M Anandaraj and R Suseela Bhai

Integrated management of *Phytophthora* diseases in spices

India is considered as the land of spices and the varying climates from tropical to subtropical to temperate favour the cultivation of one or the other spice crop. The most popular, export-oriented and most frequently used spices are black pepper, cardamom, chili, cinnamon, clove, nutmeg, mace, vanilla and seed spices such as coriander, cumin, fennel, and fenugreek besides herbal spices. The major production constraint in some of these spices is the diseases caused by *Phytophthora*. Spices are highly targeted by *Phytopthora* spp. causing serious havoc during monsoon season. Since they are export oriented and fetch a major portion of foreign exchange, the crop loss due to *Phytopthora* spp. leads to severe economic imbalance to the country.

ARANGE of *Phytophthora* spp. has been documented in diverse locations of India in association with diseases of spice crops (Table 1). Most of these diseases have both, soil and air-borne phase and occur with the onset of south-west monsoon. Cropping system and microclimate favour the incidence and spread of these diseases. The diseases can be managed only with the adoption of integrated management strategies rather than adopting individual disease control measures.

BLACK PEPPER

Foot Rot

Foot rot is the most dreaded disease of black pepper (*Piper nigrum* L.). On a global scale, an annual crop loss of around 4.5-7.5 million has been reported due to foot rot alone. In India, the disease makes its appearance mainly during the south west monsoon (June-September). All parts of the vine leaf, stem, root and spikes are vulnerable to infection.

The expression of symptoms depends on the site of infection. The infection at the collar region results in sudden death of the vine without expression of foliar yellowing. Infection of collar through roots results in foliar yellowing and ultimately leading to death of the vine. The expression of symptoms is prolonged when the infection is restricted to feeder roots and in such cases, the affected vines survive for more than three years. Infection on the foliage occurs during the south west monsoon season and starts on the tender runner shoots which gradually spreads to the upper portion of the vines through rain splashes. Adjacent vines get infected through wind driven spores carried in rain splashes.

Foliar infection is characterized by the appearance of black spots on the leaves which have typical fimbriation at advancing margins which rapidly enlarge. When infected, the tender leaves and succulent shoot tips of freshly emerging runner shoots trailing on the soil turn black and the disease

Table 1. *Phytophthora* occurring on spice crops

Major spice	Family	*Phytophthora* spp.
Black pepper (*Piper nigrum* L.)	Piperaceae	*P. capsici, P.parasitica, P.palmivora*
Cardamom(*Elettaria cardamomum* Maton)	Zingiberaceae	*P. meadii P.nicotianae*
Vanilla(*Vanilla planifolia* Jacks. ex Andrews)	Orchidaceae	*P. meadii. P. palmivora, P.capsici, and P.parasitica*
Fennel (*Foeniculum vulgare* Mill)	Apiaceace	*P. megasperma P. primulae , P. syringae*
Chilli/Capsicum (*Capsicum annum* L.)	Solanaceae	*P. parasitica var. piperina, P. nicotianae var. parasitica. P.parasitica, and P.palmivora, P. capsici P.citrophthora.*
Coriander(*Coriandrum sativum* L.)	Apiaceace	*Phytophthora sp.*
Parsley (*Petroselinum crispum* (Mill) Fuss)		*P. primulae*
Betel vine (*Piper betle* L.)	Piperaceae	*P. parasitica var. piperina P. nicotianae var. parasitica. P. capsici, P. nicotianae var. piperina, P. parasitica P. palmivora. P. parasitica and P palmivora*
Nut meg & Mace (*Myristica fragrans* Houtt)	Myristicaceae	*P. cactorum* (Java) , *P. meadii* (India)
Cassia (*Cinnamomum cassia* J.Presl)	Lauraceae	*P. cinnamomi*
Laurel (*Laurus nobilis* L.)	Lauraceae	*P. cinnamomi*

Phytophthora infection on black pepper, *(a)* foot rot affected vine; *(b)* defoliation due to foot rot; *(c)* sporangia of *Phytophthora*

spreads to the entire vine during the intermittent showers due to rain splash. When the main stem at the ground level or at the collar region is infected, the entire vine wilts, followed by shedding of leaves and spikes. The branches breakup at nodes and the entire vine collapses within a short period. When the damage is confined to the feeder roots, the expression of the symptom is delayed till the rain ceases and the vine starts showing declining symptoms such as yellowing, wilting, defoliation and drying up. This may occur during October-November months. These vines may recover after the rain and survive for more than two seasons till the root infection culminates in collar rot and death of the vine.

