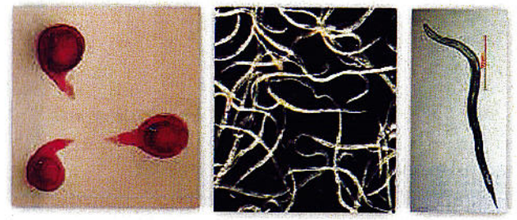
ICAR-Indian Institute of Spices Research
Marikunnu P.O., Kozhikode – 673012, Kerala, India
Phone: 0495-2731410, Fax: 0495-2731187
Email: directorspices@gmail.com
Website: www.spices.res.in



Plant-Parasitic Nematodes as Production Constraints in Black Pepper, Turmeric, Ginger, and Cardamom: Challenges and Management Strategies

ICAR-Indian Institute of Spices Research
Kozhikode – 673 012, Kerala

2025/07
Technical Bulletin

Compiled and Edited by
B Manimaran
C Sellaperumal

Cover Design
A. Sudhakaran

Published by
Director
ICAR- Indian Institute of Spices Research, Kozhikode

Correct Citation
B Manimaran, C Sellaperumal (Eds.) 2025. Plant-Parasitic Nematodes as Production Constraints in Black Pepper, Turmeric, Ginger, and Cardamom: Challenges and Management Strategies. ICAR- Indian Institute of Spices Research, Kozhikode, Kerala, India.

Year of Publication: 2025

Introduction:

India is lauded as the 'Land of spices' which is attributed by the quantity and quality of spices produced. The spices are cultivated in ~ 4.31 M ha of area with the production of 11.83 M tonnes in the 2022-23. Some of the major spices such as, *black pepper*, *turmeric*, *ginger*, and *cardamom* alone cultivated in the area of about 8.81 Lakh ha with the production of ~35.13 Lakh tonnes. The export potential of these four spices are to the tune of 4.41 Billion USD (Spices Board India). The production and productivity of these crops are limited by various biotic stress factors such as, insect pests, disease causing pathogens and plant parasitic nematodes (PPN). Several PPN are associated with these spice crops.

These include burrowing (*Radopholus similis*), root-knot (*Meloidogyne* spp.), lesion (*Pratylenchus* spp.), reniform (*Rotylenchulus reniformis*), lance (*Hoplolaimus* spp.), spiral (*Helicotylenchus* spp.), needle (*Longidorus* spp.), stunt (*Tylenchorhynchus* spp.) nematodes (Fig. 1). However, the former four species reported to be potential threats (Eapen and Pandey, 2018; Sellaperumal *et al.*, 2023).These nematodes damage root systems, impair nutrient uptake, predispose plants to secondary infections, and cause considerable yield losses. The PPN are responsible for the yield losses to the tune of 37-64% in black pepper, 46% in cardamom, 45.3% in *turmeric* and 29% in ginger (Eapen

and Pandey, 2018). Understanding their distribution, symptomatology, and management is critical for safeguarding spice production in India.

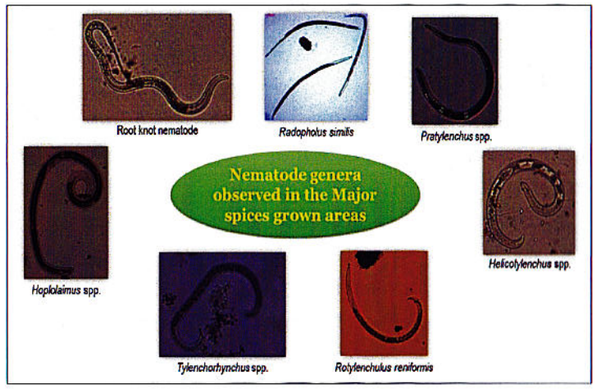


Figure 1. Major plant parasitic nematodes associated with the spice crops

Black pepper

Though many plant parasitic nematodes have been reported on black pepper, but the only two known to cause serious damage to the crop are *Radopholus similis* and *Meloidogyne* spp.

Radopholus similis and 'slow wilt' disease or 'yellows disease':

The association between the burrowing nematode *Radopholus similis* and the 'yellows disease' of pepper was first documented in 1936 and later confirmed by Van der Vecht (1950). This nematode was reported to be responsible for causing the loss of approximately 22 million pepper vines over a span of 20 years on Bangka Island, Indonesia, due to yellows disease (Christie, 1957; 1959). Subsequent reports identified

R. similis in black pepper plantations in India (Koshy *et al.*, 1978), as well as in Malaysia, Thailand (Sher *et al.*, 1969; Reddy, 1977), and Sri Lanka (Gnanapragasam *et al.*, 1985). In India, the nematode has also been linked to 'slow wilt' disease in black pepper, a condition closely resembling Indonesia's 'pepper yellows' (Van der Vecht, 1950; Mohandas and Ramana, 1987). Due to their similarities, both conditions are generally studied together.

