Journal of Spices & Aromatic Crops 4 (1) : 1-16, 1995

Parasitic nematodes and their management in major spices

K V RAMANA & SANTHOSH J EAPEN

National Research Centre for Spices
Calicut – 673 012, Kerala, India.

ABSTRACT

Black pepper (*Piper nigrum*), cardamom (*Elettaria cardamomum*), ginger (*Zingiber officinale*), turmeric(*Curcuma longa*) and tree spices are the major spices cultivated in India. Several plant parasitic nematodes are reported on these spice crops and among them, root knot nematodes (*Meloidogyne* spp.), burrowing nematodes (*Radopholus similis*) and root lesion nematodes (*Pratylenchus* spp.) are the major nematode pests of economic importance. Plant parasitic nematodes are primary incitants of slow decline disease of black pepper. Root knot nematodes are a seious constraint to cardamom cultivation, especially in nurseries. In ginger and turmeric, all three of them cause significant damage. However, not much attention has been given to nematodes of tree spices. The major symptoms of nematode attack, the nature and extent of damage, their interaction with other soil borne microorganisms and various control measures are discussed. Considering the export oriented nature of these crops, emphasis has been given on integrated nematode management with minimum use of chemicals.

Key words: black pepper, cardamom, ginger, nematodes, tree spices, turmeric.

Introduction

Spices had a major role in influencing the course of history and civilization all over the world. They, even today play an important role in the national economy of many countries. India is considered as the 'Home of Spices' from ancient times and it produces an large array of spices. Under the Indian Spice Act, 51 plant species are denoted as spice crops. India earned about Rs. 540 crores through export of 175,532 t of different spices and spice products during 1993-94.

Apart from several abiotic factors, spice crops are affected by many diseases and pests, resulting in enormous loss in quality and quantity of spices. Among them, damage by plant parasitic nematodes is a serious problem in spices production. Their economic importance is now well established in many spice crops. However, nematological investigations are concentrated mainly on major spices like black pepper, cardamom, ginger, turmeric, etc. and to a lesser extent on seed spices.

Black pepper (*Piper nigrum* L.)

Plant parasitic nematodes belonging to 52 species and 31 genera were reported in association with black pepper. However, very few nematode species like *Meloidogyne* sp., *Radopholus similis, Helicotylenchus* sp. and *Trophotylenchulus piperis* are of common occurrence and economic importance (Ramana & Mohandas 1987 & 1989). Intercropping, perennial nature of the crop, use of other trees for shade or as live standards, etc. add special dimensions to nematode problems of black pepper.

Economic importance

Economic importance of plant parasitic nematodes is related to reduction in yield and growth parameters or their association with other microorganisms in disease complexes. Among the four major nematodes of black pepper, *T. piperis* is a new, semiendoparasitic nematode and not much is known on its damaging potential or nature of damage in black pepper (Mohandas, Ramana & Raski 1985). *R. similis* and *M. incognita* are the primary incitants of 'slow decline' in black pepper, though *Phytophthora capsici* can also induce similar symptoms (Anandaraj, Ramachandran & Sarma 1991; Ramana, Sarma & Mohandas 1992). Slow decline (slow wilt or yellows disease) causes up to 32 per cent crop loss in Indonesia (Sitepu & Kasim 1991) and about 30 per cent vines are damaged annually in Guyana by this disease (Biessar 1969). In Para, Brazil 91 per cent of black pepper vines were infested with root knot nematodes, mostly *M. incognita* (Ichinohe 1975). Though exact crop loss in India is not available, the disease is rampant in all black pepper growing areas in Kerala and Karnataka (Ramana 1991). A population level of 250 *R. similis* per gram of root was consistently recorded with slow decline affected black pepper vines in Kerala (Ramana, Mohandas & Balakrishnan 1987). Yield losses varied from 38.5 to 64.6 per cent in *R. similis* inoculated plants, alone or in combination with *M. incognita* (Mohandas & Ramana 1991). *M. incognita* is also highly pathogenic to black pepper particularly at higher inoculum level (Koshy *et al*. 1979; Freire & Bridge 1985 c; Mohandas & Ramana 1991).

Nature of damage

In black pepper typical galls or knots are seen on secondary or fibrous roots and elongated swellings on thick primary roots. Adult females with egg masses are generally enclosed deep within these roots.

Burrowing nematode (*R. similis*) produces typical dark brown lesions and rotting in roots of black pepper. Root knot nematodes cause dense yellowish discolouration of the interveinal areas (interveinal chlorosis) in leaves of black pepper vines (Ramana, Mohandas & Eapen 1994).

R. similis penetrated the roots through the root tips and the cortex cells immediately around the nematodes turned necrotic and some xylem vessels were plugged with a gum like substance (Freire & Bridge 1985 a). *M. incognita* increased the total phenols in black pepper (Ferraz, Orchard & Lopez 1984) and there were several changes in levels of aminoacids, organic acids and sugars compared to uninfected plants (Freire &

Bridge 1985 b). The total chlorophyll content of leaves was significantly reduced in black pepper plants inoculated with *M. incognita* (Ferraz, Lordello & Gonzaga 1989). Absorption and translocation of P, K, Zn, Mg, Cu, etc., were also severely affected because of root knot nematode infestation (Ferraz, Lordello & Santana 1988).

Biology and environmental factors

Radopholus similis completes its life cycle in black pepper in 25-30 days at a temperature range of 21-31°C (Koshy 1986). Maximum population of *R. similis* in roots of black pepper is observed during September-October and minimum during April-June (Mohandas & Ramana 1988). *M. incognita* is seen in very high numbers during December - January (Ramana 1992).