Integrated Disease Management

Disease free planting material: Most often the pathogens are introduced in to the plantation inadvertently through planting material as incipient infection or infected soil. The recent propagation methods involving soil free medium would ensure the planting material are free from pathogens. The production and distribution of healthy planting material is the first step in disease management.

Phytosanitation: Phytosanitation is the practice by which the plantation is hygienically maintained to prevent the onset of infection and spread of disease. The pathogen is soil-borne and the propagules are passively carried along with soil particles. In black pepper plantation, infected vines serve both as inoculum source and focus of secondary spread. Removal and destruction of partially or fully dead vines along with root system from the garden is necessary to reduce the buildup of pathogen inoculum.

Cultural practices: Cultural practices are measures taken before the onset of monsoon to protect the crops from infection by destructive pathogens as well as to prevent the development of pathogen inoculum. Being wet weather pathogen availability of excess moisture in the rainy season in the soil is congenial for the pathogen to multiply and predisposes the roots to infection. Ensuring adequate drainage prevents soil inoculums build-up. Aerial infection is favoured by humidity build-up and reduced canopy temperature due to the shade provided by the support trees. Foliar infection can be prevented by altering the microclimate at the canopy by lopping off of the branches of shade/support trees. Black pepper produces succulent runner shoots at the onset of monsoon and trail on the ground. These are the ones to take up infection first and serve as source

Biological Control

Pseudomonas fluorescens and *Trichoderma harzianum* are efficient in protecting black pepper roots from root infection caused by *Phytophthora*. Mass multiplication techniques were standardized and formulations were developed using various organic (sorghum meal, coffee husk, tea waste, decomposed coir pith, neem cake etc.) and inorganic media (talc) and as liquid formulations. The latest delivery mechanism is through biocapsules that reduces the volume of the product one hundred times. In place of one kg talc formulation ten capsules can be used. A bioconsortium was also developed with potential rhizobacteria. Recently promising endophytic bacteria, viz. *Pseudomonas putida* and Bacillus *megaterium* were identified as promising against *P. capsici* and proved effective against foot rot under field conditions. Actinomycetes belonging to the species *Streptomyces* are also identified and tested as effective in inhibiting the pathogen both *in vitro* and *in planta* and in managing the disease is also under field evaluation. Field application of biocontrol agents, viz. *T. harzianum* and *P. fluorescens* to manage foot rot disease in black pepper has got wide acceptability among the farming community as it is environmentally safe and economical. Biocontrol application has to be repeated for 2-3 consecutive years to check the prevalence of the pathogen and continuous application may also be required to maintain the population of biocontrol agents.

of further spread. The freshly emerging runner shoots should not be allowed to trail on the ground. It should be either pruned or keep tied above on a support at the onset of monsoon to prevent the infection and spread to the main stem.

Host resistance: Black pepper originated in the Western Ghats of India and the pathogen has co-evolved and there is no resistant source in any of the cultivated or wild relatives. However efforts made to locate resistance to *P. capsici* by screening the germplasm collections of ICAR-IISR, Kozhikode and a large number of cultivars, hybrids, open pollinated progenies and wild accessions have resulted in identifying moderately resistant lines and released as IISR Shakthi. A seedling progeny of IISR Shakthi viz. 04-P24 was also found to be resistant to *P. capsici* and is under field evaluation. From among the germplasm of *Piper,* related species viz. *P. colubrinum* and *P. arboreum* are found resistant to *P. capsici. P. colubrinum* is susceptible to virus diseases and the late incompatibility deters its use as resistant rootstock.