Investigations into the 'slow wilt' disease complex in India have shown that high populations of *R. similis* are significantly more common in affected plants than in healthy ones. Black pepper, originally introduced to Indonesia from Kerala, India (Nambiar, 1977), may have brought the burrowing nematode along with it through rooted cuttings. Further studies in India have demonstrated that black pepper plants develop wilting

symptoms more rapidly when inoculated with root-knot and burrowing nematodes, followed by *Phytophthora capsici* (Ramana *et al*., 1992; Anandaraj *et al*., 1996).

Symptoms

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. Yellowing is followed by shedding of leaves, cessation of growth and dieback symptoms (Fig. 2). 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 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, 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-colored lesions. Lesions are not clearly seen on older roots, being brown in color. The root system exhibits extensive rotting, and the main roots are devoid of fine feeder roots that rot quickly (Fig. 3). Extensive necrosis of larger lateral roots develops over time.

Dynamics:

Figure 2. 'Slow wilt' or 'pepper yellows' symptoms caused by the burrowing nematode *Radopholus similis*

Figure 3. Root lesions caused by the burrowing nematode *Radopholus similis*

Root-knot nematode:

The root-knot nematode *Meloidogyne* spp. was the first plant PPN reported to infest black pepper, with the earliest record made by Delacroix in 1902 from Cochinchine (Vietnam). Subsequently, in 1906, Butler documented the presence of root-knot nematodes on black pepper in Wayanad, Kerala, India. Among the species reported, *Meloidogyne incognita* and *M. javanica* are the most widespread, having been identified in

several pepper-growing regions across the globe—including India, Brazil, Sarawak (Borneo), Cochin-China (Vietnam), Malaysia, Brunei, Cambodia, 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*., 1979; Ramana and Mohandas, 1983). Additionally, *Meloidogyne arenaria* has been recorded from Sri Lanka (Lamberti *et al*., 1983), and a distinct species, *Meloidogyne piperi*, was described from Kerala, India by Sahoo *et al*. (2000).

Symptoms:

Root-knot nematodes (RKN), primarily *Meloidogyne incognita* and *M. javanica*, are common pests infesting black pepper. These nematodes feed on plant roots, inducing the formation of characteristic galls or "knots" across the root system (Fig. 4). The second-stage juveniles, often present in the soil, are the primary infective stage. Upon infestation, pepper plants exhibit distinct above-ground symptoms such as yellowing and chlorosis of leaves, and overall stunted growth, which significantly impacts yield. Below ground, the damage is more evident. The roots become extensively galled, and egg masses containing females are often embedded deep within the root tissues. The size and texture of the galls vary across pepper cultivars—some develop large,

smooth galls (cv. *Panniyur* I), while others form smaller ones (cv. *Karimunda*).

Dynamics:

RKN populations in pepper roots typically peak during April to May and reach their lowest levels in December and January. However, nematodes remain present year-round. Their numbers are influenced by environmental factors such as soil temperature, moisture, and the availability of young, tender roots. Conditions in September to October - characterized by moderate temperatures and adequate soil moisture - are especially conducive to RKN population build up. Rainfall and ambient temperature also play key roles in shaping their seasonal dynamics.

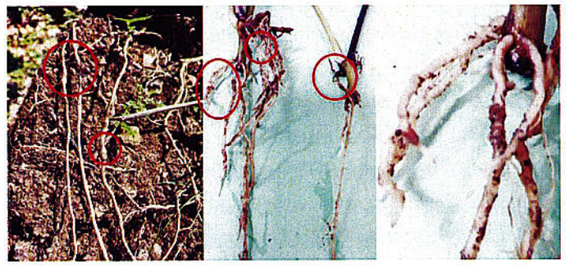


Figure 4. Damage symptoms caused by root-knot nematode in Black pepper

Nematode management strategies in black pepper:

Management measures

Nursery:

- ✓ Soil solarization or steam sterilization can be adopted for sterilizing the nursery mixture
- ✓ The sterilized nursery mixture may be fortified with biocontrol agents like *Pochonia chlamydosporia* or *Trichoderma harzianum* @ 1g/Kg of soil. The fungus load in the substrate should be 10^8cfu/g
- ✓ Apply fluopyram 34.48SC (Velum® Prime) @ 50 ml/bag (0.5ml of Velum® Prime/L) or carbosulfan 0.1% @ 50 ml/bag or carbofuran 3 CG @ 3 g/bag to control nematodes. While applying nematicides make three equidistant holes of 2-3 cm depth in the bag around the cuttings and ensure sufficient moisture in the soil
- ✓ The pits for planting should be treated with fluopyram34.48SC (Velum® Prime) @ 3-5litres (0.5ml of Velum® Prime /L) or carbofuran 3 CG @ 50 g at the time of planting.

