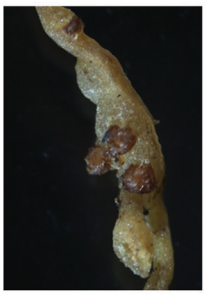
Technical Bulletin

Screening techniques for major diseases, insect pests and nematodes infecting vegetatively propagated spices



ICAR-All India Coordinated Research Project on Spices

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SCREENING TECHNIQUES FOR MAJOR DISEASES INSECT PESTS AND NEMATODES INFECTING VEGETATIVELY PROPAGATED SPICES

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THE CONTENT

SCREENING TECHNIQUES FOR MAJOR DISEASES INSECT PESTS AND NEMATODES INFECTING VEGETATIVELY PROPAGATED SPICES

BLACK PEPPER

Black pepper (*Piper nigrum* L.), popularly known as 'King of Spices' representing the family Piperaceae is one of the most important and widely used spice globally. Black pepper originated in the moist evergreen forests of Western Ghats, which is also considered as its primary centre of origin. The spice valued for its dried, mature fruits (berries) is cultivated on a commercial scale in India, Indonesia, Vietnam, Brazil, Malaysia and Sri Lanka.

Foot rot

In black pepper, the most devastating Phytophthora foot rot was earlier referred to as either "quick wilt" or "wilt" and the pathogens associated were reported as *Phytophthora palmivora* var. *piperis*, *P. palmivora* and *P. palmivora* MF_4, which was later redescribed as *P. capsici*. Recently, Jeevalatha *et al*. (2021) and Suseela Bhai *et al*. (2022) reported the association of two species *viz*., *Phytophthora capsici* and *P. tropicalis* with foot rot of black pepper. Generally, the disease appears and proliferates during monsoon (June to September). The pathogen survives in the soil and plant debris and spreads through infected planting material, rain splashes, wind, and run-off water. The disease development under field conditions is favoured by low temperature and high rainfall, high soil moisture and high relative humidity.

Symptomatology

The pathogen infects all the aerial as well as subterranean plant parts, including the stem, spikes, leaves and roots. In nurseries, on the leaves, blackish spots with fimbriate margins appear initially which subsequently enlarge leading to defoliation. Infection on the collar region manifests as blackening of tissues which extend both upwards and downwards whereas, root infection culminates in collar infection leading to withering. Under field conditions, the disease appears during south-west monsoon and manifests initially as black spots on leaves with characteristic fimbriations formed along the advancing margins. The infected tender leaves and succulent shoot tips of newly emerging runner shoots become necrotic. During the advanced stage of disease progression, as a result of collar infection the entire vine wilts, leading to severe defoliation and spike shedding. If the damage is confined only to the feeder roots, expression of symptoms is delayed wherein the vine exhibits declining symptoms like yellowing, defoliation and wilting.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries along with known/reported susceptible and resistant checks [five replications each; one replication consists of four vines (age range 3-6 years)] should be used to screen for disease resistance. The location/field should be endemic/conducive to natural infection of foot rot disease wherein recurring infection is recorded/observed during the period of

experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than foot rot. The disease incidence should be recorded consecutively for three years (July, August, September and October). The observations on foliar infection and defoliation should be recorded (Shashidhara, 2007; Rini and Remya, 2020).

(i) Foliar infection: For recording the intensity of leaf infection, three areas (0.5 m^2) randomly selected in the canopy of black pepper vines, preferably each at lower level, middle level and upper level of the canopy. From each vine, a minimum of 60 leaves (20 each at lower, middle and upper levels) should be observed on a random basis and score should be assigned. The observations on foliar infection should be recorded for each replication for each month separately and average should be calculated by combining data from other replications (average of four month data would represent the disease level of a particular entry/check for a particular year of screening).

Disease rating scale for foot rot-foliar infection (0-5 scale)	
Scale	**Symptoms on leaves**
0	No infection
1	1 to 10%
2	11 to 25%
3	26 to 50%
4	51 to 75%
5	More than 75%
Rini and Remya (2020)	

Disease Severity Index (DSI)* =

$$\frac{\text{0 x number of leaves falling in the scale +1 x number of leaves falling in the scale + 2 x number of leaves falling in the scale + 3 x number of leaves falling in the scale + 4 x number of leaves falling in the scale + 5 x number of leaves falling in the scale}}{\text{240 (minimum of 60 leaves per vine and 4 vines per one replication) x 5 (maximum disease rating scale)}} \times 100$$

*DSI calculated for one replication consisting of 4 vines (similarly DSI should be calculated for other four replications separately)

(ii) Defoliation: Number of vines showing defoliation should be recorded and presented as per cent defoliated vines. For intensity of defoliation, grades are given based on visual observation using following scale, preferably at lower level, middle level and upper level and presented as defoliation index (Shashidhara, 2007).

Index defoliation	
0	Nil
1	Up to 25%
2	25 to 50%
3	More than 50%

Disease Severity Index (DSI)* =

$$\frac{\text{0 x number of vines falling in the scale + 1 x number of vines falling in the scale + 2 x number of vines falling in the scale + 3 x number of vines falling in the scale}}{\text{4 (total number of vines in one replication) x 3 (maximum index defoliation rating)}} \times 100$$

*DSI calculated for one replication consisting of 4 vines (similarly DSI should be calculated for other four replications separately)

Final rating of entries should be made based on overall mean DSI of foliar infection and defoliation. Based on the overall mean DSI, the entries are categorized as follows:

Categorization based on reaction towards foot rot	
Category	**Overall mean Disease Severity Index (DSI)**
Resistant	Less than 30%
Moderately resistant	31 to 40%
Susceptible	More than 40%
Prakash *et al.* (2019)	

Selected references:

- Jeevalatha, A., Biju, C. N. and Suseela, R. Bhai. (2021). *Ypt1* gene-based recombinase polymerase amplification assay for *Phytophthora capsici* and *P. tropicalis* detection in black pepper. *European Journal of Plant Pathology*. 159: 863-875. https://doi.org/10.1007/s10658-021-02211-0.
- Prakash, K. M., Bhai, R.S., Jiji, J., Saji, K. V., Sujatha, V. S. and Santhoshkumar, A. V. (2019). Exploitation of resistant sources to *Phytophthora capsici* Leon. from genetic stocks of black pepper (*Piper nigrum* L.). *International Journal of Current Microbiology and Applied Sciences.* 8(5): 1487-1496.
- Rini, C. R. and Remya, J. (2020). Management of *Phytophthora capsici* infection in black pepper (*Piper nigrum* L.) using new generation fungicides and biopesticide. *International Journal of Agriculture, Environment and Biotechnology*. 13(1): 71-74.

- Shashidhara, S. (2007). Studies on foot rot of black pepper caused by *Phytophthora capsici* Leonian, emend, Alizedeh and Tsao. M. Sc. Thesis submitted to University of Agricultural Sciences, Dharwad. p. 75.

  (https://krishikosh.egranth.ac.in/displaybitstream?handle=1/81669&fileid=6ac7cf86-b505-439b-a048-14f7f1f03d5b)

- Suseela Bhai, R., Jeevalatha, A., Biju, C. N., Vinitha, K. B., Jose Cissin, Rosana, O. B., Fayad, A., Praveena, R., Anandaraj, M. and Santhosh J. Eapen. (2022). Sympatric occurrence of sibling *Phytophthora* species associated with foot rot disease of black pepper in India. *Brazilian Journal of Microbiology.* https://doi.org/10.1007/s42770-022-00716-2.

Anthracnose

Anthracnose/fungal pollu is an economically important disease, prevalent throughout the black pepper growing tracts of India. *Colletotrichum gloeosporioides* was earlier reported as the incitant of anthracnose. Later, Chethana *et al*. (2015) reported the association of five species of *Colletotrichum viz*., *C. syzygicola*, *C. queenslandicum*, *C. siamense*, *C. endophytica* and *C. guajavae* with the disease. Generally, the disease appears and proliferates during July to September. The pathogen survives in the infected plant parts of preceding season, microsclerotia (on runner shots) and perithecia (on leaves) and spreads through infected planting material, rain splashes and wind. Maximum temperature has negative correlation, while minimum temperature, rainfall and number of rainy days have a positive correlation with the disease incidence and spread.

Symptomatology

The anthracnose which generally affects the foliage and spikes is prevalent among black pepper cultivating tracts especially in higher elevations and often attains severity during misty conditions. In nurseries, yellowish to dark brown circular spots with a chlorotic halo are formed on the leaves. While under field conditions, the symptoms manifest as circular/angular brownish lesions surrounded by yellow halo on leaves. In later stages, laminar expansion is adversely affected resulting in a crinkled appearance. The affected berries exhibit brown sunken patches during early stages and in the later stages, the discolouration gradually increases and the berries exhibits characteristic cross splitting.

Symptoms under nursery conditions

Symptoms under field conditions

The berries subsequently turn black and dry. Infection on spikes leads to spike shedding whereas, infection on mature berries results in formation of brownish splits. On shoots (climbing and runner), the symptoms appear as brown to black necrotic lesions.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries along with known/reported susceptible and resistant checks [five replications each; one replication consists of four vines (age range 3-6 years)] should be used to screen for disease resistance. The location/field should be endemic/conducive to natural infection of anthracnose disease wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than anthracnose. The disease incidence should be recorded consecutively for three years (from July, August, September and October). From each vine, a minimum of 50 leaves should be observed on a random basis and a score should be assigned. Per cent Disease Index (PDI) should be calculated for each replication for each month separately and average PDI should be calculated by combining data from other replications (average of four month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during the first year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for black pepper anthracnose (0-8 scale)	
Scale	**Infection on leaves**
0	Nil
1	Isolated spots
2	Sparse spots on young leaves
3	Coalescing spots on young leaves and isolated spots on old leaves
4	Clear coalescing spots on young leaves and old leaves, defoliation of infected young leaves
5	Infection on all aerial parts, distinct crinkling of infected leaves, defoliation of young leaves
6	Infection on all aerial parts, shedding of young leaves and deformity of old leaves
7	Infection on all aerial parts, shedding of young leaves and deformity of old and young leaves
8	Infection on all aerial parts, deformity and defoliation of old as well as young leaves
Biju *et al.* (2013)	

Per cent Disease Index (PDI)* =

$$\frac{\text{0 x number of leaves falling in the scale + 1 x number of leaves falling in the scale + 2 x number of leaves falling in the scale + 3 x number of leaves falling in the scale + 4 x number of leaves falling in the scale + 5 x number of leaves falling in the scale + 6 x number of leaves falling in the scale + 7 x number of leaves falling in the scale + 8 x number of leaves falling in the scale}}{\text{200 (minimum of 50 leaves per vine and 4 vines per one replication) x 8 (maximum disease rating scale)}} \times 100$$

*PDI calculated for one replication consisting of 4 vines (similarly PDI should be calculated for other four replications separately)

Categorization based on reaction towards anthracnose	
Categories	**Per cent Disease Index (PDI)**
Highly resistant	Less than 5%
Resistant	5.1 to 10%
Moderately resistant	10.1 to 20 %
Moderately susceptible	20.1 to 30%
Susceptible	30.1 to 40%
Highly susceptible	More than 50%
Faisal *et al.* (2023)	

Selected references:

- Biju, C. N., Praveena, R., Ankegowda, S. J., Darshana, C. N. and Jashmi, K. C. (2013). Epidemiological studies on black pepper anthracnose caused by *Colletotrichum gloeosporioides*. *Indian Journal of Agricultural Sciences.* 83: 1199-1204.
- Chethana, C. S., Chowdappa, P., Pavani, K. V., Biju, C. N., Praveena, R. and Sujatha, A. M. (2015). Morphological and multi-loci gene analysis of five species of *Colletotrichum* responsible for anthracnose on black pepper in South India. *International Journal of Advanced Biotechnology and Research*. 6(3): 327-342.
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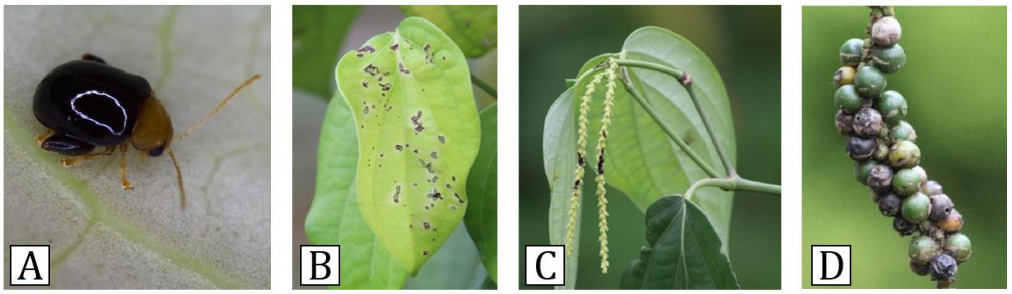
Pollu beetle

The *pollu* beetle, *Lanka ramakrishnai* Prathapan and Viraktamath (Chrysomelidae: Coleoptera) is the most destructive insect pest of black pepper (*Piper nigrum* L.) in India. The pest infestation is higher in the plains and midlands below an altitude of 300 MSL in Kerala and up to 32% of the crop loss due to this pest infestation has been reported in some plantations (Premkumar and Nair, 1988). The pest is more severe in shaded areas in the plantation and on vines trailed on standards that produce heavy shade than under open conditions (Devasahayam, 2000).

Symptomatology

The adult beetles feed on tender leaves, shoots and spikes and lay eggs on them. On tender leaves, the feeding activity of beetles results in the formation of small irregular circular holes. Severely infested shoots, leaves and spikes often rot and drop due to the invasion of secondary microorganisms. Young grubs, on hatching, bore into the developing berries and feed upon the internal contents, making the berries empty and crumble when pressed earning the name *pollu* (Devasahayam, 2000).



(a) Adult *pollu* beetle (b) Tender leaf damaged by adults (c) Tender spikes damaged by adults and (d) Berries damaged by grubs

Screening for pest resistance

Experiments should be conducted under field conditions for a minimum period of three years. The plants should be raised following the standard agronomic practices for black pepper (ICAR-Indian Institute of Spices Research, 2015), except for the non-application of pesticides throughout the study period.

Design	Randomized Block Design
Number of replications	Four (each vine is considered as a replication)
Plot size	3 X 3 m spacing
Observations to be recorded	Screening of black pepper germplasm to *pollu* beetle is to be carried out for a minimum period of 3 years. Ten spikes from each vine should be selected randomly and the number of infested and healthy berries have to be recorded to work out the per cent berry damage/vine/year.

Classification of *Piper* accessions based on berry damage	
Category	**Berry damage**
Highly resistant	No infestation
Moderately resistant	Below 1% infestation
Moderately susceptible	Between 1% and 5% infestation
Susceptible	Above 5% infestation

Data analysis

The mean per cent berry damage in each accession obtained by pooling the years need to be subjected to ANOVA after suitable transformation. The mean and the standard error of per cent berry damage in each accession irrespective of the year shall be taken for calculating pest susceptibility ratings (Devasahayam *et al*., 1997).

Selected references:

- Devasahayam, S. (2000). Insect pests of black pepper. In: Ravindran, P. N. (Ed.) *Black pepper* Piper nigrum. Harwood Academic Publishers, Amsterdam. pp. 309-334.
- Devasahayam, S., Banerjee, S., Premkumar, T., Gautam, S. S. S., Koya, K. M. A., Balakrishnan, R., Abraham, J. and Zachariah, T. J. (1997). *Bionomics of major pests of black pepper and evolving integrated control measures against them.* Final Report of Research Project, Indian Institute of Spices Research, Calicut. p. 13.
- ICAR-Indian Institute of Spices Research (ICAR-IISR). (2015). *Black pepper-Extension Pamphlet*. ICAR-Indian Institute of Spices Research, Kozhikode, India. p. 25.
- Premkumar, T. and Nair, M. R. G. K. (1988). Effect of some planting conditions on infestation of black pepper by *Longitarsus nigripennis* Mots. *Indian Cocoa, Arecanut and Spices Journal*. 10: 83-84.

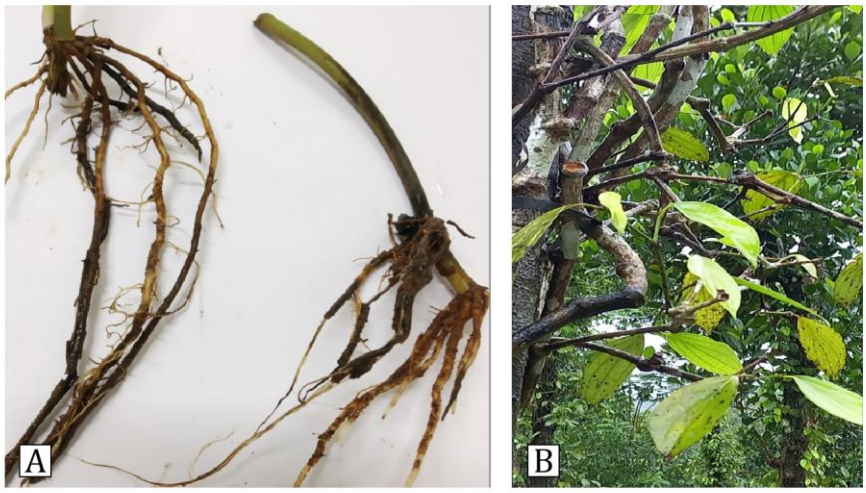
Burrowing nematode

The burrowing nematode, *Radopholus similis* is the most important nematode that attacks black pepper and causes significant yield loss (Jacob and Kurian, 1979; Ramana and Mohandas, 1987). *R. similis* is primarily attributed as the causal organism for slow wilt or slow decline disease in black pepper causing yield loss up to 59%. Every year, on average 20% of vines perish in the infected plantations. These nematodes mostly spread through rooted cuttings.

Symptomatology

The burrowing nematode is a migratory endoparasite causing slow wilt disease in black pepper. The foliar symptoms of nematode infection are pale yellow or whitish yellow leaves that droop and shed. Later, the dieback symptoms appear due to decreased nutrient and water uptake which will be more pronounced during the dry season. The vine recovers during the onset of south-west monsoon, producing new leaves. The disease will re-emerge in the dry season and the cycle continues, but in 3-5 years, the entire vine will

become dead. This nematode is known to interact with *Phytophthora* sp. and *Fusarium solani*, which causes enhanced and quick root rot followed by death of the black pepper vines and seedlings. The below ground symptoms exhibited by roots are elongate brown to dark brown necrotic lesions on cortical tissues. In advanced stage of nematode infection, the necrotic lesions coalesce and encircle root cortex leading to disintegration of distal end of the roots. Such infected roots would be devoid of feeder roots. Occasionally, the nematodes also attack underground portion of the stem causing dark brown stem lesions (Ramana *et al.,* 1994).



(a) Root lesions caused by *Radopholus similis* (b) Yellowing of leaves

Screening for burrowing nematode resistance

- An *in situ* screening experiment can be laid out at selected locations to confirm the resistance of black pepper germplasm accessions that are shortlisted from preliminary screening.
- A susceptible check Panniyur 1 should be included.
- Each treatment is to be replicated four times (4 vines/replication) in a randomized block design.
- The yellowing of the vines would be visually indexed every year during January-February using a 1-5 scale (1 = no yellowing, 2 = up to 25% yellowing, 3 = 26-50% yellowing, 4 = 51-75% yellowing and 5 = >75% yellowing) (Eapen *et al*., 2011).
- The nematode incidence would be assessed by drawing root samples (5 g) every year during the post-monsoon period and processing through standard procedures. The yield to be recorded by harvesting the mature berries from individual plants from second year of planting up to four years (Ravindran *et al.,* 1993).

Organism	Burrowing nematode, *Radopholus similis*
Number of replications	4 replication (each 4 vines)
Design	Randomized Block Design
Plot size	Naturally infested field
Variety	• Any accession/cultivar/variety • Susceptible check (Panniyur 1 or Karimunda) as control
Observations to be recorded	Root Lesion Index, Root population (5 g), Soil population (100 cc), Per cent leaves yellowing and yield, R factor

Root lesion Index (0-5 scale)		
Host status	**Scale**	**Symptom on root**
Immune	0	No lesions
Highly resistant	1	Trace of infection with a few lesions
Resistant	2	≤ 25% roots with lesions
Moderately resistant	3	25 to 50% roots with lesions
Susceptible	4	50 to 75% roots with lesions
Highly susceptible	5	More than 75% roots with lesions
Eapen *et al.* (2011)		

Selected references:

- Jacob, J. A. and Kurian, R. J. (1979). Nematodes associated with pepper in Kerala and the extent of damage done by *Meloidogyne incognita* on the crop. Proceedings of PLOCROSYM II. Central Plantation Crops Research Institute, Kasaragod, India. pp. 31-38.
- 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.
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- Ramana, K. V., Mohandas, C. and Ravindran, P. N. (1987). Reaction of black pepper germplasm to the burrowing nematode (*Radopholus similis*). *Journal of Plantation Crops*. 15: 65-66.
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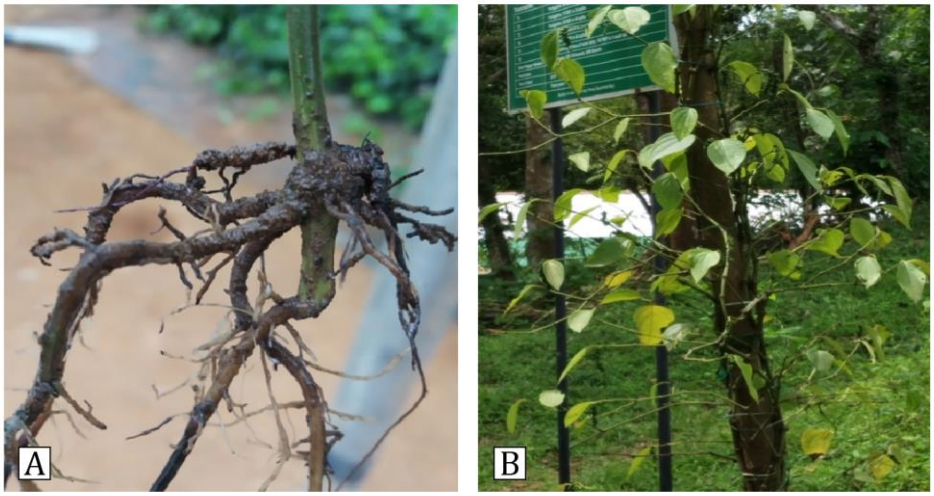
- Coolen, W. A. and D' Herde, C. J. (1972). A method for the quantitative extraction of nematodes from plant tissue. Ghent State Agriculture Research Centre, Merelbeke, Belgium. p. 77.
- Eapen, S. J., Ramana, K. V. and Saji, K. V. (2011). Host resistance in black pepper (*Piper nigrum* L.) against root knot and burrowing nematode. *Journal of Plantation Crops*. 39(3): 341-346.

