Title

Diseases of Black Pepper and Cardamom

Short running title

Diseases of Black Pepper and Cardamom

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1 **Introduction**

In India, Black pepper is mainly confined to Western-Ghats of South India (Ravindran et al., 2000) and its cultivation requires hot, humid climate with high rainfall, uniform temperature and high relative humidity throughout the year (Sadanandan, 2000). The hot and humid climate of Western Ghats is ideal for its cultivation. Decline in the production of black pepper distorted India's position in the global market. The decline occurred mainly due to biotic and abiotic stress apart from socio economic problem. Crop is susceptible to many fungal, viral, bacterial and Mycoplasma infections that cause severe crop losses. Foot rot / *Phytophthora* rot is a serious infection that occurs in the nurseries as well as in the main field. On a global scale, an annual crop loss of around 4.5-7.5 million has been reported due to foot rot alone (De waard, 1979). Sarma and Anandaraj (1998) reported a crop loss of 2000t valued at Rs. 320 million in Kerala due to foot rot. Other diseases of importance are slow decline caused by feeder root damage by *P. capsici* and plant parasitic nematodes, anthracnose by *Colletotrichum gloeosporioides,* stunt disease by *Cucumber Mosaic Virus* (CMV) and bacilliform DNA virus (BADNA) and Phyllody by *Phytoplasma*. Being propagated vegetatively crop, the risk of non-symptomatic plants as source of infection is huge.

Cardamom is mainly confined to the evergreen forests of Western Ghats of South India, growing at an altitude of 750-1500 m MSL. It requires an annual rainfall of 1500-5000 mm, temperature of 10-35 ^{0}C, moderate shade, provision of good drainage and protection from wind for its growth and productivity. The microclimate prevailing in the cardamom habitat like perennial shade, heavy rainfall and humid conditions are congenial for the development of several fungal, bacterial and viral diseases. Capsule rot (*Azhukal*), clump rot (rhizome rot), leaf blotch and leaf blights are important fungal diseases that affect cardamom. The cardamom mosaic (*Katte),* cardamom vein-clearing disease (*Kokke Kandu),* and the necrosis due to Nilgiri necrosis virus are other important diseases (Naidu and Thomas 1994; Sarma *et al.* 1994; Venugopal 1995). Cropping system and microclimate appear to be the deciding factors in the incidence and spread of the diseases. These diseases will lead to huge crop loss if left unnoticed or if no timely and proper plant protection measures are adopted.

2 Diseases of Black Pepper

2.1 *Phytophthora* Foot Rot

2.1.1 Distribution

The disease was known since 1902, however the etiology remained inconclusive. The disease is present in all black pepper growing areas of India (Sarma and Anandaraj 1988) and wherever black pepper is grown.

2.1.2 Economic Importance

Crop loss due to this disease was reported up to 20% by Samraj and Jose (1966). Nambiar and Sarma (1977) reported 25-30 per cent loss in Kerala. Death of the vines up to 9.4 % and 3.7 % resulting in an annual loss of 905 and 119 tonnes in Kannur and Kozhikode districts of Kerala, respectively (Balakrishnan *et al.* 1986, Anandaraj *et al.* 1989 and Prabhakaran 1995).

2.1.3 Symptoms

Symptoms are classified into aerial, collar and root infections. Infection on the runner shoots, foliage, spikes and branches (aerial infection) causing blight, spike shedding, defoliation and dieback and ultimately death of vines (Anandaraj and Sarma 1995 and Ramachandran *et al.* 1986). Infection on the runner shoots often reaches the collar and causes foot rot leading to sudden wilting of vines (Anandaraj *et al.* 1994; Anandaraj 1997; Anandaraj 2000;). Leaf infection is characterized by dark brown necrotic lesions in the centre with fimbriate advancing margins which spread rapidly resulting in defoliation. Top shoot infections are seen as black lesions leading to dieback (Anandaraj *et al.* 1991) (Fig.1). Flaccidity, drooping, yellowing and defoliation are the characteristic symptoms during disease progression (Fig. 2).

Fig. 1. Symptoms due to Aerial infections a) Leaf spot with fimbriate margin b) Infection on spikes and berries c) Defoliated vine

Fig. 2 Types of collar infections a) Through runner shoots or roots of upper tier resulting in sudden wilting b) Infection spreading to collar through roots of the lower tier showing yellowing preceding wilting c) Feeder root loss resulting in gradual yellowing and defoliation and reduction in canopy size

2.1.4 Causal Organism

Phytophthora infecting black pepper was originally reported as *P. palmivora*, later renamed as *P. palmivora* MF4 and further based on extensive morphological and biochemical studies, identified as *P. capsici* (Tsao and Alizadeh 1988; Tsao 1991). Recently association of *P.*

tropicalis among *Phytophthora* isolates of black pepper has been reported (Jeevalatha *et al*. 2021; Suseela Bhai *et al*. 2021; Sheji *et al*. 2009;). Both *P. capsici* and *P. tropicalis* are heterothallic where A1 and A2 mating types are required for sexual reproduction. Wide morphological diversity was found among the isolates and also with respect to virulence and sensitivity towards Metalaxyl to which the pathogen has reported to evolve resistance (Vinitha *et al*. 2016). Morphological characterization of black pepper *Phytophthora* was done by many researchers (Santhakumari 1987; Sarma *et al.* 1988; Vijaya 2005; Vinitha *et al.* 2016). Diversity in host-specific pathogenicity and genetic variability within black pepper *Phytophthora* populations were reported by Cissin *et al*. (2016).

2.1.5 Epidemiology and Disease Cycle

The disease incidence followed more or less the annual rainfall pattern (Mammootty *et al.* 1991). Significant positive correlation exists between foot rot incidence and rainfall, number of rainy days and relative humidity whereas a negative correlation exists in the case of maximum temperature and sunshine hours. A combination of factors such as daily rainfall of 15.8 – 23.0 mm, temperature range of 22.7 – 29.6ºC, relative humidity of 81-99 % and sunshine 2.8 –3.5 hours per day favour the spread of aerial infection (Ramachandran *et al.* 1988; 1990; Anandaraj 1997; 2000). The spread of the disease is in centrifugal pattern from the source of inoculum (Nambiar and Sarma 1982) . Spatio-temporal distance class analysis showed that both initial occurrence and subsequent spread followed a strictly non-random pattern and the infection clustered around the previously infected vines (Anandaraj 1997; Anandaraj and Sarma 2000a). The foliar infection spreads within the bush through rain splashes from the lower portions to upper portions whereas spread to the adjacent plants is through both rain splashes and also through wind-blown water droplets (Ramachandran *et al.* 1988; 1991).

2.1.5.1Survival

The inoculum of *P. capsici* survives in the soil up to 19 months in the absence of host plant and concentrated on the surface 0-30 cm of soil from the source and it gets reduced as the distance and depth increases (Ramachandran *et al.* 1986). The survival in the soil is by means of chlamydospore and thickened mycelium . The population build up is dependent on weather and is positively correlated with soil moisture (Anandaraj 1997).

2.1.5.2 Detection and Diagnosis

Soil baiting using *Albizzia falcataria* leaflets was found suitable for the detection of *P. capsici* in the soil that could be confirmed within 72 hours (Anandaraj and Sarma 1990). A species specific primer for detection of *P. capsici* in diseased plant tissues and soil has been developed (Anandaraj *et al.* 2008; Cissin *et al.* 2015; Sheji 2010). Recently Jeevaletha *et al.* (2021)developed end-point PCR and RPA assays for detection and differentiation of *P. capsici* and *P. tropicalis* infecting black pepper.

2.1.6 Disease Management

Soil borne *P. capsici* is a difficult pathogen to deal with because of its ability to overcome any limitations. In black pepper, all parts and all stages of the plant and all popular cultivars are susceptible. Considering, the above factors and severity of the disease, a single method may not offer good control unless integrated with various other factors to provide a holistic management strategy.

2.1.6.1 Cultural Practices

Provision of good drainage, growing cover crops, shade regulation, phytosanitation and eradication are the major cultural practices adopted for managing the disease. Water stagnation is the most conducive factor and hence the provision of good drainage would reduce the severity of infection (Sarma and Nambiar 1982). Cover crops like grass and *Mimosa* sp. reduced the movement or spread of contaminated soil through surface water and rain splashes and might increase the activity of antagonistic microflora which in turn reduced the rot in black pepper gardens (Ramachandran *et al*. 1990) whereas Anandaraj (1997) found that growing cover crops have increased the population of *P. capsici* and suggested clean cultivation. Utmost care should be exercised while collecting source planting material for nursery since infected tissues are the main source of inoculum for further spread of disease (Ramachandran *et al*. 1986). Lopping of branches during rainy season is essential to facilitate better sunlight and reduction of relative humidity in the garden, which in turn reduces the leaf wetness besides increasing the temperature within the garden (Ramachandran *et al*. 1991; Anandaraj and Sarma 2000b).

2.1.6.2 Disease Resistance

In black pepper, the variability for resistance to *P. capsici* is limited as none of the cultivars are resistant. Screening germplasm of pepper was done adopting stem and root inoculation techniques (Nambiar and Sarma 1977). Sarma *et al.* (1982) screened 48 cultivars and 73 wild *Piper* sp. against *Phytophthora* adopting dip inoculation technique and found none of the cultivars or wild species as resistant. Sarma and Anandaraj (1992) identified P24 (later named as IISR Shakti) and P 1352 as field tolerant to *P. capsici* and wild germplasm such as *P. colubrinum, P. obliqum* and *P. guinense* as resistant to *Phytophthora* foot rot(Sarma *et al.* 1994 Vanaja *et al*. 2007,). However, cultivars such as *Narayakodi, Kalluvally, Uthirankotta* and *Balankotta Neelamundi* and *Cholamundi* were tolerant or with low disease incidence (Sarma and Anandaraj 1997). Several open pollinated progenies of *Perambramundi, Kalluvally, Cholamundi* and hybrid involving *Panniyur* 1 x *Karimunda* and *Narayakodi* x *Neelamundi* showed tolerant reaction. The seedling progenies from susceptible parents showed varying levels of resistance and the mapping populations showed a modified dihybrid ratio in segregation suggesting the involvement of more than one gene (Cissin 2018; Cissin *et al*. 2020).

Grafting of black pepper on *P. colubriinum* has proven to be a viable method in water logging areas. Grafting at 50 cm height has been reported to be ideal. Though there were initial problems due to late incompatibility, the modified double rootstock method recorded better success and survival (78%). Scions with single nodes took more time for sprouting than two or three nodded scions and regardless of the varieties, February and March are the best periods for graft production and the grafted top shoots started bearing in the first year itself (Prakash *et al*. 2015; Vanaja *et al.* 2007).