Field conditions:

- ✓ Follow strict phytosanitation by uprooting and destroying severely affected vines along with root system that are beyond recovery.

- ✓ Intercrops and standards susceptible to nematodes should be avoided. Coconut and arecanut are reported as hosts of *R. similis*. Standards like *Garuga pinnata*, *Macaranga indica*, *Erythrina indica* and *Gliricidia sepium* that are less susceptible or not affected by nematodes can be used to trail the vines.
- ✓ Biocontrol agents like *P. chlamydosporia* or *T. harzianum* can be applied @ 50 g/ vine twice a year (during April-May and September-October)
- ✓ Nematode free rooted cuttings raised in fumigated or steam sterilized nursery mixture should be used for planting in the field.
- ✓ Apply fluopyram34.48SC (Velum® Prime) two times per season@ 3-5 litres/ vine(0.5ml of Velum® Prime /L). 1st application on May/June (with the onset of south west monsoon) followed by 2nd application at September/October.
- ✓ Carbofuran 3 G @ 100 g/vine should be applied during May/June (with the onset of south west monsoon) and September/October. Along with nematicides the basins should be drenched with either copper oxychloride (0.2%) or potassium phosphonate (0.3%) or metalaxyl-mancozeb (0.125%). A light irrigation may also be given to ensure adequate soil moisture after nematicide application.

- ✓ While applying nematicides, the soil should be raked in the basin of the vine lightly without causing damage to the root system and the nematicide should be spread uniformly in the basin and covered with soil immediately. Sufficient soil moisture should be ensured at the time of nematicide application. The control measures should be taken up during early stages of the disease.
- ✓ The variety *Pournami* was found to have tolerance to root-knot nematode and can be considered for planting.
- ✓ Severely affected vines should be removed from the plantation and destroyed, as it is impossible to recover them whenever high population of nematode are noticed.

Turmeric

Turmeric (*Curcuma longa* L.), a vital spice crop in India, is widely cultivated for its medicinal, culinary, and industrial applications. However, its production is increasingly threatened by plant-parasitic nematodes (PPNs), which cause significant yield losses by affecting root health and nutrient uptake. Among these, *Meloidogyne* spp. (root-knot nematodes), *Pratylenchus* spp. (lesion nematodes), and *Radopholus similis* (burrowing nematodes) are the most destructive, leading to stunted growth, poor rhizome development, and

secondary infections. Despite being an overlooked problem in turmeric cultivation, recent surveys and research indicate a growing prevalence of PPNs across major turmeric-growing regions in India. The infestation of PPNs often remains unnoticed until severe damage occurs, making early detection and management crucial. The root lesion nematode is becoming a significant issue in the intensive turmeric cultivation areas of India, particularly in Andhra Pradesh, Telangana, West Bengal, Tamil Nadu, Kerala, Maharashtra, and Assam. It infects the economic part 'rhizome' and affects turmeric cultivation both qualitatively and quantitatively. Moreover, this nematode issue is often overlooked because its above-ground symptoms can be confused with those of nutrient deficiencies and water stress. This article discusses the emerging threat of PPNs, especially the lesion nematode (*Pratylenchus* spp.) in turmeric cultivation, their economic significance, and potential management strategies to safeguard turmeric production in India.

Damage symptoms caused by plant parasitic nematodes in turmeric:

***Pratylenchus* spp.**

It produces classic symptoms of brownish root lesions or necrosis on rhizomes and roots, leading to 'rhizome rot' in conjunction with other soil-borne pathogens. In the initial stage, fresh rhizomes display

dark brown spots on their surfaces. As they mature, they become low, dry, and have a wrinkled appearance, lacking turgidity and weight. When an infected rhizome is broken open at the affected area, a light to dark brown discoloration can be seen, extending 3-5 mm from the surface to the center. The nematode affects all parts of the underground portion of the plant, including the roots, fingers, and mother rhizomes, though the latter is typically less affected.

Figure. 5 Brownish lesion on rhizomes a) foliar symptom b) & c) shrunken and mummified rhizomes d) cross-section of the infected rhizome

When attempting to remove a turmeric clump from the soil, it can be easily pulled out due to the damage done to the anchoring roots. Above ground, symptoms include a patchy appearance, stunted growth, weakness, early maturity, and subsequently, yellowing and drying of the leaf tips and margins (Fig. 5).

