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Bio-intensive approaches for management of pests and diseases in small cardamom and black pepper

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Abstract

Black pepper and cardamom are the two important high value spice crops that flavor most foods all over the world. Pest and diseases are the major production constraints for the successful cultivation of these crops. To manage these menaces, farmers are over using synthetic chemical pesticides indiscriminately and this result in environmental degradation and high pesticide residue levels in the produces. Now the focus is on organic spice production, therefore a search for safer measures of pest and disease management is gaining importance. Integration of various approaches like use of resistant/tolerant varieties, disease or pest free planting materials and exploitation of biological means such as bio-control agents, bio-pesticides, entomo-pathogens, parasitoids and predators at the right time paved the way to achieve this goal. This enables the farming community to manage the diseases and insect pests more economically with ecologically safer means. Most of the crop protection technologies needed for farmers are either already available or in its advanced stages of development. This review attempts to disclose the major pest and diseases of cardamom and

black pepper and their symptomatology as well as available bio-intensive measures including viable cultural practices for their management.

Key words: Pest and disease management, Host plant resistance, Cultural practices and Biological control

Introduction

India has been acclaimed as the land of spices from the time immemorial. Black pepper, rightly called as king of spices is one of the most important and most widely used spices in the world (Ravindran 2000). Cardamom across the world recognized as the queen of spices because of its very pleasant aroma and taste, and is a native of the moist tropical evergreen forest of the Western Ghats (WG) in southern India. The WG also considered as center of origin and diversity for black pepper (Ravindran 2002). Among pests shoot and capsule borer, thrips, root grub, whitefly, nematodes and diseases like capsule and panicle rot, clump rot, *Fusarium* rot, leaf blight and viral diseases are reported as major threats to commercial cardamom cultivation. Likewise, pests like pollu beetle, scales, top shoot borer, thrips and root mealy bugs as well as diseases such as foot rot, slow wilt, fungal pollu and viral diseases contribute to the loss of black pepper.

Indiscriminate use of synthetic pesticides to manage these pest and diseases results in tremendous buildup of residues in export oriented produce, which has recently invited debate and queries. This had significantly affected the world wide acceptability of the king and queen of spices. Now, the demand for organic spices is growing among consumers at the rate of 20% annually (Krishnakumar 2015). The mission at the moment is to capture India's pre-eminent position as spice bowl of the world by producing and exporting safer spices and spice products to the world market. For safer and continuous higher sustainable production, attention is needed on good agricultural practices through eco-friendly management of pests and diseases. If India to recapture its lost glory of spices, there should be considerable sincere efforts to achieve a quantum jump in the productivity of cardamom and black pepper through adoption of physical/cultural and biological/botanical tools that allow co-existence of natural enemies and beneficial microorganisms which in turn bring backs the ecosystem balance in cardamom and black pepper production system.

Diseases of cardamom

Among the fungal diseases capsule and panicle rot, clump rot, *Fusarium* rot and leaf blight are the major problems. In addition to this, viral diseases like *katte* and chlorotic streak also seriously affect plant and

cause considerable yield loss.

A. Fungal diseases

a) Capsule and panicle rot

This disease popularly known as *azhukal* is the most serious disease in cardamom (Menon et al. 1972). Studies on etiology of the disease confirmed that two species of *Phytophthora viz., P. meadii* and *P. nicotianae* var. *nicotianae* are involved this disease (Murugan et al. 2016).

Symptoms

Disease symptoms appear during the rainy season on leaves, tender shoots, panicles and capsules. On the infected leaves, water soaked lesions appear first and rotting and shredding of leaves along the veins occur thereafter. The infected capsules become dull greenish brown and rot. This emits a foul smell and subsequently shed off. Infection spreads to panicles and tillers resulting a complete decay of panicles and capsules (Murugan et al. 2016).

Management

Cultural practices

Peethambaran et al. (2008) have informed that proper control of *azhukal* could be achieved through phytosanitation, shade regulation and proper drainage. They have reported that application of neem cake ahead of monsoon as a soil amendment has been effective in reducing the population of the pathogen.

Botanicals

Attempts were made recently to manage disease using antagonistic plant products. Ajay et al. (2015) reported that 1% cashew shell is effective in suppressing *P. meadii* by 70.8% without inhibiting the growth of *T. harzianum* in soil.

Biocontrol

Bio-agents play an important role in eco-friendly disease management system to fight against plant pathogens in a totally safe manner avoiding the use of expensive synthetic chemical fungicides. The isolates of *Trichoderma viride*, *T. harzianum* and *Laetisaria* sp. harbouring native cardamom soils have been screened and effective strains for biocontrol potential have been identified and developed (Bhai et al. 1992; Dhanapal and Thomas, 1996). Thomas et al. (1991) observed inhibition of *P. meadii*

under laboratory condition using *T. viride, T. harzianum* and *Bacillus subtilis* whereas, Bhai et al. (1993) shown significant levels of field control of this disease by soil application of the above bioagents even in disease prone soils. Josephrajkumar et al. (2007) confirmed that pre-monsoon and post-monsoon application of *T. harzianum* @ 100g (along with 5 kg farm yard manure and 500g neem cake per plant and as sole application @ $3L^{-1}$ $plant^{-1}$ respectively) as the best management strategy against the disease. *T. harzianum* (10^8 cfu/g) @ 50 g/clump (multiplied in decomposed coffee compost and mixed with cow dung) applied during May-June and August-September has effectively managed the *azhukal* disease of cardamom (Devasahayam et al. 2015a). According to Bhai and Sarma (2003), spraying the culture suspension of *P. fluorescens* could effectively check the capsule rot of cardamom. Dhanya et al. (2015) emphasized that prophylactic application of *Pseudomonas fluorescens* (2% spray) along with basal application of *Glomus fasciculatum* (*Arbuscular Mycorrhizal Fungi* - AMF) @ 50g and *T. viride* @ 100g/plant at monthly interval during rainy season significantly managed the capsule and panicle rot disease. The efficacy of basal application of *T. harzianum* (MTCC-5179) mixed in ½ kg neem cake along with bacterial consortium containing *P. fluorescens* strains (IISR-6 and IISR 859) each @ 25g was proved in controlling capsule rot of cardamom (Dhanya et al. 2017).

Application of peat formulation of *B. subtilis* strain Bs increased the activity of phenolic enzymes and phenols in the infected cardamom plants and this bacterial strain could be effectively utilized for the management of capsule rot disease in cardamom (Sivakumar et al. 2015a). Soil application of *T. harzianum* (23 x 10^6 cfu/g) in carrier media @ 1kg/ plant twice a year was effective in reducing the infection by *Phytophthora* spp. and decreasing the disease incidence by 83% (Thomas, 2000). The above studies support that field control of *azhukal* disease of cardamom has become very effective, which is environmentally safe and cost effective due to the bio-control potential of *Trichoderma* spp., *P. fluorescens*, *B. subtilis* and AMF.