Root knot nematode

Plant parasitic nematodes belonging to 29 genera and 48 species are reported to attack black pepper (Sundaraju *et al.,* 1979; Koshy and Bridge, 1990). The first report of root knot nematode, *Meloidogyne* sp. infecting black pepper was by Delacroix (1902) which is one of the major nematode pests besides burrowing nematode, *Radopholus similis* attacking black pepper. The slow decline disease was caused by *Phytophthora capsici* either alone or in combination with *R. similis, M. incognita* on black pepper in India (Anandaraj *et al.,* 1994). Root knot nematodes alone could damage the roots, causing yellowing of foliage which in turn leads to considerable yield loss (12 to 46.9%).

Symptomatology

The root knot nematodes are widely distributed, infecting numerous crop plants. These sedentary endoparasites invade the vascular cylinder resulting in hypertrophy and hyperplasia which leads to formation of galls on the roots, which blocks the water and nutrient transportation. During sunny, warm weather conditions, affected plants show yellowing of leaves which is popularly called as '*day wilt*' symptom. Heavily affected vines show yellowing with drooping of leaves, shedding of spikes, reduced spike and leaf size and subsequent plant death (Ramana *et al*., 1994). These nematodes reproduce parthenogenetically and complete their life cycle in 30 days at 25-30˚C.



(a) Root galls caused by *Meloidogyne* sp. (b) Yellowing of leaves caused by *Meloidogyne* sp.

Screening for root knot nematode resistance

- The confirmed resistant lines should be evaluated under field conditions to confirm the resistance and also to understand the effect of nematode population on growth and yield of the plant.
- Susceptible check Karimunda/Panniyur 1 should be included.
- Each treatment should be replicated four times (4 vines/replication) in a randomized block design.
- All the recommended agronomic practices should be followed as per POP.
- The yellowing of the vines would be visually indexed every year during January-February using a 1-5 scale (1 = no yellowing, 2 = up to 25% yellowing, 3 = 26-50% yellowing, 4 = 51-75% yellowing and 5 = >75% yellowing) (Eapen *et al.*, 2011).
- The nematode incidence would be assessed by drawing root samples (5 g) every year during the post-monsoon period and processing through standard procedures. The yield to be recorded by harvesting the matured berries from individual plants from second year of planting for four year (Ravindran *et al.,* 1993).

Organism	**Root knot nematode, *Meloidogyne incognita***
Number of replications	4 replications (Each consists of 4 vines)
Design	Randomized Block Design
Plot size	Naturally infested field
Variety	• Any accession/cultivar/variety • Susceptible check(Panniyur 1 or Karimunda) as control
Observations to be recorded	Root Knot Index, root and soil population (5 g), Per cent leaves yellowing and yield

Root lesion Index (0-5 scale)		
Host status	**Scale**	**Symptom on root**
Immune	0	No lesions
Highly resistant	1	1 to 10% of roots with galls (few galls)
Resistant	2	11 to 25% of roots with galls (mild galling)
Moderately resistant	3	26 to 50% of roots with galls (medium galling)
Susceptible	4	51 to 75% of galls with roots (high galling)
Highly susceptible	5	More than 76% of galls with roots (very high galling and root rotting)
Taylor and Sasser (1978)		

Selected references:

- Anandaraj, M., Ramana, K. V. and 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. National Research Centre for Spices, Calicut. p. 23.
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CARDAMOM

Cardamom (*Elettaria cardamomum Maton*), the 'Queen of Spices' is a Zingiberaceous spice originated and evolved in the biodiversity rich forest ecosystem of Western Ghats, India. Besides its centre of origin, cardamom is widely cultivated in Sri Lanka, Guatemala, Papua New Guinea and Tanzania. The diverse species has morphologically evolved into Malabar, Mysore and Vazhukka types distinguished based on plant stature, leaf, panicle and capsule characters.

Rhizome rot/Clump rot

Small cardamom (*Elettaria cardamomum* Maton) holds immense importance as a spice crop cultivated in the Western Ghats due to its high value in both the national and international markets. India has a rich history as a traditional producer and exporter of small cardamom. However, the production of this crop faces significant challenges, with diseases being one of the most prominent constraints, particularly in subtropical regions. More than 20 pathogens, including oomycete, fungal, bacterial and viral agents, are known to target the cardamom crop, but only a limited number, less than a dozen, result in significant economic losses. One of the major diseases responsible for about 30 per cent crop loss is rhizome/clump rot, caused by pathogens such as *Pythium vexans*, *Rhizoctonia solani* and *Fusarium oxysporum* (Thomas and Vijayan, 1996).

Symptomatology

The disease typically initiates during the monsoon season and tends to escalate with the prolonged duration of monsoon (June to August). It manifests as yellowing of the foliage, followed by the drooping of leaves, while the collar region of the plant becomes brittle and easily breaks off even with slight disturbance (Faisal *et al.,* 2018). As the disease progresses, the rotting spreads to the rhizomes and roots of the plant. Severely affected tillers eventually detach from the plant. Rotten rhizomes become soft, dark brown in colour and emit a foul smell. The incidence of rhizome rot and lodging of shoots is particularly severe during the monsoon season.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design and the duration would be three years. The area under the experiment should be maintained under uniform shade level to provide 40-60% filtered light. The test entries and the check varieties (reported susceptible and resistant checks) should be planted in 3 X 3 m spacing to comprise 12 plants per plot which constitutes single replication. Such three replications should be maintained for each entry and checks (36 plants per entry/check). Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. Timely sprays/soil application of recommended plant protection chemicals

should be adopted to manage insect pests and diseases other than rhizome rot. Natural incidence of rhizome rot should be recorded at least for five months during monsoon and post-monsoon period (June, July, August, September and October) employing 1-5 scale as described. Per cent disease index (PDI) should be calculated for each replication for each month separately and average PDI can be calculated by combining data of other replications (average of five month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for rhizome rot (1 to 5 scale)	
Scale	**Symptoms**
1	No symptoms
2	Positive infection; infection on one tiller
3	Advancing infections, infections on 2-5 tillers or 25% of the tillers of the plant
4	Spreading of infections to 50% of the total tillers
5	All the tillers infected, plant decaying or dead
Venugopal *et al.* (2006)	

Per cent Disease Index (PDI)* =

$$\frac{\text{1 x number of plants falling in the scale + 2 x number of plants falling in the scale + 3 x number of plants falling in the scale + 4 x number of plants falling in the scale + 5 x number of plants falling in the scale}}{\text{12 (total number of plants in one replication) x 5 (maximum disease rating scale)}} \times 100$$

PDI calculated for one replication consisting of 12 plants (similarly PDI should be calculated for other two replications separately)

Categorization based on to reaction towards rhizome rot	
Category	**PDI**
Highly resistant	Less than 5%
Resistant	5.1 to 10%
Moderately susceptible	10.1 to 25%
Susceptible	25.1 to 50%
Highly susceptible	More than 50%
Venugopal *et al.* (2006)	

Selected references:

- Thomas, J. and Vijayan, A. K. (1996). Occurrence, severity, causal organisms and control of rhizome rot disease of small cardamom (*Elettaria cardamomum* Maton). *Journal of Plantation Crops*. 24: 179-183.
- Faisal, M. P., Biju, C. N., Praveena, R., Gowri, R. and Ankegowda, S. J. (2018). Isolation, characterization and antagonistic efficacy of fungal endosymbionts from allied genera of cardamom. *Journal of Plantation Crops*. 46(1): 1-7.
- Venugopal, M. N., Prasath, D. and Mulge, R. (2006). IISR Avinash-a rhizome rot resistant and high yielding variety of cardamom (*Elettaria cardamomum* Maton). *Journal of Spices and Aromatic Crops*. 15: 14-18.

Azhukal/Capsule rot

The '*Azhukal*' disease, also known as capsule rot of cardamom, was first reported by Menon *et al*. (1972) from the Idukki District of Kerala. This disease is of significant concern as it is estimated to cause a loss of 30 per cent (Nambiar and Sarma, 1976). Initially, the pathogen responsible for the disease was identified by Thankamma and Pillai in 1971 as *Phytophthora nicotianae* var. *nicotianae*. However, further research by Nambiar and Sarma in 1976 revealed the involvement of *Pythium vexans* with '*Azhukal*' disease. Subsequent studies provided more insights into the pathogenic fungus responsible for '*Azhukal*' disease, identifying *P. meadii* McRae of A_2 mating type (ICRI, 1986).

Symptomatology

The '*Azhukal*' disease, or capsule rot of cardamom, exhibits characteristic symptoms with the onset of the south-west monsoon. It initially appears as water-soaked lesions on tender leaves and capsules. As the disease progresses, the lesions develop into dead areas encircled by a yellow halo. The leaves then undergo rotting and shredding along the veins. During the later and advanced stages of the disease, the infection spreads to the panicles and tillers. In severe cases, the infection may even reach the rhizomes, leading to rotting, and eventually, the entire plant perishes. Immature capsules are particularly susceptible to infection, resulting in rotting with a foul smell, whereas mature capsules become shrivelled upon drying. Excessive shade and closer spacing of plants, combined with favourable climatic conditions, create a conducive environment for the disease to thrive and spread.

Screening for disease resistance

Procedure:

The trial should be laid out in a randomized block design and the duration would be three years. The area under the experiment should be maintained under a uniform shade level to provide 40-60% filtered light. The test entries and the check varieties (reported susceptible and resistant checks) should be planted in 3 X 3 m spacing to comprise 12 plants per plot which constitutes a single replication. Such three replications should be maintained for each entry and check (36 plants per entry/check). Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than capsule rot. Natural incidence of capsule rot should be recorded at least for five months, monsoon and post-monsoon period (June, July, August, September and October) employing a 1-5 scale as described. Per cent disease index (PDI) should be calculated for each replication for each month separately and average PDI can be calculated by combining data from other replications (average of five month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for capsule rot (1 to 5 scale)	
Scale	**Symptoms**
1	No symptoms
2	Positive infection; infection on one capsule/tiller
3	Advancing infections, infections on 2-5 panicles or 25% of the panicles of the plant
4	Spreading of infections to 50% of the total panicles
5	All the panicles infected
Annual Research Report, Spices Board (2014)	

Per cent Disease Index (PDI)* =

$$\frac{\text{1 x number of plants falling in the scale + 2 x number of plants falling in the scale + 3 x number of plants falling in the scale + 4 x number of plants falling in the scale + 5 x number of plants falling in the scale}}{\text{12 (total number of plants in one replication) x 5 (maximum disease rating scale)}} \times 100$$

*PDI calculated for one replication consisting of 12 plants (similarly PDI should be calculated for three replications separately)

Categorization based on to reaction towards capsule rot	
Category	**PDI**
Resistant	0
Tolerant	0.1 to 10
Moderately tolerant	10.1 to 20%
Susceptible	20.1 to 50%
Highly susceptible	More than 50%
Annual Research Report, Spices Board (2014)	

Selected references:

- Bhai, R. S., Joseph, T. and Naidu, R. (1992). Evaluation of promising selections of cardamom against *Azhukal* disease. *Journal of Plantation Crops*. 20: 90-91.
- Menon, M. R., Sajoo, B. V., Ramakrishnan, C. K. and Ramadevi, L. (1972). A new *Phytophthora* disease of cardamom. *Current Science.* 41: 231.
- Nambiar, K. K. N. and Sarma, Y. R. (1974). Chemical control of capsule rot of cardamom. *Journal of Plantation Crops*. 2: 30-31.
- Thankamma, L. and Pillai, P. N. R. (1973). Fruit rot and leaf rot of cardamom in India. *FAO Plant Protection Bulletin.* 21: 83-84.