The study on anatomical and biochemical investigation of *Piper* sp. to disease resistance revealed that *P. colubrinum* (immune to foot rot) and *P. nigum* and two genotypes of *P. nigrum i.e.Panniyur* 1 and *Kalluvally* differed significantly in various parameters. Similarly tolerant type (P24) expressed higher content of defense related enzymes like phenylalanine ammonialyase and PR proteins (Stephen *et al.* 2001) when compared to susceptible (*Panniyur* 1 and *Subhakara*) pepper genotypes to *P. capsici*

IISR Shakti, an open pollinated seedling progeny of Perambramundi was released as moderately resistant to *P. capsici* (Suseela Bhai *et al.* 2007). Also identified one open pollinated progeny (04-P24) from the moderately resistant IISR Shakti (Bhai *et al*. 2010). The mechanism of resistance in this progeny was attributed to cell membrane integrity, increased cell wall reinforcement, higher level of OD phenols besides higher lignifications and peroxidase activity with higher expression of (cAPX) gene (Vandana *et al.* 2014; 2019; Vandana and Suseela Bhai 2017). The direct response of infection as phenotypic symptoms and defense response imparted by lignin and peroxidase activity showed differential response to *Phytophthora* infection. The resistant line 04-P24 showed no symptoms of infection and having highest peroxidase activity with higher lignin content and suggested peroxidase activity as a marker for screening *Phytophthora* resistance in black pepper (Suseela Bhai *et al*. 2021).

2.1.6.3 Biological Control

Several strains of biocontrol agents including Fluorescent pseudomonads and *Trichoderma* spp. effective in protecting black 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; Rajan *et al.* 2002; Saju 2004; Saju et al. 2003; Saju and Sarma 2011). The most exhaustively studied biocontrol agent is *Trichoderma* species. Investigations on antagonistic microflora against *P. capsici* in black pepper plantations of Kerala and Karnataka showed the predominance of *T. viride*, *T. harzianum, T. hamatum* and *Gliocladium virens*. The combined effect of *T. harzianum, G. virens* and *Verticillium tenerum* in reducing the *P. capsici* infection in black pepper was also studied (Anandaraj and Sarma, 1994a; Prakash *et al*. 1999; Rajan and Sarma 2002). Developed a native microbial inoculum based technology involving Vesicular Arbiscular Mycorrhizae (VAM) for the management of *P.capsici* (Anandaraj and Sarma 1994b; Anandaraj *et al.* 1991; 1996a; 1996b). *G. fasciculatum* recorded the lowest mortality and foot rot index (53.35% and 62.50%) as against 100% mortality and 98.50% rot index in control and suggested incorporating of VAM for enhancing growth and suppressing root rot. Studies on the rejuvenative capacity of fluorescent pseudomonas in black pepper indicated the potential of these strains for nursery management of black pepper (Diby *et al*. 2005).

For managing foot rot , it is recommended to apply *T. harzianum* around the base of the vine @ 50g along with organic manure such as neem cake, farmyard manure, decomposed coffee pulp or coir pith with the onset of monsoon (May-June) and August-September and to be repeated for 2-3 consecutive years to check the pathogen spread (Rajan *et al.* 2002; Saju *et al.* 2002) and suggested to maintain the soil pH at 4.5-6.0 in order to facilitate the growth and proliferation of *Trichoderma* (Suseela Bhai *et al.* 2010). A liquid medium for the long term storage of *T. harzianum* was also formulated (Suseela Bhai and Anandaraj 2014). The potential of endophytic bacteria and actinobacteria was also exploited for managing the disease (Agisha et al. 2017; Anusree *et al*. 2019; Kumar *et al.* 2015; 2019b; Vibhuti *et al.* 2016; Suseela Bhai *et al*. 2016; Anusree and Suseela Bhai 2017a; 2017b). Endopytic fungi from black pepper viz, *Annulohypoxylon nitens, Daldinia eschscholtzii, Fusarium* spp. *Ceriporia lacerata, Diaporthe* sp. and *Phomopsis* sp. were antagonistic to *P.capsici* showing more than 50% inhibition (Sreeja *et al*. 2016; 2019a;).

2.1.6.4 Chemical Control

Prophylatic treatments with BM *(*Pasting base of the vines at one foot height with 10 % Bordeaux mixture coupled with 1 % BM spraying) was most effective for foot rot management (Sasikumaran *et al.* 1981; Sarma and Nambiar 1982; Ramachandran *et al* 1991; Nair and Sasikumaran 1991; Melabennur *et al.* 1991; Lokesh and Gangadarappa 1995). However, based on the studies on epidemiology and disease progression leading to collar infection, the practice of pasting the collar with Bordeaux mixture was discontinued (Anandaraj *et al.* 1996a; 1996b). Ramachandran and Sarma (1988) found that the pepper plants readily took up Metalaxyl and its systemic activity was noticed even one hour after the application and its inhibitory effect persisted in the plants for 50 days. Also several formulations of metalaxyl such as Ridomil granules and Ridomil-Ziram have been reported to be effective (Ramachandran *et al.* 1988;Sarma *et al.* 1992). Significant difference between BM treatment and Metalaxyl and BM and Captafol + BM treatments were observed by Melabennur *et al.* (1991) .

Also evaluated systemic fungicides like Ethazole, Propamocarb and Oxadixyl along with Metalaxyl, Fosetyl- Al, and found Ethazole and Metalaxyl the most toxic to mycelial growth and sporangiogenesis of *P.capsici* (Ramachandran and Sarma, 1990) The fungicides Ridomil, Cuman, Kitazin, Thiride, Bayer 5072 and Emisan were also effective at concentrations 1000 and 2000 ppm (Nair and Sasikumaran 1991; Melabennur *et al.* 1991;). Drenching Fosetyl-Al

(0.2%) four times at monthly interval was also recommended.. Though Fosetyl- Al was less toxic to mycelial phase of the pathogen, it showed good suppression of sporangial production and spore germination.

In disease prone areas, the current recommendation is prophylactic spraying of 1% BM with the onset of South West monsoon and basal drenching at a radius of 45-50cm with 0.2% copper oxychloride @ 5-8 lit per vine and repeating after about 45 days are suggested. As an alternative, first round with copper fungicides and a second time drenching and spraying with 0.3% Potassium phosphonate during August-September was also recommended. A third round of drenching during October is preferable to check the proliferation of inoculums in severely disease prone areas (Sarma *et al*. 2001; Veena and Sarma 2000). Higher concentrations of Potassium phosphonate (1200 ppm to 4000ppm) provided prolonged protection with zero phytotoxicity. It is ambimobile in nature and move fast in black pepper plant from the site of application to the root system and leaves no residue in the soil (Anilkumar *et. al*. 2006; 2009; 2010).

A novel observation by a farmer, that common salt is effective in controlling foot rot of black pepper, was validated and found that 3 to 4 M concentrations of Sodium chloride destroys soil inoculum of *P. capsic*i but was found phytotoxic. However, the method was suggested as a pre-planting practice while rejuvenating a diseased garden or while gap-filling or while raising nursery plants in potting mixture by washing off the soil after treatment with NaCl (Suseela Bhai *et al*. 2009). Soil application of Kresoxim methyl 500 g L-1 SC at 7000 ppm is effective in nullifying the infection or mortality with 100% inhibition of lesion development (Suseela Bhai et al. 2015).

2.1.6.5 Integrated Disease Management

Nursery hygiene, phytosanitation and other cultural practices, chemical and biocontrol measures coupled with host resistance are important components of IDM, which would reduce the cultivation cost and pesticide load in the produce. Selection of disease-free planting materials, resistant cultivars, cultural practices and timely use of fungicides are required for reducing the *Phytophthora* infection Ramachandran *et al.* (1991). In addition to fungicides, application of neemcake @ 1kg per vine and Arbuscular Mycorrhizal Fungi (AMF) boost the plant growth and suppressess root infection (Sarma *et al*.(1994). Fungicide application along with biocontrol agents prevented the build-up of *P. capsici* in black pepper.

Spraying and drenching Metalaxyl (2.5g/l) and application of *Trichoderma* sp. registered more than 75% control of *Phytophthora* foot rot (Mammootty and Koshy 2007; Mammooty *et al.* 1992).Cultural practices, Neemcake and phorate application in soil, drenching and pasting Bordeaux mixture before the onset of monsoon and spraying Akomin (0.04%) or Ridomil-Mz (100 ppm) as spray and drench during the second week of July and September reduced disease incidence significantly (Lokesh and Gangadharappa 1995) whereas organic amendment and fungicide application was recommended in Karnataka. Treatment with *Curtobacterium luteum* (TC10) + Metalaxyl-Mz showed significant reduction in nematode population as well as *Phytophthora* infection with better growth and yield (Suseela Bhai *et al*. 2017a; 2017b).

2.1.6.6Integrated Management of *Phytophthora* Rot in Nursery

In black pepper, planting materials are produced as rooted cuttings. Since the disease affecting the nursery occur in a short span of 3-4 months, an integrated management strategy has to be followed to prevent infection caused by various pathogens..Use of pathogen free material is the foremost requirement along with good agricultural practices and phytosanitation helps to reduce spread of infection to a greater extent.

Nursery disinfestation can done either by solarization or steam sterilization (Mammootty *et al.* 2007; Sarma and Saju 2004) followed by fortification with biocontrol agents. A combination of VAM and biocontrol agents like *T. harzianum* and *P. fluorescens* is reported to give healthy robust planting material (Anandaraj and Sarma 2003; Kandiannan *et al*. 2000; Sangeeth *et al*. 2008; 2012; Suseela Bhai *et al*. 2018; 2019; Thankamani *et al.* 2005). Disinfestation of nursery mixture using 3 to 4 M concentrations of Sodium chloride is also suggested (Suseela Bhai *et al*. 2009). After the establishment of plants in the nurseries, spraying 1% Bordeaux mixture or 0.2% Carbendazim on the above soil portion and drenching the soil with 0.2% Copper oxychloride or 0.125% Metalaxyl-Mancozeb or 0.3% Potassium phosphonate at monthly intervals is recommended.

2.2 Anthracnose (Fungal Pollu)

2.2.1 Distribution

Anthracnose or 'fungal *pollu*' disease was first identified in Malabar region of Kerala as 'berry spot' and 'berry split' and later named as fungal *pollu*.

2.2.2 Economic Importance

Generally sporadic, the disease often reaches epiphytotic proportions under misty conditions leading to severe defoliation and spike shedding. The severity of the disease was reported to be in the magnitude of 28-34% resulting in a crop loss of 1.9-9.5% (Anandaraj 2000).

2.2.3 Symptoms

Initial symptoms are manifested on the leaves, tender shoots and berries as chlorotic specks wherein only physiologically active leaves were affected. Under dry conditions, formation of a well-developed circular to irregularly shaped spots indicate the incidence of *pollu* disease. Under humid moist conditions, the spots enlarge and the holonecrotic area turns ashy white in colour. The disease generally initiates as minute necrotic spots with a yellow halo on the foliage. Under severe conditions, the entire leaf lamina is affected, leading to crinkling leading to defoliation. Infection of pedicel leads to spike shedding and berry infection results in the development of brownish splits. As the disease advances, the discolouration gradually increases and the berries display typical cross splitting. The disease appears on orthotropic and runner shoots as linear black necrotic lesions (Anandaraj 2000; Biju *et al*. 2017).