Interaction with other microorganisms

Several reports are available on the possible involvement of a nematode - fungus complex for the black pepper yellows disease in Indonesia (Hubert 1957; Bridge 1978). An Indonesian isolate of *R. similis* predisposed black pepper seedlings to attack by a weak pathogenic isolate of *Fusarium solani*, causing severe root damage (Freire 1982). *M. incognita* and *F. solani* f.sp. *piperis* together caused more damage than either of them alone (Lopes & Lordello 1979; Hamada, Hirakata & Uchida 1985). Sheela & Venkitesan (1990) also found a similar association with *M. incognita* and *Fusarium* species. According to Mustika (1991& 1992), *Fusarium solani* along with *M. incognita* alone did not induce any symptoms of slow decline, though wilting and drying occurred. *R. similis* alone or in combination with *M. incognita* or *F. solani* caused foliar yellowing with stiff droop of leaves (Mustika 1984 & 1991). In Malaysia, Winoto (1972) reported increased susceptibility of *M. incognita* and *M. javanica* infected black pepper (cv.Kuching) to *Phytophthora* infection. Recent studies in India showed that feeder root loss caused by *R. similis, M. incognita* and *P. capsici* either alone or in combination lead to slow decline disease in black pepper (Anandaraj, Ramana & Sarma 1994).

In black pepper, *Rotylenchulus reniformis* was found to inhibit the multiplication of *M. incognita* and its damage (Ferraz & Sharma 1979). Root gall development and population build up of *M. incognita* were suppressed in black pepper on inoculation with *R. similis* (Sheela & Venkitesan 1981).

Control

Cultural : Plant hygiene has a vital role in nematode management. Use of healthy and nematode - free planting material can ensure better establishment, survival and higher yield. Mass production of such disease free planting material can be achieved in black pepper nurseries by raising planting material in disinfected soil. Soil fumigation of potting mixture is reported to be effective in black pepper nurseries (Sarma *et al.* 1987).

In perennial crops, suitable crop combinations can be decided based on the host suitability of various intercrops, shade trees or live standards to the important nematode fauna. Arecanut, coconut, black pepper, cardamom, banana etc. are the major components in high density multispecies cropping systems prevalent in India. All these crops are susceptible to *M. incognita* and *R. similis* and therefore aggravate nematode problems. *Artocarpus heterophyllus, A. hirsutus, Ailanthes malabarica, Mesopsis emini, Peltophorum pterocarpum, Swietenia macrophylla, Tamarindus indica, Garuga pinnata* and *Macaranga peltata* are resistant to *M. incognita* and can be used as live standards for black pepper (Koshy, Sosamma & Sunadaraju 1977; Ramana 1986).

Mulching reduced the slow decline incidence in black pepper gardens in Bangka (Pasril 1976; de Waard 1979). Growing a non - host cover plant, siratro (*Macroptilium artopurpureus*) in the interspace and mulching with Guatemala grass (*Imperata cylindrica*) reduced populations of *M. incognita* on black pepper in the Amazonian region (Ichinohe 1980 & 1985). In black pepper, neem cake application reduced nematode populations and increased the yield (Ramana, Sarma & Mohandas 1992).

In vitro studies showed that crude methanol extracts of leaves of *Piper colubrinum,* a related species of *P. nigrum,* which is resistant to both *R. similis* and *M. incognita,* exhibited nematicidal property against root knot nematodes of black pepper (NRCS 1993).

Chemical : Application of nematcides like phorate 10G (1 g) or carbofuran 3G (3 g) per polybag is recommended to bring down the initial nematode load in black pepper rooted cuttings (Mohandas & Ramana 1987). In adult vines phorate or carbofuran 3 g ai per vine, twice a year reduced nematode populations significantly (Mohandas & Ramana 1987; Ramana, Sarma & Anandaraj 1993).

Host resistance : A black pepper selection, Ottaplackal - 1 is resistant to root knot nematode and has been released as Pournami (Ramana & Mohandas 1986; Ramana 1992). In Sri Lanka, another selection, PW14 was resistant to *R. similis* (Gnanapragasam 1989). Sources of resistance to root knot nematodes were located in two related species of black pepper, *P. colubrinum* and *P. aduncum* (Ramana 1992; Paulus *et al.* 1993). *P. cloubrinum* is resistant to *R. similis* also. Moderate resistance to root knot nematodes has been located in some lines of black pepper (Venkitesan & Setty 1978; Jacob & Kuriyan 1979; Koshy & Sundararaju 1979; Ramana, Mohandas & Ravindran 1987; Paulus *et al.* 1993).

Biological : *Paecilomyces lilacinus, Verticillium chlamydosporium* and *Bacillus* spp. gave good control of root knot nematodes of black pepper (Freire & Bridge 1985 d; Ramana 1994; Sheela, Venkitesan & Mohandas 1993). However, none of them are effective against *R. similis.* VAM fungi viz., *Glomus fasciculatum, G. etunicatum* and *Acaulospora laevis* reduced root knot nematodes and enhanced growth of black pepper (Sivaprasad *et al.* 1990 & 1992; Anandaraj, Ramana & Sarma 1991).

Cardamom (*Elettaria cardamomum* Maton.)

In cardamom, plant parasitic nematodes belonging to 28 species and 19 genera are reported. Among them, root knot nematodes (*Meloidogyne* spp.) pose serious problems in nurseries and also in plantations in India (Ali & Koshy 1982 b; Ali 1984 & 1986 b).