Chemical control: Since this disease occurs during monsoon, a fixed fungicide schedule is being followed as a prophylactic method for aerial infection. In disease prone areas, prophylactic spraying of 1% BM to all the vines with the onset of south west monsoon and drenching the plant basins at a radius of 45-50 cm with 0.2% copper oxychloride @ 5-8 litres/vine and repeating this after about 45 days is effective in managing the disease.

Once the foliar infection is seen, a systemic fungicide like metalaxyl (100 ppm) or potassium phosphonate (3,000 ppm) is recommended. A second application of the same can be given during August-September or as an alternative, first round with copper fungicides and a second time with systemic fungicides during August-September is also recommended. A third round of drenching during October is preferable to check the proliferation of the soil borne inoculums in severely disease prone areas. Potassium phosphonate is reported to move fast in black pepper plant from the site of application reaching the tip and downwards to the root system showing its amphimobile nature and leaves no residue in the soil. Application of the metalaxyl six months prior to harvest was recommended to prevent traces of metalaxyl residues in the final product.

Use of certified planting material: As mentioned earlier, pathogen free planting material is the foremost requirement for the production of disease free planting material. Since the pathogens is soil-borne and the propagules are passively carried in the adhering soil particles, it is recommended that the planting materials must be collected from disease free gardens and certified nurseries raised preferably in disinfested soil to prevent the spread of inoculum in a newly planting garden. Good agricultural practices and phytosanitation helps to reduce the incidence spread to a greater extent.

Disinfestation of nursery mixture: Solarization or steam sterilization of nursery mixture (soil: sand: FYM-1:2:1) followed by fortification with biological control agents like *T. harzianum/ T. viride* or *P. fluorescens* help in preventing the build up of pathogen inoculum. Since nematode infestation is a common problem in nurseries, the nursery mixture can also be fortified with *Pochonia chlamydosporia*, nematicidal fungi especially root not nematode *Meloidogyne incognita.* The mixture can also be incorporated with vesicular arbuscular mycorrhizae viz., *Glomus mossae, G. fasciculatum, and Acaulospora laevis, Gigaspora margarita,* which are suppressive of nematodes also.

A combination of VAM and other biocontrol agents can also be used to get healthy robust planting material. Studies on the rejuvenative capacity of fluorescent pseudomonas in black pepper indicated the potential of these strains for nursery management of black pepper, especially to protect the plants from *P. capsici* infection. Recently Streptomyces species were identified as growth promoters as well as biocontrol agents against *P. capsici.*

Chemical control: After the establishment of plants in the nurseries, spraying with either 1% Bordeaux mixture and drenching the soil with 0.2% copper oxychloride or spray cum drenching with metalaxyl – mancozeb 0.125% or spraying potassium phosphonate 0.3% at monthly intervals is recommended for preventing the incidence and spread of *Phytophthora* rot in nurseries.

CARDAMOM

Capsule Rot

The disease is locally known as 'Azhukal' meaning rotting. Occurrence of the disease is noticed with the onset of south west-monsoon which becomes severe during August-September and continues to prevail up to November, depending on rainfall conditions. Capsule rot is very common and severe and frequently observed in Idukki and Wayanad districts of Kerala and in isolated pockets of Anamalai hills in Tamil Nadu where no plant protection measures are taken on time. During years of heavy and continuous rainfall, severe disease incidence and crop losses has been reported.

The symptom of the disease appears as water soaked lesions on young leaves and capsules which enlarge to spread the entire capsule at the initial stages of infection. Infected capsules show dull green discoloration which develop into rotting. Rotten capsules are shed from the panicle emitting a foul smell. Visible symptoms of rotting appear simultaneously on capsules and leaves or first on capsules followed by lesions on leaves. The disease is caused by *Phytophthora meadii* Mc Rae of A2 mating type. Presence of soil inoculum, thick shade in plantation, close spacing, high soil moisture and water logging together with favorable climatic conditions such as low temperature, high relative humidity and continuous rainfall predisposes the cardamom plant to infection.

