MANAGEMENT OF *PHYTOPHTHORA* INFECTIONS IN BLACK PEPPER

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Among the diseases of black pepper, 'foot rot' (quick wilt) caused by *Phytophthora capsici* ('*P. palmivora*' MF_4) is the most destructive. The disease is prevalent in all the pepper growing countries, and in Brazil infection due to fungus *Fusarium solani* is relatively more widespread (Oliveira and Pereira, 1983). *P. capsici* affects all parts of the pepper vine. Its infection on the underground parts namely roots and collar results in 'foot rot' (quick wilt) causing outright death of the vines. The external symptoms are usually manifested during September and October. Infection on aerial parts like leaves and spikes occurs during south west monsoon period and spreads rapidly under favourable micro-environment causing varying degrees of defoliation and occasionally complete destruction of the vines in severe cases. The aerial symptoms usually appear 2 or 3 weeks after the onset of the south-west monsoon. *P. capsici* being a wet weather pathogen is quite exacting in its requirements of physical environment and so the infections are mainly confined to the south-west monsoon period (June-September). But expression of aerial 'wilt' symptoms might be delayed some times because of late season infections or slow progress of infection due to onset of adverse conditions.

As far as disease management is concerned, soil-borne *Phytophthora* spp. are difficult pathogens to deal with (Ribeiro, 1978) because of their ability to:

(1) Survive in soil at considerable depths and thus become inaccessible to the action of fungicides as well as

antagonistic microflora which usua--lly does not thrive at these depths (2) Produce perennating structures like chlamydospores and oospores that can withstand extreme environmental conditions (3) Produce secondary inoculum from primary survival structures and (4) Produce motile disseminating structures called zoospores that can spread both aerially (through rain splashes and wind-borne water droplets) and in soil having high moisture regimes resulting in severe infections with amazing rapidity.

In black pepper the problem of disease control is further compounded since all parts of the plant are susceptible and prone to infection. Added to this, most of the popular cultivars are highly susceptible. This further clubbed with highly favourable microenvironment coinciding with the availability of abundant suscept tissue in the gardens, narrows down our option in disease management to chemicals. As a result fungicides continue to be the sole tool for control atleast until the availability of host resistance or a viable method of biological control. However, only about 10% of the farmers are known to adapt chemical control measures in Kerala and Karnataka, where the disease is widely prevalent. In view of the severity of *Phytophthora* infections in black pepper, the control methods such as chemical, cultural and biological including host resistance may not individually offer acceptably good levels of control unless integrated to supplement one another. Disease management employing different cultural, chemical and biological means is discussed in this paper.

CULTURAL METHODS

Cultural practices render the microclimate inhospitable to the pathogen in a garden are relevant. They will enhance the effectiveness of the fungicides used because fungicide dose required is directly proportional to the quantity of inoculum (Richardson and Munnecke, 1964) and may also further increase the useful life of the fungicides and resistant cultivars which will otherwise be lost in the situations of high disease pressure. The following are some of the important cultural operations.

Provision of good drainage conditions

Water stagnation is the single most important factor as far as *Phytophthora* diseases are concerned

(Ribeiro, 1978). High soil moisture levels are required to activate survival structures of *Phytophthora*. Poor internal drainage and excessive water were associated with *P. cinnamomi* infections on avocadoes (Zentmyer and Richards, 1952) and with foot rot of betelvine (Singh and Chand, 1973). Flooding is known to affect the balance of metabolites in root exudates (Mc Manmon and Crawford, 1971) which finally influence the chemotaxis of zoospores towards roots (Allen and Newhook, 1973). High soil moisture also helps in diffusion of root exudates over longer distances (Stanghellini and Hancock, 1971). Since water helps in spreading the inoculum in black pepper gardens (Sarma and Nambiar, 1982) provision of good drainage conditions would reduce the severity of infection.

Growing cover crops

Cover crops are generally recommended to reduce the spread of *Phytophthora* diseases (Ribeiro, 1978). Retention of grass and legumes in pepper gardens was found effective in Sarawak (Holliday and Mowat, 1963). Our studies also (Table I) agreed with this (Fig. 1). The cover crops reduce the movement or spread of contaminated soil in a garden through surface water and rain splashes. These crops enhance the organic matter content of top soil and might increase the activity

Table I: *Effect of cover crop (grass and* Mimosa *sp) on the incidence of black pepper foot rot*

Treatment	Total vines	Vines infected (%)
With cover crop		
Block–I	94	4.2
Block–II	56	8.9
Without cover crop		
Block–I	89	10.1
Block–II	88	13.6

Fig. 1. Grass cover maintained in a pepper plantation

of antagonistic microflora. In avocadoes this is achieved by underplanting with cover crops like legumes or through addition of straw and organic fertilizers (Broadbent and Baker, 1975).