Economic importance

Microplot studies under simulated field conditions showed 46.6 per cent yield loss in cardamom, at an initial inoculum level of 4 nematodes/100 cm^3 soil (Eapen 1994). *Pratylenchus* sp. is commonly seen in cardamom - coffee mixed plantations, while *R. similis* is prevalent in cardamom - arecanut mixed gardens.

Nature of damage

In cardamom, the galls are seen only in young seedlings but not on roots of mature plants in the plantation (Eapen 1992). Stunting, narrowing of leaves and poor tillering are major aerial symptoms of root knot nematode infestation in cardamom (Eapen 1994). In cardamom nurseries, they cause significant reduction (more than 50 per cent) in seed germination and the infested seedlings fail to establish on transplantation (Ali & Koshy 1982 b).

Biology and environmental factors

Root knot nematode population in cardamom plantations is very high during the post - monsoon season (Eapen 1993). These fluctuations in nematode population are generally influenced by rainfall and its subsequent effect on soil moisture, soil temperature and root regeneration of the host plant.

Interaction with other microorganisms

In cardamom, *M. incognita* is the predisposing factor for *Rhizoctonia solani* infection, causing damping off and rhizome rot, prevalent in cardamom nurseries (Ali & Venugopal 1992 & 1993). However, cardamom plants infected with 'katte' mosaic virus supported 5-10 times more *M. incogita* population (Ali 1989).

Control

Cultural : Nematode problems are more severe in cardamom nurseries and hence utmost importance may be given for production and distribution of nematode free seedlings. Traditionally, cardamom nurseries are retained at the same site for a number of years resulting in nematode population build up. This unhealthy practice should be discontinued. Soil fumigation or soil solarization of nursery sites can minimise nematode problems to a greater extent (Ali & Koshy 1982 a; NRCS 1993).

Cardamom soils are generally rich in organic content and the status of these soils has to be preserved or enhanced. Application of neem oil cake reduced nematode populations and increased the yield of cardamom (Ali 1987 a).

Chemical : In cardamom nurseries, apart from soil fumigants, several granular formulations like phorate, carbofuran, fenamiphos, etc. were found effective (Ali 1986 a; 1987 b). Phorate @ 2.5-5.0 g a i/ plant or carbofuran @ 5.0 g a i/ plant (twice a year) reduced root knot nematodes and increased the yield (Ali 1987 a; Eapen 1994).

Biological: *Paecilomyces lilacinus* and *Trichoderma* spp. were found to reduce root knot nematode problems in cardamom nurseries(NRCS 1993). Two VAM fungi viz., *G. fasciculatum* and *Gigaspora margarita* were also found to minimize root knot nematode problems in cardamom seedlings (Thomas *et al.* 1989).

Ginger (*Zingiber officinale* Rosc.) and turmeric (*Curcuma longa* L.)

M. incognita, M. arenaria, R. similis, Pratylenchus coffeae and *P. zea* are the major nematode parasites of ginger and turmeric (Routaray, Sahoo & Das 1987; Kaur & Sharma 1988; Kaur, Sharma & Khan 1989). *Rotylenchulus reniformis* is widely distributed in turmeric fields of Andhra Pradesh (Mani & Prakash 1992).

Economic importance

The economic threshold levels of root knot nematode in ginger were reported variously as 1 infective juvenile of *M. incognita* per 30 g of soil (Sukumaran & Sundararaju 1986), 50 larvae of *M. incognita* and *M. hapla* per 100 ml soil (Kaur 1987) and 2 nematodes per gram of soil (Parihar & Yadav 1986; Routary, Mohapatra & Das 1987) to cause significant reduction in growth and yield. *P. coffeae* is reported to cause ginger yellows disease (Kaur & Sharma 1990). An inoculum of 1000 *M. incognita* juveniles or more per plant causes significant reduction in growth of turmeric (Sukumaran, Koshy & Sundararaju 1989).

Nature of damage

The fleshy roots of ginger evidently are more sensitive to root knot nematode infestation than fibrous roots. Root knot nematodes produced brown, water soaked areas on rhizomes of ginger (Huang 1966; Shah & Raju 1977). Because of galling and rotting, turmeric rhizomes loose their bright yellow colour (Mani, Naidu & Madhavachari 1987). In ginger and turmeric, shallow, sunken, water soaked lesions are seen on the surface of *R. similis* infested rhizomes (Vilsoni, Mac Clure & Butler 1976; Sosamma, Sundararaju & Koshy 1979; Sundararaju, Sosamma & Koshy 1979). The visible symptoms of nematode infestation are stunting, chlorosis, poor tillering and necrosis of leaves. The affected plants mature and dry faster than healthy ones, resulting in a poor crop stand. *M. incognita* enters the cortex and stelar regions of ginger root tissues forming giant cells (Lanjewar & Shukla 1988). These giant cells were with thickened walls in vascular tissues including phloem parenchyma of stelar regions (Routaray, Mohapatra & Das 1987).

Biology and environmental factors

In ginger roots, root knot nematodes develop to maturity in 21 days but in rhizomes they require 40 days at 30°C (Cheng & Tu 1979). Optimum temperature for reproduction of root knot nematode of ginger is 31.5°C (Nadakal 1964).

