery beds with fumigant nematicides is effective in controlling root knot infestation in both primary and secondary nurseries (Ali and Koshy, 1982b).

It has been demonstrated that application of aldicarb at 5 kg a.i./ha three times, every 3 months, results in increased growth and vigour of seedlings in both primary and secondary nurseries (Koshy *et al.*, 1979a; Jacob and Chandrasekharan, 1984; Ali, 1986b, 1987). Drenching of nursery beds with fenamiphos also significantly reduced root knot nematodes (Ali, 1986c). Aldicarb, carbofuran and phorate at 5, 10 or 15 kg a.i./ha, respectively, have been applied in primary nurseries of cardamom for control of *M. incognita*. None of the nematicide treatments totally prevented nematode infestation, but there was significant reduction in root knot densities. Aldicarb at the very high level of 15 kg a.i./ha reduced nematode numbers by 90% (Ali, 1987). Application of aldicarb/carbofuran/phorate at 5 and 10 g a.i./plant and neem oil cake at 500 and 1000 g/plant twice a year increases yield of cardamom plants infested with *M. incognita* from 47 to 88%. Maximum yield was obtained from the plants receiving neem oil cake at a rate of 1000 g/plant followed by 500 g/plant (Ali, 1984). However, in another study, application of phorate at 2.5–5.0 g a.i./plant reduced the nematode population and increased the yield by more than 40% (Eapen, 1995b). Since these nematicides do not kill but only inactivate nematodes, repeated use is necessary to ensure good yield.

Cardamom nurseries are ideal for practising biological control. There are reports that *Gigaspora margarita* and *Glomus fasciculatum* reduced *M. incognita* infestation and enhanced growth and vigour of seedlings (Thomas *et al.*, 1989). *P. lilacinus* reduced root knot nematodes by 48.5–57% in pot culture studies and by 19.7% in field studies (Eapen, 1995b; Eapen and Venugopal, 1995). Some native isolates of *Trichoderma harzianum* and other *Trichoderma* spp. are potential antagonists of root knot nematodes. Reduction of root knot nematode infection by this fungus has been clearly shown in laboratory, greenhouse and also in cardamom nurseries (Eapen *et al.*, 2000a,b).

Ginger

Ginger is the rhizome or underground stem of *Zingiber officinale* Rosc., a herbaceous perennial belonging to the family Zingiberaceae. Although the country of origin is not known with certainty, it is presumed to be either India or China. It is grown in many countries of the tropics and subtropics and is used widely in food, beverages, confectionery and medicines. India is the largest producer of dry ginger in the world, contributing about 30% of the world's production. In India, the total area under cultivation during 1999–2000 was 77,610 ha and the total production was 263,170 t (Selvan, 2002). The other ginger-producing countries are Jamaica, Sierra Leone, Nigeria, southern China, Japan, Taiwan and Australia.

Ginger is propagated by seed rhizomes or setts. Seed rhizomes are cut into small pieces of 2.5–5 cm length, weighing 20–25 g each, having one or two good buds. It is grown either as a monocrop or as an intercrop in many farming systems. In India, mulching of ginger beds with green leaves is a traditional practice to enhance the germination of seed rhizomes and conservation of soil moisture. The first mulching is done at the time of planting itself, with green leaves at 10–12 t/ha and repeated with 5 t/ha, 40–90 days after planting, immediately after weeding and application of fertilizers.

Nematodes of Ginger

Plant parasitic nematodes belonging to 17 genera were reported on ginger (Colbran, 1958; Reddy, 1977; Sundararaju *et al.*, 1979b; Rama and Dasgupta, 1985; Kaur, 1987; Ramana and Eapen, 1998); the most important parasites are *Meloidogyne* spp., *R. similis* and *P. coffeae*. In Kerala, *M. incognita* and *R. similis* were the major nematode species found in the rhizosphere of ginger (Mammen, 1973; Charles, 1978; Sheela *et al.*, 1995). *R. reniformis* and *M. incognita* were the dominant plant parasitic nematodes associated with ginger in Orissa (Routaray *et al.*, 1987b). The most prominent nematode pests of ginger in Sikkim (Srivastava *et al.*, 1998) and Himachal Pradesh (Kaur *et al.*, 1989; Khan and Makhnotra, 1998) were *M. incognita* and *P. coffeae*, while in Madhya Pradesh *M. incognita* was the predominant nematode species (Vadhera *et al.*, 1998a). *M. arenaria* was also reported from Himachal Pradesh (Kaur and Sharma, 1988). In west Bengal, *R. reniformis*, *Hoplolaimus indicus* and *P. coffeae* recorded the highest relative density in ginger rhizosphere (Rama and Dasgupta, 1998, 2000).

Meloidogyne

Nagakura (1930) in Japan was the first to report *Meloidogyne* sp. on ginger, and subsequently the species *M. arenaria*, *M. hapla*, *M. incognita* and *M. javanica* have been reported as parasites of ginger in various countries.

Symptoms of damage

The root knot nematodes cause galling and rotting of roots and underground rhizomes. The second stage juveniles of *M. incognita* invade the rhizome through the axils of leaf sheaths in the shoot apex. In fibrous roots, penetration occurs in the area of differentiation and, in fleshy roots, the entire length of root is invaded. In both fleshy and fibrous roots, the nematode develops to maturity in 21 days, but in rhizomes it requires 40 days at 30°C (Cheng and Tu, 1979). Galls are formed on the fibrous roots. Abnormal xylem and hyperplastic parenchyma are observed in all infested tissue except rhizome meristems. Extensive internal lesions are formed in the fleshy roots and rhizomes. Wound cork around the lesions is suberized only in old rhizomes after harvest (Huang, 1966; Shah and Raju, 1977). Infested rhizomes have brown, water-soaked areas in the outer tissues, particularly in the angles between shoots. Nematodes continue to develop after the crop has matured and been harvested, and induce breakdown of the seed rhizomes. Heavily infested plants are stunted, poorly tillered and have chlorotic leaves with marginal necrosis. The affected ginger plants mature, dry faster and die sooner than healthy ones, leaving a poor crop stand at harvest. Infested rhizomes serve as a source of infection and means of dissemination.