Resistant cultivars

According to Madhusoodanan (2012) ICRI 5 and ICRI 6 (*malabar* type) were considered to be moderately tolerant to rot diseases and suitable for cardamom growing regions of Kerala and parts of Tamil Nadu.

b) Clump rot

Clump rot otherwise called as rhizome rot occurs during monsoon

period. This disease is widely distributed across cardamom growing regions in Kerala and Karnataka as well as heavy rain fall areas of Tamil Nadu such as the Anamalai hills. The disease was first reported by Park (1936) and later Rao (1938) described it as clump rot disease.

Symptoms

This disease is caused by combined infection of *Pythium vexans*, *Rhizoctonia solani* and *Fusarium* sp. Major symptoms of the disease are decaying of tillers at the collar region and toppling of tillers as the disease advance. Affected tillers can be pulled out easily. Additionally, discoloration on the basal portion of the infected clump can be seen (Murugan et al. 2016).

Management

Cultural practices

Since higher soil moisture levels are conducive for disease development irrigation schedule should be made according to that. Removal of mulch from the base of the plant, providing good drainage, weeding and trashing before the commencement of monsoon as well as removal and destruction of infected clumps can manage the disease effectively (Peethambaran et al. 2008).

Botanicals

Dhanapal et al. (1993) reported effective use of botanicals like neem seed extract (neem gold) and garlic extract against the disease.

Biocontrol

Attempts of rhizome-rot control by the use of *Trichoderma* spp. (*T. viride* and *T. harzianum*) were made by many researchers (Thomas et al. 1991; Joseph et al. 1993). A study by Sivakumar et al. (2012) confirmed that rhizome bacterization and soil application of bacterial consortium (*P. fluorescens* Pf51 and *Bacillus subtilis* Bs45) could effectively control rhizome rot of cardamom. Devasahayam et al. (2015a) used *T. harzianum* (10^8 cfu/g) multiplied in mixture of decomposed coffee compost and cowdung @ 50g / clump during May – June and August – September to manage the disease. Decreased incidence of rhizome rot and increase in yield of cardamom for the basal application of *T. harzianum*, *P. fluorescens* and *B. subtilis* from cardamom growing region of Tamil Nadu was also reported (Gopakumar et al. 2006). Pot culture experiment on rhizome rot management using endophytes by Peeran et al. (2018) explained that

Tulasnella sp. (*Alpinia galanga* isolate) showed an inhibition of *Rhizoctonia solani* and *F. oxysporum* while *Phoma* sp. (an isolate from Appangala-1) showed inhibition of *Pythium vexans*. Endophyte treated plants also showed higher activities of defense related enzymes like peroxidase and polyphenol oxidase.

Resistant Cultivars

According to these researchers (Peethambaran et al. 2008; Eapen and Bhai 2012) the resistant variety IISR-Avinash can be recommended in hot spot areas of the disease. Aravind et al. (2015) also identified an accession FGB118 (germplasm collection of IISR regional station at Appangala) as highly resistant to rhizome rot.

(c) *Fusarium* rot

This disease is also called as stem rot or stem lodging, normally appears during post - monsoon period. The disease was first reported in the cardamom plantations of Idukki district by Thomas and Vijayan (2002).

Symptoms

This disease caused by a fungus "*Fusarium oxysporum"*. The pathogen usually attacks middle portion of the tillers and produces a pale discoloured lesion leading to dry rotting. The infected tillers are weakened at the point of infection and leads to partial breakage of the tillers. The partially broken tillers bend down and hang from the point of infection. The infected tillers fall off and give lodged appearance if the infection occurs at lower part of the tillers (Murugan et al. 2016).

Management

Cultural practices

Phytosanitation as well as providing adequate shade in the plantation areas reduce stem rot disease in cardamom (Anonymous, 2016).

Biocontrol

In vitro and greenhouse studies of Thomas and Vijayan (2002) showed that four biocontrol agents namely *T. viride*, *T. harzianum*, *B. subtilis* and *P. fluorescens* effectively inhibited the causal organism *F. oxysporum* and reduced the severity of the disease. Vijayan et al. (2012) also reported that basal application of *T. harzianum*, along with spraying and drenching of *P. fluorescens* provided a significant control of symptoms (root tip rot and leaf yellowing, pseudostem rot and panicle wilt) associated with *Fusarium* rot disease and reduced the population of *F. oxysporum* to

the minimal. Maya et al. (2012) stated that basal application of *T. harzianum* @ 50g with one kg neem cake and aerial spray with either *P. fluorescens* or consortium containing *P. fluorescens* strains IISR 6 and IISR 859 @ 2% was an effective management strategy against pseudostem rot.

d) Leaf blight

This disease caused by foliar infection of *Colletotrichum gloeosporioides* is becoming serious especially during post monsoon periods.

Symptoms

The symptoms develop as brownish spots and patches on the leaf lamina which expand and the affected leaf wither and dry (Devasahayam et al. 2015a).

Management

Cultural practices

Providing adequate shade in the plantation could reduce the disease incidence (Mathew 2007).

Biocontrol

The disease can be managed by spraying the plants with 1-2 percent *P. fluorescens* as a prophylactic measure 3-4 times a year (Mathew 2007).

Resistant Cultivars

Manju et al. (2014) stated that cardamom varieties CL-730 and CL-726 showed improved field tolerance to *Collectotrichum* leaf spot, whereas CL-722, CL-726 and Mudigere-3 showed moderate disease tolerance.

B. Viral diseases

a) Katte

It is otherwise called as mosaic disease mainly transmitted by banana aphid (*Pentalonia nigronervosa*) as well as infected rhizomes. The virus comes under 'Potyvirus' group (Murugan et al. 2016).

b) Chlorotic streak

This disease is caused by *Banana bract mosaic virus* and in recent surveys its widespread prevalence in major cardamom cultivating tracts of Kerala has been noticed (Bhat et al. 2018).

Symptoms

The first visible symptom of katte appears on the youngest leaf of the affected tiller as slender chlorotic flecks. Later these flecks develop into pale green discontinuous stripes. These stripes run almost parallel to each other from the mid-rib to the margin of the leaves, which form a mosaic pattern. Such stripes are also seen on the leaf sheaths and young shoots as the disease advance. The infected clumps will be smaller in size with fewer tillers. Plants of all stages are susceptible to virus infection and the infection is systemic in nature (Murugan et al. 2016).