Phytophthora Leaf Blight

Leaf blight is another *Phytophthora* infection in cardamom occurs during the post-monsoon season of October-November and may even extend up to January-February. Thick shade, low night temperature and fog prevailing during the winter period pre-dispose the plants. to leaf blight infection. The infection starts on the young and unopened leaves as water soaked patches which soon become necrotic and dry off. A burned appearance is seen under conditions of severe infection in the plantations. The disease is caused by *P. nicotianae var. nicotianae*, which can be easily identified from infected leaf using water-floating technique.

Phytophthora infection in cardamom. a) capsule rot affected plant; b) infected panicle; c) *P. meadii* causing capsule rot; d) leaf blight

Integrated Disease Management of Capsule Rot

As the incidence of the diseases is closely associated with monsoon showers, any plant protection operation has to be initiated prior to initiation of primary infection. To achieve maximum protection from *Phytophthora* infection, the following management strategies have to be followed.

Phytosanitation: The capsules rot affected cardamom plant parts serve as the reservoir of inoculum for next season's disease incidence. Hence, removal and destruction of the infected plant parts along with root system from the plantation is necessary to reduce the buildup of inoculum. In cardamom plantations, trashing- a process followed to remove all dried up leaves and leaf sheath from basal portions of the plant has to be done regularly and at the onset of monsoon.

Cultural practices: Soil moisture plays an important role in the buildup of inoculums of *Phytophthora,* besides predisposing the plant to infection. So water stagnation must be prevented. This is done by providing adequate drainage channels that reduces the chance of multiplication of *Phytophthora* in water stagnant areas. Other important practice to be adopted is to facilitate adequate penetration of sunlight by regulating the overhead shade by lopping of the branches of shade trees. Shade lopping greatly alters the microclimate of the canopy and helps in reducing the primary disease incidence. Injury to the root system due to cultural practices like digging should be avoided. Earthling up is another practice where the plant base is protected from water stagnation by heaping soil around the plant

Chemical control: In cardamom early detection of the disease and timely application of adequate plant protection measures are important in managing capsule rot disease. As the incidence of the disease is closely associated with monsoon rains, any plant protection operation has to be initiated prior to initiation of primary infection. The first round application of fungicide should be given with the onset on south west monsoon for which, spraying 1% one per cent Bordeaux mixture or simultaneous drenching the plant basin with 0.2% copper oxychloride prior to the onset of monsoon is very effective in destroying the soil inoculum. This could effectively control the spread of the disease. Alternatively fungicides like fosetyl - aluminum (0.2%) or potassium phosphonate (0.3%) can be sprayed @ 500-750ml / clump. Application of fungicides after the commencement and spread of disease had only little of effect. Three rounds of Spraying alternate rounds of Bordeaux mixture and metalaxyl-mz 0.12% is also effective in reducing the disease incidence.

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 Bordeaux mixture 1% or potassium phosphonate at 0.3 % during the post monsoon season during September –October is effective in limiting the spread of the disease.

Biological control: Soil application of *T. harzianum* and *Bacillus subtilis* are recommended in the biological control of the disease. *T. harzianum* mass multiplied on suitable carrier media like coffee husk or farmyard manure or neem cake may be applied at the plant basins@1kg during May and September-October. Soil amendments with neem cake activate the growth of native *Aspergillus, Trichoderma* and actinomycetes species which are antagonistic to the pathogen .

Integrated disease management is possible by one initial round foliar application of potassium phosphonate (0.3%) with two subsequent rounds of

soil application of *Trichoderma harzianum* having a cfu of $2x10^9$/g. If the soil is drenched with copper oxychloride or other fungicides, *Trichoderma* should be applied only after 15 days.