Disease complexes

Incidence of rhizome rot of ginger caused by *Pythium aphanidermatum* is reported to be severe when rhizomes are infested with nematodes such as *M. incognita* and *P. coffeae* (Dohroo *et al.*, 1987). However, Doshi and Mathur (1987) could not observe any interaction with these two organisms. Similarly, there was also no interaction between *M. incognita* and *Pythium myriotylu* (Lanjewar and Shukla, 1985). Recent studies have shown that ginger plants inoculated with root knot nematodes developed disease symptoms earlier when inoculated with *P. aphanidermatum* (Ramana *et al.*, 1998). Bacterial wilt of ginger caused by *Ralstonia solanacearum* was also shown to be influenced by *M. incognita* (Samuel and Mathew, 1983); however, there are contradictory reports on the subject (Ramana *et al.*, 1998).

Other hosts

Most of the weeds that are present in ginger-growing areas are known hosts of root knot nematodes.

Economic importance and population damage threshold levels

In Queensland, Australia severe infestation of rhizomes reduces yields by 57% as determined by fumigation (Pegg *et al.*, 1974). Treatment of infested soil with DD before planting nematode-free seed rhizomes has increased yields by 80%. *M. incognita* is widely distributed in ginger fields in India and causes a loss of 46.4% (Charles, 1978). A reduction of 74% rhizome weight has been recorded with an initial inoculum level of 10,000 nematodes/plant over a period of 6 months under potted conditions (Sudha and Sundararaju, 1986).

Both *M. incognita* and *M. hapla* cause significant reduction in shoot length and shoot and root weight following inoculation with root knot nematodes. The economic threshold level of this nematode varied from 2 nematodes/g of soil to 50 larvae/100 ml of soil (Parihar and Yadav, 1986; Sudha and Sundararaju, 1986; Kaur, 1987; Routaray *et al.*, 1987a). At higher initial inoculum levels, *M. incognita* and *M. hapla* cause partial or complete withering of aerial shoots. Typical symptoms of drying and twisting of leaves were observed with *M. arenaria* (Kaur, 1987).

Significant damage is noticeable at 0.5 and 1.25 nematodes/g of soil and above in sterilized soil under potted conditions. The fibrous roots are very much reduced at 2 nematodes/g of soil (Parihar, 1985; Routaray *et al.*, 1987a). Ginger treated with Carbofuran at 1 kg a.i./ha showed an increase of 20% in yield (Makhnotra and Luqman, 1997b). In another study, an avoidable yield loss of 43% was observed at an initial population level of 166 *M. incognita* juveniles/250 g of soil (Sheela *et al.*, 1995).

Management measures

Being an export-oriented crop, the nematodes of ginger have to be managed in an ecofriendly manner. Besides, as ginger is consumed raw, nematicides should be used with extreme care. A careful blend of the following measures may provide adequate management of the nematode problems in this crop.

PRODUCTION OF NEMATODE-FREE PLANTING MATERIAL. Since the seed rhizome generally harbours nematodes, selection of seed rhizomes is very critical for the management of nematodes. Nematode-free planting material should be selected from fields of known history. The control schedule for *M. javanica* involving the use of clean seed and a ginger–taro–fallow rotation has been recommended in Fiji (Haynes *et al.*, 1973). *In vitro* ginger plantlets are used to solve root knot nematode problems in South Africa. Hot water treatment of seed rhizomes at 50–55°C for 10 min was found to reduce the nematode incidence in ginger (Colbran and Davis, 1969; Anonymous, 1971). Disinfestation of rhizomes was also achieved by hot water treatment at 45°C for 3 h (Vadhera *et al.*, 1998a,b).

ORGANIC AMENDMENTS. Mulching or applying well decomposed cattle or poultry manure, compost or neem oil cake reduced nematode build-up (Colbran, 1974; Kaur, 1987; Stirling, 1989; Mohanty *et al.*, 1992; Dohroo *et al.*, 1994; Vadhera *et al.*, 1998b). Growing under sawdust mulch reduced root knot nematode infestation in Australia (Pegg *et al.*, 1974). Pre-plant application of neem cake at 1 t/ha reduced *M. incognita* and increased the yield (Mohanty *et al.*, 1995). Ginger plots mulched with mahaneem leaves at 2.5 kg/m^2 reduced root knot (Das, 1999). Studies in Australia have suggested that root knot on ginger can be controlled by alternating ginger with a green manure crop and applying at least 150 m^3/ha/year of poultry manure (Stirling, 1989; Stirling and Nikulin, 1998). Intercropping bell pepper with ginger significantly reduced both *P. penetrans* and *M. incognita* and improved the yield of ginger (Sharma and Bajaj, 1998). Incorporation of organic materials fortified with biocontrol agents such as *Trichoderma* spp., *P. lilacinus*, *P. chlamydosporia*, etc. is another option to prevent the nematode build-up (Eapen and Ramana, 1996).

HOST RESISTANCE. There are very few reports on resistance in ginger to root knot. In a preliminary evaluation, a few lines of ginger (Accession Nos 36, 59 and 221) were found resistant to *M. incognita* (Eapen *et al.*, 1999b). One of these has been recommended for release as 'IISR Mahima' (Sasikumar *et al.*, 2003).

CHEMICAL CONTROL. Soil fumigation or application of granular pesticides such as fenamiphos or dip treatment with fenamiphos are all recommended for control of nematodes of ginger. The efficacy of several granular nematicides was assessed in Queensland against root knot nematodes (Colbran, 1972; Willers, 1985). Nemacur was found to be the most effective, increasing rhizome yield by up to 15%. Split and late applications at 22.4 kg/ha are more promising than higher doses applied early in the season (Colbran, 1972). A high level of control of root knot nematodes has been obtained with sawdust mulching at a depth of 5–7.5 cm, combined with post-plant application of Nemacur. Application of phenamiphos at 3 kg a.i./ha has resulted in a 70–144% increase in yield of ginger in fields infested with *M. incognita* and *P. coffeae* either singly or in combination (Kaur, 1987).

Dipping ginger rhizomes in fenamiphos at 0.26 and 0.1% a.i. for 30 and 60 min, respectively, controlled root knot nematodes and increased the yield (Willers, 1991). Application of carbofuran at 1 kg a.i./ha 45 days after planting coupled with pre-planting application of neem cake reduced *M. incognita* and increased the yield of ginger (Mohanty *et al.*, 1995).