Disease complexes:

Occasionally, higher yield losses can occur due to the synergistic interactions between nematodes and other pathogenic microbes in the soil. For instance, various species of *Pratylenchus* have been noted to associate with fungi; specifically, *P. thornei* has been found in conjunction with *Verticillium dahliae* in potatoes in Israel. Additionally, *Pratylenchus coffeae* has been reported alongside *Pythium aphanidermatum* in turmeric in India. These pathogens not only infect *Curcuma longa* but also affect related species, leading to the 'brown rot' disease in other cultivated turmeric species like *C. aromatica*, which is caused by *Fusarium* spp., and the lesion nematode, *Pratylenchus* spp.

***Meloidogyne* spp.**

Two species of root-knot nematodes, *Meloidogyne incognita* and *M. javanica*, have been reported to parasitize turmeric (*Curcuma longa*), with *M. incognita* being the more extensively studied and economically significant species.

Infestation by *M. incognita* results in prominent root gall formation, stunted plant growth, chlorosis, marginal and apical leaf desiccation, and reduced tillering, often accompanied by galling and decay of the root system. Under field conditions, high population densities of *M. incognita* lead to conspicuous symptoms such as severe yellowing, stunting, and patchy wilting (Fig.6). In heavily infested areas, premature plant mortality is common, contributing to poor crop stand and reduced yields at harvest. Additionally, affected rhizomes often exhibit a loss of their characteristic bright yellow pigmentation, further diminishing market quality.

Figure 6. Damage symptoms caused by root-knot nematode in turmeric a) foliar symptom b) Galls on roots

Nematode management strategies in turmeric:

- ✓ Select sites free from nematodes by prior sampling and screening for nematodes. Deep summer ploughing in turmeric fields during April-May minimizes the soil population of nematodes.
- ✓ Soil solarization using transparent polythene sheets (100 gauge) during summer season for 40-50 days can also reduce nematode population in soil.
- ✓ Allelopathic effect by sunnhemp and marigold also reduces the nematode population. Avoid planting of turmeric after cultivation of banana or solanaceous vegetables.
- ✓ Use only healthy and nematode free rhizomes as planting material.
- ✓ Application of *Glyricidia* compost or neem seed cake @ 1 t/ha or FYM @ 25-30 t/ha will increase organic content, enhance beneficial microorganisms and reduce nematode population.
- ✓ *Pochonia chlamydosporia* can be applied to the beds at the time of sowing @ 20 g/bed (10^6 cfu/g) for management of nematode problem.
- ✓ The variety *IISR Pragati* is moderately resistant to root-knot nematodes.

- ✓ Application of fluopyram 34.48 SC (Velum® Prime) @ 3litres/ bed (0.5ml of Velum® Prime /L) 15 days after planting or application of carbofuran 3 CG @1kg a.i/ha at 3rd month and 5th month of sowing can effectively control nematodes.
- ✓ Intercropping with repellent plants like marigold, *Glyricidia*, *Asparagus*, *Dahlia* etc @ 5:1 (5 rows of turmeric followed by one row of repellent plant) helps in reducing nematode problems.
- ✓ Crop rotation with *Marigold*, *Chrysanthemum*, *Sesbania*, *Crotalaria* spp., *Gaillardia, Cluster bean and Desmodium spp*can be followed

Ginger

Over 17 genera of plant-parasitic nematodes have been reported on ginger, with *Meloidogyne* spp. (root-knot nematodes), *Radopholus similis* (burrowing nematode), and *Pratylenchus coffeae* (lesion nematode) being the most damaging (Table 1). These pests weaken the plant by feeding on roots and rhizomes, making ginger susceptible to secondary infections and reducing overall productivity (Eapen and pandey, 2018). In India, different species of PPN occupies different levels of prominence (Table 2)

Table 1. Major plant-parasitic nematodes reported to be associated with ginger crops globally

S.No.	Nematode species	Country	Reference
1.	*Meloidogyne spp.*	Japan	Nagakura (1930)
2.	*Meloidogyne incognita*	Australia	Colbran (1958)
		India	Mammen (1973)
		Fiji	Haynes et al., (1973)
		China	Guo et al., (2004)
3.	*M. javanica*	Mauritius and Rodrigues	Lamberti et al. (1987)
		Brazil	Santos and Lozano, (1993)
		India	Singh and Gupta (2011)
		USA	Hajihassani et al., 2019
		Vietnam	Phan et al. (2020)
4.	*M. arenaria*	India	Kaur and Sharma (1988)
		Brazil	Santos and Lozano (1993)
5.	*Rotylenchulus reniformis*	India	Routray (1987)
6.	*M. enterrolobii*	China	Xiao et al. (2018)
7.	*M. thailandica*	Thailand	Handoo et al., (2005)
8.	*Radopholus similis*	USA	Hart,1956
		Fiji	Vilsoni et al. (1976)
		India	Sundararaju et al. (1979)
9.	*Pratylenchus zeae*	India	Kaur et al. (1989)
10.	*Pratylenchus coffeae*	India	Kaur and Sharma (1990)