Interaction with other microorganisms

Concomitant infections by *M. incognita* and *Pythium myriotylum* did not result in soft rot disease of ginger but the fungus was antagonistic to the nematode (Lanjewar & Shukla 1985). It is also reported that there is no interaction between *M. incognita* and *P. aphanidermatum* (Doshi & Mathur 1987). However, there are reports that incidence of rhizome rot in ginger was more severe when the rhizomes are infected by nematodes and fungal pathogens like *Pythium* spp., and *Fusarium* spp. (Dohroo, Shyam & Bhardwaj 1987). Basal sheath rot, a new disease of ginger is suspected to be caused by the combined infection of *Aphelenchus* spp. and a *Fusarium* sp. (Magar & Mayee 1988). Bacterial wilt of ginger, caused by *Pseudomonas solanacearum* is also influenced by *M. incognita* (Samuel & Mathew 1983)

Control

Cultural : For ginger cultivation in Fiji, a ginger - taro - fallow rotation has been recommended to minimise nematode problems (Haynes, Partridge & Sivan 1973). Application of well-decomposed cattle manure, compost, saw dust, green leaves or neem cake helps in reducing nematode multiplication in ginger (Colbran 1974; Pegg, Moffett & Colbran 1974; Mohanty, Mohapatra & Patnaik 1992).

Physical : Soil solarization has been successfully employed in ginger fields (Balakrishnan, Usman & Sarma 1993). Hot water treatment of ginger and turmeric rhizomes reduce nematode problems (Colbran & Davis 1969; Anonymous 1971; Pegg, Moffet & Colbran 1974; Chen, Li & Lii 1986).

Chemical : Use of nematicides in annual crops like ginger and turmeric should be done with utmost care to avoid residues in the produce. However, among the various chemicals, fenamiphos (2.5 - 3.0 kg ai/ha) and carbofuran (1.0 - 4.0 kg ai /ha) were found to be the most effective (Colbran 1972; Kaur 1987; Patel, Makadia & Shah 1982; Mani, Naidu & Madhavachari 1987).

Host resistance : Mani, Naidu & Madhavachari (1987) screened several turmeric lines and the following lines viz., 5379-1-2, 5363-6-3, 5335-1-7, 5335-27, Ca-17/1, Cli-124/6, Cli-339, Armoor, Duggirala, Guntur - 1, Guntur - 9, Rajampet, Sungandham and Uppalapadu were resistant to root knot nematodes. Moderate resistance to root knot nematodes is observed in several other turmeric lines (Chen, Li & Lii 1986; Mani & Sri Hari 1989). However, no resistant/tolerant lines have been identified so far in ginger (Charles & Kuriyan 1982).

Tree spices

Cinnamon (*Cinammomum verum* Brecht & Presl.), nutmeg (*Myristica fragrans* Houtt.) and clove (*Syzygium aromaticum* (L.) Merr. & Perry) are the important tree spices in the country. Little information is available on the damage and yield loss caused by plant parasitic nematodes on these crops. But several plant parasitic nematodes are reported in association with these crops (Table 1).

Table 1. Plant parasitic nematodes associated with tree spices

Nematode species	Cinnamon	Clove	Nutmeg
Basirolaimus indicus	+	–	–
Caloosia sp.	–	+	–
C. paradoxa	–	+	–
Criconemella sp.	+	+	–
Discocriconemella barberi	+	–	+
Dolichodorus sp.	–	+	–
Helicotylenchus sp.	+	+	+
H. dihystera	–	+	–
Hoplolaimus sp.	–	+	+
Meloidogyne sp.	+	–	–
Meloidogyne incognita	–	+	+
Paratylenchus sp.	–	+	+
Pratylenchus sp.	–	+	–
P. zeae	+	–	–
Radopholus similis	–	+	+
Rotylenchus sp.	+	+	+
Rotylenchulus reniformis	+	+	+
Trichodorus sp.	–	+	–
Tylenchorhynchus sp.	–	+	–
Xiphinema sp.	+	+	+

Source : Goodey, Franklin & Hopper 1965; Sundararaju, Koshy & Sosamma 1979; Kumar, Viswanathan & D'Souza 1971; Chawla Samathanam 1980; Dasgupta & Rama; 1987 Koshy & Bridge 1990.

Conclusion

Nematode-induced damages are difficult to differentiate as nematodes are only one of the several agents which may impair root function. But as such there is insufficient information on their biology, variability, mode of survival, etc. Increased knowledge on these and several other aspects will enable to develop new, effective and environment friendly control measures. Many potentially useful cultural and biological methods for nematode control have been neglected in the past because of the pre-eminence of nematicides. Specific organic amendments that may stimulate microflora, antagonistic to nematodes should be identified. All efforts should be made to exploit host resistance already available in many crops. Recent advances in cellular and molecular biology will be of immense help in future nematode research programmes.

References

Ali S S 1984 Occurrence of root knot nematodes in cardamom plantations of Tamil Nadu. In: Proc. PLACROSYM-V 1982 (pp. 615-620). Indian Society for Plantation Crops, Kasaragod, India.

Ali S S 1986 a Evaluation of nemacur against *Meloidogyne incognita* in a cardamom nursery. Indian J. Nematol. 16 : 48-50.

Ali S S 1986 b Occurrence of root knot nematodes in cardamom plantations of Karnataka. Indian J. Nematol. 16 : 269-270.

Ali S S 1987 a Preliminary observations on the effect of some systemic nematicides and neem oil cakes in a cardamom field infested with root knot nematodes. In: Proc. PLACROSYM-VI 1984 (pp.215-223). Indian Society for Plantation Crops, Kasaragod, India.

Ali S S 1987 b Effect of three systemic nematicides against root knot nematodes in a cardamom nursery. Nematol. medit. 15 : 155-158.

Ali S S 1989 Influence of 'katte' mosaic virus of cardamom on the population of *Meloidogyne incognita*. Nematol. medit. 17 : 121-122.

Ali S S & Koshy P K 1982 a A note on use of Methyl Bromide for control of root-knot nematodes in cardamom nurseries. Indian J. Nematol. 12 : 147-150.