BIOLOGICAL CONTROL. A large number of bacterial and fungal isolates of biocontrol agents were isolated from ginger fields through random surveys (Ramana *et al.*, 2002). Many of the fungal isolates parasitized root knot nematode egg masses and suppressed their egg hatching. Toxic metabolites of some of them caused mortality of second stage juveniles in addition to direct parasitization. These studies indicated that five biocontrol agents, namely *P. chlamydosporia*, *P. lilacinus*, *Fusarium* sp., *Aspergillus nidulans* and *Scopuloriopsis* sp., reduced root knot nematode populations significantly. Although none of these organisms is registered presently for use on ginger, they are potential tools for nematode management that may become available in the near future.

Radopholus similis

Parasitism of ginger by the burrowing nematode, *R. similis*, was first reported by Hart (1956) in Florida, USA. Later, Butler and Vilsoni (1975) reported heavy infestation of ginger by *R. similis* in Fiji and its further spread through infested seed rhizomes. Occurrence of *R. similis* along with *M. incognita*, *Pratylenchus* sp. and *Helicotylenchus* sp. has also been reported from roots of ginger in India (Charles, 1978; Charles and Kurian, 1982).

Symptoms of damage

Infected plants exhibit stunting, reduced vigour and tillering. The topmost leaves become chlorotic with scorched tips. Affected plants tend to mature and dry out faster than healthy plants. Incipient infections of the rhizomes are evidenced by small, shallow, sunken, water-soaked lesions (Plate 22C) (Vilsoni *et al.*, 1976; Sundararaju *et al.*, 1979a). The nematodes migrate intracellularly through tissues, producing large infection channels or galleries within the rhizomes.

Means of dissemination

R. similis infestation in Fiji of ginger fields appears to have originated through bananas as the areas once used for banana cultivation have been used for growing ginger (Vilsoni *et al.*, 1976). The coconut isolate of *R. similis* in Kerala (India) also reproduces well on ginger (Koshy and Sosamma, 1975, 1977). The perpetuation and dissemination of the nematode is through infested seed rhizomes used for planting.

Economic importance and population damage threshold levels

In Fiji, *R. similis* has been reported from more than 50% of the total area, with a rate of infection ranging from 10 to 50% resulting in yield reductions of about 40%. An initial inoculum level of 10,000 nematodes/plant has been reported to cause 74% reduction in rhizome weight, and an initial inoculum level of ten nematodes per plant reduced shoot weight, root weight and rhizome weight by 43, 56 and 40%, respectively, in a pot experiment (Sundararaju *et al.*, 1979c).

Management measures

Few studies have been done on the control of *R. similis* on ginger, but the measures suggested for control of root knot nematodes, including hot water treatment, could help in reducing the loss.

Pratylenchus coffeae

Several species of *Pratylenchus*, namely *P. brachyurus*, *P. coffeae*, *P. indicus*, *P. pratensis* and *P. zeae*, are reported on ginger (Charles, 1978; Das and Das, 1986; Kaur *et al.*, 1989; Kaur and Sharma, 1990).

Economic importance and symptoms

P. coffeae is reported to cause 'ginger yellows' disease, prevalent in Himachal Pradesh, India (Kaur and Sharma, 1990). The nematode is highly pathogenic to 15-day-old ginger seedlings even at very low initial inoculum levels (Kaur, 1987). Nematode infestation caused yellowing of leaves and dry rot symptoms on rhizomes. Dark, brown necrotic lesions were observed within the infected rhizomes (Kaur and Sharma, 1990).

Turmeric

Turmeric, *Curcuma domestica* Val., is best known as a condiment, although the plant has uses in the social and religious lives of people in South-east Asia, its probable origin. Commercial turmeric is the processed rhizome of *C. domestica*. It is grown mostly in India, and to a small extent in China, Indonesia, Peru and Jamaica. In India, the total area under cultivation during 1999–2000 was 161,300 ha with a production figure of 653,600 t (Selvan, 2002). It is cultivated as either a monocrop or an intercrop in many farming systems.

It is indispensable in the preparation of curry powder, and is an important source of natural yellow dye. It is also used as a colouring additive in the drug, confectionery and food industries. The rhizomes of *C. aromatica* Salisb., a close relative of *C. longa*, are also a source of turmeric.

Nematodes on Turmeric

A number of species of plant parasitic nematodes have been reported in association with turmeric (Nirula and Kumar, 1963; Sundararaju *et al.*, 1979b; Chen *et al.*, 1986; Dasgupta and Rama, 1987; Gunasekharan *et al.*, 1987; Rama, 1987; Routaray *et al.*, 1987b; Bai *et al.*, 1995) of which *Meloidogyne* spp., *R. similis* and *P. coffeae* are of economic importance. *R. reniformis* and *M. incognita* were the most predominant and frequently recorded nematode species in the Chittor and Cuddapah districts of Andhra Pradesh (Mani and Prakash, 1992) and in Bihar (Haider *et al.*, 1995) in India. *R. reniformis* was reported to be more harmful to turmeric than *M. incognita*, and caused a significantly higher reduction in plant growth (Haider *et al.*, 1998a).

Meloidogyne

Two species of root knot nematodes, *M. incognita* and *M. javanica*, have been reported on turmeric, but most investigations have been concerned with *M. incognita*. Turmeric plants infested with *M. incognita* have large root galls (Fig. 21.4), stunted growth, yellowing, marginal and tip drying of leaves, and reduced tillering with galling and rotting of roots. In the field, high densities of *M. incognita* cause yellowing and severe stunting and wilting in large patches. Plants die prematurely, leaving a poor crop stand at harvest. Infested rhizomes tend to lose their bright yellow colour (Mani *et al.*, 1987). Levels of protein, carbohydrate, chlorophyll a and b, and curcumin were lower in plants infested with *M. incognita* (Poornima and Sivagami, 1998a).

The highest nematode multiplication and gall index were seen in peat soils (Poornima and Sivagami, 1998b). The population density of *M. incognita* increased with crop age and decreased with crop senescence (Poornima and Sivagami, 1999).