Minimum tillage

In perennial crops, tillage results in root damage which is harmful to the plant. Since pepper is grown as a mixed crop in arecanut and coconut gardens etc. cultural operations cannot be avoided totally but utmost care should be exercised during these operations and restricted tillage may be resorted to wherever possible. Minimal tillage also increases populations of beneficial organisms and biological control of pathogens (Baker and Cook, 1974).

Phytosanitation and eradication

Use of disease free planting material is the first step towards the establishment of a healthy crop. Black pepper *Phytophthora* being soil-borne pathogen, is very difficult to control once it gains entry into a garden. Usually the runner shoots are collected for preparation of rooted cuttings. It is a common practice with many farmers to plant these runner shoots directly in the field. Runner shoots meant for raising rooted cuttings should never be collected from infected gardens since they are prone to infection due to soil contamination. Utmost care should be exercised while collecting source material for the nurseries. Since the nursery soil can harbour both nematodes (Anonymous, 1986) and *Phytophthora,* it is advisable to use fumigated nursery mixture for raising rooted cuttings. This avoids introduction of these pathogens into newly established or previously uninfected gardens. The first visible symptoms appear on the runner shoots. The infected tissues produce profuse sporulation of the fungus which form a dangerous source of inoculum for further disease spread. Their immediate removal combined with a fungicide application would help in arresting or atleast reducing the rate of spread of infection.

According to Sastry (1982) '*P. palmivora*' present in the infected plant material does not survive from one season to another. But the fungus survives for more than an year in the debris mixed with the soil (Anonymous, 1986) and in mounds of infected plants (Kueh and Khew, 1982). The infected plants be completely uprooted and burnt as they form potential source of inoculum. The soil in the root zones of such plants should be treated with fungicide because the propagules are known to occur at higher levels in the root zones (Ramachandran, Sarma and Nambiar, 1986).

Shade regulation

The micro-climate in the pepper garden is rendered more favourable to the disease because of the dense canopies of live standards/supports, grown to train pepper and for shade. This factor attains importance during the season when the macro-climate is not continuously favourable. Our studies have shown that low temperature, shorter duration of sunshine, high relative humidity and rainfall contributed to the increase in foliar infection (Ramachandran et al., 1988). High relative humidity is required for sporulation by all species of *Phytophthora* that sporulate aerially on host surfaces (Waterhouse, 1931). Pruning of overhead canopies of trees in a garden prior to the onset of south-west monsoon helps in better sunlight penetration, which in turn reduces the leaf wetness, relative humidity, besides increasing the temperature within the plantation. Even marginal changes in these factors might be significant in reducing the disease considerably. In case of late blight of potato, the reduction in foliage due to earlier infection is known to change the micro-climate and also to reduce the foliar infection (Hirst and Stedman, 1960).

CHEMICAL CONTROL

Protectant fungicides

For a very long time protectants and soil sterilants were the only means of control for diseases caused by oomycetous fungi. According to Schwinn (1983) the *Phytophthora* infections on roots and crowns that are locally systemic and the local infections on hypocotyles, crowns and roots are difficult to control with conventional protectants that lack systemic action, whereas the foliar infections can be controlled to some extent. The era of protectants started with 'Bordeaux mixture' (Millardet, 1885). This copper based fungicide has been in use for over a century and has some advantages compared to other related compounds. They are: (1) High tenacity on foliage; (2) Higher solubility of copper in this formulation compared to other fixed copper compounds and (3) Remain of the earlier applications are known to promote better adhesion of the fungicide applied later (Martin and Worthing, 1976).

Bordeaux mixture is used against *Phytophthora* in black pepper in India, the practice being spraying the foliage with 1% and pasting the collar region of the vines with 10% mixture (Fig. 2). besides drenching the soil with 1% Bordeaux mixture or 0.2% copperoxychloride. This treatment is given once before the onset of south-west monsoon in May/June period and again during August/September.

Fig. 2. Bordeaux paste application to the collar of the pepper vine

In the field control experiments Bordeaux mixture spray combined with soil drenching with ceresan wet (0.1% @3 lit. per vine) had given good control of the disease (13.3% incidence in treated vines compared to 41.9% in control) (Anonymous, 1976) but the results obtained in subsequent years were inconsistent (Anonymous; 1979; 1981).