2.2.4 Causal Organism

Colletotrichum gloeosporioides was associated with berry malformation in black pepper Nambiar *et al*. (1978)

2.2.5 Epidemiology and Disease Cycle

Misty conditions generally favour the *Colletotrichum* spp. to produce abundant conidia on necrotic lesions that are eventually disseminated through wind and rain. Delayed emergence of spikes or leaves is coinciding with monsoon season is one of the major reasons for disease proliferation under field conditions. Biju *et al*. (2013) reported less disease incidence during summer (February to May) and an increase during June with a peak registered during September. The maximum temperature had a negative correlation, whereas minimum temperature, number of rainy days and rainfall had a positive correlation with the disease incidence and progression. Biju *et al*. (2017) reported over-summering of *Colletotrichum* as microsclerotia in the runner shoots of black pepper as well as teleomorphic stage of *C. gloeosporioides sensu lato* (Biju *et al*. 2020).

2.2.6 Disease Management

Cultural operations encompassing irrigating black pepper vines @ 40 to 50 liters per vine at an interval of 5-7 days from March and shade regulation to provide 7500-10000 lux light were found to be effective in reducing anthracnose incidence and spike shedding under field conditions. Pre-planting treatment of two to three node cuttings with Carbendazim-Mancozeb (0.1%) for 30 minutes and subsequent sprays with Bordeaux mixture (1%) and Carbendazim (0.1%) were found effective to manage the disease in nurseries (Biju *et al.* 2017). Under field conditions, aerial sprays with Bordeaux mixture (1%) or Carbendazim-Mancozeb (0.2%) or mancozeb (0.2%) were found promising in delaying disease initiation and subsequent spread (Sainamole *et al*. 2008; Vijayan *et al*. 2014). Biju and Praveena (2018) reported, phytoextracts of *Solanum nigrum* (5%), *S. torvum* (20%), and *Azadirachta indica* (5%) were promising against *Colletotrichum* under *in-vitro* conditions.Screening of black pepper genotypes against *C. gloeosporioides* revealed that, except *Vellanamban* II, all the other genotypes exhibited varying percentage of disease incidence (Mammootty and Koshy 2007). In endemic regions of anthracnose/spike shedding, field tolerant cultivars namely, *Aimpiriyan* and *Arakulammunda* are recommended for cultivation.

2.3 Yellowing and Wilting

2.3.1 Distribution

Yellowing and vine death is a severe problem in majority of the plantations in the high ranges of Kerala and Karnataka, where moisture depletion is found very high during the post monsoon season. Black pepper vines in all the major growing areas especially in the districts of Idukki, Kasaragod, Kozhikode, Malappuram, Palakkad and Wayanad (Kerala) and Kodagu (Karnataka) are affected by this disease (Subila and Suseela Bhai 2020a).

2.3.2 Symptoms

The disease is characterized by yellowing and wilting of vines followed by defoliation and drying up during the post monsoon season. In advanced stages, wilting leads to spike shedding that results in severe crop loss. This post monsoon yellowing is entirely different from foot rot or slow decline diseases (Subila and Suseela Bhai 2020a).

2.3.3 Causal Organism

The pathogen is identified as *Pythium deliense* characterised *by* filamentous inflated or torulated sporangia (Subila and Suseela Bhai 2020b)

2.3.4 Disease Management

Trichoderma harzianum and *Streptomyces albulus* registerd 100% inhibition *in vitro* followed by *Streptomyces* sp. viz. *S. rimosus*(75.33%). No root infection was noticed with *T. harzianum* and *S. albulus* where the inoculated plants showed good regeneration of roots. Greenhouse and field evaluation also showed the protective efficacy of *T. harzianum* and *S. albulus* with a reduction in the intensity of yellowing to an extent of 73.1% and 71.2%, respectively (Subila and Suseela Bhai 2021).

2.4 Stunt Disease

2.4.1 Distribution and Economic Importance

Higher incidence (29 to 45%) and severity of stunt disease were noticed in black pepper plantations located at higher altitudes. The yield loss due to the disease varies from negligible to 85% depending on the severity (Bhat *et al.* 2005b: 2018).

2.4.2 Symptoms

Mosaic, mottling, and formation of malformed as well as reduced leaf size are the most common symptoms observed in the field (Fig. 3). When the infection becomes severe, leaves become rough, leathery, and narrow in the form of a sickle. The length between nodes of the stem reduces drastically leading to stunting of the plants. The symptom expression is mainly influenced by abiotic factors including soil nutrition. Severe symptoms appear when plants are subjected to high temperatures and high relative humidity under poor soil nutrition (Umadevi *et al*. 2016; Ahamedemujthaba *et al*. 2021).

Fig. 3 Symptoms of stunt disease affected black pepper plant

2.4.3 Causal Organism

The disease is caused by the *Piper* yellow mottle virus (PYMoV) that belongs to the genus, *Badnavirus* and family, *Caulimoviridae* (Bhat *et al.* 2005a; 2018). PYMoV is a circular double-stranded DNA virus with bacilliform particle morphology. Besides black pepper, PYMoV is also known to infect betelvine, Indian long pepper, and other related species. The

full genome sequence of PYMoV isolates contained 7559 to 7584 nucleotides and possessed four open reading frames (ORFs) (Hany *et al*. 2014; Deeshma and Bhat 2015). Besides, some PYMoV infected black pepper plants also showed the association of cucumber mosaic virus (CMV) that belongs to the genus, *Cucumovirus* of the family *Bromoviriade*(Prakasam *et al*; 1990; Sarma *et al*. 2001). CMV contains isometric particles with a single-stranded RNA genome. The full genome sequence of the CMV infecting black pepper revealed that it comprises three RNA species namely, RNA1, RNA2, and RNA3 with 3429, 3049, and 2237 nucleotides respectively (Revathy and Bhat 2017). Molecular diagnostic assays such as PCR, real-time PCR, loop-mediated isothermal amplification (LAMP), recombinase polymerase amplification (RPA) have been established and validated for the detection of both CMV and PYMoV in black pepper and related species (Bhat and Siju, 2007; Bhat*et al*. 2005c; 2009; 2013; Bhat and Siljo 2014; Hareesh and Bhat 2008; 2010).

2.4.4 Epidemiology and Disease Cycle

The primary spread of the disease occurs through the use of virus-infected planting materials. Of the two viruses, PYMoV is also spread through seeds. In addition, the secondary spread of PYMoV occur through mealybug vectors (*Ferrisia virgata, Planococcus citri, Planococcus elisae*) and black pepper lace bug (*Diconocoris distanti*) in a semi-persistent method while CMV is mechanically transmissible to many herbaceous hosts (Sarma *et al*. 2001; Bhat *et al*. 2003). PYMoV infects mainly black pepper and related species while CMV infects more than 1200 plant species. High temperature and high humidity coupled with poor soil nutrition favour disease severity. Further, the severity of the disease increase in plants infected by both PYMoV and CMV.

2.4.5 Disease Management

2.4.5.1Production of Virus-free Plants

There is no resistant variety of black pepper available against both the viruses. Hence efforts should be made to reduce sources of infections to limit the spread of viruses by vectors and to minimize the effect of infection on yield. Identification and propagation of virus-free planting material are important to reduce the source of viruses. As symptoms are not reliable criteria for the identification of virus-free plants, sensitive laboratory-based assays such as PCR, real-time PCR, LAMP, and RPA need to be used for the identification of virus-free mother plants (Bhat and Siju 2007; Bhat*et al*. 2004; 2009; 2010; 2013, Bhat and Siljo 2013).

Meristem-tip culture and somatic embryogenesis-based methods have been reported for the production of virus-free stocks from the PYMoV-infected plants (Sasi and Bhat 2018). A mother block may be established using virus-free plants under protected conditions monitored for freedom from viruses regularly. Planting materials collected from the mother block may be multiplied in nurseries under protected conditions. The virus-free plants from nurseries should be used for commercial planting (Bhadramurthy *et al*. 2005; 2008; Bhat *et al*. 2018).

2.4.5.2 Integrated Management in the Field

Under field conditions, the infection in plants may be asymptomatic, mild, moderate, or severe. Symptom expression mainly depends on environmental conditions such as temperature, humidity, and soil nutrition. The severely diseased plants should be cut and burnt or buried deep in the soil. To recover and endure the health and yield of plants that express mild and moderate symptoms, the following methods are recommended (i) application of lime or dolomite to correct soil pH, and NPK for optimum nutrients available for the plants (ii) application of plant growth-promoting rhizobacteria and *Trichoderma*, two times a year (pre and post-monsoon) by mixing with FYM (and applied 10-15 kg per plant) or by drenching (2-3 litres per plant) (iii) spraying with micronutrient mix @ 5g per litre twice, after spike emergence and after spike set (Srinivasan *et al*. 2017). Other methods include the removal of alternate hosts of the virus and management of vectors using environmentally safe insecticides and biopesticides. Because of the absence of a natural resistance source against viruses in the black pepper, the production of virus-resistant black pepper plants through either transgenic or gene editing approaches may be a good alternative.

2.5 Phyllody

Phyllody disease of black pepper was first reported during 1986 from Wayanad District of Kerala, India. The disease was characterized by malformation of the entire spike. The stalk of affected spike increases in length, the bracts and the flowers get transformed in to small leaf like structures (Sarma *et al*. 1988) (Fig. 4). The internodes of the lateral branches become abnormally short and the size of leaves get substantially reduced and affected branches give a typical witches broom appearance. During early phase (up to two years after infection) plants look as if more or less normal, gradually disease symptoms increase and within five to seven years' typical symptoms of the disease is seen. At severe stage plant

will be extensively stunted and produce only malformed spikes without any berries thus causing total yield loss (Paily *et al*. 1981).

Fig. 4 Symptoms of phyllody affected black pepper plant

Investigations based on electron microscopy, cloning and sequencing of 16S ribosomal DNA of the pathogen employing primer pairs P1/P7 and R16F2n/R16R2 (F2n/R2) revealed the association of a phytoplasma belonging to aster yellows group (16Sr I) (Ca. Phytoplasmaasteris) as the causal agent of the disease (Bhat *et al*. 2006). Later association of phytoplasma belonging to the same group was also reported from black pepper plants showing yellowing and curling of leaves from Kodagu region of Karnataka, India (Adkar-Purushothama *et al*. 2009). The causal phytoplasma is not transmitted through seed. The primary spread of the pathogen is through the use of infected stem cuttings. Generally, phytoplasma are spread by leaf hoppers and plant hoppers. Although colonization of two kinds of plant hoppers on black pepper is seen, their role in the transmission of phytoplasma infecting black pepper is not yet established. Phytoplasmas are systemic in nature, hence it is essential to find and use phytoplasma-free plants for vegetative propagation of the crop. For early diagnosis, symptoms cannot be used as phytoplasma has long incubation period in the host depending on the environmental conditions particularly the temperature. Hence for fool-proof identification of healthy plants, use of PCR based diagnostic is required (Bhat *et al.* 2006). Thus, the most successful method to manage the disease would be the production and use of phytoplasma-free plants. Other methods include regular inspection and removal of infected plants and replanting with healthy plants and management of insect vectors such as plant hoppers or leaf hoppers on the plant or standards with recommended insecticides

2.6 Minor Diseases

2.6.1 Stump Rot

Stump rot is caused by *Rosellina bunodes* (Menon 1949). The disease was first reported from Wyanad district of Kerala. The fungus affects the root system which results in drying up of plants. The fungus was also found infecting *Grevillea robusta* which is being used as a standard for black pepper mostly in tea plantations. Isolation of affected plants by making trenches is recommended to prevent the spread of the disease to adjacent plants (Anandaraj 2000).