Table 2. Plant-parasitic nematodes reported to be associated with ginger crops in India

S.No.	Nematode species	State/region	Reference
1.	*M. incognita* and *R. similis*	Kerala	Mammen, 1973; Charles, 1978; Sheela *et al*., 1995
2.	*R. reniformis*and *M. incognita*	Orissa	Routaray*et al*., 1987b
3.	*M. incognita* and *P. coffeae*	Sikkim	Srivastava *et al*., 1998
4.	*M. incognita, M. arenaria* and *P. coffeae*	Himachal Pradesh	Kaur *et al*., 1989; Khan and Makhnotra, 1998; Kaur and Sharma, 1988
5.	*M. incognita*	Madhya Pradesh	Vadhera*et al*., 1998
6.	*R. reniformis*, *Hoplolaimus indicus* and *P. coffeae*	West Bengal	Rama and Dasgupta, 1998, 2000

Symptoms of damage:

Root-knot nematodes (Meloidogyne spp.)

The root-knot nematode induces gall formation on roots (Fig. 7), restricting water and nutrient uptake. Infected rhizomes develop brown, water-soaked areas, leading to internal decay. Affected plants exhibit stunted growth, chlorotic leaves, and premature drying. The nematode infestation reduces essential micronutrients like iron and zinc while altering plant hormone levels, further weakening the crop.

Figure 7. Damage symptom (root galling) caused by root-knot nematode in ginger

Lesion nematodes (Pratylenchus spp.)

The nematode *P. coffeae* is linked to 'ginger yellows,' a disease characterized by leaf yellowing and dry rot of rhizomes. Dark brown necrotic lesions appear on infected rhizomes, leading to significant yield losses

Burrowing nematode (Radopholus similis)

It attacks roots and rhizomes, causing small, water-soaked lesions that turn brown and lead to rotting. Aboveground symptoms include yellowing leaves, stunted growth, fewer shoots, and premature drying of the plant. The infected plants typically show *stunted growth*, *less vigor*, and *poor tillering*. The uppermost leaves develop chlorosis, characterized by scorched tips, which progresses to yellowing at the base of the shoots and the lower leaf sheaths. Severely infected rhizomes become soft and discoloured, leading to total crop loss.

Disease complexes and secondary infections

Nematode infestations often interact with fungal and bacterial pathogens, worsening crop damage. Rhizome rot, caused by *Pythium aphanidermatum*, is more severe when ginger is already infested with *Meloidogyne* or *Pratylenchus* nematodes. Bacterial wilt (*Ralstonia solanacearum*), a major ginger disease, has also been linked to *Meloidogyne* infections, accelerating disease progression and severity.

Remedies and management strategies

Ginger is a valuable export crop, and keeping it free of nematodes is essential—not only for a healthy harvest but also for eco-friendly farming practices. Since people often eat ginger raw, managing these pests with minimal chemical use is very important. Managing nematodes in ginger requires an integrated approach combining cultural, biological, and chemical control methods.

Preventive measures

Prevention is better than cure, the nematode infestation can be prevented by adopting following practices such as,

- Soil testing at regular intervals to determine the presence of nematodes in the soil
- Planting nematode-free rhizomes
- Adopting crop rotation for 3-4 seasons of ginger with non-host crops
- Wash off soil from farm tools and disinfect.
- Solarize the soil by ploughing field, moisten soil and cover using plastic sheet for 4 - 6 weeks during summer

Cultural Practices

- ***Crop rotation:*** Avoid planting ginger in the same field consecutively; rotate with non-host crops like maize or sorghum.
- ***Soil solarization:*** Covering soil with transparent plastic sheets during peak summer kills nematodes and soil-borne pathogens.
- ***Use of healthy seed rhizomes:*** Always plant certified, disease-free rhizomes to prevent nematode introduction.
- ***Mulching:*** Applying green leaves or organic matter improves soil health and reduces nematode populations.

Physical Control

- ***Hot water treatment:*** It provide an eco-friendly solution. Studies have shown that dipping seed rhizomes in water heated to about 51°C for around 10 minutes can significantly reduce nematode populations. Other approaches have involved longer treatments at slightly lower temperatures to disinfect the rhizomes. These methods help to kill the nematodes without relying on harsh chemicals.