Chenthal/Leaf blight

Leaf blight was first reported from Idukki District of Kerala, India. The name "*Chenthal*" is owing to the typical shredding of leaves and burnt-like appearance of the plant due to severe infection. Earlier the disease was reported to be caused by *Colletotrichum gloeosporioides* (Govindaraju *et al*., 1996). However, later studies employing molecular tools revealed the association of six species of *Colletotrichum* (*C. karstii, C. gloeosporioides, C. siamense, C. syzygicola,* unknown *Colletotrichum* sp. and *C. guajavae*) with the disease (Chethana *et al*., 2016). In addition, Biju *et al*. (2018) reported the association of *Neopestalotiopsis clavispora* with leaf blight which aggravates the severity of the disease. Generally the disease appears and proliferates during the post-monsoon period. The pathogen survives in the infected crop residues of the preceding season and spreads through rain splashes and wind. Maximum and minimum temperatures have a positive correlation and rainfall as well as number of rainy days have a negative correlation with disease progression.

Symptomatology

The disease normally appears during the mid-monsoon period and records peak during October and November. The symptoms initially manifest on the leaves as water-soaked oblong to rectangular lesions which later elongate to form parallel arranged streaks. The lesions later turn chlorotic with a necrotic center, which subsequently withers off. Under severe conditions, several necrotic lesions coalesce and impart a burnt-like appearance to the plants. The plant loses vigour due to excessive loss in the photosynthetic area and produce a fewer number of flowers and panicles. The disease is generally severe under less shaded conditions.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries along with known/reported susceptible and resistant checks [three replications each; one replication consists of 12 plants/clumps (age range 4-5 years)] should be used to screen for disease resistance. The location/field should be endemic/conducive to natural infection of leaf blight disease wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than leaf blight. The area under the experiment should be maintained under a uniform shade level to provide 40-60% filtered light. The test entries and the checks should be planted at 3 X 3 m spacing to comprise 12 plants per plot which constitutes a single replication. Such three replications should be maintained for each entry and susceptible/resistant checks (36 plants per entry/check variety). The disease incidence should be recorded consecutively for three years. Natural incidence of leaf blight should be recorded for three months during post-monsoon period (September, October and November) employing a 1-6 scale as described. For scoring, peripheral portion of the clump comprising of senile tillers should be avoided and the scoring should be strictly based on the manifestation of foliar symptoms on the inner tillers (minimum 8-12 tillers should be considered) of the clump. Per cent disease index (PDI) should be calculated for each replication for each month separately and average PDI can be calculated by combining data of other replications (average of three month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for leaf blight (1-6 scale)	
Scale	**Symptoms on leaves**
1	No symptoms
2	Isolated spots
3	Sparse elongated spots on young and mature leaves
4	Coalescing elongated spots on young and mature leaves, 25% of leaf area affected
5	Extensive elongated spots on all leaves, up to 50% of leaf area affected, plant looks green from a distance
6	Total infection of all leaves, plant looks blighted from a distance
Praveena *et al.* (2013), Biju *et al.* (2018)	

Per cent Disease Index (PDI)* =

$$\frac{\text{1 x number of plants falling in the scale + 2 x number of plants falling in the scale + 3 x number of plants falling in the scale + 4 x number of plants falling in the scale + 5 x number of plants falling in the scale + 6 x number of plants falling in the scale}}{\text{12 (total number of plants in one replication) x 6 (maximum disease rating scale)}} \times 100$$

*PDI calculated for one replication consisting of 12 plants (similarly PDI should be calculated for other two replications separately)

Categorization based on reaction towards leaf blight	
Category	**Per cent Disease Index (PDI)**
Highly resistant	Less than 10%
Resistant	11 to 20%
Moderately resistant	21 to 30%
Moderately susceptible	31 to 40%
Susceptible	41 to 50%
Highly susceptible	More than 51%
Praveena *et al.* (2013), Biju *et al.* (2018)	

Selected references:

- Chabanahalli Somashekar Chethana, Pallem Chowdappa, Chakkiyanickal Narayanan Biju, Ravindran Praveena and Annaiah Mukkatira Sujatha. (2016). Molecular and phenotypic characterization revealed six *Colletotrichum* species responsible for anthracnose disease of small cardamom in South India. *European Journal of Plant Pathology*. 146(3): 465-481.
- Chakkiyanickal Narayanan Biju, Mohammed Faisal Peeran and Rajan Gowri. (2018). Identification and characterization of *Neopestalotiopsis clavispora* associated with leaf blight of small cardamom (*Elettaria cardamomum* Maton). *Journal of Phytopathology*. 166: 532-546.
- Biju, C. N., Peeran, M. F., Gowri, R., Praveena, R., Sharon, A. and Ankegowda, S. J. (2018). Epidemiological parameters to delineate weather-disease interactions and host plant resistance against leaf blight in small cardamom (*Elettaria cardamomum* Maton). *Journal of Spices and Aromatic Crops*. 27(1): 22-31.
- Govindaraju, C., Thomas, J. and Sudharsan, M. R. (1996). *Chenthal disease of cardamom caused by Colletotrichum gloeosporioides Penz. and its management*. In: Mathew, N. M. and Jacob, C. K. (Eds.). Developments in Plantation Crop Research, Allied Publishers, New Delhi. pp. 255-259.
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- Senthil Kumar, R., Sharon Aravind, Biju, C. N. and Ankegowda, S. J. (2018). Characterization of genotypes of small cardamom (*Elettaria cardamomum* Maton) for yield parameters and disease resistance. *Journal of Plantation Crops*. 46(2): 143-146.

Cardamom thrips

Cardamom thrips (*Sciothrips cardamomi* Ramk.) (Thysanoptera: Thripidae) is a major limiting factor in cardamom production (*Elettaria cardamomum* Maton.) (Zingiberaceae), (Ravindran, 2002). Thrips damaged capsules have very low market value causing severe economic losses to growers. The extent of capsule damage by thrips is 30-90%, and the estimated crop loss is up to 48% in major cardamom producing countries (Gopakumar and Chandrasekar, 2002).

Symptomatology

The insect damages panicles, flowers and developing capsules by sucking the sap, leading to premature shedding of flowers and capsules. The pest infestation also results in scab formation on the capsule surface with poorly developed seeds inside presenting a shriveled appearance and lacking the characteristic aroma.

(a) Healthy and (b) thrips damaged cardamom capsules

Screening for pest resistance

Experiments should be conducted for at least three years to screen the cardamom accessions against the natural population of cardamom thrips under field conditions. The observations have to be carried out on minimum five clumps of each accession, which are 5-6 years old and yielding, maintained with a plant-to-plant spacing of 3 X 3 m. Each clump can be considered as a replication. The plants should be raised following the standard agronomic practices for cardamom (ICAR-Indian Institute of Spices Research, 2015), except for the non-application of pesticides throughout the study period.

Design	Randomized Block Design
Number of replications	5
Plot size	3 X 3 m spacing
Observations to be recorded	Cardamom capsules after attaining physiological maturity should be harvested separately from each clump during July, September and December each year and have to be cured following the standard procedures (ICAR-Indian Institute of Spices Research, 2015). The cured capsules should be pooled accession-wise and stored in polythene bags at ambient room temperature for further observations. Capsule damage by thrips can be assessed by drawing 100 g of sample from each clump of every accession. The total number of capsules and the number of capsules that showed characteristic scab formation due to thrips infestation have to be visually recorded for calculating the per cent capsule damage. The mean per cent capsule damage for an accession in a year can be calculated, pooling the plant-wise harvest data.

Data analysis

The overall mean per cent capsule damage (M) and standard error (SE) for all the accessions have to be calculated to determine the thresholds for resistance and the accessions are categorized as highly resistant, resistant, moderately susceptible, susceptible and highly susceptible to thrips following Jacob *et al*. (2020).

Classification of cardamom accessions based on thrips incidence	
Category	**Capsule damage**
Highly resistant	No infestation
Resistant	Below 15%
Moderately susceptible	Between 16% and 25%
Susceptible	Between 26% and 50%
Highly susceptible	Above 50%

Selected references:

- Gopakumar, B. and Chandrasekar, S. S. (2002). Insect pests of cardamom. In: Ravindran, P. N. and Madhusoodanan, K. J. (Eds.) *Cardamom-The genus* Elettaria. Taylor and Francis, London, England. pp. 180-206.
- ICAR-Indian Institute of Spices Research (ICAR-IISR). (2015). *Cardamom-Extension pamphlet*. ICAR-Indian Institute of Spices Research, Kozhikode, India. p. 23.
- Jacob, T. K., Senthil Kumar, C. M., Devasahayam, S., *et al*. (2020). Plant morphological traits associated with field resistance to cardamom thrips (*Sciothrips cardamomi*) in cardamom (*Elettaria cardamomum*). *Annals of Applied Biology*. 177: 143-151.
- Ravindran P. N. (2002). Introduction. In: Ravindran, P. N. and Madhusoodanan, K. J. (Eds.). *Cardamom-The genus* Elettaria. Taylor and Francis, London, England. pp. 1-10.

GINGER

Ginger (*Zingiber officinale* Rosc.), a rhizomatous herbaceous spice representing the family Zingiberaceae is considered as one among the most ancient spices with multifarious uses. The modified subterranean stem i.e., the rhizome constitutes the economic part which is also extensively used for vegetative propagation. Globally, the major ginger producing countries are Bangladesh, Cameroon, China, India, Indonesia, Japan, Nepal, Nigeria, Philippines and Thailand.

Rhizome rot

Soft rot disease caused by *Pythium* was recorded for the first time from India and presently, the disease occurs in all ginger growing countries throughout the world (Dohroo, 2005). The pathogens responsible for soft rot can infect host plants at any stage of growth and postharvest storage and can lead to severe losses. Stirling *et al*. (2009) reported more than 50% loss of plants used for seed ginger production in Australia. In most cases these heavy losses have occurred in years when weather conditions were favourable for pathogen growth. The impact of *Pythium* spp. can also be high in storage; losses ranging from 24 to 50% have been reported with rates occasionally exceeding 90% in India. Six species of *Pythium viz*., *P. aphanidermatum*, *P. butleri*, *P. deliense*, *P. myriotylum*, *P. pleroticum*, *P. ultimum*, and *P. vexans* are associated with soft rot of ginger. Of these, *P. myriotylum* is the predominant species (Kumar *et al*., 2008).

Symptomatology

If the rhizomes used for planting are infected, they do not germinate due to the rotting of young buds. If infection occurs after sprouting, the infection occurs through the root or collar region, later spreading to the rhizomes. In mature plants, collar infection results in yellowing of foliage which starts from the leaf tip and proceeds downwards leading to drying of leaves, which droop until the entire shoot dries. The basal part of the stem develops translucent discolouration which then turns water-soaked, leading to the falling of infected shoots. The affected rhizomes first become brown, slowly decomposes, and transforms into a wet mass of rotting tissue surrounded within rhizome skin and releasing foul smell. The roots of the infected rhizomes become soft and later rot.