Treatment consisting of one pre-monsoon collar pasting coupled with two sprays with Bordeaux mixture during May/June and July-August is reported to give good control (Sasikumaran et al., 1981). According to Mammootty, Abicheeran and Peethambaran (1979), Agallol, Bayer 5072, Thiride, Dithane Z - 78, Dithane M-45, Ziride and Bordeaux mixture were effective when applied two hours before inoculating the leaves. Different adhesives are advocated with Bordeaux mixture in order to improve its tenacity (Abicheeran, 1981) but adhesives did not improve the retention of Bordeaux mixture in arecanut (Anandaraj, 1985).

Most often the conventional fungicides fail to give acceptable levels of control because (1) The main infection sites namely roots and underground collar portions are not accessible for treatment; (2) Loss of protective cover of the fungicide on the treated plant surfaces due to heavy rainfall; (3) Insufficient coverage of the foliage with a single premonsoon spray because of continuous new flush emergence following pre-monsoon showers; (4) In most cases these are applied erroneously as curative treatments by the farmers.

Systemic fungicides

Systemic fungicides effective against *Phytophthora* spp. in particular and oomycetes in general were not available for a long time because of some physiological and biochemical peculiarities of these fungi (Bruin and Edgington, 1983). They are: (1) Unlike many fungi they contain glucan and cellulose in addition to chitin in their cell walls. This makes them insensitive to polyoxin antibiotics; (2) They don't require sterols for vegetative growth (McCorkindale, 1976; Elliot, 1977) and their inability to synthesize sterols renders them insensitive to one of the most important groups of fungicides namely 'Sterol Biosynthesis Inhibitors' (3) Presence of tubulin proteins and enzymes that are different from those of other fungi makes them insensitive to benzimidazoles (Davidse, 1986), oxathiin and hydroxypyrimidine fungicides.

With the advent of highly effective systemic fungicides in the seventies, the chemical control of diseases caused by oomycetous fungi has taken a new turn (Schwinn, 1979; Staub and Hubele, 1980; Schwinn, 1983; Bruin and Edgington, 1983; Schwinn and Urech, 1986; Cohen and Coffey, 1986). Though a few chemicals having systemic activity against *Phytophthora* spp., were introduced in sixties their use was, however, limited because of different reasons. Chloroneb introduced in 1967 (Bruin and Edgington, 1983) showed high activity against oomycetes but was withdrawn later due to phytotoxicity. Pyroxychlor the first fungicide to show good basipetal translocation in plants was also withdrawn because of its toxic side effects inspite of its excellent control of some of the *Phytophthora* diseases (Spencer, 1977).

Five systemic fungicides namely metalaxyl, fosetyl-Al, ethazole, propamocarb and oxadixyl were evaluated for their effect on different stages of the life cycle of *P. capsici* (Ramachandran, 1990) and the field performance of the first three fungicides. Ethazole and metalaxyl were the most toxic to mycelial growth of the fungus. Ethazole followed by metalaxyl, fosetyl-Al and oxadixyl were effective in inhibiting the sporangiogenesis (Table II). Though fosetyl-Al was less toxic to mycelial phase of the pathogen it showed good activity on sporangial production and also on spore germination. These characters of metalaxyl and fosetyl-Al must have contributed to their good performance in controlling the disease in pot culture (Ramachandran and Sarma, 1985a) and also in field condition (Table III). Following soil application, metalaxyl was readily taken up by the pepper plants and its systemic activity was noticed even one hour after the application. Its inhibitory effect persisted in the plants for 50 days (Ramachandran and Sarma, 1985b). Residues were not detectable in pepper samples harvested from vines treated with metalaxyl (Ramachandran, 1990).

Though ethazole was highly effective on different stages of the life cycle of the pathogen *in vitro* the results obtained under field conditions were not satisfactory. Its low water solubility and limited soil mobility (Helling, Dennison and Kaufman, 1974) might account for its poor performance because water solubility is considered to be an important attribute of a fungicide in order to be effective against oomycetous fungi in view of their

Table II. *Effect of systemic fungicides on different stages of the life cycle of* Phytophthora capsici

Treatments	Mycelial growth	Sporangial production	Zoospore release	Zoospore germination
Metalaxyl	++*	++	—	—
Fosetyl-Al	—	++	—	++
Ethazole	++	++	—	+
Oxadixyl	—	++	+	+
Propamocarb	—	+	+	+

++* = High efficacy + = Low efficacy — = No effect

Table III. *Efficacy of fungicides in the control of foot rot of black pepper*

Location	% Disease incidence (vine death)				
	Metalaxyl–Ziram	Fosetyl-Al	Ethazole	Bordeaux mixture (1 %)	Control
Kannara	5.0	10.0	30.0	20.0	27.5
Thiruvambady	1.6	10.0	11.6	13.3	20.0

aqueous habitats (Kerkenaar and Kaars Sijpesteijn, 1981; Bruin and Edgington, 1983).