2.6.2 Leaf Blight

Leaf blight is a serious disease of black pepper in the nursery during April-May when warm humid condition prevails. Infection occurs on both leaves and stem. Greyish sunken spots and mycelial threads appear on the leaves and the infected leaves are attached to one another with the mycelial threads. On stems, the infection occurs as dark brown lesions which spread both upwards and downwards. In advanced stages of infection, new flushes subtending the points of infection gradually dry up and drop off (Anandaraj 2000). The disease is caused by *Rhizoctonia solani* Kuhn. *Colletotrichum* sp. is found associated with leaf spots (Mammootty *et al*. 1992).

2.6.3 Basal Wilt

The disease is mainly noticed in the nurseries during June-September months and is caused by the fungus *Sclerotium rolfsii* Sacc. Symptoms appear as greyish lesions on stems and leaves. On the leaves white mycelium are seen at the advancing edge of the lesions. The mycelial threads later girdle the stem resulting in drooping of leaves beyond the point of infection. In advanced stages the rooted cuttings dry up. Small whitish to cream coloured grain like sclerotial beads appear on the mature lesions (Anandaraj 2000).

2.6.4 Other Minor Diseases

Thread blight of black pepper was reported by Ramakrishnan (1957). The disease is caused by *Marasmius scandens.* The fungus grows underneath the leaves and on stem causing drying up of leaves and spikes. *Pellicularia filamentosa* (*Corticium solani*) was also reported to be associated with the disease. The disease can be controlled by using copper oxychloride not exceeding 0.5%. Velvetblight is caused by *Septobasidium* sp. whereas pink disease is caused by *Corticium salmonicolor*. These diseases can also be reduced significantly by applying copper oxychloride, cuprous oxide or captafol.

3 Diseases of Cardamom

Cardamom is affected by a number of diseases occurring in the main plantations and in nurseries. Among them, four major diseases in plantations and two major diseases in nurseries seriously affect the plant and cause considerable damage. Diseases such as the rots, leaf blights and nematode infestation are often wide spread and lead to crop losses while

other diseases generally affect the foliage and occur in minor proportions. Diseases alone can cause up to 50 per cent crop loss if not managed properly. Capsule rot, rhizome rot and *Fusarium* infections are comparatively severe and affect crop production while the widespread leaf blight lead to weakening of plants, and subsequent reduction in productivity.

3.1 Capsule Rot

Capsule rot, commonly known as *Azhukal* in Malayalam language means rotting and is one of the severe disease of cardamom during the rainy season. Menon *et al.* (1972) reported it for the first time from plantations of Idukki in Kerala.

3.1.1 Distribution

Initially, rotting symptoms were observed on the capsules only and accordingly it was named as capsule rot. Later, the symptoms have been observed in several other plant parts like panicle, rhizome etc. It is still a major problem affecting cardamom cultivation in Idukki and Waynad areas of Kerala and Anamalai hills in Tamil Nadu (Thomas *et al.* 1989). The disease makes its appearance after the onset of southwest monsoon rains. However, capsule rot is not reported in low rainfall areas in Tamil Nadu.

3.1.2 Economic Importance

A crop loss of 30 per cent has been estimated by Nambiar and Sarma (1976). However later it has been shown that as high as 40 per cent crop loss can occur in severely affected plantations (Anonymous, 1989).

3.1.3 Symptoms

Disease symptoms develop mainly on the capsules, young leaves, panicles and tender shoots. The first visible symptom appears as discoloured water-soaked lesions on young leaves or capsules. These lesions enlarge and the affected portions decay. Infection takes place on capsules or tender leaves simultaneously or first on capsules followed by foliar infection (Thomas *et al*. 1991a). When foliage infection occurs, water-soaked lesions appear on leaf tips or leaf margins which later enlarge and adjacent lesions coalesce to form large patches. Immature unopened leaves fail to unfurl following infection. As the disease advances, the lesion areas turn necrotic, the leaves decay and shrivel and finally they give a shredded appearance. Infected capsules show water soaked discoloured areas which turn brownish and

later decay and drop off. Such rotten capsules emit a foul smell. Capsules of all ages are susceptible to infection. However, young capsules are seriously affected by the disease. During favourable climatic conditions the disease is aggravated and infection from the capsules extends to panicles and tender shoots also. In extreme situations the whole panicle or the whole psuedostem decays completely. In such cases the rotting extends to underground rhizomes also. The root system of such plants gets decayed and the entire plant destroyed. Nair (1979) described similar symptoms and observed that the disease severity is uniform in the three major cardamom cultivars, *viz*. Mysore, Vazhukka and Malabar (Fig. 5a).

3.1.4 Causal Organism

Menon *et al*. (1972) first reported *Phytophthora* sp. as the causal organism of capsule rot. Other studies identified it as *P. nicotianae* Brede de Haan var. *nicotianae* Waterhouse (Thankamma and Pillai 1973) and *P. palmivora* Butler (Radha and Joseph 1974). Later, Nambiar and Sarma (1976) reported the association of *Pythium vexans*, *Fusarium* sp. and *Phytophthora* sp. with the disease. However, studies by Nair (1979) showed that *P. nicotianae* var. *nicotianae* is the causative organism which could be successfully isolated from all infected plant parts. *P. meadii* Mc Rae A2 mating type has also been widely observed as causing *Azhukal* disease (Anonymous 1986). At present, *P. nicotianae* var. *nicotianae* and *P. meadii* are involved in causing the capsule rot disease (Chowdappa 2011; 2017; Suseela Bhai 2011).

Host range studies show that *P. palmivora* from coconut and rubber is infective to cardamom (Radha and Joseph 1974), *P. palmivora* from cardamom is infective to cocoa, coconut, arecanut, black pepper and rubber (Manomohanan and Abi 1984) and *P. meadii* from cardamom is infective to cocoa, black pepper and citrus (Sastry and Hedge 1987: 1989). Nair (1979) observed that wild *Colocasia* plants in cardamom plantations serve as collateral hosts for *P. nicotianae* var. *nicotianae*. Seven different isolates of *P. meadii* from various localities causing infection on capsules, leafy stems, rhizomes and leaves of cardamom have been characterized based on their culture characters, sporangial morphology, sexual behaviour and pathogenic virulence (Bhai and Sarma 2005;; Anonymous 1989). These seven isolates fall in two groups in their requirement for optimum temperature for growth and mean sporangial dimensions(Bhai and Sarma 2003). In single cultures no oospores are formed but when

paired with A1 mating type, five of them readily formed sex organs and oospores confirming that most of these isolates belong to the A2 mating type. The type species of *P. meadii* from cardamom readily grows on carrot agar and sporulates. The sporangia are caducous, ellipsoid, papillate and with short to medium pedicels. Although these seven isolates morphologically differ slightly, all of them were found to be pathologically virulent types. *P. nicotianae* var. *nicotianae*, survives in the soil and plant debris in the form of chlamydospores and in moist soil up to 48 weeks (Nair 1979). However, in the case of *P. meadii* no chlamydospore formation has been observed either in moist field soils or under laboratory conditions.

3.1.5 Epidemiology and Disease Cycle

Nair (1979) studied the epidemiology of a*zhukal* disease and observed that high disease incidence is correlated to high and continuous rainfall during the monsoon seasons. The number of *Phytophthora* propagules increases in soil and results in heavy disease incidence coinciding with high soil moisture levels (34.3 – 37.6%), low temperatures (20.4 – 21.3°C), high relative humidity (83 – 90.6%) and high rain fall (320 – 400 mm) during the months of June to August (Nair and Menon 1980). Presence of high level of soil inoculum, thick shade in the plantation, close spacing, high soil moisture, water logging together with favourable weather conditions such as high relative humidity, continuous rainfall and low temperature predispose the plants to *P. meadii* infection. Nair (1979) also found that the density of *Phytophthora* population reduces with increasing distance from plant base and from soil surface.

3.1.6 Disease Management

3.1.6.1 Disease Resistance

Natural capsule or panicle rot incidence on 93 genotypes were recorded on a 0-4 rating scale and 24 genoptypes were found resistant without any disease. There were 19 genotypes which were found as tolerant with 0.1 to 10 disease index range (Saju *et al*. 2014). Suseela Bhai *et al*. (1993a) also reported that some selections of cardamom as tolerant to *azhukal* disease The high yielding varieties of cardamom *viz.*, ICRI 5 and ICRI 6 which are moderately tolerant to the disease could be recommended in hot spot areas (Madhusoodanan 2012).

3.1.6.2 Biological Control

Bio-agents play an important role in disease management in a safe manner avoiding the use of expensive and hazardous chemical fungicides. Inhibition of *P. meadii* under laboratory conditions and disease suppression in cardamom nurseries have been studied by Thomas *et al*. (1991b) using *Trichoderma viride*, *T. harzianum*, *Laetisaria arvalis* and *Bacillus subtilis*. Suseela Bhai *et al.* (1993b) reported field control of *azhukal* disease using *Trichoderma viride* and *T. harzianum* and have further developed a simple carrier cum multiplication medium for *Trichoderma* application in the field (Suseela Bhai *et al*. 1994; 1997). *Trichoderma viride* and *T. harzianum* isolates harbouring native cardamom soils have been screened and effective strains for high biocontrol potential have been developed (Dhanapal and Thomas 1996). Management of a*zhukal* disease of cardamom has become effective environmentally safe and cost effective due to the biocontrol potential of *Trichoderma* sp. (Dhanapal *et al*. 2012; Thomas *et al*. 1997; Vijayan 2011; Vijayan *et al*. 1992; 1994; 2015). Application of *T. harzianum* and consortium of bacteria @ 25g per plant was found to reduce panicle and capsule infections (Dhanapal *et al.* 2012). Combined application of cashew shell extract and *T. harzianum* reduced the population of the pathogen in soil without affecting the bioagent (Ajay *et al.* 2011). Sivakumar *et al.* (2015) reported that compounds like phenols and phenolic enzymes has got a role in disease suppression as a response to *B. subtilis* application.