Chlorotic streak disease is characterized with the formation of spindle shaped intra venous streaks along the veins and mid-ribs. This streak subsequently join together imparting yellow or light green colour to the veins. The petioles and pseudo-stem of infected plants show spindle shaped mottling. As the disease advances, number of tillers produced in the infected plants gets reduced (Bhat et al. 2018).

Management

Cultural practices

Raising nursery or planting material multiplication site away from the *katte* affected gardens, use of healthy and virus free planting material, removal of infected plants, weeds and collateral hosts like colocasia and caladium which might act as reservoirs for the virus and multiplication of the vector should be advocated for the management of disease (Bhat et al. 2018).

Botanicals

Neem products significantly reduced the population of aphids on cardamom leaves even at 0.1 per cent concentration and were lethal to aphids at higher concentrations (Mathew et al. 1997). Saju et al. (1998) explained the repellant action of turmeric essential oil against the cardamom aphids. Studies of Mathew et al. (1997) detailed the adverse effect of aqueous extracts of *Acorus calamus*, *Annona squamosa* and *Lawsonia inermis* on the breeding potential of the aphids.

Biocontrol

Entomogenous fungi like *Beauvaria bassiana* (Bals-Criv) Vuill, *Verticillium chlamydosporium* Goddard and *Paecilomyces lilacinus* (Thom.) Samson were promising in suppressing aphid population (Mathew et al. 1998). The cardamom aphid population gets reduced drastically during

rainy season due to the infection of *Verticillium intertextum* (Deshpande et al.1972). Mathew (2007) also reported the beneficial effect of *B. bassiana* and *L. lecanii* @ 2% on the control of vectors. Natural enemies such as *Peragum indica*, *Cocinella transversalis*, and *Ischiodon scutellaris* were also observed to predate over the cardamom aphids (Gopakumar and Chandrasekar 2002).

Resistant cultivars

According to Babu (2018) IISR Vijetha and IISR-Appangala-2 were suitable for mosaic affected areas of Karnataka.

C. Insect pests of cardamom

a) Shoot and capsule borer

The shoot and capsule borer (*Dichocrocis punctiferalis*) is the most serious insect pest of cardamom consumes major share of pesticide used in cardamom (Murugan et al. 2016).

Symptoms

The earlier stages of larvae bore the panicles leading to drying up of the entire panicle and also bore the immature capsules and feed on the inner contents of the seeds which leads to empty capsules. The late stages larva feed on the central core of the stem and affect the phloem vessels interrupting the passage of food materials to the growing parts finally leading to drying of central leaf tip known as "*dead heart*" symptom (Murugan et al. 2016).

Management

Cultural practices

Removal and destruction of alternate host plants as well as infested suckers during September -October (when the infestation is less than 10%) and collection and destruction of adults reduce the pest infestation considerably (Devasahayam et al. 2015a). It is suggested that destroying the alternate host plants in and around cardamom plantations during September-October reduced the pest population (Josephrajkumar et al. (2002a).

Botanicals

Deepthy et al. (2015) described about the effectiveness of 0.2% poneem (1:1 mixture of pungam oil and neem oil) against cardamom shoot borer.

Biocontrol

Earlier study conducted by David et al. (1964) revealed that under natural conditions, *C. punctiferalis* was a host for number of parasites like *Angitia trochanterata* (Ichneumonidae), *Threonia inareolata, Bracon brevicornis, Apanteles* sp. (larval parasite) and *Brachymeria emploeae* (pupal parasite). Patel and Gangrade (1971) noticed *Microbracon hebetor* as its larval parasite. Joseph et al. (1973) reported two hymenopterans (*Brachymeria nosatoi* and *B. lasus*) parasitizing on *C. punctiferalis*. Jacob (1981) observed *Myosoma* sp., *Xanthopimpla australis* and a nematode as parasites on *C. punctiferalis*. Additionally, Varadarasan et al. (1990) stated that *Temelucha* sp., *Agrypon* sp. and *Friona* sp. as parasites of *C. punctiferalis*. Devasahayam et al. (2015a) said that destruction of adults and conservation of natural enemies (parasitoids) such as *Eriborus trocheanteratus*, *Xanthopimpla australis*, *Friona* spp. and *Agrypone* spp. helped reducing the pest infestation. Ali et al. (2015) observed 20-30% natural parasitation of shoot borer by the braconids *Apanteles taragamae* and *Glyptapanteles.* Josephrajkumar et al. (2007) reported two ichnuemonid solitary parasitoids *Agrypon* sp. and *Temeluchus* sp. as well as one mosquito like unidentified gregarious parasitoid with plumose antennae against cardamom shoot and capsule borer. About 61.2% parasitization was reported in this study by ichnuemonids as well as dipterans.

Resistant cultivars

According to Madhusoodanan (2012) tolerant *malabar* variety Mudigere-1 is suitable for the Malanad areas of Karnataka and moderately tolerant *malabar* variety ICRI 6 is preferred to Kerala and parts of Tamil Nadu. Josephrajkumar et al. (2002a) pointed out that stem girth is one of the important features conferring the tolerance to cardamom shoot and capsule borer as increased diameter accommodates the growing immature stages of the pest. Therefore, among the three types of cardamom investigated (*malabar*, *mysore* and *vazhukka*), variety PV-1, (*malabar* type) having prostrate panicle and lanky stem was found to be tolerant to borer damage.

b) Thrips

The cardamom thrips (*Sciothrips cardamomi*) is one of the most destructive insect pests of cardamom. The population of this pest builds up rapidly during the post monsoon and summer months and declines with the onset of monsoon rains (Bhatti 1969).

Symptoms

The adults and larvae lacerate the tissues of leaves, shoots, panicles, flowers and immature capsules and feed on the exuding sap resulting in shedding of flowers and immature capsules as well as scab formation on mature capsules (Murugan et al. 2016).

Management

Cultural practices

Removal of dried leaf sheaths, drooping leaves and older plant parts during January - February, regulation of shade level in the plantation by pruning lower branches of shade trees and removal of collateral host like (*Panicum longipes*, *Amomum* spp., *Aframomum* sp. *Colocasia* sp. and *Alocasia* sp.) in the vicinity of plantations helps reducing the build-up of thrips population in the field (Murugan et al. 2016).

Botanicals and biorationals

Josephrajkumar et al. (2002b) observed that among the bio-rationals evaluated, fish oil insecticidal soap (Na) 2.5% + tobacco extract 2.5% significantly reduced the damage caused by cardamom thrips. The studies conducted by Jacob et al. (2014) indicated the potential of natural product spinosad 0.0135% (derived from *Sacharopolyspora spinosa*) for thirps management in cardamom.