Disease resistance: Two cultivars each of Mysore and Malabar types' viz. MCC 60, 61, 12 and 40 (ICRI selections) were found moderately tolerant to Azhukal disease. Planting moderately resistant lines are also to some extend reduce the disease incidence. Two cultivars each of Mysore and Malabar types' viz. MCC 60, 61, 12 and 40 (ICRI selections) were found moderately tolerant to Azhukal disease.

VANILLA

Stem and Bean Rot

Vanilla the second costlier spice is also not an exception to *Phytophthora* infection. Bean rot is a severe disease in vanilla incited by *P. meadii* which has also been isolated from infected leaves, stem and roots. The disease was noticed in many vanilla plantations of Karnataka and Kerala. The disease appears during the onset of south west monsoon causing rotting of beans initially, rotting symptoms develop at the tips of beans, spreads to the whole bunch. Affected beans are soft, brown colored and show abundant mycelial growth. In later stages, the disease advances to the stem, leaves, aerial roots and extend towards the basal portions. The whole vine shows decaying symptoms and the entire vine perishes. The disease is caused by *P. meadii*.

Phytophthora infection on vanilla; (a) stem rot; (b) bean rot

Excess shade in the plantations, continuous rains, crowding of vines, water logged conditions and presence of *Phytophthora* inoculum in the field are the pre-disposing factors for the advancement of this disease. The fully infected bunch falls off in 10-15 days emitting a foul smell. In advanced stages of infection, the rotting extends to the stem and leaves also. The pathogen could be isolated from affected beans, stems, leaves and aerial roots. Excess shade in the plantations, continuous rains, crowding of vines, water logged conditions and presence of *Phytophthora* inoculum in the field are the pre-disposing factors for the advancement of this disease. Occasionally, species of *Phytophthora* was also found associated with shoot tip rot and die back disease.

Phytophthora infections in nutmeg: (a) leaf and fruit fall (b) leaf infection

Tip Rot and Die Back

The symptoms of tip rot or die back start at the funnel like tip which extends to the intermodal regions resulting in the rotting of the tip. Disease is caused by *Phytophthora meadii* in case of *Phytophthora* rot, the fungus forms thick white mycelial cover along the water soaked black lesion.

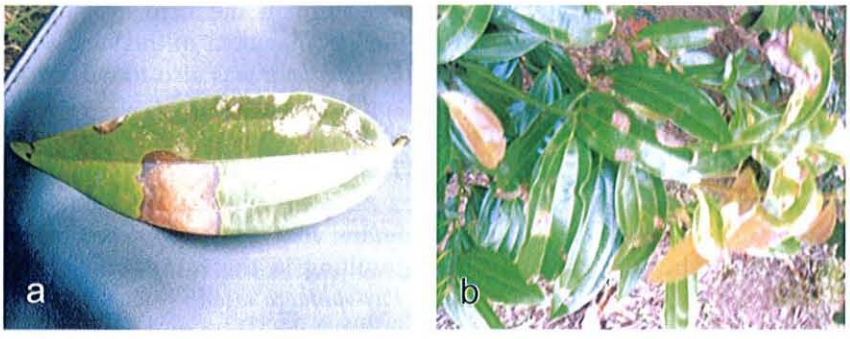
Integrated Disease Management

Excess shade in the plantation, overcrowding of vines, continuous and heavy rains, waterlogged conditions and presence of pathogen inoculum in the field predisposes the plant to infection by *Phytophthora* sp. The infections can be managed to a greater extent by removing and destroying the infected plant parts and mulch during rainy season. In case of tip rot, nip of the infected tip below the next node prevent the spread of infection. Shade lopping to regulate the overhead canopy to allow at least 30-50 % light to fall on the vines, during monsoon period prevents the buildup of humidity .. Spraying 1% Bordeaux mixture and soil drench with 0.25% copper oxychloride 2-3 times depending on the severity of infection and as prophylactic measure helps to prevent the incidence and spread of the disease. Spraying potassium phosphonate 0.4% is also effective in reducing the incidence.