3.1.6.3 Chemical Control

As the outbreak of disease is during the monsoon season, disease management measures have to be initiated sufficiently in advance *i.e*. before the primary infection occurs. Earlier various types of fungicides have been extensively used for controlling the disease. Spraying and drenching of Copper fungicides such as 1% Bordeaux mixture and 0.2 % Copper oxychloride was recommended as the control measure (Menon *et al*. 1973; Nambiar and Sarma 1974; Nair 1979; Nair *et al.* 1982). Inhibition of the fungus under *in vitro* conditions was reported following treatments with organomercurials (Wilson *et al*. 1974). Nair (1979) observed 86% reduction in soil population levels of *Phytophthora* when drenched with 1% Bordeaux mixture or 100 ppm Dexon (Bay-5072). Alagianagalingam and Kandaswamy (1981) observed that the disease could be controlled by spraying the plants with 0.2% Dexon (Bay-5072) at the rate of 4 kg per ha. Although a number of fungicides have been reported to control the disease, often disease control in the field has been a challenging at various times. The factors responsible for the constraints in achieving satisfactory disease control include

lack of phytosanitation, effective and timely application schedules, high cost and unavailability of fungicides and the continuous rain that makes any fungicidal application ineffective. Thomas *et al.* (1989; 1991a) evaluated a number of contact and systemic fungicides under field conditions and concluded that two to three rounds of sprays involving one round of prophylactic spray with 1% Bordeaux mixture or 0.3% Aliette (Fosetyl-Aluminium) after proper phytosanitation effectively controlled the spread of the disease. Fosetyl-Al (0.1%) and a combination fungicide Cymoxanil 8% + Mancozeb 64% were proved effective against the disease (Dhanya *et al*. 2011; 2017)

3.2 Rhizome Rot

Rhizome rot, also known as clump rot, is a common disease occurring in cardamom plantations during the monsoon period.

3.2.1 Distribution

The disease is widely distributed throughout cardamom plantations in Kerala and Karnataka states and in heavy rain fall areas of Tamil Nadu such as the Anamalai hills.

3.2.2 Economic Importance

In severely affected areas as much as 20% disease incidence was recorded. Infections culminating in clump rot results in plant death and total yield loss.

3.2.3 Symptoms

The disease makes its appearance during south-west monsoon period. The first visible symptom is the development of pale yellow colour in the foliage and premature death of older leaves which show wilting symptoms. The collar portion of the pseudostem becomes brittle and the tiller breaks off at slight disturbance. Symptoms of rotting develop at the collar region, which becomes soft and brown coloured. At this stage the affected pseudostem fall off emitting a foul smell. Mayne (1942) reported the incidence of the disease in cardamom hills of Kerala. The tender shoots or the young tillers also turn brown coloured and rot completely. As the disease advances, all the affected pseudostem fall off from the base. The panicles and young shoots attached to this also are affected by rot. The rotting extends to the rhizomes and roots also (Thomas *et al*. 1988). Falling off shoots resulting from rhizome rot infection becomes severe during July–August months (Fig. 5b).

3.2.4 Causal Organism

Ramakrishnan (1949) reported *Pythium vexans* de Barry as the causal organism. A collection of 36 isolates of *Pythium* made during the monsoon period of 2012-13 was identified as *P. vexans* by morphological characters which indicated the prevalence of the pathogen (Bijitha and Suseela Bhai 2015).

3.2.5 Epidemiology and Disease Cycle

The disease is usually observed in previously affected area. Presence of inoculum in the soil and plant debris, overcrowding of plants, and thick shade are congenial conditions for disease development.

Fig. 5 (a) Capsule rot of cardamom, (b) Rhizome rot affected plant

3.2.6 Disease Management

3.2.6.1 Disease Resistance

A rhizome rot resistant variety of cardamom, IISR Avinash is developed which is having potential to perfrom well at water logged areas (Venugopal 2006). In a study, natural rhizome rot incidence on 116 genotypes were recorded on a 0-4 rating scale and 9 genoptypes were found resistant without any disease. There were 32 genotypes which were found as tolerant with 0.1 to 10 disease index range (Saju *et al*. 2013). A hybrid cardamom MHC 24 showed tolerant reaction to *Pythium vexans*, *Phytophthora meadii* and *Fusarium oxysporum* in screening tests (Vijayan *et al*. 2006).

3.2.6.2 Biological control

Attempts to control rhizome rot by the use of *Trichoderma viride* and *T. harzianum* was reported to reduce rhizome rot incidence in plantations (Suseela and Thomas 2010; Thomas *et al*. 1991b; Thomas and Vijayan 2003). A formulation of *T. harzianum* in a carrier medium consisting of farmyard manure and coffee husk mixture has been developed for field application in the integrated disease management strategy to control of rot diseases of cardamom (Thomas *et al*. 1990; 1991; 1994; 1996; 1997; Vijayan and Thomas 2002).

3.2.6.3 Chemical control

Phytosanitation plays a major role in disease management. Soil drenching with 1% Bordeaux mixture or 0.25% Copper oxychloride or neem oil cake at the rate of 500 g per plant followed with one round pre-monsoon and two rounds post monsoon soil drenching with 0.25% Copper oxychloride at one-month interval has been reported to be effective for controlling the disease (Thomas and Vijayan 1994).

3.3 *Fusarium* Disease

Fusarium infections in the form of pseudostem rot, stem lodging, root rot, root tip rot, leaf yellowing has gained importance in recent years especially during the summer season.

3.3.1 Distribution

Fusarium infections have been found to occur in several plantations in Idukki district of Kerala and in lower Pulney area in Tamil Nadu (Dhanapal and Thomas 1988; Thomas *et al*. 2006; Thomas and Vijayan 2002; Vijayan *et al*. 2009).

3.3.2 Economic Importance

The disease manifests itself towards the end of rainy seasons and become very severe in dry areas. Sometimes it lasts throughout the summer months. Severe root and collar infections lead to plant death and consequent loss in yield (Thomas and Vijayan 2002).

3.3.3 Symptoms

The disease attacks the middle portion of tillers in the form of pale discoloured patches, which lead to a sort of dry rotting. The pseudostem is weakened at this portion and leads to partial breakage and these tillers bend downwards and lodge. The lesion occurs at the collar region also and such tillers become brittle and break off and lacks foul smell as that *Pythium* infections. Exposed tips of roots are seen rotting. The leaves of affected tillers become yellow in colour and dried off (Fig. 6a). Drying of panicles are also seen from tip to back (Vijayan *et al*. 2009).

3.3.4 Causal Organism

The disease is caused by *Fusarium oxysporum* Schlect (Thomas and Vijayan 1994; 2002). Vijayan *et al*. (2013) studied molecular variation of *Fusarium* isolates infecting small cardamom.

3.3.5 Epidemiology and Disease Cycle

The disease is usually observed in previously affected area. Presence of inoculum in the soil and plant debris, lack of ideal shade and irrigation during summer months are congenial conditions for disease development (Thomas and Vijayan 1996).

3.3.6 Disease Management

3.3.6.1 Biological control

The biocontrol agents, *T. harzianum* and *P. fluorescens* were found to be effective in controlling the *Fusarium* infections (Vijayan *et al*. 2008; 2009; 2012). In addition, *T. viride* and *Bacillus subtilis* also was found to be potential biocontrol agents against the disease (Vijayan *et al.* 2011). Prophylactic application of *P. fluorescens, T. viride* and *Glomus fasciculatum* followed by *P. fluorescens* spray at monthly intervals during summer were also found effective (Dhanya *et al*. 2018; Thomas *et al*. 1993; 2018; Vijayan 2008; Vijayan *et al.* 1989; 2000; Vijayan and Thomas 1996).

3.3.6.2 Chemical control

Trashing and cleaning the plant base, covering exposed roots with soil during post monsoon period, mulching, providing irrigation and optimum shade minimizes the disease. Basal application of Copper oxychloride 0.2% can be given during August-September as a prophyoactic measure (Vijayan *et al.* 2012). Three rounds of spray on pseudostem and leaves and basal application of Carbendazim 50 WP 0.2% or Thiophanate methyl 70 WP 0.2% were effective (Vijayan *et al.*, 2009). Use of the combination fungicide Captan 70% + Hexaonazole 5% was found to be curative in affected plantations (Dhanya *et al*. 2018; Vijayan *et al*. 1993).

3.4 Leaf blight (*Chenthal*)

Leaf blight disease popularly known as *chenthal* has been reported in cardamom plantations. The disease occurrence is faster in partially deforested areas and less shaded plantations. Though it was reported as a minor disease, presently it is noticed in all areas and is a major concern.

3.4.1 Distribution

Leaf blight disease was first reported in cardamom plantations (George *et al.* 1976) of Idukki district of Kerala state. Since then, the occurrence of the disease has been observed in many plantations along the cardamom growing tract.

3.4.2 Economic Importance

George and Jayasankar (1979) reported reduction in plant height, panicle length and crop loss due to failure in panicle formation in severely affected plants. However, Govindaraju *et al*. (1996) studied the symptomatology in detail and found that *chenthal* infection affects only the leaves and not the plant height, panicle emergence or crop yield.

3.4.3 Symptoms

Chenthal makes its appearance mostly during the post-monsoon period and becomes severe during summer months. Symptoms develop on the foliage as water soaked rectangular lesions, which later elongate to form parallelly arranged streaks. The length of these streaks varies from a few millimeters up to 5 cm. The lesion areas become yellowish-brown to orange-red in colour and often the central portions become necrotic. Usually the two or three younger leaves on a tiller are not affected by the disease. As the disease advances more and more lesions develop on older leaves, adjacent lesions coalesce and these areas begin to dry up. Severely infected plants show a burnt appearance (Fig. 6b).

3.4.4 Causal Organism

Chenthal was originally reported as a bacterial disease caused by *Corynebacterium* sp. (George and Jayasankar 1977). They also recommended penicillin spray for controlling the disease. As later workers could neither isolate *Corynebacterium* sp. nor could control the disease with penicillin sprays, the bacterial etiology was suspected and the cause of the disease remained obscure for more than a decade. Govindaraju *et al*. (1996) conducted detailed investigations on symptomatology, etiology and management strategies of *chenthal* and have clearly shown beyond doubt that the causal organism is the fungus *Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc. The fungus closely resembles *C. gloeosporioides* causing anthracnose disease of capsule (Suseela Bhai *et al*. 1988). Both the leaf and capsule isolates showed similar cultural and morphological characters and were cross-infective to capsules and leaves and *vice versa*. However, these two isolates exhibited considerable differences in their period of occurrence, type of symptoms, distribution and spread of the

disease. Further studies also confirmed the occurrence of *C. gloeosporioides* causing leaf blight (Athulya, 2021; Praveena and Biju, 2012). Chethana *et al*. (2016) characterised isolates of *Colletotrichum* obtained from leaves of small cardamom in Karnataka, Kerala and Tamil Nadu through morphological studies and multilocus phylogenetic analysis (ITS, ACT, CHS-1, GAPDH, TUB2, CYLH3, GS and ApMat gene regions) and identified the presence of *C. karstii*, *C. gloeosporioides*, *C. siamense*, *C. syzygicola*, *Colletotrichum* sp., and *C. guajavae* as the cause of anthracnose on small cardamom for the first time. They also confirmed the pathogenicity of the above six species identified.