Biocontrol

The entomopathogenic fungus *Lecanicillium psalliotae* is effective for the management of cardamom thrips (Kumar et al. 2015 and 2018; Devasahayam et al. 2015a). Jacob and Bhai (2007) found an anthocorid bug and *chrysoperla* sp. that feed on the thrips.

Resistant cultivars

According to Madhusoodanan (2012) tolerant *malabar* variety Mudigere-1 is suitable for Malanad areas of Karnataka and moderately tolerant variety ICRI 6 (*malabar* type) is recommended to Kerala and parts of Tamil Nadu. Murugan et al. (2016) reported the suitability of thrips tolerant variety PV-1 (*malabar* type) for endemic areas of pest infestation. Higher concentration of 1,8 cineole and ratio of 1,8, cineole to α-terpinyl acetate in *kattelam* and *malabar* types of cardamom provided enhanced tolerance to thrips infestation (Josephrajkumar et al. 2002b).

c) Root grub

The root grub (*Basilepta fulvicorne*) is one of the serious subterranean insect pests in cardamom plantations (Murugan et al. 2016).

Symptoms

The larvae feed on young roots and the above ground symptoms start as yellowing of leaves, which later result in the drying up and death of the plant (Anonymous 2016).

Management

Cultural practices

Collect the beetles using hand nets or sticky traps at the time of mass emergence (March-April and August-September) and destroy them manually. This can reduce the pest population in the field considerably (Anonymous 2016).

Biocontrol

Murugan et al. (2016) recommended entomopathogenic fungi, *Metarrhizium anisopliae* @ 2 % and entomopathogenic nematode, *Heterorhabditis indicus* @ 100IJs/grub that effectively control the root grubs. The entomopathogens, *M. anisopliae* and *B. bassiana* (infection on beetles and grubs) and *Heterorhabditis* spp. (infection on grubs) were noticed to play an important role in reducing the population of the pest in the field (Devasahayam et al. 2015a).

d) Whitefly

Recently, the cardamom whitefly (*Kanakarajiella cardamomi*) is fast becoming a serious insect pest in Kerala and Tamil Nadu, especially during the dry and summer seasons (Devasahayam et al. 2015a).

Symptoms

Colony of nymphs and adults desap from the lower surface of the leaves. Chlorotic patches appear initially on leaves, which turns yellow and become necrotic in the advanced stages. Nymphs secrete sticky honey dew which drop on the lower leaves. This invites sooty mould fungi to invade thereby interrupts photosynthetic efficiency (Murugan et al. 2016).

Management

Cultural practices

Josephrajkumar et al. (2007) reported about the use of yellow

sticky traps as well as application of neem oil @ 0.5% on the leaves for the suppression of cardamom whitefly population whereas, Devasahayam et al. (2015a) observed yellow sticky trap and 5 % neem oil spray as better management strategy. A chitin based bio-pesticide (Eco-1) was found to be effective against nymphs and adults of white fly as reported by Ali et al. (2014).

Biocontrol

Under natural environmental conditions, whitefly has been found susceptible to a number of natural enemies such as predators like *Mallada bonninensis*, an unidentified neuropteran, dipteran, coleopteran and mite; parasitoids such as *Encarsia septentrionalis* and *E. dialeurodes*, and a pathogen *Aschersonia placenta* (Selvakumaran et al. 1996a). Josephrajkumar and Murugan (2001) also strongly advocated the use of entomopathogenic fungi *Aschersonia placenta* and *Verticillium* sp. against cardamom whitefly.

D. Nematode

Nematode infestation in cardamom is a major problem often amounting to heavy crop loss. The root knot nematode, *Meloidogyne incognita* causes severe damage to crop that is widely observed in almost all cardamom plantations, while the lesion nematode *Pratylenchus coffeae* and the burrowing nematode *Radopholus similis* are noticed in mixed plantations (Ramana and Eapen 1992).

Symptoms

Infested plants exhibit stunting, reduced tillering, reduced leaf size, yellowing of foliage, immature capsule drop and increased incidence of rhizome rot (Ramana and Eapen 1992).

Management

Cultural practices

Present research efforts on the bio-intensive management of pests and diseases of cardamom include cultural practices, use of tolerant or resistant cultivars as well as application of bioagents. Cultural control which basically involves the exploitation of agro-techniques utilized for enhancing crop productivity, is a safe and powerful tool for pests and disease suppression. Various cultural practices being followed in cardamom plantations to contain the pests and diseases and their effects were briefed as Table 1.

Table 1: Cultural operations that significantly influence the pests and diseases of cardamom (Eapen and Bhai 2012)

Cultural operation	Impact on Pest and disease
Trashing	Reduces thrips and root grub damage
Roguing	Restricts the spreads of *Katte*, white fly
Mulching	Minimizes *chenthal* disease
Weeding	Lessens viral disease and thrips infestation
Earthing up	Contracts root grub damage
Providing drainage	Decreases clump rot and *azhukal* incidence
Disease free planting materials	Diminishes the incidence of viral and soil borne diseases
Shade regulation	Declines capsule rot, clump rot, *chenthal* disease, leaf blotch and root grub attack
Avoiding planting of alternate hosts like banana, colocasia, jack and dadaps	Shortens population of aphids spreading *katte*, lace wing bugs, root grubs and root knot nematodes
Excess application of nitrogenous fertilizers	Aggravates spider mites, white flies, shoot and capsule borers
Use of yellow sticky traps	Decreases whiteflies
Mechanical collection of adult beetles/ larvae of caterpillars and Irrigation @ 15-20 l/plant	Lowers root grub population

Mulching the plant base with leaves of weeds like wild sunflower, *Eupatorium, Clerodendron* etc. reduces the nematode population in soil (Mathew 2007). Planting of nematode-free seedlings, application of organic manures and neem cake twice a year @ 250-1000 g also recommended for reducing the nematode populations (Devasahayam et al. 2015a). Ali (1985) also suggested application of neem cake to reduce nematode population and increase the yield of cardamom.

Biocontrol

Experiments by Eapen and Venugopal (1995) revealed that bioagents like *Trichoderma* spp. and *Paecilomyces lilacinus* controlled nematode in cardamom. Studies conducted by Narayana et al. (2011) proved that Jeevamrutha @ 10 l along with *Azospirillum* and *T. viride* (10g each) /plant increased plant growth and yield of nematode infested cardamom plantation. Mathew (2007) achieved good results by dipping the cardamom

rhizomes in 1% mixture of *P. fluorescens* and Azadirachtin solution for 10 minutes along with the application of cow dung + Neem cake + Marotti cake + AMF + *P. lilacinus* (90 kg: 5 kg : 2 kg :2 kg :1 kg) mixture @ 1 kg/ pit before planting. Two AMF fungi viz., *G. fasciculatum* and *Gigaspora margarita* were also found effective in minimizing the root knot nematode problems in cardamom seedlings (Thomas et al. 1989). According to Sheela (2007), *P. lilacinus* reduced root knot nematodes by 48.5 to 57 percent in pot culture studies and by 19.7 per cent in filed studies. She also reported that native isolates of *T. harzianum* and other *Trichoderma* spp. were potent antagonists of root knot nematode.