Biological Control

- Beneficial microbes like *Trichoderma* and *Pseudomonas* spp., can suppress nematode populations.
- Nematode-trapping fungi such as *Paecilomyces lilacinus* have shown effectiveness in reducing *Meloidogyne* infections.
- Use of *P. chlamydosporia* (@20 g/bed with 106 cfu/g) suppresses root-knot nematodes in ginger
- Neem cake and other organic amendments enhance soil microbial activity and reduce nematode impact.

Exploring host plant resistance

- **Use of resistant or tolerant varieties:** While ginger naturally has few varieties that resist nematodes, some research has identified certain ginger lines that show promise in resisting root-knot nematodes. One of these resistant varieties has even been released under the name *IISR Mahima*, offering farmers an additional tool for managing these pests.

Chemical control

- Nematicides like carbofuran and carbosulfan can help control severe infestations but should be used cautiously due to environmental concerns.

- Experimental evidences proves that newer molecules such as Nimitz® (fluensulfone), Velum® Prime (fluopyram) are showing promising results.
- Application of fluopyram 34.48 SC (Velum® Prime) @ 500 g a.i. /haat the time of planting or application of carbofuran 3 CG @1kg a.i. /ha at 3rd month and 5th month of planting or fluensulfone 2% GR @ 512 g a.i. /ha can effectively control nematodes.

Cardamom

Research on nematode infestations in this crop has been extensively conducted in India, revealing the presence of several plant-parasitic nematodes (Eapen& Pandey, 2018). Among these, root-knot nematodes (*Meloidogyne* spp.) pose the most significant threat. In addition, the lesion nematode *Pratylenchus coffeae* and the burrowing nematode *Radopholus similis* are also known to contribute to root rot in the crop (D'Souza *et al*., 1970; Kumar *et al*., 1971; Khan and Nanjappa, 1972; Viswanathan *et al*., 1974; Sundararaju *et al*., 1979). The reniform nematode, *Rotylenchulus reniformis*, has also been reported from cardamom (Eapen, 1995).

Symptoms of damage:

Severe infestation by root-knot nematodes (*Meloidogyne* spp.) in mature cardamom plants results in a range of physiological and morphological symptoms, including stunted growth, reduced tillering, chlorosis, premature desiccation of leaf margins and tips, narrowing of leaf blades, delayed flowering, immature fruit abscission, and significant yield reduction. Unlike many other host crops, conspicuous root galling is generally absent in mature cardamom plants (Fig. 8a). However, affected roots often exhibit excessive lateral branching, resembling'witch's *broom'* morphology (Fig. 8b).

In primary nurseries, nematode infestation poses a critical threat to early seedling establishment. Infection of the radicle and plumule by second-stage juveniles (J2) of *Meloidogyne* spp. leads to failure in emergence in over 50% of germinating seeds. Infected seedlings at the two-leaf stage typically show marginal chlorosis, desiccation of foliage, and pronounced root galling. Upon transplantation to secondary nurseries, these seedlings frequently display abnormal leaf development, including curling of unopened leaves and delayed emergence following pseudostem rupture. Establishment failure in secondary nurseries may occur in up to 40% of such transplants.

In secondary nurseries, nematode-infested plants are characterized by pronounced stunting, foliar yellowing, reduced tillering, tip and marginal leaf necrosis, and extensive root galling. Young seedlings exhibit a higher susceptibility to *Meloidogyne* spp. infection compared to mature plants, with root galling being more prominent in early developmental stages.

In field conditions, nematode infestation often manifests as scattered patches of stunted, weak plants with narrow, pale leaves—an indicator of localized nematode population buildup.

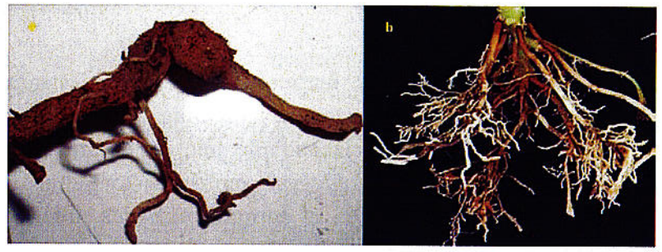


Figure 8. Damage symptom caused by root-knot nematode in cardamom roots. A) Small galls on the roots. B) Witch's broom appearance of the *Meloidogyne* spp., infested roots (photo courtesy Dr.S.J. Eapen)

Nematode management strategies in cardamom:

Under Nursery

- ✓ Frequent change of nursery beds will help to reduce nematode infection in nurseries
- ✓ Disinfest the nursery by application of any granular insecticides or Carbosulfan may be used @ 2 ml/litre at Carbofuran banned areas like Kerala

Under Plantation

- ✓ Ensure planting of nematode free seedlings.
- ✓ Provide mulching, particularly in the exposed areas.
- ✓ Regular application of organic manures such as neem cake twice a year @ 250-1000 g depending on the clump size reduces nematode infestation.
- ✓ Spot application of granular insecticides like (Carbofuran @ 15-50 g) (Non-banned areas can be applied) depending on the size of the plant twice a year in May/June and September. Banned areas Carbosulfan 25EC may be used @ 2ml/liters.
- ✓ Application of nematicides during pre-monsoon period followed by neem cake application in mid-monsoon period is the safest approach to reduce residue problem in the capsules.