Phytophthora on Tree Spices

Nutmeg (*Myristica fragrans*) is one of the major tree spices prone to the attack of *Phytophthora*. It is cultivated as an intercrop in coconut and arecanut gardens. The plant is susceptible to a number of diseases of

which fruit rot caused by *Phytophthora* species is a severe problem. The disease appears during the monsoon season when there is heavy and continuous rain fall. Symptoms are expressed only on half matured or unripe fruits which later turn brown in colour followed by premature splitting of the pericarp and rotting of the mace and seed. The infection on the fruit stalk results in dropping of the fruit. The disease is also characterized by severe defoliation. In case of leaf fall, symptoms appear as dark brown water-soaked lesions on the midrib of the leaves which enlarged and spread along the lateral veins to leaf lamina resulting in blighting. Petioles of the infected leaves showed black discoloration. Black lesions were also observed on young shoots which enlarge resulting in rotting and drying up of shoots from the tip downwards. Leaf and stem infections resulted in extensive defoliation. Based on detailed morphological and molecular investigations the causal organism was identified as *Phytophthora meadii.*



Leaf infection in Cinnamon caused by *Phytophthora* sp.

In recent years, prolonged dry spell for almost six months followed by continuous rains for two months have resulted in the sudden spurt in *Phytophthora* infections in nutmeg plantations. The adverse weather conditions certainly predispose the tress to infection.

In clove (*Syzygium aromaticum* L.) of family *Myrtaceae*, *Phytophthora* was reported to be associated with Sumatra disease. Seedling wilt was also found to be caused by *Phytophthora* species along with *Colletotrichum*, *Fusarium* and *Rhizoctonia bataticola.* The Genus *Cinnamomum*, belongs to the family *Lauraceae* is highly prone to infection by *Phytophthora* spp. The most important disease of cinnamon is stripe canker by *P. cinnamomi*, which causes severe damage to forest trees. The pathogen was reported from other species of cinnamon viz s *C. camphora*, *C. culitlawan* and *C. sintok.* In Indonesia Stripe canker is found on the trunks and branches, particularly of young trees of *C. verum* and *C. burmannii.* Vertical stripes are seen on the stems with amber colour exudates that harden later at the advancing margins. Vertical stripes of dead bark are most numerous near ground level. A recent survey conducted in Kodagu district of Karnataka revealed the incidence of foliar infection in *Cinnamon zeylanicum* characterized by the presence of reddish brown spreading necrotic areas on the margin of the foliage. Two different growth of *Phytophthora* was isolated from the same lesion indicating the presence of two different species of which one isolate showed 99% similarity to *P. citrophthora.*

Disease Management

In case of tree spices phytosanitation by removing the infected and fallen leaves / nuts from the basin is very essential to reduce the inoculum load and further spread of the disease. Prophylactic spraying with 1% Bordeaux mixture before the onset of south west monsoon prevents the development of the disease. Once the disease appears, spraying the same can be done at 20-25 day interval twice to prevent the spread of the disease.

CONCLUSION

Disease management is most successful and economical when all available pertinent information on the crop, epidemiological data and environmental and human health concerns are taken into account. If more than one pathogen occur at the same time, combination products are more effective. In spice crops, integrated management strategy is most appropriate as they are perennial and the disease occurrence is dependent on monsoon. Phytosanitation plays a crucial role crucial in reducing the initial inoculum followed by fixed fungicide spray as prophylactic measure. Predisposing factors such as soil condition needs special attention. Soil health management has also to be taken in to account to maintain the pH and organic carbon so that sustained availability of nutrition is assured and the survival of biological control agents such as *Trichoderma/ Pseudomonas* is ensured. Since major diseases are soil borne and often inadvertently carried from the nursery to main field, introduction of pathogen from the planting material has to be avoided by resorting to planting disease free planting material. The accreditation facilities available for pathogen detection have to be used effectively for production and distribution of planting material.

For further interaction, please write to:
Drs M. Anandaraj and R. Suseela Bhai (Scientists), ICAR-Indian Institute of Spices Research, Marikunnu PO, Calicut 673 012, Kerala.