Economic importance and population damage threshold levels

One hundred juveniles of *M. incognita* caused significant reduction in growth characters of turmeric (Haidar *et al.*, 1998a). Significant reduction in growth and yield of turmeric were noticed in plants inoculated with more than 1000 root knot nematode juveniles/plant (Sudha *et al.*, 1989). When four varieties of turmeric were tested against *M. incognita*, maximum reduction of 18% fresh rhizome weight was observed in Suvarna at 2 juveniles/g of soil (National Research Centre for Spices, 1993). Poornima and Sivagami (1998a) reported that an initial inoculum level of more than 5000 *M. incognita* larvae/plant was highly pathogenic to turmeric. By applying carbofuran at 3 kg a.i./ha, 3 weeks after planting, avoidable yield losses to the extent of 33.61 and 26.30% were observed in turmeric and ginger, respectively (Ray *et al.*, 1995). Avoidable yield loss under field conditions was 45.3% due to *M. incognita* but was

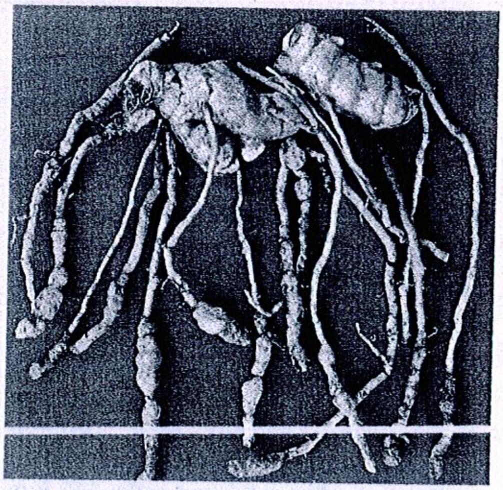

Fig. 21.4. Root galling on turmeric infested with *Meloidogyne* sp. (Photo: V.K. Sosamma.)

only 33.3% in a mixed infestation of *M. incognita* and *R. reniformis* (Bai *et al.*, 1995).

Management measures

RESISTANCE AND TOLERANCE. The cultivars and breeding lines 5379-1-2, 5363-6-3, Kodur, Cheyapuspa 5335-1-7, 5335-27, Ca-17/1, Cli-124/6, Cli-339, Armoor, Duggirala, Guntur-1, Guntur-9, Rajampet, Sugandham and Appalapadu have been reported as resistant to *M. incognita* (Gunasekharan *et al.*, 1987; Mani *et al.*, 1987). The species *C. zedoaria* is more resistant to *M. incognita* than *C. domestica* in China (Chen *et al.*, 1986). In Andhra Pradesh, India, the high yielding varieties such as PCT8, PCT10, Suguna and Sudarshana were free from root knot nematode infestation (Rao *et al.*, 1994). Recently, eight turmeric accessions (Accession Nos 31, 82, 84, 142, 178, 182, 198 and 200) were identified as resistant to root knot nematode (Eapen *et al.*, 1999b).

PHYSICAL. Immersing turmeric rhizomes in hot water at 55°C for 10 min or 45°C for 50 min can kill *M. incognita* inside rhizomes (Chen *et al.*, 1986), and this could be used for establishing nematode-free multiplication plots but is unlikely to be economic for large-scale field use.

CHEMICAL. Application of dibromochloropropane (DBCP; now banned in many countries) at 15 l a.i./ha 15 days prior to planting results in a yield increase of 253–270% compared with a 59–187% increase in yield with application of phenamiphos at 2.5 kg a.i./ha 1 day before planting (Patel *et al.*, 1982). Aldicarb and carbofuran applied at 1 kg a.i./ha increased the yield by 71 and 68%, respectively over control, with a cost:benefit ratio of 1:6 in aldicarb and 1:2 in carbofuran treatments (Gunasekharan *et al.*, 1987). Carbofuran at 4 kg a.i./ha applied in rows to a 4-month-old turmeric crop has resulted in a 81.6% reduction in root knot nematode population as against a 45% increase in untreated plots (Mani *et al.*, 1987). Similarly, application of carbofuran or phorate at 1 kg a.i./ha reduced root knot nematodes (Haidar *et al.*, 1998b).

BIOLOGICAL. The biocontrol agents *Pochonia chlamydosporia* (syn. *Verticillium chlamydosporium*), *Paecilomyces lilacinus*, *Fusarium* sp., *Aspergillus* sp. and *Scopuloriopsis* sp. controlled root knot nematodes in field trials but have not been tested in growers fields (Ramana *et al.*, 2002).

Radopholus similis

Symptoms of damage

Roots of turmeric damaged by *R. similis* become rotted, and most of these decayed roots retain only the epidermis devoid of cortex and stelar portions. The infested plants show a tendency to age and dry faster than healthy plants. Infested rhizomes are of a yolk yellow colour compared with the golden yellow colour of healthy rhizomes and have shallow water-soaked brownish areas on the surface. The scale leaves harbour *R. similis* (Sosamma *et al.*, 1979).

Survival and means of dissemination

The nematodes are disseminated through infested planting material. Populations of *R. similis* from coconut are known to infest turmeric (Koshy and Sosamma, 1975), and the use of turmeric as an intercrop in *R. similis*-infested coconut- and arecanut-based farming systems should be avoided.

Economic importance and population damage threshold levels

Pathogenicity studies show that an initial inoculum level of ten nematodes per plant can cause a reduction of 35% of the rhizome weight after 4 months and a 46% reduction at the end of the season (8 months). With 100,000 nematodes, the extent of reduction in rhizome weight is 65 and 76% after 4 and 8 months, respectively (Sosamma *et al.*, 1979).

Management measures

Control has not been studied under field conditions. However, use of clean, nematode-free rhizomes for planting should be the first step in developing an integrated management system for the burrowing nematode on turmeric.

Pratylenchus coffeae

P. coffeae has been reported to be associated with discoloration (Plate 22D) and rotting of mature rhizomes of 'wild turmeric', *C. aromatica*. In advanced stages of infection, the rhizomes become deep red to dark brown in colour, less turgid and wrinkled with dry rot symptoms. The fingers are more severely affected than the mother rhizomes. Internally, the affected rhizomes show dark brown necrotic lesions (Sarma *et al.*, 1974).

Future prospects

Turmeric has received very little input in terms of nematological research, although *M. incognita*, *M. javanica*, *R. similis* and *P. coffeae* are known to damage the crop. Detailed investigations including surveys, pathogenicity experiments and control through resistant/tolerant cultivars, cultural, chemical and biological methods are warranted.