3.4.5 Epidemiology and Disease Cycle

The disease spread is faster in partially deforested areas and less shaded plantations. Studies were conducted to decipher the resistant nature of Malabar, Mysore and Vazhukka genotypes based on epidemiological parameters to delineate weather-disease interactions and host plant resistance. The results indicated that, Vazhukka and Mysore types might possess horizontal resistance and Malabar with vertical resistance (Biju *et al*. 2018b).

Fig. 6 (a) Fusarium infections on cardamom, (b) Leaf blight of cardamom

3.4.6 Disease Management

3.7.6.1 Biological Control

Vijayan *et al*. (2015) isolated and evaluated 29 native *Trichoderma* spp. against *Colletotrichum gloeosporioides* and found inhibitory. In dual cultures, three isolates of *Trichoderma* showed above 34 % reduction in the growth of *Colletotrichum*.

3.4.6.2 Disease Resistance

Praveena *et al*. (2013) recorded natural incidence of leaf blight among 50 cardamom accessions on a 1-6 disease rating scale and reported that IC-349613 and IC-349588 exhibited highly resistant reaction with a disease index of 9.1 and 10.3, respectively. Eight accessions were found to be resistant with 11.9 to 20.2 disease index. Similarly, natural leaf blight incidence on 142 genotypes were recorded using a 0-4 rating scale and one genoptype within disease index range of 0.1 to 10.0 was found tolerant. There were 16 genotypes which were found as moderately tolerant with 10.0 to 20 disease index range (Anonymous 2014). Sharon

et al. (2020) reported that based on screening for disease resistance, 35 accessions of cardamom were identified as resistant to leaf blight.

3.4.6.3 Chemical Control

As the disease was considered to be caused by *Corynebacterium* sp. penicillin spray was suggested as a control measure for the disease (George and Jayasankar 1977). But it was not effective and was not followed by planters. Govindaraju *et al.* (1996) reported that three sprays at monthly intervals with Carbendazim (0.3 %) or Mancozeb (0.3 %) or Copper oxychloride (0.25 %) effectively controlled chenthal disease spread in the field. Manju *et al.* (2018) found that combination fungicide (Carbendazim + Mancozeb) @ 0.2 % and Carbendazim @ 0.1 % were more effective in cardamom leaf blight disease management fallowed by Hexaconazole in arecanut based intercropping system. Athulya (2021) found that the fungus was highly sensitive to Copper oxychloride, Carbendazim, Mancozeb, Tebuconazole and Hexaconazole even at lower doses *in-vitro*.

3.5 Mosaic (*Katte* or Marble) Disease

3.5.1 Distribution and Economic Importance

The disease is distributed in all cardamom cultivating regions with incidence up to 85% with a higher incidence and severity in Karnataka (Biju *et al.* 2010). Yield loss up to 38%, 62%, and 68% for the first, second, and third year of infection respectively is reported. In general, a complete decline of the plants occurs within 3 to 5 years of infection (Venugopal 2002; Bhat *et al*. 2018).

3.5.2 Symptoms

The typical symptoms of the disease include discontinuous yellowish stripes from the midrib to the margin on young leaves (Fig. 7a). With time, the size of leaves gets reduced progressively and the plant loses vigour and remains stunted. Yellow mottling develops on leaf sheath also. Immature plants when infected rarely produce panicles and set fruits. Whereas, older plants may produce a few lean crops. Variation in symptoms could be attributed to the genotype of the host, different strains of the virus, and environmental conditions. Being systemic, the virus slowly invades all the tillers in the clump leading to the production of lean, short tillers with limited small panicles (Venugopal 2002; Biju *et al.* 2010; Siljo *et al.* 2013).

3.5.3 Causal Organism

Electron microscopy of the diseased plant showed the presence of flexuous rod-shaped virus particles and pinwheel type inclusion bodies in the cytoplasm typical to the members of *Potyviridae*. Based on the nucleotide sequence of the coat protein (CP) gene and 3' untranslated region (3' UTR), the causal virus shown to belong to the genus *Macluravirus* of the family *Potyviridae*for which the name cardamom mosaic virus (CdMV) was proposed (Jacob and Usha 2001). The different isolates of the virus could be grouped into three based on the coat protein gene sequence identitiesin which the isolates originating from Karnataka (except for the Sirsi isolate) were clustered into one group whereas Kerala isolates represented the other group (Jacob *et al.* 2003; Siljo *et al.* 2013). The complete genome of the virus consists of a single molecule of linear ssRNA of 8249 nucleotides coding for a single polypeptide (Elangovan *et al*. 2019).

3.5.4. Epidemiology and Disease Cycle

The primary disease spread occurs through CdMV infected suckers, volunteer plants, and alternate hosts while secondary spread within a plantation is through viruliferous aphid vector (*Pentalonia caladii*) which transmits the disease in a non-persistent manner. The virus is not transmitted through seeds. The primary spread may be random while, the secondary spread occurs within a radius of 40 m around the primary infection (Deshpande *et al.* 1972; Venugopal *et al*. 1997a). The latent period of the virus in the plant from infection to expression of symptoms ranges from 20 to 114 days depending on the environmental condition and growth stage of the plants. The incubation period is the lowest in young plants and during May to November, while it is the highest in older plants and during December to March (Naidu and Venugopal 1989). *P. caladii* breeds on cardamom, *Colocasia*, and *Caladium* (Venugopal 2002). Both the nymphal and adult stages of the aphid can transmit the virus. In plantations, the aphids are prevalent throughout the year, though a slight reduction in the population occurs during the rainy season. The maximum alate population is seen during November-May (Saju *et al*. 1997b).

3.6 Chlorotic Streak

3.6.1 Distribution and Economic Importance

Chlorotic streak disease was first reported from Sirsi in Karnataka. However, later surveys revealed its occurrence in all cardamom growing regions of Karnataka and Kerala with disease incidence up to a maximum of 15%.

3.6.2 Symptoms

The initial symptoms of the disease are the formation of spindle-shaped intravenous streaks along the veins and midribs (Fig. 7b). The streaks later connect giving yellow or light green colour to the veins. The petiole and pseudostem of infected plants also show spindle-shaped mottling. As disease advances, the number of tillers produced in the infected plants gets reduced (Siljo *et al.* 2012).

3.6.3 Causal Organism

Electron microscopy of infected leaves showed the occurrence of flexuous rod-shaped particles resembling the members of potyviruses. Amplification and sequencing of the conserved region of the coat protein of the virus using genus-specific primers revealed the association of banana bract mosaic virus (BBrMV) with the disease (Siljo *et al.* 2012). The complete genome sequence of BBrMV-cardamom revealed that it has 9708 nucleotides excluding poly (A) tail and has a genome organization that is similar to that of BBrMV isolates infecting banana and flowering ginger (*Alpinia purpurata*) (Bhat *et al.* 2018). The virus has a single open reading frame of 9372 nucleotides that encodes for a polypeptide of 3124 amino acids which is later cleaved into ten matured proteins. The length and arrangements of different proteins in BBrMV-Cardamom were similar to other BBrMV isolates except for the P1 protein that showed a single amino acid deletion. Diagnostic assays such as RT-PCR, real-time RT-PCR, and RT-LAMP have been developed and validated for the detection of CdMV in cardamom plants (Siljo *et al*. 2012; Siljo and Bhat 2014; Siljo *et al*. 2014).

3.6.4 Epidemiology and Disease Cycle

The infected cardamom and banana plants serve as the primary source of the virus. The secondary spread of BBrMV occurs non-persistently through aphids.

3.7 Vein Clearing Disease (*Kokkekandu*)

3.7.1 Distribution and Economic Importance

Vein clearing disease was first witnessed during 1993 in the Hassan and Uttara Kannada Districts of Karnataka, India. The disease is so far not reported from other cardamom cultivating regions of India and other countries. The disease may occur either alone or in combination with CdMV. The plants affected with vein clearing disease decline rapidly with a yield reduction of up to 84% during the first year itself. Due to the severity of the disease, many farmers in the endemic region have stopped the cultivation of cardamom (Bhat *et al*. 2018).

3.7.2 Symptoms

The initial symptoms of the disease consist of uninterrupted or intermittent vein clearing (Fig. 7c). Later rosetting, loosening of the leaf sheath, and tearing of leaves are observed. The freshly developing leaf gets intertwined in the older leaf leading to a hook-like appearance, hence the name *kokke kandu* (Venugopal 2002). With the advancement of the disease, the infected plant produces several excessively short tillers that do not produce any inflorescence and capsules leading to a total loss in yield.

3.7.3 Causal Organism

This disease is caused by the cardamom vein clearing virus (CdVCV) belonging to the genus, *Nucleorhabdovirus* and family, *Rhabdoviridae*. Virions of CdVCV are bacilliform in shape and its genome consists of a single molecule of linear negative-sense ssRNA of ~13 kb (Bhat *et al*. 2020). Assays such as RT-PCR, real-time RT-PCR, RT-LAMP, and RT-RPA are available for the detection of CdVCV (Naveen and Bhat 2020).

3.7.4 Disease Cycle

The primary source for infection includes infected clones while the secondary spread is through the cardamom aphid, *P. caladii* and the incubation period for the virus within the plant ranges from 22-128 days (Bhat *et al*. 2018; Saju *et al*. 1997b; Venugopal 1997b).

3.7.5 Management of Viral Diseases

The mosaic (*katte*) resistant variety, IISR-Vijetha is recommended for cultivation in areas where the mosaic disease is prevalent (Venugopal 1999). Because of the absence of resistant varieties against BBrMV and CdVCV the production and use of virus-free planting material is an important component in the integrated disease management package. To produce virus-

free planting material, the nurseries should be established using indexed virus-free suckers in virus-free locations (Venugopal 2002). As symptoms cannot be used as the criteria for determining virus-free nature, the diagnostics such as RT-PCR, real-time RT-PCR, or RT-LAMP would help to identify virus-free mother genotypes for subsequent propagation (Biju *et al*. 2010; Siljo and Bhat 2014; Siljo *et al*. 2014; Naveen and Bhat 2020a). In the plantations, regular monitoring, removal of infected plants including collateral hosts such as *Colocasia* and *Caladium* that serve as breeding sites of aphids are important (Saju *et al.* 1997a). Trashing of old and senile leaves followed by spraying with recommended insecticides or biopesticides would reduce vector load (Venugopal 2002). Similarly, neem products, essential oil, plant extracts, biopesticides, entomopathogens like *Verticillium chlamydosporium, Beauveria bassiana,Paecilomyces lilacinus* and predators were also found to control aphids (Mathew *et al*. 1997a; 1997b 1998a; 1998b; 1998c; 1999a; 1999b; 1999c; 1999d; Saju *et al*. 1998).

Fig. 7 Symptoms of cardamom plant infected with cardamom mosaic virus (a) banana bract mosaic virus (b) and cardamom vein clearing virus (c).

3.8 Diseases in Nurseries

Cardamom is propagated mainly through seeds in Karnataka state, which are raised in nurseries. The seedlings are retained for about 10–18 months in the nursery before they attain the age of field planting. Normally the nurseries consist of two stages, the primary nursery on raised beds and the secondary nursery in poly bags.