Screening for disease resistance

Procedure:

The trial should be laid out in beds of size 3 X 1 m with a plant population of 40 plants per bed. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than rhizome rot. Natural incidence of rhizome rot should be recorded during 30, 60 and 90 days after planting (DAP) using 1-5 scale as described. To calculate disease index, disease scoring should be done based on the disease rating scale (40 plants per bed) and calculate the average disease index. Based on average disease index (DI), the plants can be grouped into different categories of susceptibility or resistance.

Disease rating scale for rhizome rot (1 to 5 scale)	
Category	**Description/Symptoms**
1	No symptoms or 100% tillers green and healthy
2	1 to 25% tillers yellow or dead
3	26 to 50% Shoots yellow or dead
4	50 to 75% shoots yellow or dead
5	More than 75% shoots yellow or dead

Per cent Disease index (PDI) = $\frac{(n \times 1 + n \times 2 + n \times 3 + n \times 4 + n \times 5) \times 100}{N \times 5}$

Where, n = Number of plants in each score, 5 = Maximum disease grade, N = Total number of plants under observation.

Classification of ginger based on DI	
Category	**Description/Symptoms**
Highly resistant	Less than 10%
Resistant	11 to 20%
Moderately resistant	21 to 50%
Susceptible	51 to 75%
Highly susceptible	76 to100%

Selected references:

- Irulappan, V., Mali, K. V., Patil, B. S., Manjunatha, H., Muhammad, S. and Senthil Kumar, M. (2012). A sick plot-based protocol for dry root rot disease assessment in field-grown chickpea plants. *Application in Plant Sciences.* doi: 10.1002/aps3.11445.
- Kavitha, P. G. and Thomas, George. (2007). Evaluation of Zingiberaceae for resistance to ginger soft rot caused by *Pythium aphanidermatum* (Edson) Fitzp. *Plant Genetic Resources Newsletter*. 152: 54-57.
- Le, D. P., Smith, M. K. and Aitken, E. A. B. (2016). An assessment of *Pythium* spp. associated with soft rot disease of ginger (*Zingiber officinale*) in Queensland, Australia. *Australasian Plant Pathology.* 45: 377-387. https://doi.org/10.1007/s13313-016-0424-5.
- Kavitha, P. G. and Thomas George. (2008). Population genetic structure of the clonal plant *Zingiber zerumbet* (L.) Smith (Zingiberaceae), a wild relative of cultivated ginger and its response to *Pythium aphanidermatum*. *Euphytica*. 160: 89-100. 10.1007/s10681-007-9557-5.
- Kumar, A., Reeja Susan Thomas, Jooju, B., Bhai, R. S. and Shiva, K. N. (2008). Distribution of *Pythium myriotylum* Drechsler causing soft rot of ginger (*Zingiber officinale* Roscoe.) *Journal of Spices and Aromatic Crops*. 17: 5-9.

- Dohroo, N. P. (2005). Diseases of ginger. In: Ravindran, P. N. and Babu, K. N. (Eds.). *Ginger: The genus Zingiber*. CRC Press, Boca Raton. pp. 305-340.
- Stirling, G. R., Turaganivalu, U., Stirling, A. M. *et al.* (2009). Rhizome rot of ginger (*Zingiber officinale*) caused by *Pythium myriotylum* in Fiji and Australia. *Australasian Plant Pathology*. 38: 453-460. https://doi.org/10.1071/AP09023.

Bacterial wilt

Bacterial wilt caused by *Ralstonia pseudosolanacearum* race 4 biovar 3/4, is one of the important rhizome-borne diseases of ginger. In India, biovar 3 causes rapid wilt in ginger in 5-7 days under artificial stem inoculation and in 7-10 days under soil inoculation. The rhizome-borne inoculum is primarily responsible for disease initiation which further spreads horizontally aided by high rainfall and cool weather under field conditions. Generally the disease appears and proliferates during June to August. The pathogen survives in the soil and infected planting material and spreads through rhizome/soil-borne inoculum, rain splash and run-off water. High rainfall and warm weather favours disease development and subsequent spread.

Symptomatology

The initial conspicuous symptom of bacterial wilt is mild drooping and curling of leaf margins of lower leaves (green wilt). In the advanced stage, plants exhibit severe yellowing and wilting symptoms. The vascular tissues of affected pseudostems exhibit dark streaks. The affected pseudostem and rhizome when pressed gently extrudes milky ooze from the vascular strands. The affected rhizome putrefies, emit foul smell and the affected plants withers within 2-3 weeks.

Green wilt (initial stage) | Advanced stage

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. The area under the experiment should be maintained under uniform shade level. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries shortlisted along with known/reported susceptible and resistant checks [five replications each; one replication consists of three beds] should be used to screen for disease resistance. The test entries and the check varieties should be planted in 3 X 1 m^2 size beds with a spacing of 20 X 30 cm (rhizome to rhizome X row to row) to comprise a minimum of 30 plants per bed. The location/field should be endemic/conducive to natural infection of bacterial wilt disease

(sick plot) wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than bacterial wilt. Disease-free healthy rhizomes weighing about 20-25 g should be planted during the second fortnight of April and the rhizomes should be treated with recommended fungicides/insecticides before planting (Suseela Bhai *et al*., 2019). Three beds would constitute a single replication and five replications (total of 15 beds per entry/check) should be maintained for each entries and checks. The disease intensity should be assessed at 90th day after planting and disease intensity should be calculated (Indrasenan *et al*., 1982; Suseela Bhai *et al*., 2019).

$$\text{Disease intensity (DI)} = \frac{\text{Number of tillers infected}}{\text{Total number of tillers}} \times 100$$

For disease scoring, observations on disease intensity should be recorded on all the plants (minimum of 30 plants per bed/replication) from all five replications. Based on average DI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years. A minimum of 150 plants should be screened per entry/checks and the average score should be recorded.

Categorization based on reaction towards bacterial wilt	
Category	**Disease Intensity (DI)**
Resistant	0 to 5%
Moderately resistant	6 to10%
Mildly susceptible	11 to 25%
Moderately susceptible	26 to 40%
Highly susceptible	More than 40%
Indrasenan *et al*. (1982)	

Selected references:

- Indrasenan, G., Sreekumar, V., Mathew, J. and Mammen, M. K. (1982) Reaction of different types of ginger to bacterial wilt caused by *Pseudomonas solanacearum* (Smith) Smith. *Agricultural Research Journal of Kerala*. 20: 73-75.
- Suseela Bhai, R., Prameela, T. P., Vincy, K., Biju, C. N., Srinivasan, V. and Nirmal Babu, K. (2019). Soil solarization and amelioration with calcium chloride or *Bacillus licheniformis*-an effective integrated strategy for the management of bacterial wilt of ginger incited by *Ralstonia pseudosolanacearum*. *European Journal of Plant Pathology*. 154: 903-917. https://doi. 10.1007/s10658-019-01709-y.

Phyllosticta leaf spot

Leaf spot incited by *Phyllosticta zingiberi* is a major foliar disease of ginger which was reported for the first time in Godavari and Malabar regions of India (Ramakrishnan, 1942). Generally the disease appears towards end to June. The pathogen survives in the infected plant parts (leaf debris) and soil and spreads through rain splashes as well as wind. The disease development is favoured by temperature (23-30^{o}C), relative humidity (83-90%) and intermittent rainfall. Six to seven months old plants are more vulnerable and two weeks old leaves are most susceptible to the disease.

Symptomatology

Initially small, spindle to oval or elongated spots with white papery center and dark brown margins surrounded by yellow halo appear on younger leaves. The spots later expand and coalesce to form larger spots, which eventually reduce the effective photosynthetic area. The infected areas often dry at the center, forming shot-holes and subsequently, the entire leaf dries. In the advanced stage, the crop develops a greyish disheveled appearance.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. The area under the experiment should be maintained under uniform shade level. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries shortlisted along with known/reported susceptible and resistant checks [five replications each; one replication consists of three beds] should be used to screen for disease resistance. The test entries and the check varieties should be planted in 3 X 1 m^2 size beds with a spacing 20 X 30 cm (rhizome to rhizome X row to row) to comprise a minimum of 30 plants per bed. The location/field should be endemic/conducive to natural infection of Phyllosticta leaf spot wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than Phyllosticta leaf spot. Disease-free healthy rhizomes weighing about 20-25 g should be planted during second fortnight of April and the rhizomes should be treated with recommended fungicides/insecticides before planting. Three beds would constitute single replication and five replications (total of 15 beds per entry/check) should be maintained for each entries and checks. Natural incidence of Phyllosticta leaf spot should be recorded during September and October employing 0-8 scale as described. For disease scoring, observations from all the leaves of 15 randomly selected plants per bed should be recorded. Disease index (DI) should be calculated for each replication for each month separately and average DI can be calculated by combining data of other replications (average of two month data would represent the disease level of a particular entry/check

for a particular year of screening). Based on average DI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for Phyllosticta leaf spot (0-8 scale)	
Scale	**Symptoms on leaves**
0	No symptoms/disease
1	1 to 2 spots per leaf
2	3 to 5 spots per leaf
3	6 to 9 spots per leaf
4	10 to 15 spots per leaf
5	20 to 35% leaf area covered
6	36 to 60% leaf area covered
7	61 to 80% leaf area covered
8	Leaves completely dried
Senapati *et al.* (2012)	

The Disease Index (DI) should be calculated at monthly intervals adopting the disease rating scale (Senapati *et al.*, 2012) and averaged.

Disease Index (DI)* =

$$\frac{0 \times \text{number of leaves falling in the scale} + 1 \times \text{number of leaves falling in the scale} + 2 \times \text{number of leaves falling in the scale} + 3 \times \text{number of leaves falling in the scale} + 4 \times \text{number of leaves falling in the scale} + 5 \times \text{number of leaves falling in the scale} + 6 \times \text{number of leaves falling in the scale} + 7 \times \text{number of leaves falling in the scale} + 8 \times \text{number of leaves falling in the scale}}{\text{Total number of leaves observed}}$$

*DI calculated for one replication consisting of 15 randomly selected plants (similarly DI should be calculated for other four replications separately).

Categorization based on reaction towards Phyllosticta leaf spot	
Category	**Disease Index (DI)**
Highly resistant	Less than 0.4619
Moderately resistant	0.4619 to 1.0403
Tolerant	1.0403 to 1.6187
Moderately tolerant	1.6187 to 2.1971
Susceptible	2.1971 to 2.7755
Highly susceptible	More than 2.7755
Senapati *et al.* (2012)	

Selected references:

- Dohroo, N. P., Shyam, K. R., Bhardwaj, S. S. and Korla, B. N. (1986). Reaction of ginger germplasm to Phyllosticta leaf spot. *Indian Phytopathology*. 39: 605-606.
- Senapati, A. K., Mukherjee, A. K. and Ghose, S. (2012). Identification of resistance sources in ginger cultivars against Phyllosticta leaf spot. *Indian Journal of Plant Protection*. 40(1): 80-81.
- Nageshwar Rao, T. G., Sasikumar, B. and Johnson K. George. (1995). Field reaction of ginger germplasm to *Phyllosticta zingiberi*. *Indian Phytopathology*. 48(4): 463-465.
- Ramakrishnan, T. S. (1942). A leaf spot disease of ginger caused by *Phyllosticta zingiberi* sp. n. *Proceedings of Indian Academy of Sciences*. 15: 167-171.