Ali S S & Koshy P K 1982 b Occurrence of root knot nematodes in cardamom plantations of Kerala Nematol. medit. 10 : 107-110.

Ali S S & Venugopal M N 1992 Interaction between *Meloidogyne incognita* and *Rhizoctonia solani* in damping off and rhizome rot disease of cardamom seedlings. Nematol. medit. 20 : 65-66.

Ali S S & Venugopal M N 1993 Prevalence of damping off and rhizome rot disease in nematode infested cardamom nurseries in Karnataka. Curr. Nematol. 4:19-24.

Anandaraj M, Ramachandran N & Sarma Y R 1991 Epidemiology of foot rot disease of black pepper (*Piper nigrum* L.) in India. In: Sarma Y R & Premkumar T (Eds.) Diseases of Black Pepper (pp. 113-135). National Research Centre for Spices, Calicut.

Anandaraj M, Ramana K V & Sarma Y R 1991 Interaction between vesicular arbuscular mycorrhizal fungi and *Meloidogyne incognita* in black pepper. In: Bagyaraj D J & Manjunath A (Eds.) Mycorrhizal Symbiosis and Plant Growth (pp. 110-112). University of Agricultural Sciences, Bangalore.

Anandaraj M, Ramana K V & Sarma Y R 1994 Role of *Phytophthora capsici* in the etiology of slow decline disease of black pepper (*Piper nigrum* L.). In: Abstracts of Papers. International Symposium on Plantation Crops, 30 November - 3 December 1994 (p.23), Calicut. National Research Centre for Spices, Calicut.

Anonymous 1971 Fiji Department of Agriculture - Report for the year 1970 (p.34). Fiji Parliament, Fiji.

Balakrishnan P K, Usman N M & Sarma Y R 1993 Disease management of rhizome rot of ginger by solarization. In: Abstracts of Papers, Symposium on Management of Plant Diseases through Resistance, Bioagents and Chemicals, 25-26 November, 1993. University of Agricultural Sciences, Dharwad, India.

Biessar S 1969 Plant parasitic nematodes of crops in Guyana. PANS 15 : 74-75.

Bridge J 1978 Plant nematodes associated with cloves and black pepper in Sumatra and Bangka, Indonesia. ODM Technical Report on Visit to Indonesia, July 9-19, 1978. UK Ministry of Overseas Development, Imperial College of London University, Silwood Park, Sunninghill, Ascot, Berks, U. K.

Charles J S & Kuriyan K J 1982 Relative susceptibility of ginger cultivars to the root knot nematode, *Meloidogyne incognita*. In: Nair M K, Premkumar T, Ravindran P N & Sarma Y R (Eds.) Proc. National Seminar on Ginger and Turmeric, 7-8 April - 1980, Calicut (pp. 133-134). Central Plantation Crops Research Institute, Kasaragod, India.

Chawla M L & Samathanam C J 1980 Two new speies of the superfamily Longidoridae (Dorylaimida: Nematoda) from India. Indian J. Nematol. 10 : 205-210.

Chen C M, Li H & Lii D Y 1986 The study on root knot nematodes of common turmeric (*Curcuma domestica* Valet). Herald agric. Sci. 1 : 16-22.

Cheng Y H & Tu C C 1979 Pathogenesis of *Meloidogyne incognita* to edible ginger. J. agric. Res. China 28 : 91-99.

Colbran R C 1972 Studies of root knot nematode control in ginger with non-volatile nematicides applied at and after planting. Qd. J. Agric. Anim. Sci. 29 : 275-280.

Colbran R C 1974 Nematode control in ginger with nematicide, selection of planting materials and saw dust mulch. Qd. J. Agric. Anim. Sci. 31 : 231-235.

Colbran R C & Davis J J 1969 Studies of hot water treatment and soil fumigation for control of root knot in ginger. Qd. J. Agric. Sci. 26 : 439-445.

Dasgupta M K & Rama K 1987 Plant parasitic nematodes associated with plantation crops. Rev. Trop. Plant Path. 4 : 289-304.

Dohroo N P, Shyam K R & Bhardwaj S S 1987 Distribution, diagnosis and incidence of rhizome rot complex of ginger in Himachal Pradesh. Indian J. Plant Pathol. 5 : 24-25.

Doshi A & Mathur S 1987 Symptomatology, interaction and management of rhizome rot of ginger by xenobiotics. Korean J. Plant Prot. 26 : 261-265.

Eapen S J 1992 Influence of plant age on root knot nematode development in cardamom. Nematol. medit. 20 : 193-295.

Eapen S J 1993 Seasonal variations of root knot nematode population in a cardamom plantation. Indian J. Nematol. 23: 63-68.

Eapen S J 1994 Pathogenicity of root knot nematode on small cardamom (*Elettaria cardamomum* Maton). Indian J. Nematol. 24 : 31-37.

Ferraz E C A & Sharma R D 1979 Interaction and pathogenicity of *Meloidogyne incognita* (Kofoid & White 1919) Chitwood 1949 and *Rotylenchulus reniformis* Linford & Oliveira 1940 on black pepper. Revista Theobroma 9 : 45-53.

Ferraz E C A, Lordello L G E & Gonzaga E 1989 Influence of *Meloidogyne incognita* (Kofoid & White 1919) Chitwood 1949 on chlorophyll content of black pepper (*Piper nigrum* L.). Agrotropica 1 : 57-62.

Ferraz E C A, Lordello L G E & Santana C J L De 1988 Nutrient absorption of black pepper vine (*Piper nigrum* L.) infested with *Meloidogyne incognita* (Kofoid & White 1919) Chitwood 1949. Boletin Tecnico Centro de Pesquisas do Cacau, Brazil No. 160, 34 pp.