Diseases of black pepper

The diseases of black pepper were reviewed by Sarma et al. (1991) and they reported at least seventeen diseases that are known to affect black pepper. In India, foot rot is the major disease causing severe economic loss (Sarma et al. 1992). Other important diseases include slow decline, anthracnose and viral diseases like stunted disease (Sarma et al. 1991) and wrinkled leaf disease (Kueh and Sim, 1992).

A. Fungal diseases

a) Foot rot

Foot rot caused by *Phytophthora capsici* is the most destructive of all diseases causing an annual crop loss of 5-10% (Kueh, 1990) and upto 95 % for individual farmers (Manohara et al. 2004). In India, the disease (previously known as *quick wilt*) was first reported as early as 1902 by Menon (1949).

Symptoms

All parts of the vine are vulnerable to this disease. On leaves, one or more black spots having distinctive fimbriate margin appear, which rapidly enlarge and cause defoliation. The entire vine wilts fast followed by shedding of leaves and spikes when the main stem at the collar region is infected. Infection of feeder roots causes their rotting and degeneration resulting in yellowing, defoliation and drying up of whole plant (Anandaraj, 2000).

Management

Cultural practices

Soil moisture plays an important role in the buildup of inoculum of *Phytophthora*, besides predisposing the plant to infection (Anandaraj,

1997). Providing adequate drainage, raising pepper cuttings in solarized soil fortified with biocontrol agents, planting healthy cuttings in the field, removal of dead vines along with the root system and removal of infected plants form the management strategy against the disease (Peethambaran et al. 2008). Since the disease initiation and spread is found to be more near the previously infected plants, removal of such infected plants would reduce the infection and spread of the fungus. At the onset of monsoon, lopping of the branches of support trees is essential to allow penetration of sunlight and avoid buildup of high humidity favouring the disease (Anandaraj, 2000). To prevent soil splashes and consequent disease initiation, live mulch in the form of legume or grass cover are suggested (Ramachandran et al. 1991; Sarma et al. 1992). But after the rainy season, it is better to remove the weed mulch and rake up the soil to conserve soil moisture and to eliminate the saprophytic survival of *P. capsici* on weeds (Anandaraj, 1997). Mulching with polythene may aid in creating a congenial environment for profuse development of *Trichoderma* and divert the excess rain water away from the root zone avoiding wet foot conditions which is favourable for *Phytophthora* (Hegde and Hegde, 2015).

Different organic amendments like FYM, neem oil cake, ground nut cake etc., added to soil as nutritional supplements serve both as a nutrient source for boosting the health of vine as well as a medium for profuse development of *Trichoderma.* The competitive saprophytic ability of *P. capsici* is very low and addition of organic matter to the soil containing *P. capsici* enhances the growth of saprophytes and *P. capsici* population drops to undetectable level (Anandaraj, 1997).

Botanicals

Experiment by Manohara et al. (1992) revealed that root exudates of some plants such as *Allium* spp. were inhibitory to zoospores of *Phytophthora*. Garlic clove extracts and leaf extracts of *Chromolaena odorata*, neem and lantana were found to be toxic to *P. capsici* (Anandaraj and Leela, 1996; Shashidhara et al. 2008). An antifungal substance β-asarone, isolated from ethyl acetate extract of *Acorus calamus* L. has completely inhibited mycelial growth of *P. capsici* (Suvarna et al. 2011)

Biocontrol

As the *Phytophthora* inoculum is soil borne, the population build up could be reduced by efficient strains of bio-agents such as *Trichoderma, Gliocladium* and *Pseudomonas*. (Rajan et al. 2002; Dhanapal et al. 2012; Sivakumar et al. 2014). In a study conducted by Diby et al. (2005),

fluorescent *Pseudomonas* and *Trichoderma* sp. were isolated from black pepper roots and rhizosphere soil collected from different places in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh and Sikkim revealed the potential of these strains for nursery management of black pepper, especially to protect the plants from *P. capsici* infection. Devasahayam et al. (2015a) recommended *T. harzianum* around the base of the vine @ 50 g/ vine (10^8 cfu/g) with the onset of monsoon (May-June and August-September) in Kerala. In order to ensure proliferation of *Trichoderma* in the rhizosphere of black pepper, Anandaraj and Bhai (2015) suggested commercial product of *T. harzianum* to be given around the base of the vine @ 50 g/vine along with organic manure (neem cake, farmyard manure, decomposed coffee pulp or coir pith) twice in an year with the onset of monsoon. The application has to be repeated for 2-3 consecutive years to check the pathogen spread. Parallel growth, coiling, penetration, hyphal vacuolization, sporangial parasitism, deformation and proliferation as well as shortening of hyphal tips were observed as antagonistic interaction of *Trichoderma* with *P. capsici* by Saju and Sarma (2015). According to Sivakumar et al. (2015b), *T. harzianum* has effective action against the pathogen and the fungi could be utilized for the integrated management of *Phytophthora* foot rot in black pepper. Anith and Manomohandas (2001) proved the role of *T. harzianum* and *Alcaligenes* sp. strain AMB as sole or in combination against the incidence of *P. capsici* induced nursery rot disease of black pepper. Anith et al. (2003) conducted a rapid screening assay on shoots for the selection of efficient bacterial antagonists which can colonize and protect the planting material against *P. capsici*-induced wilt of black pepper in the nursery. In the assay, fluorescent pseudomonad, isolate PN-026 was the most efficient antagonist showing highest suppression of lesion development in the nursery. According to Anandaraj and Sarma (2003), among isolates of *Trichoderma* sp. the percent inhibition of *P. capsici* varied from 0 to 84 per cent and isolates of bacteria inhibited *P. capsici* up to 50 per cent under *in vitro* evaluation. The role of actinomycetes in foot rot management has also been established (Bhai et al. 2014; Bhai et al. 2015). According to them, the inhibition of *Phytophthora* sp. by actinomycetes was 89.69%.

Incorporation of AMF alone or in combination with other beneficial microorganisms like *Azotobacter* and *Azospirillum* enhanced rooting and growth of pepper vine (Govindan and Chandy, 1985). AMF @ 1000 cc kg^{-1} and solarized soil spiked with *T. harzianum* and AMF registered minimum incidence of foot rot in black pepper (Josephrajkumar et al. 2007). Similar findings with AMF inoculation were also made by Anandaraj and Sarma (1994) and Sivaprasad et al. (1995). It is highly recommended to apply

native AMF, *Trichoderma* and *P. fluorescens* at the time of planting and during the pre-monsoon period in the established plantations to control foot rot (Anonymous, 2016).