3.8.1 Damping Off

Wilson *et al*. (1979b) observed the incidence of damping off in young seedlings at the age of 2-3 months. Affected seedlings become pale green and wilt suddenly in masses, as their collar portion rots. Overcrowding of seedlings and excess soil moisture are the predisposing factors of this disease. The causal organism of damping off was identified as *Rhizoctonia solani* (Wilson *et al*. 1979b) and *Pythium vexans* (Nambiar *et al.* 1975).

3.8.2 Seedling or Clump Rot

This disease is similar to the rhizome rot disease in plantations. Usually, the disease is observed in nurseries where the seedlings attain an age of 6–12 months and is often seen during rainy season when the plants are overcrowded. The disease symptoms are characterized by wilting and drooping of leaves. Leaves turn pale yellow, followed by rotting of the collar portion of seedlings. As infection advances the young tillers fall off and the entire seedling collapses. The causal organisms reported are *R. solani* and *P. vexans*. In some nurseries, seedlings are affected by root rot alone. In such cases only *Fusarium* sp. was found to be the pathogen. Ali and Venugopal (1993) have reported the association of root knot nematode, *Meloidogyne incognita*, along with *R. solani* and *P. vexans*.

Siddaramaiah (1988a) reported the occurrence of seedling rot disease resulting in the wilting of seedlings. The disease is caused by *Fusarium oxysporum*. Another seedling disease caused by *Sclerotium rolfsii*, which results in the rotting of leaves, leaf sheath and leafy stem was also reported by Siddaramaiah (1988b).

3.8.2.1 Disease Management

Pattanshetty *et al*. (1973) reported that pre-sowing treatment of nursery beds with 2% Formaldehyde improved seed germination and reduced damping off incidence. Thomas *et al*. (1988) reported fungicidal control of seedling rot and damping off by soil drenching with Emisan 0.2% or Mancozeb 0.4% or Brassicol 0.2%. At present the disease is controlled by drenching 0.2% Copper oxychloride. Seed dressing with *Trichoderma harzianum* followed by one or two rounds of *T. harzianum* in nursery beds at 30 days' intervals has been found to reduce the incidence of seedling rot disease.

3.8.3 Nursery Leaf Spot

Incidence of leaf spot is a serious problem in nurseries amounting to severe loss of seedlings. The disease was reported in 1939 and the causal organism was identified as *Phyllosticta* sp. in 1942. The pathogen was studied in detail by Chowdhary (1948) who identified it as *Phyllosticta elettariae* Chowdhary. The disease occurs mainly in the primary nursery on tender leaves as minute water soaked lesions almost circular in shape with light coloured periphery and a depressed necrotic centre. This central portion later dries off and becomes papery white. In later stages, shot holes are formed at the lesion centre. As disease advances numerous such lesions of varying sizes develop and the entire leaf dries off.

Several minute dark pinheads like pycnidia of the fungus can be seen in the lesion areas. The older leaves of the seedlings are less susceptible to the disease. As the seedlings grow old they develop resistance to infection. Rao and Naidu (1974) suggested spraying with fungicides such as Difolatan (0.2%) or Bordeaux mixture (1%) or Dithane (0.2%) at 15 days' intervals.

3.8.4 Leaf Spot in Secondary Nursery

Another type of leaf spot is observed in 6–12 months old seedlings in the secondary nursery. The disease is characterized by the development of many rectangular water soaked lesions on the foliage. These lesions enlarge longitudinally and are parallely arranged along the side of the veins. As they mature, they exhibit a muddy red colour and become necrotic. The leaves dry off as too many lesions occur side by side. The disease is caused by *Colletotrichum gloeosporioides.* Spraying the foliage with Mancozeb (0.25%) is effective in reducing the disease spread (Thomas and Suseela Bhai 2002).

3.9 Minor Diseases

There are several diseases which occur sporadically in minor proportions. However, under highly favourable conditions some of them are causing concern.

3.9.1 Leaf Blotch

Agnihothrudu (1968) reported a foliar disease in cardamom characterized by typical blotch symptoms on leaves. The disease appears during June to August under heavily shaded conditions. Thick shade, continuous rainfall and high atmospheric humidity predispose plants to infection. Leaf blotch was thought to be a minor disease. However, recently it was found spreading in high proportions in certain localities. High incidence ranging from 15.8 to 92.1% was reported during 2010 and 2011 in Idukki district. The fungus infected the pseudostem and capsules also in the pathogenicity tests (Ajay *et al.* 2013).

3.9.1.2 Symptoms

Symptomatology of leaf blotch disease has been studied in detail (Nair 1979). During rainy period, round, ovoid or irregular water-soaked lesions develop on middle leaves, usually near the leaf tips or at the mid rib areas. These areas enlarge in size, become dark brown with a

necrotic centre. In moist weather, a thick, gray coloured fungal growth is seen on the underside of these blotched areas. The periphery of lesion shows a dark band of water-soaked zone as the lesions spread. The lesion areas enlarge and characteristic dark and pale brown zonations develop in the blotched areas. However, the lesion spread is limited in size following a dry period.

3.9.1.3 Causal Organism

Leaf blotch disease is caused by *Phaeodactylium venkatesanum* (Agnihothrudu 1969) and later identified as *P. alpiniae* (Sawada) M. B. Ellis (Ellis 1971). The pathogen grows profusely on the underside of leaves and also grows abundantly on potato dextrose agar medium. Hyphae are hyaline, smooth, partially submerged, 6–10 m thick, dichotomously or often trichotomously branched with conidia formed at their tips. Conidia are solitary, hyaline with three transverse septa, smooth, elliptical with tapered basal end and broad apices measuring 15–25 µm x 4–7 µm. The pathogen infects and produces typical symptoms on *Alpinia* sp., *Amomum* sp. and *Hedychium* sp.

3.9.1.4 Management

Nair (1979) observed that the fungus was completely inhibited under *in vitro* conditions by Bordeaux mixture (1 %), Bavistin (0.1 %), or Hinosan (0.15 %). Fungicidal spray with Copper oxychloride or Bordeaux mixture and Propiconazole were reported to control leaf blotch infection in the field (Ajay *et al*. 2013; Ali 1982).

3.9.2 *Phytophthora* Leaf Blight

Leaf blight incidence is observed during the post-monsoon season. The infection starts on the young middle aged leaves in the form of elongate or ovoid, large, brown coloured patches which soon become necrotic and dry off. These necrotic dry patches are seen mostly on leaf margins and in severe cases the entire leaf area on one side of the midrib is found affected. The disease appears during October –November and may even extend up to January – February. Thick shade, low night temperature and fog prevailing in isolated pockets pre-dispose the plants to leaf blight infection. The disease is caused by *P. nicotianae var. nicotianae*, which can be easily isolated from infected leaf portions using water-floating technique (Anonymous 1986; Thomas and Suseela Bhai 1995,Suseela Bhai 1998; Suseela Bhai and Sarma 2003, 2005). The infection is aerial and the infected plant debris serves as

the source of primary inoculum. The pathogen grows internally and under moist or misty conditions produce abundant sporangia, which are disseminated by wind spreading the disease to other areas. Disease symptoms are seen only on the leaves. Although *Phytophthora* is a potential pathogen infecting all parts of cardamom, the leaf blight isolate is seen specific to only leaves under natural conditions. However cross inoculations of *P. meadii* leaf isolate on capsules and *vice versa* were found to be infective on plant parts tested under laboratory conditions.

3.9.2.1 Disease Management

Leaf blight infection can rapidly spread to adjacent areas and can result in severe leaf necrosis and leaf drying unless the disease is controlled at the initial stage itself. One round of foliar spray with 1% Bordeaux mixture, Aliette 0.3% or Akomin at 0.3% were found to be effective in limiting the spread of the disease.

3.9.3 Leaf Rust

This disease appears after monsoon during October–May. Disease symptoms appear on leaves in the form of numerous yellowish rusty coloured pustules distributed on leaf surface in several patches. These are mostly seen on the underside of leaves. As disease advances, pustules or uredosori become reddish-brown in colour and they protrude out from the leaf surface. The mature pustules break open and release uredospores. In severe cases infected leaves show several yellowish patches with numerous rusty coloured pinhead spots distributed in these yellowish areas on leaf surface. These areas later dry off as the disease advances.

The disease is caused by the rust fungus *Phakospora elettariae* (Racib.) Cummins (Syn: *Uredo elettariae* Racib.). Naidu (1978) reported a mycoparasite *Darluca filum* (Biv.) Cast. hyperparasitising this rust fungus. The mycoparasite produces dark brown to black coloured pycnidia in large numbers, and they protrude out from the uredosori. The hyperparasitised uredospores shrivel off and they do not germinate. *Darluca filum* develops only in advanced stage of rust development. However, it helps to prevent further secondary spread of the rust fungus. The spread of leaf rust infection can be minimized by spraying fungicides such as 0.2% Mancozeb.

3.9.4 *Sphaceloma* Leaf Spot

Muthappa (1965) reported the occurrence of this leaf spot for the first time from Kodagu area of Karnataka. Symptoms of the disease appear on leaves in the form of scattered spherical blotches measuring a few millimetre in diameter. The adjacent lesions coalesce to form large necrotic patches. In Kodagu it was reported as a major disease problem. Although the disease is present throughout the year, its abundance and sever-ity are more during the post-monsoon period. This disease is caused by *Sphaceloma cardamomi* Muthappa. Naidu (1978) reported that Ceylon and Alleppey Green cultivars in Coorg area showed resistance to *Sphaceloma* leaf spots. Cultivars having erect panicles are mostly resistant to leaf spot while cultivars with creeping or prostrate panicles are susceptible.

3.9.5 *Cercospora* Leaf Spot

Another leaf spot occurring in Kodagu area was reported by Rangaswamy *et al.* (1968). Symptoms originate on the leaf blade as water-soaked linear lesions, which are rectangular and parallelly arranged alongside the veins. On upper leaf surface, lesions turn dark brown with dirty white long patches in the centre. In advanced stages, lesions become grayish-brown in colour and later these areas dry off. The disease is caused by *Cercospora zingiberi* Togashi Katsaki. The fungus produces conidiophores in clusters from many-celled dark brown stroma. Conidiophores are simple or branched rarely, septate, straight or curved, geniculate and often undulate at the tip and light brown coloured measuring 17.5–56 µm x 5.23–3.5 µm. Conidia are formed singly, linear, indistinctly septate with 3–6 septa, mostly curved with obtuse base measuring 37–195 µm x 1.75–2.5 µm. Naidu (1978) observed that cultivars having erect (var. Mysore) panicle are relatively resistant to *Cercospora* leaf spot compared to var. Malabar having prostrate panicles.