Other Spices

Although a number of spice crops including tree spices and seed spices are cultivated over large areas in the tropics and subtropics, there is very little information available on the damage and yield loss caused by plant parasitic nematodes on some of these crops. This is not to say that nematode problems do not exist on these crops but only that there has been a lack of nematological investigations. The plant parasitic nematodes that have been reported in association with these crops in surveys and host range studies are given in Table 21.1. Nematodes have been found associated in clove (Ghesquiere, 1921; Goodey *et al.*, 1965; Sharma and Loof, 1974; Bridge, 1978; Sundararaju *et al.*, 1979b), nutmeg (Goffart, 1953; Goodey *et al.*, 1965; Kumar *et al.*, 1971; Sundararaju *et al.*, 1979b; Chawla and Samathanam, 1980), cinnamon (Goffart, 1953; Goodey *et al.*, 1965; Sundararaju *et al.*, 1979b; Chawla and Samathanam, 1980; Dasgupta and Rama, 1987; Rama, 1987), cumin (Swarup *et al.*, 1967; Verma and Prasad, 1969; Shah and Raju, 1977; Shah and Patel, 1979; Patel *et al.*, 1986; Midha and Trivedi, 1991), fennel (Midha and Trivedi, 1991), fenugreek (Chandwani and Reddy, 1967; Krishnamurthy and Elias, 1967; Khan and Khan, 1969, 1973; Mathur *et al.*, 1969; Rashid *et al.*, 1973; Khan, 1975), coriander (Chandwani and Reddy, 1967; Krishnamurthy and Elias, 1967; Sen and Dasgupta, 1977; Das and Sultana, 1979; Midha and Trivedi, 1991) and vanilla (Orton Williams, 1980; Stier, 1984 in Bridge, 1988). All these spices are hosts of *Meloidogyne* spp. The roots of cumin also can be severely galled by *M. incognita* and *M. javanica* (Patel *et al.*, 1986). *Pratylenchus brachyurus* is reported to be a parasite of vanilla in the Pacific island of Tonga, causing reduced growth of vines (Stier, 1984 in Bridge, 1988).

Related Crops

Betel Vine

The betel vine *Piper betle* L. is a perennial, dioecious, semi-woody creeper, probably native of Malaysia. Its leaves are used for chewing, extraction of essential oils such as methyl eugenol and in traditional herbal (ayurvedic) medicines and religious ceremonies. It is grown throughout Asia and also in Africa, the Philippines, Indonesia and the Pacific islands. The area under betel vine cultivation in India is about 30,000 ha with an annual turnover of 7000 million Indian rupees. The yield varies from 7.5 to 22.5 million leaves/ha/year (Shenoy, 1985).

Its cultivation is labour intensive and requires heavy investment. Betel vine is propagated by cuttings of 3–5 nodes from 2-year-old vines. It is trailed on coconut, arecanut or other straight-stemmed plants such as *Sesbania grandiflora* Pers., *Moringa oleifera* Lam and *Erythrina variegata* L. Non-living standards such as bamboo, wooden poles or granite stone supports are also used. The crop is usually heavily manured with farmyard manure, oil cakes, fish manure, sheep manure, etc.

Nematodes on Betel Vine

Numerous plant parasitic nematodes have been reported associated with the betel vine in India and elsewhere (Timm, 1965; Reddy, 1978; Ganguly and Khan, 1983; Sivakumar and Marimuthu, 1984, 1985; Jagdale *et al.*, 1986a,b; Acharya *et al.*, 1988; Ganguly, 1988; Nema, 1997). Nematodes known to cause damage to the crop are *M. incognita*, *R. similis* and *R. reniformis*. Betel vine was also reported as a host for *P. coffeae* (Ganguly and Khan, 1990).

Meloidogyne incognita

M. incognita has been reported to be associated with betel vine decline from all areas in India (Dhande and Sulaiman, 1961; Venkata Rao *et al.*, 1973; Mammen, 1974; Sivakumar and Marimuthu, 1984; Jagdale *et al.*, 1986a).

Symptoms of damage

Infested plants exhibit poor growth, yellowing of leaves, reduced vigour and wilting, with heavy galling and rotting of roots (Jagdale *et al.*, 1986a). Thinly spread foliage with small leaves, yellowing and premature shedding of leaves and stunting were recorded in root knot nematode-infested vines (Acharya and Padhi, 1987a).

Disease complexes

Association of *M. incognita* with severe wilt symptoms of betel vine was reported from India (Mammen, 1974). *M. incognita* predisposed betel vine to root rot caused by *Phytophthora palmivora* (Sivakumar *et al.*, 1987; Marimuthu, 1991; Jonathan *et al.*, 1996) and *P. capsici* (Sitaramaiah and Devi, 1994). Pathogenic association of *M. incognita* with *Sclerotium rolfsii* and *Xanthomonas betlicola* was also reported (Acharya *et al.*, 1987; Sitaramaiah and Devi, 1990). A disease complex involving *M. incognita* and *Colletotrichum* sp. was also reported in betel vine (Ray *et al.*, 1993).

Economic importance and population damage threshold levels

The root knot nematode is damaging to betel vine at an initial inoculum level of 100 juveniles/plant in sterile soil in pots (Jagdale *et al.*, 1985a). The leaf yield of untreated plants showed 38% loss over carbofuran-treated plants (Jonathan *et al.*, 1990). Avoidable yield losses under field conditions in Assam were estimated at 17.95% in terms of number of leaves and 29.06% in terms of fresh weight of leaves (Hazarika *et al.*, 1999b).

Management measures

CULTURAL. A crop rotation of betel vine–rice–banana–rice is helpful in reducing *M. incognita*, *Helicotylenchus* sp. and *Rotylenchulus reniformis* populations on betel vine raised in rice fields (Sivakumar and Marimuthu, 1986a; Sivakumar *et al.*, 1987). Considerable reduction in nematode populations in the soil and number of galls on roots has been reported after application of 50–75 kg of K_2O/ha (Jagdale *et al.*, 1985e; Rabindran *et al.*, 1987). Growing *Tagetes erecta* in the basins of betel vines reduced root knot nematodes (Medhane *et al.*, 1985). Nematode-susceptible standards such as *Sesbania grandiflora* and *S. sesban* should not be used for trailing the vines (Rao *et al.*, 1991). In another study, application of decaffeinated tea waste and mustard oil cake at 1 kg/plant reduced nematode populations and returned significantly higher yields (Hazarika *et al.*, 1999a).