Exserohilum leaf blight

Ginger leaf blight caused *Exserohilum rostratum* (Drechs.) Leonard and Suggs is an emerging threat to ginger cultivation (Praveena *et al*., 2022).

Symptomatology

The disease normally appears during June-July and records peak during September-October. Symptoms manifest with the formation of reddish-brown oval-shaped water soaked discrete spots with a yellow halo on the margin and distal end of the ginger leaf lamina. Later these spots gradually increase in size and often coalesce to form large discoloured areas. As the severity of the disease increases large discoloured areas coalesces leading to the blighting of the entire leaf. Infection was also observed on leaf sheath as brown oval-shaped discrete spots with dark margins and a yellow halo. Disease resulted in the severe blighting of leaves giving a burnt appearance to ginger fields. The symptoms were observed mainly on the lower and middle leaves of each tiller of ginger crop and the disease was found to be severe in most of the cultivated areas.

Screening for disease resistance

Procedure:

The trial should be laid out in beds of size 3 X 1 m with a plant population of 40 plants per bed. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than leaf blight. Natural incidence of leaf blight should be recorded during 60, 90 and 120

days after planting (DAP) using 1-5 scale as described. Per cent disease index (PDI) of 40 plants/bed should be calculated separately and calculate the average PDI. Based on average PDI during a particular year, the plants can be grouped into different categories of susceptibility or resistance.

Disease rating scale for leaf blight (1 to 5 scale)	
Category	**Symptoms on leaves**
1	No symptoms
2	1–10% leaf area covered with reddish-brown oval-shaped spots with a yellow halo
3	11–25% leaf area covered with brownish lesions especially along the margin and distal end of the leaf
4	26–50% leaf area covered with brownish lesions especially along the margin and distal end of the leaf. Lower leaves appear blighted
5	> 50% leaf area covered with brownish lesions, severe blighting of leaves giving a burnt appearance to plant
Jakhar *et al.* (2017), Debela *et al.* (2017), Badu-Apraku (2021)	

$$\text{Per cent Disease index (PDI)} = \frac{(n \times 1 + n \times 2 + n \times 3 + n \times 4 + n \times 5) \times 100}{N \times 5}$$

Where, n = Number of plants in each score, 5 = Maximum disease grade

N = Total number of plants under observation

Classification of ginger based on PDI for leaf blight	
Category	**PDI**
Highly resistant	Less than 10%
Resistant	11 to 20%
Moderately resistant	21 to 50%
Susceptible	51 to 75%
Highly susceptible	76 to 100%

Selected references:

- Jakhar, Dan Singh, Rajesh Singh and Saket Ojha, Vivek. (2017). Turcicum Leaf Blight: A ubiquitous foliar disease of maize (*Zea mays* L.). *International Journal of Current Microbiology and Applied Sciences*. 6: 825-831. 10.20546/ijcmas.2017.603.097.
- Debela, M., Dejene, M. and Mengesha, W. (2017). Management of Turcicum leaf blight [*Exserohilum turcicum* (Pass.) Leonard Suggs] of maize (*Zea mays* L.) through integration of host resistance and fungicide at Bako, western Ethiopia. *African Journal of Plant Science*. 11(1): 6-22.

- Badu-Apraku, B., Bankole, F. A., Ajayo, B. S., Fakorede, M. A. B., Akinwale, R. O., Talabi, A. O., Bandyopadhyay, R. and Ortega-Beltran, A. (2021). Identification of early and extra-early maturing tropical maize inbred lines resistant to *Exserohilum turcicum* in sub-Saharan Africa. *Crop Protection*.139: 105386. doi: 10.1016/j.cropro.2020.105386.
- Praveena, R., Kozhamburath, A., Jeevalatha, A., Bhat, A. I. and Krishnamurthy, K. S. (2022) Association of *Exserohilum rostratum* with ginger-Morphological characterization, phylogenetic relationships and pathogenicity assays. *Australasian Plant Pathology*. https://doi.org/10.1007/s13313-022-00862-z.

Ginger shoot borer

Conogethes punctiferalis (Guenée) (Crambidae: Lepidoptera) is the most serious insect pest of ginger (*Zingiber officinale* Rosc.) in India, which is a high-value spice crop of commerce. The larva bores into shoots (pseudostems) of ginger and feed the internal tissues resulting in yellowing and drying of infested shoots. The yield of the crop is significantly affected when more than 50% of the shoots in a clump are damaged by the pest (Devasahayam and Koya, 2004).

Symptomatology

The adult moth lays eggs on the tender unopened leaf and the larvae on hatching scrape and feed on the green contents of the tender leaf; later they bore into the shoots and feed on the inner core resulting in dead hearts or withered shoots. Fresh frass extruding through the bore hole is an indication of the presence of live larva inside the shoot (Devasahayam and Koya, 2004).

(a) Bore-hole symptoms of shoot borer attack in ginger and (b) Larva of shoot borer inside the pseudostem.

Screening for pest resistance

Experiments can be conducted in large cement tubs (45 cm height and 45 cm diameter) filled with potting mixture containing soil, sand and dried powdered cow dung in 1:1:1 ratio or under field conditions to screen the ginger accessions against shoot borer for at least three years. The plants should be raised following the standard agronomic practices for turmeric (ICAR-Indian Institute of Spices Research, 2015), except for the non-application of pesticides throughout the study period.

Design	Randomized Block Design
Number of replications	3
Plot size	Under field conditions, the screening can be carried out in 3 X 1 m beds with a minimum of three replications/accession.
Observations to be recorded	The number of damaged (dead hearts/shoots with bore hole) and healthy shoots need to be recorded in each clump once during October-November each year when pest damage reaches its peak. The mean per cent shoot damage can be expressed per accession per year.

Classification of turmeric accessions based on shoot borer damage	
Category	**Shoot damage**
Highly resistant	No shoot damage
Moderately resistant	Below 15% shoot damage
Moderately susceptible	Between 15% and 25% shoot damage
Susceptible	Between 25% and 45% shoot damage
Highly susceptible	More than 45% shoot damage

Data analysis:

The mean per cent shoot damage in each accession obtained by pooling the years need to be subjected to ANOVA after suitable transformation. The mean and the standard error of per cent shoot damage in each accession irrespective of the year shall be taken for calculating pest susceptibility ratings as per the method adopted by Devasahayam *et al*. (2010).

Select references:

- Devasahayam, S. and Koya, K. M. A. (2004). Insect pests of ginger. In: Ravindran, P. N. and Babu, K. N. (Eds.) *Ginger. The Genus* Zingiber. CRC Press, Washington. pp. 367-389.
- Devasahayam, S., Jacob, T. K., Abdulla Koya, K. M. and Sasikumar, B. (2010). Screening of ginger (*Zingiber officinale* Rosc.) germplasm for resistance to shoot borer (*Conogethes*

punctiferalis Guen.) (Lepidoptera: Pyralidae), in Kerala, South India. *Journal of Medicinal and Aromatic Crops*. 32: 137-138.

- ICAR-Indian Institute of Spices Research (ICAR-IISR). (2015). *Ginger-Extension Pamphlet.* ICAR-Indian Institute of Spices Research, Kozhikode, India. p. 12.

Root knot nematode

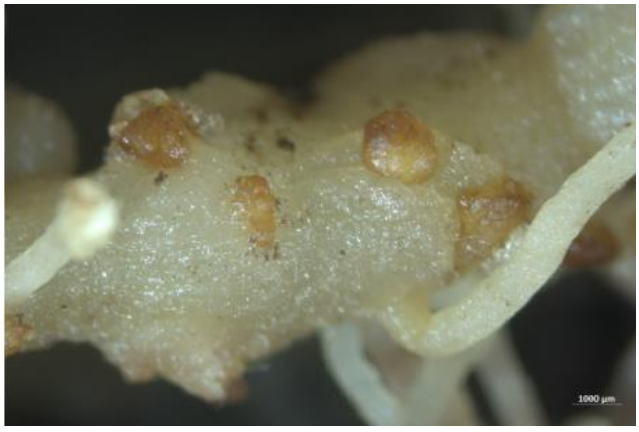
Plant parasitic nematodes belonging to 17 genera have been reported on ginger of which, the most important parasites are *Meloidogyne* spp., *R. similis* and *P. coffeae* (Eapen and Pandey, 2018). The root knot nematode (RKN) is a serious pest infesting ginger in almost all ginger growing regions of India such as Kerala, Karnataka, Odisha, Madhya Pradesh, Himachal Pradesh and West Bengal (Eapen and Pandey, 2018; Nair *et al*., 2019). The RKN are reported to be involved in disease complexes with fungi and bacteria (Eapen and Pandey, 2018). Dohroo *et al*. (1987) reported the severity of rhizome rot caused by *Pythium* spp. increased with the infestation of *M. incognita*.

Symptomatology

The root knot nematodes cause galling and rotting of roots and underground rhizomes. 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. Yellowing of leaves and prematurely senile and thin rhizomes. Infested rhizomes have brown, water soaked areas in the outer tissues, particularly in the angles between shoots. 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 the healthy plants, leaving a poor crop stand at harvest.

Poor crop stand caused by root knot nematode infection

Root knot nematode infested ginger (Singh and Gupta, 2011)



Ginger roots with prominent galls caused by root knot nematode and egg masses (Hajihassani *et al*., 2019)

Screening for root knot nematode resistance

Procedure:

- Nematode population level should be assessed by standard protocols.
- The germplasm accessions or cultivars to be screened are planted in the soil with check varieties as control e.g., IISR Mahima (Moderately resistant to *Meloidogyne* sp.).
- Standard package of practices should be followed.
- After two months, the plants should be uprooted and carefully washed free of soil and stained in Phloxine B.
- The egg masses should be graded using a 0-5 scale given by Taylor and Sasser (1978).
- Accessions with an egg mass index (EMI) of less than two or equal should be shortlisted for subsequent testing in growbags or pots with known number of infective juveniles.
- In the subsequent tests, the final nematode population (R Factor) should also estimate by staining in acid fuchsin-acetic acid solution followed by maceration in a blender
- Formula for calculating R Factor is $R= P_f/P_i$, where P_f is final population of nematodes and P_i is Initial population (in this case; 1000 juveniles)
- The host status of each accession will be rated based on nematode reproduction and EMI.