Several strains of biocontrol agents effective in protecting pepper against *P. capsici* have been isolated, screened and mass multiplied on inexpensive carrier media and applied in the field with promising results (Anandaraj and Sarma, 1995; Sarma et al. 1996). Mature coconut water, which is an agricultural waste, supports good growth of *Trichoderma* spp. and *P. fluorescens* and could be used as a cheaper nutritional liquid medium for the mass multiplication of these antagonistic organisms (Anandaraj and Sarma, 1997; Sally et al. 2010; Vidya et al. 2015). Anith et al. (2014) also developed a cheap and farmer-friendly method for mass multiplication of *P. fluorescens* using boiled coconut water under non sterile condition.

Resistant cultivars

Use of *Phytophthora* tolerant lines such as IISR- Shakthi, IISR Thevam and Panniyur 8 is recommended for *Phytophthora* prone areas (Anandaraj, 2005; Devasahayam et al 2015b). IISR Shakti is an open pollinated seedling progeny of Perambramundi (Bhai et al. 2007) and IISR Thevam is a clonal selection of Thevanmundi which have shown field tolerance to *Phytophthora* foot rot disease coupled with high yield and suited to both high altitudes and plains (Sasikumar et al. 2004). Panniyur 8 is a hybrid (HB20052) of Panniyur 6 x Panniyur 5 and, was released as high yielding variety tolerant to *P. capsici* and drought. Among the cultivars, Narayakkodi, Kalluvally, Balankotta, Neelamundi, Mundi and Uthirankotta have been identified as tolerant to *Phytophthora* (Sarma and Anandaraj 1997; Anandaraj, 2000). The hybrids involving Panniyur 1 × Karimunda, and Narayakkodi × Neelamundi have shown tolerant reaction (Sarma et al. 1994). *Piper* spp such as *P. colubrinum* and *P. obliquum* are reported to be highly resistant to foot rot disease caused by *P. capsici* (Turner, 1971; Vanaja et al., 2007). To develop foot rot tolerant planting material, *P. colubrinum* has been identified as the most promising species for grafting with rooted stem cuttings.

b) Slow wilt

It is a debilitating disease of pepper found in all pepper growing areas of Kerala and Karnataka. The affected plants survive for several years and death of the plant occurs gradually over a period of 3-4 years. The etiology of disease is fungal-nematode complex coupled with moisture stress and malnutrition (Anandaraj 2000).

Symptoms

The affected vines exhibit foliar yellowing initially. With the onset of south west monsoon, some of the affected vines recover and put forth fresh foliage. However, with the depletion of soil moisture during the post monsoon season, the symptoms reappear and they exhibit defoliation and die-back. The vines gradually lose their vigour and productivity and finally death of the vine occurs. The roots degenerate/rot due to the infestation of nematodes. Vines infested with *M. incognita* exhibit inter-veinal chlorosis and galling in roots. *R. similis* causes necrotic lesions on feeder roots which lead to disintegration of distal portion of the roots (Peethambaran et al. 2008).

Management

Cultural practices

Green mulching with *Eupatorium odoratum* at the rate of 45 tons/ ha and selection of standards that are tolerant or resistant to nematodes such as *Garuga pinnata* and *Erythrina indica* would reduce the slow wilt incidence (Peethambaran et al. 2008). Sarma et al. (1987) opined that mass production of disease free planting material can be achieved in black pepper nurseries by raising planting materials in disinfected soil by soil fumigation of potting mixture. Ramana and Mohandas (1987) suggested host plants such as *Artocarpus heterophyllus, A. hirsutus, Ailanthes malabarica, Mesopsis emini, Peltophorum pterocarpum, Swietenia macrophylla, Tamarindus indica, Garuga pinnata* and *Macaranga peitata* resistant to *M. incognita* could be used as live standards for black pepper. Crop rotation, mulching with organics, soil amendments, flooding, fallowing, phytosanitation, planting nematode free plants were some of the cultural practices recommended for nematode management (Ramana and Eapen, 2000). In the main fields, uprooting and destruction of diseased vines along with roots and exclusion of susceptible intercrops and support trees minimized nematode infestation.

Biocontrol

P. lilacinus, Verticillium chlamydosporium (Pochonia chlamydosporia) and *Bacillus* spp. has been found effective against root knot nematodes in black pepper (Ramana and Eapen, 1992; Ramana, 1994; Eapen and Venugopal, 1995). Application of antagonistic fungi, such as *Po. chlamydosporia* and *T. harzianum* around base of the vine @ 50 g/ vine (10^8cfu/g) with the onset of the monsoon (May-June and August-September) is recommended by Devasahayam et al. (2015b). Talc based

formulation (10^6 cfu/g) of *B. macerans* @10g/vine at the time of planting of vines or just before the monsoon period in established plantations for controlling burrowing and root knot nematode is also suggested (Anonymous, 2016).

Anandaraj et al. (1991) recommended VAM fungi viz., *G. fasciculatum, G. etunicatum* and *Acaulospora laevis* against root knot nematodes in black pepper. Bhai et al (2017) deployed *Curtobacterium luteum* (TC10) for mitigating foot rot and slow decline diseases of black pepper. The efficacy of *Streptomyces* spp. for the management of slow decline disease has been reported by Bhai et al. (2016). *Streptomyces* spp. when used as consortium enhanced the growth of black pepper in addition to disease suppression (Bhai et al., 2014).

Resistant cultivars

IISR variety Pournami, which is a selection from Ottaplackal was found tolerant to root knot nematode (Devasahayam et al. 2015b).

c) Fungal pollu

Anthracnose or *pollu* disease caused by *Colletotrichum* spp. is increasingly becoming serious at higher altitudes (Kurien et al. 2000). The disease is seen throughout the crop season in plantations and maximum damage is caused during August to September and ranges from 28% to 34% (Nair et al. 1987). The damage on the berries due to *C. gloeosporioides* resulted in 100% yield loss (Santhakumari and Rajagopalan 2000).

Symptoms

The fungus causes damage to the plant both in the nurseries and main fields. On older vines in the field, leaves, spikes and berries were affected. On the leaves, angular to irregular yellowish brown to dark brown spots with chlorotic halo appears. Infection on spikes resulted in spike shedding, whereas, infection on immature berries caused shrinking and development of hollow (*pollu*) berries. Formations of brownish splits on the berries were also seen. Spike shedding is more severe at higher elevations (Sainamole et al. 2008). The disease when combined with heavy shade, lack of pollination and delayed emergence of spikes resulted in large scale spike shedding.