Application of neem oil cake at 1 t/ha and sawdust at 2 t/ha can reduce nematode populations and number of galls and increase the number of leaves harvested significantly (Jagdale *et al.*, 1985b,c; Acharya and Padhi, 1988a). Significant reduction (60%) in the nematode population has been observed in beds amended with chopped and shade-dried leaves of *Calotropis gigantea* at 2.5 t/ha followed by neem oil cake and poultry manure at 44.4 and 40.9%, respectively. Beds amended with *C. gigantea* leaves yielded 14.2 kg of 4840 leaves and with neem oil cake 12.1 kg of 4220 leaves. Soil amendment with sawdust at 2 t/ha + NPK and neem oil cake at 2 t/ha was effective in reducing nematode numbers and increasing yields (Sivakumar and Marimuthu, 1986b; Rana *et al.*, 1991; Murthy and Rao, 1992, 1994). In another study, the highest reduction in nematode population (43%) was obtained with the application of neem seed cake at 0.5 t/ha together with carbofuran at 0.75 kg a.i./ha (Nema, 2001a).

RESISTANCE AND TOLERANCE. The cv. Karpoori is highly susceptible, whereas the cv. Kuljedu had the lowest root knot index and number of egg masses per plant (Jagdale *et al.*, 1985d; Sivakumar *et al.*, 1987). The cvs Kakair, Bangla, Karapaku, Gachipan, Aswani pan and Berhampuri are reported to be tolerant to root knot (Anonymous, 1987). The variety Berhampuri was also reported to be less susceptible to this nematode by other workers (Acharya and Padhi, 1988b). Another cv., Bangla Budagar, was moderately resistant to *M. incognita* (Nema, 2001a).

PHYSICAL. Solarization by mulching the land with 100 gauge black and white polythene before planting for 15 days was found to reduce plant parasitic nematode populations in India (Sivakumar and Marimuthu, 1987; Rao *et al.*, 1996).

BIOLOGICAL. The root knot nematode problem in betel vine was controlled through application of the biocontrol fungus *Paecilomyces lilacinus* (Jonathan *et al.*, 1995; Hazarika, *et al.*, 1998; Nakat *et al.*, 1998; Pathak and Saikia, 1999; Hazarika *et al.*, 2000; Jonathan *et al.*, 2000; Bhatt *et al.*, 2002b). Application of *Trichoderma viride* multiplied on linseed oil cake was also found to be highly effective in reducing the root knot incidence in betel vine (Bhatt *et al.*, 2002a).

CHEMICAL. Field application of aldicarb or carbofuran at 1.5 kg/ha reduced root knot nematode populations (Jagdale *et al.*, 1984). In another experiment, application of aldicarb and carbofuran at 0.75 kg a.i./ha reduced nematode populations by 71 and 55%, respectively, resulting in increased yields. The nematicide, at both levels, degraded to non-detectable levels 41 days after application (Sivakumar *et al.*, 1987). Aldicarb, carbofuran and benfurocarb applied at 1.5, 3.0 or 5.0 kg a.i./ha, respectively, in furrows on either side of the rows can significantly reduce *M. incognita* populations in soil and galling of the roots (Dethe and Pawar, 1987). However, the use of systemic nematicides, i.e. aldicarb and carbofuran, is generally not recommended for betel vine as the leaves are picked continuously and consumed directly without any processing. Because of problems with nematicide residues in leaves (Pattnaik, 1989; Rao *et al.*, 1993; Mahapatra and Awasthi, 1994), root knot nematode infestations on betel vine must be solved by integrated nematode management such as those outlined below:

- Crop rotation wherever possible.
- Use of resistant/tolerant cultivars.
- Use of non-living standards or nematode-resistant live standards for supports.
- Solarization by mulching with 100 gauge clear polythene before planting.
- Application of organic amendments such as neem or *Calotropis* leaves and sawdust at 2 t/ha.
- Supply of nitrogen through neem oil cake at 2 t/ha.

Radopholus similis

The burrowing nematode *R. similis* has been reported to cause 'yellows' or 'slow wilt' disease of betel vine in India. The symptoms produced on betel vine are akin to the symptoms caused by *R. similis* on black pepper vines (Koshy and Sosamma, 1975; Sundararaju and Suja, 1986; Eapen *et al.*, 1987). The integrated management schedules suggested for control of nematodes on black pepper, other than application of nematicides, can be largely adopted with modification to suit local conditions for controlling *R. similis* on betel vine. Inoculation of plants with *Paecilomyces lilacinus* 25 days prior to *R. similis* was effective in reducing plant damage (Sosamma *et al.*, 1994).

Rotylenchulus reniformis

Acharya and Padhi (1987b) and Bhatt *et al.* (2002b) found *R. reniformis* to be pathogenic to betel vine. At inoculum levels of 1000 and 20,000 nematodes/cutting, the reduction in number of leaves was 20 and 60%, respectively. Ganguly (1988) reported *R. reniformis* as the dominant species found associated with five varieties of betel vine in Maharashtra. *R. reniformis* interacted synergistically with *Phytophthora palmivora* to increase vine mortality (Jonathan *et al.*, 1997).

Kava

Kava or Yaqona (*Piper methysticum* Forst.) provides a popular narcotic drink for the peoples of the Pacific islands. The drink is made from the thick roots of this bushy shrub.

Nematodes of Kava

Root knot nematodes, *Meloidogyne* spp., have been found associated with a serious disease of kava, and the nematodes alone can greatly decrease growth of plants in Fiji and Tonga (Stier, 1984 in Bridge, 1988) (Plate 22F). Fliege and Sikora (1981) reported *M. incognita* causing severe root galling of *P. methysticum* in Western Samoa.

Other potentially damaging parasitic nematodes that has been found with kava include *R. reniformis*, *P. coffeae* and *R. similis* (Kirby *et al.*, 1980; Orton Williams, 1980). None of these have as yet been shown to cause economic damage to the crop. Further investigations are necessary to determine the economic importance of nematodes, particularly *Meloidogyne* spp., and their means of control.