Design	Randomized Block Design
Number of replications	Minimum 3
Plot size	30 m^2
Observations to be recorded	Recording the incidence of RKN using the egg mass index (EMI) and R factor

Rating scale for root knot nematode presence on roots (0-5 scale)	
Egg mass index (EMI)	**Number of egg masses**
0	0
1	1 to 2
2	3 to10
3	11 to 30
4	31 to 100
5	More than 100
Taylor and Sasser (1978)	

Designation of host status based on the degree of resistance		
Degree of resistance designation	**Gall index**	**R factor**
Resistant	≤2	≤ 1
Tolerant	≤2	> 1
Moderately tolerant	≥2	≤ 1
Susceptible	≥2	> 1
Sasser *et al.* (1984)		

Selected references:

- Dohroo, N. P., Shyam, K. R. and Bhardwaj, S. S. (1987) Distribution, diagnosis and incidence of rhizome rot complex of ginger in Himachal Pradesh. *Indian Journal of Plant Pathology*. 5: 24-25.
- Eapen, S. J. and Pandey, R. (2018). Nematode parasites of spices and medicinal plants. In: Sikora, R. A., Coyne, D., Hallmann, J. and Timper, P. (Eds.). Plant parasitic nematodes in subtropical and tropical agriculture. 3rd Edition, CABI, UK. pp. 755-794.
- Hajihassani, A., Ye, W. and Hampton, B. B. (2019). First report of *Meloidogyne javanica* on ginger and turmeric in the United States. *Journal of Nematology*. 51: 1-3. https://doi.org/10.21307/jofnem-2019-006.
- Prasath, D., Eapen, S. J. and Sasikumar, B. (2016). Performance of turmeric (*Curcuma longa*) genotypes for yield and root knot nematode resistance. *Indian Journal of Agricultural Sciences*. 86(9): 1189-92. https://doi.org/10.56093/ijas.v86i9.61516.
- Sasikumar, B., Saji, K. V., Alice, A., George, J. K., Zachariah, T. J. and Eapen, S. J. (2003). IISR Mahima and IISR Rejatha-two high yielding and high quality ginger (*Zingiber officinale* Rosc.) cultivars. *Journal of Spices and Aromatic Crops*. 12: 34-37.
- Sasser, J. N, Carter, C. C. and Hartman, K. M. (1984). Standardization of host suitability studies and reporting of resistance to root knot nematodes. Raleigh, North Carolina, USA. p. 7.
- Taylor, A. L. and Sasser, J. N. (1978). Biology, identification and control of root knot nematodes *(Meloidogyne* spp.) Coop. Pub. Dep. Plant Pathol., North Carolina State Univ. and U. S. Agency Int. Dev. Raleigh, N. C. p. 111.

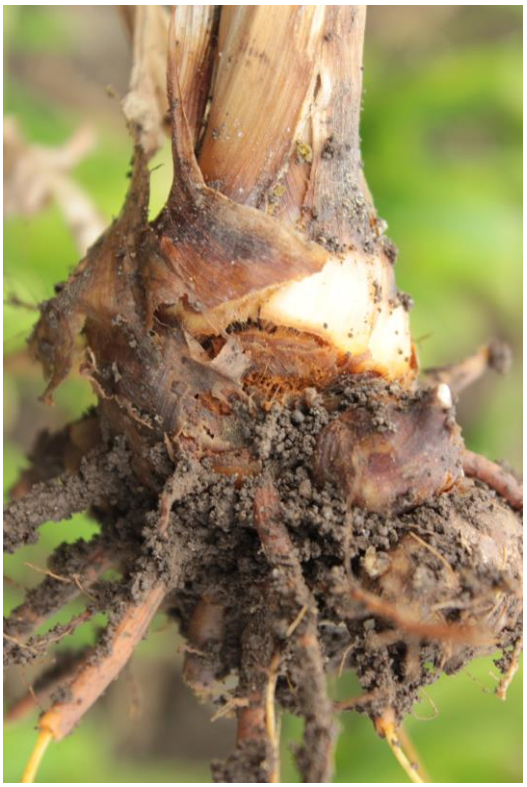
TURMERIC

Turmeric (*Curcuma longa* L.) popularly referred as the "golden spice" and the "spice of life" has been valued as a medicinal plant from time immemorial in India and elsewhere. Turmeric, a member of Zingiberaceae and probably a native of Southeast Asia, is extensively cultivated in India, followed by Bangladesh, China, Thailand, Cambodia, Malaysia, Indonesia and Philippines.

Rhizome rot

The disease is caused by different species of *Pythium*, namely *Pythium aphanidermatum*, *P. myriotylum* and *P. graminicolum* (Anoop and Suseela Bhai, 2014). Rhizome rot is a major production constraint in all turmeric growing tracts and causes more than 60% mortality in nursery and field conditions. The yield loss due to the disease could go as high as 50% and up to 80% in storage (Rajalakshmi *et al*., 2016).

Symptomatology



The infection starts with water-soaked lesions leading to the rotting of the collar region of pseudostem that slowly advances in both upward and downward directions. The rotting also spreads to the rhizomes and roots causing soft rot. The rhizome colour changes from orange to brown and the infection spreads progressively to all the fingers including the mother rhizomes finally leading to the death of the plants. The diseased rhizomes when cut opened brown fibro-vascular tissues are observed. Both rotten rhizomes and roots release foul smells in advanced stages. The above-ground symptoms initiate as yellowing of the tips of lower leaves which slowly spreads to the leaf blades. Subsequently, the yellowing spreads to other upward leaves of the plant followed by wilting and drying of pseudostems. The external appearance of symptoms depends on the time of infection and the extent of damage to the rhizome. If the infection by the fungus is confined to roots and secondary fingers no visible above-ground symptoms are observed.

Screening for disease resistance

Procedure:

The trial should be laid out in beds of size 3 X 1 m with a plant population of 40 plants per bed. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than rhizome rot. Natural incidence of rhizome rot can be recorded 30, 60 and 90 days after planting (DAP), using 0-4 scale as described. To calculate disease index, disease scoring should be done based on the disease rating scale (40 plants per bed) and calculate the average disease index. Based on average disease index (DI), the plants can be grouped into different categories of susceptibility or resistance.

Disease rating scale for rhizome rot (0 to 4 scale)	
Category	**Description/Symptoms**
0	No symptoms or 100% tillers green and healthy
1	1 to 25% tillers with water-soaked lesion on pseudostem, yellow or dead
2	26 to 50% tillers with water-soaked lesion on pseudostem, yellow or dead
3	50 to 75% tillers with water-soaked lesion on pseudostem, yellow or dead
4	More than 75% tillers with water-soaked lesion on pseudostem, yellow or dead
Praveena *et al.* (2022)	

Per cent Disease index (PDI) = $\frac{(n \times 0 + n \times 1 + n \times 2 + n \times 3 + n \times 4) \times 100}{N \times 4}$

Where, n = Number of plants in each score, 4 = Maximum disease grade, N = Total number of plants under observation

Classification of turmeric based on Disease Index (DI)	
Category	**PDI**
Highly resistant	Less than 10%
Resistant	11 to 20%
Moderately resistant	21 to 50%
Susceptible	51 to 75%
Highly susceptible	76 to 100%

Selected references:

- Irulappan, V., Mali, K. V., Patil, B. S., Manjunatha, H., Muhammad, S. and Senthil Kumar, M. (2021). A sick plot-based protocol for dry root rot disease assessment in field-grown chickpea plants. *Application in Plant Sciences*. 9(8). doi: 10.1002/aps3.11445
- Anoop, K. and Suseela Bhai, R. (2014). Evaluation of antagonistic potential of indigenous *Trichoderma* isolates against *Pythium aphanidermatum* (Edson) Fitz. causing rhizome rot in turmeric (*Curcuma longa* L.). *Journal of Science*. 4(2): 99-105.
- Rajalakshmi, J., Durgadevi, D., Harish, S. and Raguchander, T. (2016). Morphological and molecular characterization of *Pythium aphanidermatum* the incitant of rhizome rot in turmeric. *International Journal of Environment, Ecology, Family and Urban Studies*. 6(4): 1-8.
- Praveena, R., Srekha, K., Revathy, R., Srinivasan, V., Sarathambal, C., Priya George, Subila, K. P. and Dinesh, R. (2022). New rhizobacteria strains with effective antimycotic compounds against rhizome rot pathogens and identification of genes encoding antimicrobial peptides. *Rhizosphere*. June 22, 100515.

Leaf blotch

The leaf blotch disease is caused by *Taphrina maculans*, an ascomycetous fungus. Generally the disease appears and proliferates during September to November. The pathogen survives in the infected leaf debris and spreads through wind. The disease development under field conditions is favoured by relative humidity (80%) and temperature (21-23°C).

Symptomatology

Leaf blotch is characterized with the appearance of small, scattered, oily-looking translucent spots on lower side of the leaves when the plant attains 3-4 leaf stage. The spots eventually turn dirty yellow, deepen in colour to that of gold, and sometimes to bay shade. The adjacent individual leaf spots of 1-2 mm diameter coalesce to form reddish brown blotches leading to varying degrees of leaf blight. The lower leaves are more prone to infection than the upper ones, which are relatively younger in age. In severe cases of infection, several spots coalesce on both sides of the leaf, thereby significantly reducing the effective photosynthetic area.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. The area under the experiment should be maintained under uniform shade level. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries shortlisted along with known/reported susceptible and resistant checks [five replications each; one replication consists of three beds] should be used to screen for disease resistance. The test entries and the check varieties should be planted in 3 X 1 m^2 size beds with a spacing 20 X 30 cm (rhizome to rhizome X row to row) to comprise a minimum of 30 plants per bed. The location/field should be endemic/conducive to natural infection of leaf blotch wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than leaf blotch. Disease-free healthy rhizomes weighing about 20-25 g should be planted during second fortnight of April and the rhizomes should be treated with recommended fungicides/insecticides before planting. Three beds would constitute single replication and five replications (total of 15 beds per entry/check) should be maintained for each entries and checks. Natural incidence of leaf blotch should be recorded during September and October employing 0-6 scale as described. For disease scoring, observations from 20 randomly selected plants per bed should be recorded. Three leaves each from top, middle and bottom portions of the plants should be observed critically. The disease rating should be recorded by adopting the methodology suggested by Palarpawar and Ghurde (1989) and Chopada Gopalkumar Babubhai (2015). Per cent Disease Intensity (PDI) should be calculated for each replication for each month separately and average PDI can be calculated by combining data of other

replications (average of two month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for leaf blotch (0-6 scale)	
Scale	**Symptoms on leaves**
0	No infection
1	0.1 to 10% necrotic leaf area
2	10.1 to 20% necrotic leaf area
3	20.1 to 30% necrotic leaf area
4	30.1 to 40% necrotic leaf area
5	40.1 to 50% necrotic leaf area
6	More than 50% necrotic leaf area
Chopada Gopalkumar Babubhai (2015)	

Per cent Disease Intensity (PDI)* =

$$\frac{\text{0 x number of leaves falling in the scale +1 x number of leaves falling in the scale + 2 x number of leaves falling in the scale + 3 x number of leaves falling in the scale + 4 x number of leaves falling in the scale + 5 x number of leaves falling in the scale + 6 x number of leaves falling in the scale}}{\text{180 (total number of leaves in one replication) x 6 (maximum disease rating scale)}} \times 100$$

*PDI calculated for one replication consisting of 60 plants (similarly PDI should be calculated for other four replications separately)

Categorization based on PDI for leaf blotch	
Category	**Per cent Disease Intensity (PDI)**
Resistant	Up to 10%
Moderately resistant	10.1 to 20%
Moderately susceptible	20.1 to 40%
Susceptible	40.1 to 60%
Highly susceptible	More than 60%
Chopada Gopalkumar Babubhai (2015)	

Selected references:

- Chopada Gopalkumar Babubhai. (2015). Epidemiology and management of turmeric (*Curcuma longa* L.) caused by *Taphrina* sp. Ph. D. Thesis submitted to Navsari Agricultural University, Navsari. p. 101.

  (https://krishikosh.egranth.ac.in/displaybitstream?handle=1/5810036222)

- Palarpawar, M. Y. and Ghurde, V. R. (1989). Sources of resistance in turmeric against leaf spots incited by *Colletotrichum capsici* and *C. curcumae*. *Indian Phytopathology*. 42: 171-173.

- Singh, A. K. (2013). Evaluation of turmeric (*Curcuma longa* L.) genotypes for yield attributes, yield and reaction to foliar diseases. *Journal of Spices and Aromatic Crops*. 22(2): 238-240.