Management

Cultural practices

Irrigation of vines 4-5 times at an interval of 5-7 days commencing

from the third week of March, followed by shade regulation of support trees was effective for managing spike shedding (Anonymous, 2016).

Biocontrol

Isolates of *P. fluorescens* developed by the Kerala Agricultural University is highly effective for the management of fungal *pollu* of black pepper (Anonymous, 2016). Dipping cuttings in *Pseudomonas* slurry, soil drenching and spraying the affected plants with 1% *P. fluorescens* culture could be practiced for managing the disease.

B. Viral diseases

a) Stunt disease

Due to varied symptoms, diseases induced by viruses are also known by different names such as mosaic, little leaf, wrinkled leaf and stunted disease in different black pepper growing areas. The disease caused by *Cucumber mosaic virus* (CMV) and *Piper yellow mottle virus* (PYMoV) has drawn much attention especially at high altitudes. CMV is transmitted by aphids where as mealybugs (*Ferrisia virgata* and *Planococcus citri*) transmit PYMoV.

Symptoms

The diseased vines exhibit shortening of internodes and the leaves become narrow, leathery in texture, puckered and crinkled. Chlorotic spots and streaks also appear on the leaves. Severe symptoms are seen in plants that are subjected to abiotic stresses such as nutrition and high temperature (35°C) (Bhat et al. 2018).

Management

Cultural practices

Use of virus-free planting materials, vector control and cultural methods are required for the management of viral diseases (Bhat et al. 2018). Virus-free cuttings are to be used for propagation under insect-proof conditions and planting. Sasi and Bhat (2018) reported elimination of PYMoV from infected black pepper plants through meristem-tip culture. Regular inspection and removal of infected plants and replanting with healthy plants should be resorted to in the field (Peethambaran et al. 2008). Srinivasan et al. (2017) opined that mild/ moderately virus infected plants can be rejuvenated by adopting proper soil and plant health management practices whereas severely infected plants need to be removed and burnt or buried deep in soil. They suggested correction of soil acidity using soil

amendments and soil test based nutrient application along with farm yard manure at the rate of 10-15 kg per standard to improve the health of infected plants.

Biocontrol

Application of black pepper specific PGPR consortia and *Trichoderma*, either fortified with FYM at the rate of 10-15 kg or as drenching at the rate of 2-3 litres per standard during June and September was recommended by Srinivasan et al. (2017) to revive and sustain the health and yield of mild or moderately virus infected plants.

C. Insect Pests of black pepper

In India, black pepper is known to be infested by at least 56 genera/ species of insects causing damage to various parts of the vine such as roots, stems, shoots, leaves, spikes and berries. Among them, based on the nature and extent of damage, *pollu* beetle, scale insects, top shoot borer, leaf gall thrips and root mealy bugs are considered as the major insect pests (Devasahayam 2000).

a) Pollu beetle

Lanka ramakrishnai formerly called as *Longitarsus nigripennis* is the most destructive insect pest of black pepper in the lower elevation (Devasahayam and Koya 1994).

Symptoms

The adult beetle feeds on tender shoots, leaves and spikes resulting in black patches on the tender shoots and spikes and small irregular circular holes on younger leaves. The larva (grub) bores into developing spikes and berries and feed on the internal contents. The infested spikes develop necrotic patches and the berries turn black and crumble when pressed. The pest infestation is severe in heavily shaded areas across plantations (Ravindran 2000).

Management

Cultural practices

Lowering shade levels in the plantation by lopping-off branches of support and shade trees with the onset of pre-monsoon rains helps reducing the build-up of pest population.

Botanicals

Leaf extracts of *Chromolaena odoratum* and *Strychnos nuxvomica*

and seed kernel extract of custard apple possessed significant antifeedant activity against *pollu* beetle in laboratory bioassays (Devasahayam and Leela 1997). In the plantation, spraying the vines with neem product (Neemgold 0.6% and Neemazal-F 0.05%) during August, September and October was promising in reducing the damage caused by pollu beetle (Devasahayam et al. 2015a).

Biocontrol

Entomopathogenic fungi such as *B. bassiana* has been found successful for the control of the grubs of the pest (Devasahayam 2000).

b) Scale insects

Scale insects such as mussel scale (*Lepidosaphes piperis*) and coconut scale (*Aspidiotus destructor*) are becoming serious insect pests of black pepper at higher altitudes under changing climatic scenario (Selvakumaran et al. 1996b).

Symptoms

The mussel scale encrusts main stems, lateral branches, mature leaves and berries resulting in chlorotic patches, yellowing and drying of leaves and mortality of young vines. The infested branches wilt and dry resulting in vacant spaces in the canopy. The coconut scale infests mature leaves leading to chlorotic patches and sometimes also infests berries. The pest infestation was higher during post-monsoon and summer months (Selvakumaran et al. 1996b).

Management

Botanicals

Natural products such as neem oil (0.3%) or neemgold (0.3%) or fish oil rosin (3%) are effective for the management of scale insects during initial stages of infestation (Devasahayam et al. 2015a). As per Anonymous (2016), two sprays of Azadiractin (5000 ppm) at 15 days interval after the incidence of scale insect can manage the pest. Sreekanth (2013) reported the effectiveness of leaf extract (5%) of *Cleome gynandra* (Spider flower) and *Azadirachta indica* (Neem) in reducing the mussel scale population in black pepper. He also explained that, *Ageratum conyzoides* (Goat weed), *Annona squamosa* (Custard apple), *Parthenium hysterophorus* (Congress weed) and *Lantana camara* (Yellow sage) could also be used for reducing the population of scale insects.

Biocontrol

Selvakumaran et al. (1996b) recorded seventeen predators and four parasitoids against scale insects infesting black pepper (Table 2). Among them were, *Aphytis* sp. (parasitoids) and *Pseudoscymnus* sp. (predator of *A. destructor*) and *Chilocorus circumdatus* (predator of *A. destructor* and *L. piperis*) the most common natural enemies (Selvakumaran et al. 1996b; Devasahayam, 2000).