Conclusion:

Plant-parasitic nematodes, particularly *Meloidogyne incognita*, *R. similis*, and *P. coffeae*, have emerged as major constraints in the cultivation of *black pepper*, *turmeric*, *ginger*, and *cardamom*. Their impact ranges from seedling mortality and root rot to significant reductions in yield and quality. Furthermore, their synergistic interactions with other soil-borne pathogens intensify disease complexes, often leading to total crop failure if unmanaged. Integrated nematode management strategies—encompassing cultural, biological, physical, and chemical measures—are essential to mitigate their impact. Adoption of nematode-free planting material, crop rotation, soil solarization, use of biocontrol agents, and resistant varieties can contribute significantly to sustainable spice cultivation. A region-specific, holistic approach to nematode management will be vital in maintaining the long-term productivity and export quality of Indian spices.

References:

Anandaraj, M., Ramana, K.V. and Sarma, Y.R. (1996). Sequential inoculation of *Phytophthoracapsici, Radopholussimilis* and *Meloidogyne incognita* in causing slow decline of black pepper. *Indian Phytopathology*, 49: 297–299.

Castillo, M.B. (1974). Nematodes associated with stunted black pepper, beans, peas, eggplant and

celery in Benguet, Batangas, Laguna and Camarines Sur. *Philippine Agriculturist*, 57: 391–402.

Christie, J.R. (1957). The yellows disease of pepper and spreading decline of citrus. *Plant Disease Reporter*, 41: 267–268.

Christie, J.R. (1959).*Plant Nematodes: Their Bionomics and Control*. University of Florida, Gainsville, Florida.

Colbran, R.C. (1958). Studies on plant and soil nematodes. 2. Queensland host records of root-knot nematodes (*Meloidogyne* species). *Queensland Journal of Agricultural Sciences*,15: 101–136.

D'Souza, G.I., Kumar, A.C., Viswanathan, P.R.K. and Shamanna, H.V. (1970). Relative distribution and prevalence of plant parasitic nematodes in coffee tracts of South Western India. *Indian Coffee*,34: 329–342.

Delacroix, C. (1902).Unemaladieaffectant le poivrier (*Piper nigrum*) en Cochinchine. *Agriculture pratique des Payschauds*, 1: 672–680.

Eapen S. J. & Pandey R., (2018). Nematode parasites of spices and medicinal plants. In: Sikora R. A., Coyne D., Hallmann J. &Timper P. (Eds.). Plant parasitic nematodes in subtropical and tropical agriculture. 3rd ed. UK: CABI, pp. 755-794

Eapen, S.J. (1995).Investigations on Plant Parasitic Nematodes Associated with Cardamom. Final Report, Indian Institute of Spices Research, Calicut, Kerala, India

Freire, F.C.O. and Monteiro, A.R. (1978). Nematodes associaoas a pimenterira-do-reino (*Piper nigrum* L.) naregiaoamazonica. III Reuniao de Nematologica. ESAM/SOC. BRAS. NEMAT. *Colecao Mossoroense, Mossoro* 62, 28.

Gnanapragasam, N.C., Anpalagan, V.T., Dharmasena, W.A.M., Ariyaratnam, V., Jayasinghe, P.R.R. and Navaratne, N. (1985).Report of the Tea Research Institute, *Sri Lanka.*

Handoo, Z.A., Skantar, A.M., Carta, L.K. and Erbe, E.F. (2005). Morphological and molecular characterization of a new root-knot nematode, *Meloidogyne thailandica* n. sp. (Nematoda: Meloidogynidae), parasitizing ginger (*Zingiber* sp.). *Journal of Nematology* 37, 343–353.

Hart, W.H. (1956). Spreading decline of citrus caused by the burrowing nematode. *Bulletin of the California Department of Agriculture*,45: 263–267.

Ichinohe, M. (1975) Infestation of black pepper vines by the root-knot nematode, *Meloidogyne incognita*, at Tome-Acu, Para. Brazil. *Japanese Journal of Nematology*,5: 36–39.

Kaur, D.J. and Sharma, N.K. (1990). A new report on *Pratylenchus coffeae* – a cause of ginger yellows. *International Nematology Network Newsletter*, 7: 15–16.