Leaf spot

The leaf spot of turmeric is caused by *Colletotrichum capsici*, a hemibiotrophic pathogen that causes significant losses due to the destruction of active photosynthetic area. Generally the disease appears and proliferates during August to November. The pathogen survives in the infected planting material (rhizomes), leaf debris as well as collateral hosts and spreads through wind. The disease development under field conditions is favoured by high relative humidity and wet weather.

Symptomatology

The symptoms are generally confined to leaves, however, occasionally manifests on leaf sheaths also. The symptoms initiate as elliptic or oblong spots of variable size. In the initial stage, the spots are small with dimension up to 40 mm which later enlarge in size. Eventually the spots coalesce, developing into irregular patches often involving a major portion of the leaf, which subsequently dries. The spots are characterized with a greyish white center, brown margin surrounded by yellow halo with numerous black dot-like acervuli on both surfaces arranged in concentric rings. The spots, although visible on both surfaces, are more marked on the upper surface of new leaves. During severe infection, the field presents a scorched appearance.

Screening for disease resistance

Procedure:

The trial should be laid out in randomized block design (RBD) and the duration would be three years. The area under the experiment should be maintained under uniform shade level. Recommended package of practices should be adopted to raise the crop which should be uniformly adopted in all the centers. The test entries shortlisted along with known/reported susceptible and resistant checks [five replications each; one replication

consists of three beds] should be used to screen for disease resistance. The test entries and the check varieties should be planted in 3 X 1 m^2 size beds with a spacing 20 X 30 cm (rhizome to rhizome X row to row) to comprise a minimum of 30 plants per bed. The location/field should be endemic/conducive to natural infection of leaf spot wherein recurring infection is recorded/observed during the period of experiments and previous years. Timely sprays/soil application of recommended plant protection chemicals should be adopted to manage insect pests and diseases other than leaf spot. Disease-free healthy rhizomes weighing about 20-25 g should be planted during second fortnight of April and the rhizomes should be treated with recommended fungicides/insecticides before planting. Three beds would constitute single replication and five replications (total of 15 beds per entry/check) should be maintained for each entries and checks. Natural incidence of leaf spot should be recorded during September and October employing 0-6 scale as described. For disease scoring, observations from 20 randomly selected plants per bed should be recorded. Three leaves each from top, middle and bottom portions of the plants should be observed critically. The disease rating should be recorded by adopting the methodology suggested by Palarpawar and Ghurde (1989) and Chopada Gopalkumar Babubhai (2015). Per cent Disease Index (PDI) should be calculated for each replication for each month separately and average PDI can be calculated by combining data of other replications (average of two month data would represent the disease level of a particular entry/check for a particular year of screening). Based on average PDI during a particular year, the entries can be delineated into different categories of susceptibility or resistance which needs to be validated based on the observations recorded during subsequent two years.

Disease rating scale for leaf spot (0-6 scale)	
Scale	**Symptoms on leaves**
0	No infection
1	0.1 to 10% necrotic leaf area
2	10.1 to 20% necrotic leaf area
3	20.1 to 30% necrotic leaf area
4	30.1 to 40% necrotic leaf area
5	40.1 to 50% necrotic leaf area
6	More than 50% necrotic leaf area
Palarpawar and Ghurde (1989)	

Per cent Disease Index (PDI)* =

$$\frac{0 \times \text{number of leaves falling in the scale} + 1 \times \text{number of leaves falling in the scale} + 2 \times \text{number of leaves falling in the scale} + 3 \times \text{number of leaves falling in the scale} + 4 \times \text{number of leaves falling in the scale} + 5 \times \text{number of leaves falling in the scale} + 6 \times \text{number of leaves falling in the scale}}{180 \text{ (total number of leaves in one replication)} \times 6 \text{ (maximum disease rating scale)}} \times 100$$

*PDI calculated for one replication consisting of 60 plants (similarly PDI should be calculated for other four replications separately)

Categorization based on PDI for leaf spot	
Category	**Per cent Disease Intensity (PDI)**
Resistant	Up to 10%
Moderately resistant	10.1 to 20%
Moderately susceptible	20.1 to 40%
Susceptible	40.1 to 60%
Highly susceptible	More than 60%
Palarpawar and Ghurde (1989)	

Selected references:

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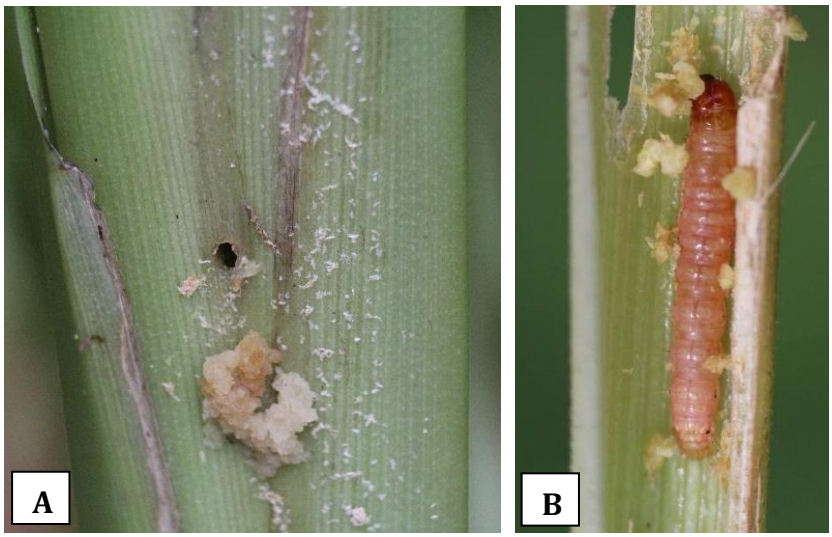
Turmeric shoot borer

Conogethes punctiferalis (Guenée) (Crambidae: Lepidoptera) is a serious insect pest of turmeric (*Curcuma longa* L.) in India, which is a high-value spice crop of commerce. The larva bores into shoots (pseudostems) of turmeric and feed the internal tissues resulting in yellowing and drying of infested shoots and cause significant reduction in yield, when more than 50% of the shoots in a clump are infested (Devasahayam and Koya, 2007).

Symptomatology

The larvae of the insect bore into pseudostems and feed on the growing shoot resulting in yellowing and drying of infested pseudostems. The presence of bore holes on the pseudostems through which frass is extruded and the withered central shoot are the characteristic symptoms of pest infestation (Devasahayam and Koya, 2007).



(a) Bore-hole symptoms of shoot borer attack in turmeric and (b) Larva of shoot borer inside the pseudostem.

Screening for pest resistance

Experiments can be conducted in large cement tubs (45 cm height and 45 cm diameter) or under field conditions to screen the turmeric accessions against shoot borer for at least three years. The plants should be raised following the standard agronomic practices for turmeric (ICAR-Indian Institute of Spices Research, 2022), except for the non-application of pesticides throughout the study period.

Design	Randomized Block Design
Number of replications	3
Plot size	Under field conditions, the screening can be carried out in 3 X 1 m beds with a minimum of three replications/accession
Observations to be recorded	The number of damaged (dead hearts/shoots with bore hole) and healthy shoots need to be recorded in each clump during October-November each year when pest damage reaches its peak. The mean per cent shoot damage can be expressed per accession per year

Classification of turmeric accessions based on shoot borer damage	
Category	**Shoot damage**
Resistant	No shoot damage
Moderately resistant	Below 15% shoot damage
Moderately susceptible	Between 15% and 25% shoot damage
Susceptible	Between 25% and 45% shoot damage
Highly susceptible	More than 45% shoot damage

Data analysis

The mean per cent shoot damage in each accession obtained by pooling the years need to be subjected to ANOVA after suitable transformation. The mean and the standard error of per cent shoot damage in each accession irrespective of the year shall be taken for calculating pest susceptibility ratings as per the method adopted by Devasahayam *et al*. (2011).

Select references:

- Devasahayam, S. and Koya, K. M. A. (2007). Insect pests of turmeric. In: Ravindran, P. N., Babu, K. N. and Sivaraman, K. (Eds.) *Turmeric. The Genus* Curcuma. CRC Press, Boca Raton. pp. 169-192.
- Devasahayam, S., Jacob, T. K., Abdulla Koya, K. M., Sasikumar, B. and Prasath, D. (2011). Screening of turmeric (*Curcuma longa* L.) germplasm for resistance to shoot borer (*Conogethes punctiferalis* Guen.) (Lepidoptera: Pyralidae), in Kerala, South India. *Entomon*. 36: 59-62.
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Root knot nematode

Sixteen members of pant parasitic nematode genera have been reported to be associated with turmeric. However, the root knot nematode (RKN), *Meloidogyne* spp.; the lesion nematode, *Pratylenchus* spp.; the burrowing nematode, *Radopholus similis* and the reniform nematode, *Rotylenchulus reniformis* are some of the most important nematodes (Eapen and Pandey, 2018). The *M. incognita* and *R. reniformis* are the most predominant and frequently recorded nematode species in Andhra Pradesh and Bihar in India. The RKN, *M*. *incognita* is a serious pest in all turmeric growing regions of India. Two species of RKN *viz*., *M. incognita* and *M. javanica*, have been reported on turmeric, but most investigations have been concerned with *M. incognita*.

Symptomatology

Turmeric plants infested with *M. incognita* have large root galls, 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. The highest nematode multiplication and gall index are seen in peat soils. The population density of *M. incognita* increase with crop age and decrease with crop senescence.

Premature drying of turmeric plants caused by root knot nematode infection

Lodging of tillers caused by root knot nematode infection

Turmeric roots with prominent galls caused by root knot nematode and egg masses (Hajihassani *et al.*, 2019)

Screening for root knot nematode resistance

Procedure:

- Nematode population level should be assessed by standard protocols.
- The germplasm accessions or cultivars to be screened should be planted in the soil with check varieties as control e.g., IISR Pragati (Moderately resistant to *Meloidogyne* sp.).
- Standard package of practices should be followed.
- After two months, the plants should be uprooted and carefully washed free of soil and stained in Phloxine B.
- The egg masses should be graded using a 0-5 scale given by Taylor and Sasser (1978).

- Accessions with an egg mass index (EMI) of less than two or equal should be shortlisted for subsequent testing in growbags or pots with known number of infective juveniles.
- In the subsequent tests, the final nematode population (R Factor) should also estimate by staining in acid fuchsin-acetic acid solution followed by maceration in a blender.
- Formula for calculating R Factor is $R= P_f/P_i$, where P_f is final population of nematodes and P_i is initial population (in this case; 1000 juveniles).
- The host status of each accession will be rated based on nematode reproduction and EMI.

Design	Completely Randomized Design
Number of replications	Minimum 3
Plot size	30 m^2
Observations to be recorded	Recording the incidence of RKN using the egg mass index (EMI) and R factor

Rating scale for root knot nematode presence on roots (0-5 scale)	
Egg mass index (EMI)	**Number of egg masses**
0	0
1	1 to 2
2	3 to10
3	11 to 30
4	31 to 100
5	More than 100
Taylor and Sasser (1978)	

Designation of host status based on the degree of resistance		
Degree of resistance designation	**Gall index**	**R factor**
Resistant	≤2	≤ 1
Tolerant	≤2	> 1
Moderately tolerant	≥2	≤ 1
Susceptible	≥2	> 1
Sasser *et al.* (1984)		

Selected references:

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