Table 2. Natural enemies recorded on scales infesting black pepper (Sivakumar et al. 1996b)

Sl.No.	Natural enemy	Order : family	Host
a.	**Predators**		
1	*Bdella sp.*	Acarina : Bdellidae	*L. piperis : A. destructor*
2	*Genus et sp. indet.*	Heteroptera : Miridae	*A. destructor*
3	*Aeolothrips fasciatus (Frank.)*	Thysanoptera: Phlaeothripidae	*L. piperis : A. destructor*
4	*Karnyothrips melaleucus (Bagn.)*	Thysanoptera: Phlaeothripidae	*L. piperis : A. destructor*
5	*Mallada boninensis (Okamoto)*	Neuroptera: Chrysopidae	*A. destructor*
6	*Cybocephalus sp.*	Coleoptera : Nitidulidae	*L. piperis : A. destructor*
7	*Chilocorus circumdatus (Gyllen.)*	Coleoptera : Coccinellidae	*L. piperis : A. destructor*
8	*C. nigrita(Fab.)*	Coleoptera : Coccinellidae	*L. piperis*
9	*Pharoscymnus horni (Wiese)*	Coleoptera : Coccinellidae	*L. piperis*
10	*Pseudoscymnus dwipakalpa Ghorpade*	Coleoptera : Coccinellidae	*A. destructor*
11	*Pseudoscymnus sp.1*	Coleoptera : Coccinellidae	*A. destructor*
12	*Pseudoscymnus sp.2*	Coleoptera : Coccinellidae	*L. piperis : A. destructor*
13	*Pseudoscymnus sp.3*	Coleoptera : Coccinellidae	*A. destructor*
14	*Sticholotis exsanguis Sicard*	Coleoptera : Coccinellidae	*L. piperis*
15	*Genus et sp. indet*	Coleoptera	*L. piperis*
16	*Genus et sp. indet.*	Coleoptera	*L. piperis*
17	*Lestodiplosis sp.*	Diptera : Cecidomyiidae	*A. destructor*

b.	**Parasitoids**		
18	*Adelencyrtus sp.*	Hymenoptera : Encyrtidae	*A. destructor*
19	*Aphytis sp.*	Hymenoptera : Aphelinidae	*A. destructor*
20	*Encarsia citrina (Craw.)*	Hymenoptera : Aphelinidae	*L. piperis*
21	*E. lounsburyi (Berlese & paoli)*	Hymenoptera : Aphelinidae	*A. destructor*

b) Top Shoot borer

The top shoot borer (*Cydia hemidoxa* Meyr.) is one of the major insect pests on young black pepper vines (1-2 years) causing up to 100% terminal shoot damage. The pest infestation causes up to 57% reduction in growth when the vines were infested during June- December. The pest infestation is higher during July-November when numerous tender shoots were available on the vines.

Symptoms

The caterpillars of the moth bore into tender terminal shoots and feed on internal tissues resulting in blackening and decaying of the affected shoots. When successive new shoots are attacked, the growth of the vine is affected (Devasahayam and Koya 1994).

Management

Biocontrol

Devasahayam and Koya (1994) reported five genera/species of parasitoids among which *Apanteles cypris* Nixon (Braconidae) was the most common parasitizing 20% of larvae of the pest. The other natural enemies recorded include *Goniozus* sp. (Bethylidae) and *Trombidium* sp. (Trombidiidae). *Hexamermis* sp (Mermithidae), an entomopathogenic nematode and *Clinotrombium* sp., a parasitic mite that has been identified against top shoot borer larvae.

d) Leaf gall thrips

Infestation by leaf gall thrips (*Liothrips karnyi* Bagn.) is more serious at higher altitudes, especially in younger vines and also in nurseries in the plains (Devasahayam and Koya 1994).

Symptoms

The thrips feed on the leaves causing the leaf margins to curl

downwards and inwards leading to formation of the marginal leaf galls. The infested leaves become thick, malformed and crinkled (Ravindran 2000). In severe cases of infestation, the growth of younger vines and cuttings in the nursery is affected.

Management

Biocontrol

A number of predators of leaf gall thrips have been identified in the field among which, *Montandoniola moraguesi* and *Androthrips flavipes* are the most common and widely distributed that feed on all stages of the pest. The other predators include *Geogarypus* sp. and *Lestodiplosis* sp., which feed on the juvenile stages (Devasahayam 2000).

Host resistance

Kalluvally is the least susceptible cultivar to the pest (Banerjee et al. 1981).

e) Root mealy bugs

Mealybugs (*Planococcus* sp., *P. citri, P. lilacinus, Dysmicoccus brevipes and F. virgata*) were found infesting the roots and basal portion of stem of black pepper vines (Mani et al. 2016).

Symptoms

Infested plants show slow or poor growth. Leaves wilt later and become pale or turn yellow or grey. Wax deposit is seen around the roots as well as on the soil or on the side of the pots. The infestation is generally severe during the post monsoon (Mani et al. 2016)

Management

Cultural practices

Since root mealybugs are very difficult to detect and control, effort should be made to prevent their spread and establishment. Use of clean planting material, removal of alternate host plants, disallowing irrigation water from infested areas, and disposal of the infested plant debris provide reduction in population of root mealybugs (Mani et al. 2016).

Botanicals

Devasahayam et al. (2010) observed that alcoholic extracts (3%) of *Azadirachta indica* and *Vitex negundo,* tobacco extract (3%), custard apple seed extract (2%) and agro spray oil (3%) cause up to 75% reduction

in root mealybug population at 30th day of treatment. He also found that among the neem products, Nimbicidine (0.5%) was most effective resulting in 60% reduction in the population of root mealybugs after 30 days of drenching. Drenching tobacco extract (2%) under the situation of mild infestations were suggested by Devasahayam et al. (2015b).

Biocontrol

The larvae of *Spalgis epius* (Apefly) were observed to predate on pepper root mealybug colonies (Devasahayam et al. 2010).

Conclusion and future prospects

Organic farming technologies and practices that are low input demanding, energy efficient and cause little or minimum disturbance to the production system need to be developed. Keeping in view of the economics of disease management as well as discouraging the synthetic chemical control measures, the identification and use of locally evolved cultivars with multiple resistant genes capable of moderately yielding could be the most effective and viable option. Development and cultivation of varieties and types that are tolerant to noxious pests and diseases of cardamom and black pepper would be a panacea to achieve this goal. Standardization of ready to use formulation of effective botanicals or bio pesticides against major pests and diseases are indeed imperative for the successful cultivation of these crops. Exploitation of bio-rationals like highly specific insect growth regulators and pheromones especially for shoot and capsule borer, thrips and root grubs adult in cardamom and *pollu* beetle in black pepper are required. Growing knowledge on the role of beneficial microbes in triggering defense mechanisms in host plant offers additional importance for shifting from toxic pesticides to more eco-friendly methods involving biological control agents (Anandaraj 2018). In the case of cardamom and black pepper, very limited work has been done on the role of endophytes in pests and disease management. Also, the suitability of documented natural enemies especially parasitoids and predators has received much attention, but studies of environmental impact as well as techniques for their easy mass multiplication and field application are limited. The possibility of transgenic plants can be explored for the pests and diseases where management with organic packages is extremely difficult.

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