Medicinal Plants

Plant parasitic nematodes are associated with all medicinal plants studied to date, and often cause significant damage. However, the magnitude of crop damage has only been established for a few of these nematode–plant interactions (Pandey *et al.*, 2003). Three species of plant parasitic nematodes are considered of economic importance on medicinal plants: the root knot nematodes (*M. incognita* and *M. javanica*), the lesion nematode (*Pratylenchus thornei*) and the stunt nematode (*Tylenchorhynchus vulgaris*). Root knot nematodes are the most important nematode parasites limiting production, with infestations reported on menthol mint, henbanes, basil, opium poppy, aswagandha, sarpgandha, coleus, kinghao, brahmi and musli (Pandey, 1998b, 2003) as well as on jaborandi (*Pilocarpus microphyllos*) (R.A. Sikora, Germany, 2004, personal communication).

Henbanes

Henbanes (*Hyoscyamus muticus*, *H. niger* and *H. albus*) are important tropane alkaloid-bearing plants belonging to the family Solanaceae and one of the chief sources of tropane alkaloids (hyoscine, scopolamine, hyoscyamine, atropine, etc.) obtained from the dried leaves and other plant parts.

Meloidogyne

ılthough many plant parasitic nematodes ave been reported associated with different species of henbane, only root knot ematodes cause serious damage to the rop. Henbanes have been reported to be eavily infested with *M. incognita* and *M. ıvanica* in India (Pandey, 1990).

Symptoms of damage

oot knot-infested plants of *H. muticus*, *H. iger* and *H. albus* show chlorosis and :unting, and the plants have fewer and naller leaves and flowers. The roots of ıfested plants are often severely galled. A re-plant density of 3–4 juveniles/g of soil ıused significant damage to the crop Iaseeb and Pandey, 1989; Pandey, 1990).

Management measures

rops resistant to root knot should be used . rotation with henbanes to reduce preant nematode densities in the soil. No ɘnbane species screened have proved to be sistant to the nematodes (Pandey, 1998b).

The nematicides carbofuran at 2 kg ı./ha of soil and monocrotophos at 0.1% solution have been used to reduce root ıot nematode damage to henbane. onocrotophos was used to soak seeds ior to planting and carbofuran was ıplied to the soil prior to sowing the crop. ıe combined treatment effectively duced root knot infestations (Pandey, 00a).

When *H. niger* was inoculated with the ınt health-promoting rhizobacteria *P. fluo-ːcens* or with one of three species of arbuslar mycorrhizal fungi (*G. aggregatum*, *G. ɔsseae* or *G. feasiculatum*), *M. incognita* nsities were reduced and plant biomass :reased. The use of a combination of tagonists proved to be the most effective ındey, 1997; Pandey *et al.*, 2000b,c).

In pot tests, essential oils of *mbopogon martinii*, *C. wintrianus*, *imum basilicum* and *Mentha arvensis* re effective in reducing *M. incognita* pulations and improving the growth of *H. niger*; the oil from *C. martinii* at 2 ml/plant was most effective).

Ashwagandha (*Withania somnifera* L.)

This important medicinal plant is a major source of a number of alkaloids (sominiferine, somnine, withanine, tropine, isopelletierine, cuscohygrine, anaferine, anahygrine, visamine, etc.) and of withanollides, a group of naturally occurring oxygenated ergostane-type steroids. The roots of *W. somnifera* are used locally to treat hiccups, coughing, dropsy, rheumatism and as a sedative. It is also useful for treating inflammatory conditions whereby leaves are used as febrifuge and applied to lesions, painful swellings and sore eyes.

Nematodes of Ashwagandha

During a survey to collect new germplasm, almost all *W. somnifera* plants sampled were found to be galled by *M. incognita* race 2 (R. Pandey, India, 2004, personal communication). Infected plants were chlorotic, stunted, less branched with fewer and smaller leaves. Roots of such plants were severely galled. When the stem touches the soil, it was also found to be infested with the nematode (Fig. 21.5, Plate 22E).

Management measures

Amendments from the neem plant (*Azadirachta indica*), marc from *Artemisia annua* as well as distillates from *Mentha* and *Murrya koengii* were found to reduce *M. incognita* densities on *W. somnifera* (Pandey *et al.*, 2003). The combination of Vermicompost with *Trichoderma harzianum* and *Mentha* distillates with *G. aggregatum* were also found to reduce nematode densities and enhanced the growth of *W. somnifera* significantly. The combined use of these organic amendments with antagonistic microorganisms was considered suitable for nematode management programmes, but still need advanced field testing (Pandey *et al.*, 2003).

Fig. 21.5. Large root galls on *Withania somnifera* infested with *Meloidogyne* sp. (Photo: V.K. Sosamma.)

Fig. 21.6. *Bacopa monnieri* plant infested with *Meloidogyne* sp. (Photo: V.K. Sosamma.)

Brahmi (*Bacopa monnieri*)

B. monnieri L., commonly known as brahmi, is the chief source of baccoside A and B, which are used extensively in formulation of medicines useful against asthma and epilepsy.

Nematodes of Brahmi

Although a number of plant parasitic nematodes are associated with brahmi, only the root knot nematode *M. incognita* causes serious damage to the crop. The nematode causes stunting and leaf chlorosis (Fig. 21.6). In greenhouse trials, a negative correlation between increasing population levels of *M. incognita* and plant growth of *B. monnieri* was demonstrated (Pandey *et al.*, 2003).

Management measures

The amendments and distillates combined with the fungal antagonists discussed above in the section on control in ashwagandha were also successful in reducing root knot densities and enhancing the growth and yield of *B. monnieri* (Pandey *et al.*, 2003).

Chlorophytum borivillianum

C. borivillianum, commonly known as safed musli, is an important medicinal plant belonging to the family Liliaceae. This plant is widely distributed throughout India. The presence of saponins and alkaloids in this plant is of medicinal importance. Progressive farmers in India are cultivating the crop for both the local and international herbal industry. The tuberous root is sold in the market for medicinal use and also saved for planting the next crop. There are several species of *Chlorophytum* grown in India.