Ferraz E C A, Orchard J E & Lopez A S 1984 Reactions of black pepper to *Meloidogyne incognita* in relation to total phenol. Revista Theobroma 14 : 217-227.

Freire F C O 1982 Interactions of fungi and nematodes of black pepper (*Piper nigrum* L.). PhD Thesis, University of London, UK.

Freire F C O & Bridge J 1985 a Histopathology of black pepper roots infected with *Radopholus similis*. Fitopatologia Brasileira 10 : 475-481.

Freire F C O & Bridge J 1985 b Biochemical changes induced in roots and xylem sap of black pepper by *Meloidogyne incognita*. Fitopatologia Brasileira 10 : 483-497.

Freire F C O & Bridge J 1985 c Influence of different inoculum levels of *Meloidogyne incognita, Nectria haematococca* f. sp. *piperis* and *Phytophthora palmivora* on black pepper plants. Fitopatologia Brasileira 10 : 559-575.

Freire F C O & Bridge J 1985 d Parasitism of eggs, females and juveniles of *Meloidogyne incognita* by *Paecilomyces lilacinus* and *Verticillium chlamydosporium*. Fitopatologia Brasileira 10 : 577-596.

Gnanapragasam N C 1989 Varietal response of pepper to infestation by the burrowing nematode, *Radopholus similis*. Sri Lanka J. Tea Sci. 58 : 5-8.

Goodey J S, Franklin M T & Hooper D J 1965 T. Goodey's The Nematode Parasites of Plants Catalogued under their Hosts. Farnham Royal, CAB, England.

Hamada M, Hirakata K & Uchida T 1985 Influence of southern root knot nematode, *Meloidogyne incognita* on the occurrence of root rot of pepper (*Piper nigrum* L.) caused by *Fusarium solani* f. sp. *piperis*. Proceedings of the Kanto-Tosan Plant Prot. Soc. 32 : 236-237.

Haynes P H, Partridge I J & Sivan P 1973 Ginger production in Fiji agric. J. 35 : 51-56.

Hedge L, Krishnappa K & Bojappa K M 1993 Reaction of different cultivars of cardamom (*Elettaria cardamomum* Maton) to root knot nematode (*Meloidogyne incognita*). Indian J. Nematol. 23 : 127-128.

Huang C S 1966 Host parasitic relationship of root knot nematodes in edible ginger. Phytopathology 56 : 755-759.

Hubert F P 1957 Diseases of some export crops in Indonesia. Plant Dis. Reptr. 41 : 55-63.

Ichinohe M 1975 Infestation of black pepper vines by the root knot nematode, *Meloidogyne incognita* at Tome-Acu, Para, Brazil. Jap. J. Nematol. 5 : 36-40.

Ichinohe M 1980 Studies on the root knot nematode of black pepper plantation in Amazon. Annual Report of the Society of Plant Protection of North Japan. No.31, pp. 1-8.

Ichinohe M 1985 Integrated control of the root knot nematode, *Meloidogyne incognita* on black pepper plantations in the Amazonian region. Agric. Ecosystems and Environment 12 : 271-283.

Jacob A & Kuriyan J 1979 Screening of pepper varieties for resistance against root knot nematode (*Meloidogyne incognita*). Agric. Res. J. Kerala 17: 90.

Kaur K J 1987 Studies on nematodes associated with ginger (*Zingiber officinale* Rosc.) in Himachal Pradesh. PhD Thesis, Himachal Pradesh University, Shimla, India.

Kaur D J & Sharma N K 1988 Occurrence and pathogenicity of *Meloidogyne arenaria* on ginger. Indian Phytopath. 41: 467-468.

Kaur D J & Sharma N K 1990 A new report on *Pratylenchus coffeae* - a cause of ginger yellows. Int. Nematol. Network News 7 : 15-16.

Kaur D J, Sharma N K & Khan M L 1989 Occurrence of *Pratylenchus zeae* Graham 1951 on ginger *Zingiber officinale* (Rosc.) in Himachal Pradesh. Indian J. Nematol. 19 : 68.

Koshy P K 1986 The burrowing nematode, *Radopholus similis* (Cobb 1896) Thorne 1949. In: Swarup G. & Dasgupta D R (Eds.) Plant Parasitic Nematodes of India - Problems and Progress (pp. 223-248). Indian Agricultural Research Institute, New Delhi.

Koshy P K & Bridge J 1990 Nematode parasites of spices. In: Luc M, Sikora R A & Bridge J (Eds.)

Plant Parasitic Nematodes in Tropical Agriculture (pp. 557-582). CAB International, Wallingford, U K.

Koshy P K & Sundararaju P 1979 Response of seven black pepper cultivars to *Meloidogyne incognita*. Nematol. medit. 7 : 123-125.

Koshy P K, Sosamma V K & Sundararaju P 1977 Screening of plants used as pepper standards against root knot nematode. Indian Phytopath. 30 : 128-129.

Koshy P K, Premachandran D, Sosamma V K & Premkumar T 1979 Effect of *Meloidogyne incognita* population on black pepper. Indian Phytopath. 32 : 221-225.

Kumar A C, Viswanathan P R K & D'Souza G I 1971 A study of plant parasitic nematodes of certain commercial crops in coffee tracts of South India. Indian Coffee 35 : 222-224.

Lanjewar R D & Shukla V N 1985 Parasitism and interaction between *Pythium myriotylum* and *Meloidogyne incognita* in soft rot complex of ginger. Indian J. Nematol. 15 : 170-173.