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

Khan, E. and Nanjappa, C.K. (1972). Four new species of Criconematoidea (Nematoda) from India. *Indian Journal of Nematology*,2: 59–68.

Koshy, P.K., Sundararaju, P. and Sosamma, V.K.(1978). Occurrence and distribution of *Radopholus similis* (Cobb, 1893) Thorne, 1949 in South India. *Indian Journal of Nematology*, 8: 49–58.

Kueh, T.K. and Teo, C.H. (1978). Chemical control of root-knot nematodes in *Piper nigrum. The Planter*, 54: 237–245.

Kumar, A.C., Viswanalhan, P.R.K. and 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.

Lamberti, F., Rohini, H.M. and Ekanayake, K. (1983). Effect of some plant parasitic nematodes on the growth of black pepper in Sri Lanka. *FAO Plant Protection Bulletin*, 31: 163–166.

Lordello, L.G.E. and Silva, H.M. (1974).Unnematoidenocivo a Pimenta-do-reino. *Revista de Agricultura* 49, 165–166.

Mammen, K.V. (1973). Root gall nematodes as a serious pest of ginger in Kerala. *Current Science* 42: 549

Mohandas, C. and Ramana, K.V. (1987). Slow wilt disease of black pepper and its control. *Indian Cocoa, Arecanut and Spices Journal*, 11: 10–11.

Nagakura, K. (1930).Über den Bau and die Lebengeschichte der *Heterodera radicicola*(Greef) Muller. *Japanese Journal of Zoology* 3, 95–160.

Nambiar, M.C. (1977).*Proceedings of the National Seminar on Pepper*, 19 December 1977, Central

Plantation Crops Research Institute, Kasaragod, Kerala, India, pp. 4–6.

Rama, K. and Dasgupta, M.K. (1998). Population ecology and community structure of plant parasitic nematodes associated with ginger in West Bengal. *Indian Journal of Nematology*, 28: 10–14.

Rama, K. and Dasgupta, M.K. (2000). Population ecology and community structure of plant parasitic nematodes associated with ginger in northern West Bengal. *Indian Journal of Nematology*, 30: 42–45.

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

Ramana, K.V. and Mohandas, C. (1983). Plant-parasitic nematodes associated with black pepper (*Piper nigrum* L.) in Calicut district, Kerala. *Abstracts of Papers, Third Nematology Symposium, Nematological Society of India*. Himachal Pradesh Krishi ViswaVidyalaya, Solan, India, p.9

Reddy, D.B. (1977). Pests, diseases and nematodes of major spices and condiments in Asia and the Pacific. *Technical Document No. 114*, Plant Protection Committee for the South East Asia and Pacific Region, FAO, Bangkok.

Sahoo, N.K., Ganguly, S. and Eapen, S.J. (2000). Description of *Meloidogyne piperis* p.n. (Nematoda: Meloidogynidae) isolated from the roots of *Piper nigrum* in South India. *Indian Journal of Nematology*, 30: 203–209.

Sellaperumal, C., Eapen, S., Manimaran, B., Berliner, J., Senthamizh, S., Mahendar, B., Giridhar, K., & Sivakumar, V. (2023). Plant-parasitic nematodes, a looming threat to turmeric cultivation in India: results of recent surveys. *Nematology*, 26(1):15-23. https://doi.org/10.1163/15685411-bja10287

Sher, S.A., Chunram, C. and Pholcharoen, S. (1969) Pepper yellows disease and nematodes in Thailand. *FAO Plant Protection Bulletin*, 17: 33.

Srivastava, L.S., Gupta, S.R., Basnet, C.P., Mahato, U.P. and Neopani, B. (1998). Microorganisms associated with ginger in Sikkim. *Journal of Hill Research*,11:120–122.

Sundararaju, P., Koshy, P.K. and Sosamma, V.K. (1979). Plant parasitic nematodes associated with spices. *Journal of Plantation Crops*, 7:15–26.

Vadhera, I., Tiwari, S.P. and Dave, G.S. (1998). Plant parasitic nematodes associated with ginger (*Zingiber officinale*) in Madhya Pradesh and denematization of infested rhizome by thermotherapy for management. *Indian Journal of Agricultural Sciences*, 68: 367–370.

Van Der Vecht, J. (1950). Plant parasitic nematodes. In: Karshoven, L.G.E. and Vecht, J.V.D. (eds) [*Diseases of Cultivated Plants in Indonesia Colonies*.] W. van Woeve, The Hague, pp. 16–15.

Viswanathan, P.R.K., Kumar, A.C. and D'Souza, G.I. (1974). Nematode association of cardamom in South India. *Cardamom News* 6, 19.