Nematodes of *Chlorophytum borivillianum*

Several nematode species are associated with *C. borivillianum*, but the root knot nematode *M. incognita* poses a major threat to successful cultivation of this crop. The nematode parasitizes the fine root system and completes its life cycle within the plant tubers. The nematode, therefore, causes severe tuber loss when present on the crop (Pandey *et al.*, 2003). Plants in infested fields are stunted and have drooping leaves that dry over time.

Management measures

Pandey *et al.* (2003) tested a number of techniques for root knot nematode control in *C. borivillianum* and suggested the following integrated approach to combat the nematode problem:

- Plant healthy tubers that are nematode free;
- Pre-treat the soil before planting with a nematicide; and
- Treat the tubers with a mixture of biological control agents.

Mint (*Mentha* spp.)

Among the different medicinal and aromatic plants, mints are of major pharmaceutical importance due to their many-fold uses. Farmers in the tropics and subtropics can grow mint as a cash crop whenever it fits into a cropping system. The crop generates significant local employment and earns foreign exchange. The main types of mints commercially cultivated in tropical and subtropical countries are: menthol mint (*Mentha arvensis*), peppermint (*Mentha piperita*), spearmint (*Mentha spicata*), scotch spearmint (*Mentha cardiaca*), bergamot mint (*Mentha citrata*) and garden mint (*Mentha viridis*).

Nematodes of Mints

Nematodes have been identified as major pests of several mint species. The important nematodes reducing yield are species of *Meloidogyne*, *Pratylenchus* and *Tylenchorhynchus*. Several other plant parasitic nematodes are associated with these mint species, but are of still unknown economic importance (Pandey, 1999).

Meloidogyne

M. incognita particularly and also *M. javanica* are important parasites on menthol mint wherever it is grown.

Symptoms of damage

Root knot-infested mint plants are stunted and chlorotic, with damage occurring in typical oval patches throughout the field. Root knot-infested suckers or roots bear galls of various sizes (Fig. 21.7) and eggs are clearly visible on the root system under the microscope (Plate 22F).

Fig. 21.7. Suckers of mint, *Mentha arvensis*, infested with *Meloidogyne* sp. (Photo: V.K. Sosamma.).

Biology

The life cycle of *M. incognita* in menthol mint is completed within 28–30 days, with up to four generations developing per season under favourable conditions. Race 2 of *M. incognita* is predominant in the Lucknow area of Uttar Pradesh, India (Pandey *et al.*, 1992).

Survival and dissemination

Because *Meloidogyne* juveniles and eggs survive inside the storage roots and suckers, the nematode is often disseminated in planting material if care is not taken to avoid contamination. Soil adhering to the suckers is also a means of spread. The presence of alternative weed hosts in a field is important in maintaining root knot nematode inoculum between crops.

Environmental factors

Meloidogyne multiplies well in the sandy soils generally used to cultivate menthol mint, therefore, damage caused by root knot nematodes in these regions is often severe (Pandey *et al.*, 1992). Menthol mint is also transplanted in January when temperatures are optimum for nematode infection and development, resulting in 3–4 generations per growing season and high levels of damage.

Economic importance

Meloidogyne species significantly reduce plant growth and oil yield. In addition, *M. incognita* multiplies on all species of *Mentha* as well as on all cultivars (Pandey, 1989). Strong reductions in plant growth as well as in the rate of photosynthesis were found to be directly correlated with initial inoculum densities. *M. incognita* and *M. javanica* caused a 25–30% reduction in oil yield in menthol mint; the quality of the mint oil is also adversely affected by nematode infection (Pandey, 1998a, 2003).

Management of nematodes in menthol mint

Root knot infection was reduced when plants were pre-inoculated with different combinations of arbuscular mycorrhizal fungi (Pandey *et al.*, 1997). The symbionts reduced nematode infection and improved yield.

Successful control of root knot was also achieved with the application of carbofuran at 1.5 kg a.i./ha or with neem cake at 500 kg/ha (Pandey, 2000b, 2003).

Management of *M. incognita* using biological control agents, organic matter and integration of both was studied by Pandey (1995, 1998, 2000). The arbuscular mycorrhizal fungi (*G. aggregatum*, *G. mosseae* and *G. fasiculatum*), the antagonist (*T. harzianum*) and the oil seed cakes from mustard (*Brassica compestris*) and from neem (*A. indica*) along with the nematicide carbofuran were effective in increasing the yield of menthol mint and in reducing root knot densities. Maximum reduction in the nematode population was recorded in the neem cake-treated soil followed by mustard cake, carbofuran and then the biological control agents. Significantly higher levels of yield were obtained in the following order: neem, mustard, *T. harzianum*, *G. aggregatum* and then carbofuran. The use of Vermicompost and different distillation waste products was also found to enhance the growth and yield of different mint species and reduce nematode populations significantly (Pandey *et al.*, 2003). The importance of these control measures to the grower needs further field testing.

Resistance

Germplasms available in the gene bank at the Central Institute of Medicinal and Aromatic Plants (CIMAP) in Lucknow, India were screened for resistance to *M. incognita* (Pandey and Patra, 2001). Moderate to high degrees of resistance were observed on SS-1-4, SS-2-7, SS-15, SS-26, SS-36, *M. piperita* cv. Kukrail, *M. spicata* cv. Neera, *M. spicata* cv. Arka, *M. citrata* cv. Kiran, *M. gracilis* and *M. viridis*.

Non-host crops such as mustard and wheat have been shown to reduce root knot populations and increase yield of menthol mint (Table 21.2). The 'Late Transplanted

Table 21.2. Utilizing crop rotation to increase yield as well as minimizing the root knot nematode populations in menthol mint (Pandey, 2003).

Crop rotation	Net benefit (Rupees)	Root knot index in menthol mint
1 Maize–potato–menthol mint	83,000	+
2 Paddy–potato–menthol mint	80,000	+
3 Paddy–pea–menthol mint	74,000	+++
4 Maize–mustard–menthol mint	76,000	++
5 Pigeonpea–menthol mint	72,000	++
6 Paddy–menthol mint	75,000	++
7 Paddy–wheat–menthol mint	68,000	++

+ = mild , ++ = moderate , +++ = severe infestations.

Mint Technology' developed at CIMAP, which allows farmers to plant these non-host crops, has also greatly benefited crop health and yield. The higher temperatures prevailing during late transplanting (April–July) adversely affect nematode population build-up and infection of the menthol mint crop (Pandey, 2003).

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