Lanjewar R D & Shukla V N 1988 Histopathological study of root knot nematode in relation to the root tissues of ginger. PKV Res. J. 12 : 164-167.

Lopes E B & Lordello L G E 1979 *Meloidogyne incognita* and *Fusarium solani* f. *piperis* associated with wilting of black pepper. Revista de Agric. 49 : 165-166.

Magar L M & Mayee C D 1988 Nematode - fungus induced basal sheath rot of ginger from Maharashtra. Indian bot. Reptr. 7 : 65-67.

Mani A & Prakash K S 1992 Plant parasitic nematodes associated with turmeric in Andhra Pradesh. Curr. Nematol. 3 : 103-104.

Mani A & Sri Hari D 1989 Phytonematodes associated with turmeric in Andhra Pradesh and reaction of certain turmeric lines to *Meloidogyne incognita*. Indian J. Nematol. 19 : 272.

Mani A, Naidu P H & Madhavachari S 1987 Occurrence and control of *Meloidogyne incognita* on turmeric in Andhra Pradesh, India. Int. Nematol. Network Newsl. 4 : 13-18.

Mohandas C & Ramana K V 1987 Slow wilt disease of black pepper and its control. Indian Cocoa, Arecanut Spices J. 11 : 10-11.

Mohandas C & Ramana K V 1988 Population behaviour of *Radopholus similis* in roots of black pepper (*Piper nigrum* L.) in Kerala, India. Indian J. Nematol. 18 : 18-21.

Mohandas C & Ramana K V 1991 Pathogenicity of *Meloidogyne incognita* and *Radopholus similis* on black pepper (*Piper nigrum* L.) J. Plantn. Crops 19 : 41-43.

Mohandas C, Ramana K V & Raski D J 1985. *Trophotylenchulus piperis* n. sp., parasitic on *Piper nigrum* L. in Kerala, India (Nemata : Tylenchulidae). Revue Nematol. 8 : 97-102.

Mohanty K C, Mahapatra S M & Patnaik P R 1992 Integrated management of root knot nematode (*Meloidogyne incognita*) infecting ginger. Indian J. Nematol. 22 : 70-71.

Mustika I 1984 Effects of nematodes and fungi on the growth of pepper and yellow disease. Pemberitaan LPTI 8 : 28-37.

Mustika I 1991 Response of four black pepper cultivars to infection by *Radopholus similis, Meloidogyne incognita* and *Fusarium solani.* Industrial Crops Res. J. 4 : 17-22.

Mustika I 1992 Effects of *Meloidogyne incognita* and *Fusarium solani* on black pepper (*Piper nigrum* L.). Industrial Crops Res. J. 4 : 7-13.

Nadakal A M 1964 Studies on plant parasitic nematodes of Kerala. Part IV. Host range, seasonal variations and summer fallow - survival of Zingiber root knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood. Indian J. expt. Biol. 2 : 203-207.

National Research Centre for Spices 1993 Annual Report for 1992-93. National Research Centre for Spices, Calicut.

Parihar A & Yadav B S 1986 *Meloidogyne incognita* on ginger (*Zingiber officinale* Rosc.) and its control. Indian J. Mycol. Pl. Pathol. 16 : 84-86.

Patel D J, Makadia B M & Shah H M 1982 Occurrence of root knot on turmeric (*Curcuma longa* L.) and its control. Indian J. Nematol. 12 : 168-171.

Pasril W 1976 Studies on yellow disease in black pepper in the island of Bangka. Pemberitaan LPTI 21 : 64-79.

Paulus A D, Eng L, Teo C H & Sim S L 1993 Screening black pepper genotypes and *Piper* spp. for resistance to root knot nematode. In: Ibrahim M Y, Bong C F G & Ipor I P (Eds.) The Black Pepper Industry - Problems and Prospects (pp-132-139). Universiti Pertanian Malaysia Bintulu Campus, Sarawak, Malaysia.

Pegg K G, Moffett M L & Colbran R C 1974 Disease of ginger in Queensland. Qd. agric. J. 100 : 611-618.

Ramana K V 1986 Slow wilt disease of black pepper and the role of plant parasitic nematodes in its etiology. J. Coffee. Res. 16 (Suppl.): 17-21.

Ramana K V 1991 Slow decline disease of black pepper (*Piper nigrum* L.) in India. In: Sarma Y R & Premkumar T (Eds.) Diseases of Black Pepper (pp. 136-257). National Research Centre for Spices, Calicut.

Ramana K V 1992 Final Report of the Project: Role of Nematodes in the Incidence of Slow Decline (Slow Wilt Disease) of Black Pepper and Screening Pepper Germplasm Against Nematodes. National Research Centre for Spices, Calicut.

Ramana K V 1984 Efficacy of *Paecilomyces lilacinus* (Thom.) Samson in suppressing nematode infestations in black pepper (*Piper nigrum* L.). J. Spices & Aromatic Crops 3 : 130-134.

Ramana K V & Mohandas C 1986 Reaction of black pepper germplasm to root knot nematode *Meloidogyne incognita*. Indian J. Nematol. 16 : 138-139.

Ramana K V & Mohandas C 1987 Plant parasitic nematodes associated with black pepper (*Piper nigrum* L) in Kerala. Indian J. Nematol. 17: 62-66.

Ramana K V & Mohandas C 1989 Endoparasitic nematodes infesting roots of black pepper (*Piper nigrum* L.) in two districts of Karnataka, India. Int. Nematol . Network News 6 : 33-35.