3.9.6 *Glomerella* Leaf Spot

Nair (1979) reported the occurrence of a leaf spot disease characterized by the presence of circular, ovoid dark brown, concentric spots on the middle leaves. This disease appears during the post-monsoon period in isolated pockets. The disease is generally seen only in var. Malabar. Infection starts as small pale yellow water-soaked lesions on leaves, which may be irregular in shape measuring 1–2 mm in size, later enlarge in size and form a depressed central area surrounded by a dark band of tissue. Later, alternate concentric dark and pale brown bands develop with yellow halo around the entire spot. Large mature spots may

coalesce and the lesion areas start drying. Sometimes the lesion areas measure as large as about 4 cm in diameter. The fruiting bodies of the fungus are seen as dark brown dot-like structures in the lesion areas.

The causal organism is identified as *Glomerella cingulata* (Stoneman) Spaulding and Schrenk. The fungus forms grayish white mycelial growth in potato dextrose agar medium which becomes dark gray with zonations. Acervuli are produced in cultures. Conidiophores short, hyaline, conidia cylindrical, hyaline and aseptate measuring 12–25µm x 3–5µm in size. Perithecia are globose dark brown coloured, ostiolate and measure 85–135 µm in diameter.

3.9.7 *Phaeotrichoconis* Leaf Spot

Itwas reported by Dhanalakshmy and Leelavathy (1976) and the symptoms formed on young and old leaves are characterized by irregular papery white spots with brown margins on leaf blade. Under moist conditions the lesions enlarge and coalesce. During dry weather the central portion of lesions dries off. Causal organism is identified as *Phaeotrichoconis crotalariae* (Salam and Rao) Subram. The pathogen grows profusely in culture and produces yellowish-brown mycelium with numerous dark brown sclerotia. Conidiophores are indistinguishable from the hyphae, conidia solitary, elongate, fusoid, straight or slightly curved and 5–8 septate.

3.9.8 *Ceriospora* Leaf Spot

Ceriospora leaf spot is seen rarely on cardamom leaves and reported from Coorg (Ponnappa and Shaw 1978) caused by the fungus *Ceriospora elettariae* Ponnappa and Shaw. The symptoms are appearance of numerous spots on the foliage, which are circular or oval, up to 8 mm diameter and they coalesce to form larger patches. The lesion centre is dirty white surrounded by light brown, circular necrotic areas.

3.9.9 Sooty Mould

A sooty mould infection on leaves of cardamom growing under the shade tree *Cedrella toona* Roxb. was reported by Nair (1979). The disease appears during January–February months when the shade trees are in blossom. Infection starts as minute scattered dark mycelial growth on the upper leaf surface. This spreads rapidly and covers the entire lamina and in severe cases extends to the petioles and leafy stems, which are later, covered with black mycelial

growth. In advanced stages, leaves tear off at margin along the veins and dry prematurely. The sooty mould fungus is identified as *Trichosporiopsis* sp.

3.9.10 Anthracnose

Anthracnose occurring on cardamom capsules was reported as a minor disease in certain localities of cultivation (Suseela Bhai *et al*. 1988). Symptoms appear on capsules as reddish brown round or oval spots of 1–2 mm diameter, often with a soft depressed centre. The lesions vary in number and size and in rare cases coalesce to form large lesions. Often less than 2 % disease incidence is noticed. However, in Anamalai areas of Tamil Nadu as high as 10–28 % incidence was noticed.

3.9.10.1 Causal Organism

Colletotrichum gloeosporioides (Penz.) Penz. and Sacc. has been shown to be the causative organism of anthracnose disease (Suseela Bhai *et al*. 1988). The fungus grows profusely in potato dextrose agar medium producing dark, gray coloured, dense mycelium. Setae are dark brown, conidia abundant, cylindrical, straight measuring 12–24 µm x 2.5–5µm. A similar infection of *C. gloeosporioides* on capsules resulting in the formation of much large lesions often extending up to three-fourth area of the capsules occur in plantations of Karnataka state. This severe form of anthracnose leads to decay and loss of infected capsules. Fungicides such as Cuman-L, Foltaf or Bavistin when sprayed 3 times at 0.3% concentration was found to control the disease. Bhuvaneswari *et al*. (2017) reported the association of *Colletotrichum falcatum* Went. on infected capsules of cardamom.

3.9.11 *Fusarium* Capsule Disease

Wilson *et al*. (1979a) reported a type of capsule disease caused by *Fusarium moniliforme* Sheld. Infection appears as small lesions on capsule rind which later decays and the lesion's periphery turns reddish-brown in colour. In severe infection, entire capsules decay during rainy period. Though the symptoms closely resemble those of anthracnose, *Fusarium* infections often leads to decay of capsules.

3.9.12 Capsule Ring Spot

A rare infection of capsules is noticed in certain plantations in Karnataka. The symptoms are characteristic reddish-brown concentric rings or zonations, which develop on capsule rind.

These areas turn necrotic and later dry off. This infection is suspected to be caused by *Marasmius* sp., however it requires further detailed investigations (Joseph and Suseela Bhai 2002).

3.9.13 *Phoma* Disease

Dhanya (2021) reported a fungal disease in various parts of cardamom hill reserves of Idukki district in Kerala. The symptoms on leaves initiated as reddish brown round to oval spots. When enlarged the centre of the spot becomes creamish white surrounded by reddish brown margin. Later these spots were coalesced to give a blighted appearance. In the advanced stages, the centre portion turned papery and shred. Similar symptoms were also observed on leaf axils and tillers. On tillers, the lesions spread to several centimeters in length at times. The affected portion had straw coloured centre with reddish brown margin. On advanced condition, the infection proceeds to the inner sheaths which split open longitudinally leading to collapse of the plant. On isolation, white to mouse black, floccose colonies with fuscus black colour on the reverse side was developed 2-3 days after incubation. The hyphae were olivaceous to dark brown with constriction near septa, branched, septate and up to 8.5 µm thick. The fruiting bodies or conidiomata were globose to sub-globose, oval and brown. Thick walled brown chlamydospores were formed in chains. The conidia were cylindrical, hyaline, smooth walled, aseptate mesuring 3.72-5.77 x 1.5-2.5 µm in dimension. Based on the morphological, microscopical and molecular studies, the pathogen was identified as *Phoma* sp. Under *in-vitro* condition, systemic fungicides like Propiconazole 25 EC, Hexaconazole 5 SC as well as combination fungicides like Captan 70 + Hexaconazole 5 WP and Propiconazole 13.9 + Difenaconazole 13.9 WP were found effective against the pathogen.

3.9.14 *Marasmiellus* Disease

Dhanya *et al*. (2021) reported the incidence of a disease on cardamom in various locations of Idukki district of Kerala during wet humid season. The symptoms developed as brown discolouration on the outer sheath. Within the sheath, pathogen developed white mycelial growth which slowly progressed to inner sheaths leading to drying and death of the tiller. On isolation, fluffy white colony was developed on culture media which later turned cream in colour and was non-sporulating with branched hyaline hyphae. The identity was confirmed by partial sequencing of ITS region which showed 99.57% similarity with *Marasmiellus* sp.

based on BLAST analysis. Among the 11 fungicides evaluated under *in vitro*, complete inhibition was shown by Mancozeb 75 WP and Copper oxychloride 50 WP as well as systemic fungicides such as Propiconazole 25 EC and Hexaconazole 5 SC and combination products *viz*., Propiconazole 13.9 + Difenaconazole 13.9 WP and Captan 70 + Hexaconazole 5 SC. +Among the bioagents evaluated, *Trichoderma* viride showed more than 55% inhibition in mycelial growth whereas, *Pseudomonas fluorescens* showed no inhibition in the growth of the pathogen.

3.9.15 Capsule Canker

Agnihothrudu (1974) reported a type of capsule spot suspected to be caused by *Xanthomonas* sp. This is locally known as Vythiri spot and was initially found in Waynad areas. Later, occurrence of the disease was observed in several cardamom plantations. Symptoms develop on capsule rind as raised shining blisters or eruptions, which are pale to silvery white in colour, sometimes extending to cover almost half the area of the capsules. The nature of the causal organism is not established beyond doubt, as no pathogenic fungi or bacterium was found associated with these spots. The disease occurs only in minor proportions and is not alarming since no crop loss is observed due to infection. However, infected capsules fetch lesser price in cardamom auctions, as these blisters are clearly visible on cured capsules.

3.9.16 *Sarocladium* Disease

Dhanya et al (2021) reported a disease on cardamom caused by *Sarocladium kiliense* (MN962925) from the cardamom growing hill tracts of Idukki. The maximum inhibition (100%) in the mycelial growth of *S. kiliense* was observed with the fungicides Mancozeb (0.3%), Carbendazim (0.1%), Propiconazole (0.1%) and Hexaconazole (0.1%), and the combination products Captan + Hexaconazole (0.05%), Propiconazole + Difenaconazole (0.1%) and Carbendazim + Mancozeb (0.25%).

3.9.17 Phyllody

Phyllody was noted in Mavady area of Idukki (Anu *et al*. 2019). Initially, the tillers show an outward bending and brittleness. In some cases, production of numerous tillers from the base was noticed and in other cases number of tillers produced and height were found reduced. The lowermost flower buds on the panicle were modified into vegetative tillers that looked similar to normal tillers and in most cases the tillers generated roots. Such tillers developed

scaly leaves which are dark green and leathery. The capsules were large, bold with very hard rind.

3.9.18 *Neopestalotiopsis* leaf blight

Leaf blight is a major foliar disease prevalent in all cardamom-cultivating tracts, manifesting in diverse forms of symptoms. In a study, six symptomatological variants were delineated based on the expression of foliar symptoms in cardamom genotypes Malabar, Mysore and Vazhukka. Subsequent isolation, morphological and molecular characterisation yielded *Neopestalotiopsis clavispora*. The pathogenicity was established on Malabar, Mysore and Vazhuka cultivars (Biju *et al*. 2018a).

3.9.19 Shoot Proliferation

This phytoplasma induced disease of cardamom was first reported in the *Njallani* cultivar during 2017 from Nedumkandam in Idukki. The symptoms of the disease included excessive shoot proliferation accompanied by stunting of stalks with fewer flowers and fruits. The associated phytoplasma was identified as '*Ca*. P. australasia' (16Sr II) subgroup D based on the sequence analysis of the conserved 16 SrDNA region. The association of 16SrII group was further established and validated by amplifying phytoplasma-specific multilocus candidate genes by utilizing specific primers of *sec*A, *sec*Y, *SAP11* and *tuf*genes (Mishra et al. 2019). The primary spread of the pathogen occurs throughsuckers collected from infected plants. Phytoplasmas are systemic in nature, hence it is essential to find and use phytoplasma-free plants for vegetative propagation of the crop. For early diagnosis, symptoms cannot be used as phytoplasma has long incubation period in the host depending on the environmental conditions particularly the temperature. Hence, accurate identification of healthy plants, use of PCR based diagnostic is required.

4 Conclusions

Fungal diseases of cardamom are relatively easier to control than the more devastating systemic infections caused by viruses. However, the use of fungicides and insecticides are being discouraged due to the strong antipathy of consumers for the use of phytochemicals. More over, the impact of climate in the cradmom tract is very evident in many ways (Vijayan *et al.* 2012). In view of the increased importance and interest in organically grown spices, it is essential to adopt the effective biocontrol strategies against the prevalent diseases.

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