Ramana K V, Mohandas C & Balakrishnan R 1987 Role of plant parasitic nematodes in the slow wilt disease complex of black pepper (*Piper nigrum* L.) in Kerala. Indian J. Nematol. 17 : 225-230.

Ramana K V, Mohandas C & Eapen S J 1994 Plant parasitic nematodes and slow decline disease of black pepper. Tech. Bull., National Research Centre for Spices, Calicut.

Ramana K V, Mohandas C & Ravindran P N 1987 Reaction of black pepper germplasm to the burrowing nematode (*Radopholus similis*). J. Plantn. Crops 15 : 65-66.

Ramana K V, Sarma Y R & Anandaraj M 1993 Nematode management in black pepper. In: Ibrahim MY, Bong C F G & Ipor I P (Eds.) The Pepper Industry : Problems and Prospects (pp.118-131). Universiti Pertanian Malaysia Bintulu Campus, Sarawak, Malaysia.

Ramana K V, Sarma Y R & Mohandas C 1992 Slow decline disease of black pepper (*Piper nigrum* L.) and role of plant parasitic nematodes and *Phytophthora capsici* in the disease complex. J. Plantn. Crops 20 (Suppl.): 65-68.

Routaray B N, Sahoo H & Das S N 1987 Nemic association of ginger and turmeric in Orissa. Indian J. Nematol. 17 : 122-123.

Routaray B N, Mohapatra M P & Das S N 1987 Effects of *Meloidogyne incognita* on ginger, *Zingiber officinale* Rosc. Indian J. Nematol. 17 : 327-329.

Samuel M & Mathew J 1983 Role and association of root knot nematode *Meloidogyne incognita* in the induction of bacterial wilt of ginger incited by *Pseudomonas solanacearum*. Indian Phytopath. 36 : 398-399.

Sarma Y R, Premkumar T, Ramana K V, Ramachandran N & Anandaraj M 1987 Disease and pest management in black pepper nurseries. Indian Cocoa, Arecanut & Spices J. 11 : 45-49.

Shah J J & Raju E C 1977 Histopathology of ginger (*Zingiber officinale*) infected by soil nematode *Meloidogyne* sp. Phyton 16 : 79-84.

Sheela M S & Venkitesan T S 1981 Interrelationship of infectivity between the burrowing and root knot nematode in black pepper, *Piper nigrum* L. (Abstract). Indian J. Nematol. 11 : 105.

Sheela M S & Venkitesan T S 1990 Interaction between *Meloidogyne incognita* and the fungus *Fusarium* sp. on black pepper vine (*Piper nigrum* L.). Indian J. Nematol. 20 : 184-188.

Sheela M S, Venkitesan T S & Mohandas N 1993 Status of *Bacillus* spp. as biocontrol agents of root knot nematode (*Meloidogyne incognita*) infesting black pepper (*Piper nigrum* L.). J. Plantn. Crops 21 (Suppl.) : 218-222.

Sitepu D & Kasim R 1991 Black pepper diseases in Indonesia and their control strategy. In: Sarma Y R & Premkumar T (Eds.) Diseases of Black Pepper (pp. 13-28). National Research Centre for Spices, Calicut.

Sivaprasad P, Jacob A, Nair S K & George B 1990 Influence of VA mycorrhizal colonization on root knot nematode infestation in *Piper nigrum* L. In: Trends in Mycorrhizal Research (pp.110-101). Haryana Agricultural University, Hissar, India.

Sivaprasad P, Jacob A, Sulochana K K, Visalakshy A & George B 1992 Growth, root knot nematode infestation and phosphorus nutrition in *Piper nigrum* (L.) as influenced by vesicular arbuscular mycorrhizae. In: Proc. Third International Conference on Plant Protection in the Tropics. 6 : 34-37. Kualalumpur, Malaysia.

Sosamma V K, Sundararaju P & Koshy P K 1979 Effect of *Radopholus similis* on turmeric. Indian J. Nematol. 9 : 27-31.

Sukumaran S & Sundararaju P 1986 Pathogenicity of *Meloidogyne incognita* on ginger (*Zingiber officinale* Rosc.). Indian J. Nematol. 16 : 258-259.

Sukumaran S, Koshy P K & Sundararaju P 1989 Effect of root knot nematode, *Meloidogyne incognita* on growth of turmeric. J. Plantn. Crops 16 : 293-295.

Sundararaju P, Koshy P K & Sosamma V K 1979 Plant parasitic nematodes associated with spices. J. Plantn. Crops 7 : 15-26.

Sundararaju P, Sosamma V K & Koshy P K 1979 Pathogenicity of *Radopholus similis* on ginger. Indian J. Nematol. 9 : 91-94.

Thomas G V, Sundararaju P, Ali S S & Ghai S K 1989 Individual and interactive effects of V A mycorrhizal fungi and root knot nematodes, *Meloidogyne incognita* on cardamom. Trop. Agric. 66 : 21-24.

Venkitesan T S & Setty K G H 1978 Reaction of 27 black pepper cultivars and wild forms to the burrowing nematode, *Radopholus similis* (Cobb) Thorne. J. Plantn. Crops 6 : 81-84.

Vilsoni F, Mac Clure M A & Butler L D 1976 Occurrence, host range and histopathology of *Radopholus similis* in ginger (*Zingiber officinale).* Plant Dis. Reptr. 60 : 417-420.

de Waard P W F 1979 'Yellow disease' complex in black pepper on the island of Bangka, Indonesia J. Plantn. Crops 7 : 42-49.

Winoto S R 1972 Effect of *Meloidogyne* species on the growth of *Piper nigrum* L. Malaysian Agric. Res. 1 : 86-90.