Metalaxyl was highly effective in suppressing soil population of *P. capsici* and no mortality was seen in seedlings planted in contaminated soil treated with 100 μg/ml of the fungicide. None of the fungicides could completely inhibit the lesion expansion when they were applied as post symptom treatments. Metalaxyl at 200 μg/ml concentration showed the highest lesion inhibition of 87.9%.

Compatibility of metalaxyl with insecticides and nematicides

Spraying insecticides to control 'pollu' beetle (*Longitarsus nigripennis*) and fungicides to control *Phytophthora* are undertaken simultaneously in black pepper. Hence studies were carried out on the compatibility of metalaxyl with insecticides like endosulfan and quinaalphos which are effective against 'pollu' beetle. These insecticides were fungitoxic and at their recommended doses against the insect namely 500 μg/ml they could completely inhibit the growth and sporangia production by *P. capsici in vitro* (Tables IV) (Ramachandran and Sarma, 1988). These insecticides also showed their fungitoxicity *in vivo* (Table V). Metalaxyl was compatible with these insecticides and also the nematicide carbofuran. Based on these studies the insecticides and metalaxyl can be mixed and applied together, the advantages being (1) reduction in the cost of application as a single spray can control both 'pollu' beetle and *Phytophthora,* (2) possible reduction in the dose of fungicide, and (3)

Table IV. *Effect of endosulfan and quinalphos on growth and sporulation of* Phytophthora capsici

Treatment	ED_{50} (μg/ml)		Concentration (μg/ml)			
	Cornmeal agar	Carrot agar	10	50	100	150
			Sporangial inhibition (%)			
Endosulfan	56.1	52.8	26.2	81.5	88.5	89.5
Quinalphos	58.4	276.7	8.6	6.4	Not tested	92.5

use of insecticide as a partner with systemics which are required to be admixed with contact fungicides as a counter-measure to cope fungicide resistance.

BIOLOGICAL CONTROL

Besides naturally occurring disease suppressiveness (Weste and Marks, 1987), certain nitrogenous organic amendments are known to suppress different *Phytophthora* species in soil (McIntosh, 1972; Tsao and Zentmyer, 1979; Zentmyer, 1963; Tsao and Oster, 1981). However, in the field conditions since *Phytophthora* can survive at considerable depths, it is not easily accessible to the action of antagonistic microflora. Tsao and Oster (1981) attributed the suppression of *Phytophthora* population following urea and chicken manure amendments to formation of ammonia and nitrous acid which are toxic to the fungus. Different amendments are known to increase the activity of antagonistic microflora by increasing the organic

Table V. *Effect of endosulfan and quinalphos on* P. capsici *infection in black pepper*

Treatment	No. of lesions/ 4 plants	Mean lesion diam. (cm)
Endosulfan	1	1.3
Quinalphos	3	0.2
Control	13	1.2

matter content of the soil. In Australia, infertile gravel and sandy soils containing low organic matter are known to be conducive to *P. cinnamomi* compared to red basaltic soils and red brown earths with high organic matter which are disease suppressive (Weste and Marks, 1987).

With regard to black pepper *Phytophthora*, the available information on the effects of different amendments are preliminary. Cotton seed meal and groundnut cake (Dutta, 1984) are reported to suppress '*P. palmivora*' in soil. Neem cake applied to soil also could reduce the foot rot to a limited extent.

DISEASE RESISTANCE

Black pepper is known to have originated from the Western ghats of the Malabar coast in Kerala. Hence this state forms a rich source of cultivated and wild pepper germplasm. Since the process of natural selection for resistance to *Phytophthora* must have been in operation for a long time, the available germplasm on proper evaluation may give valuable plant material having resistance or tolerance. This if incorporated with other disease management practices would help in solving the problem of foot rot disease to a larger extent. Until 1987, 140 cultivars, 174 hybrids, 72 wild types of pepper and a large number of seedlings raised from OP seeds were screened for reaction to *Phytophthora capsici* at National Research Centre for Spices, Calicut. Among them tolerant reaction was shown by 15 cultivars, 12 hybrids and 50 OP seedlings. These plants are at different stages of field evaluation. Some of the cultivars namely Narayakodi, Kalluvally, Uthirankotta and Balankotta showed some tolerance to *Phytophthora* (Sarma, Nambiar and Nair, 1982).

EPIDEMIOLOGICAL CONSIDERATIONS IN DISEASE MANAGEMENT

Though fairly good amount of information is available on the epidemiology of *Phytophthora* infections of black pepper, the chemical control measures are still based on fixed application schedule. A survey in Calicut and Cannanore districts, Kerala revealed that in most cases application of Bordeaux mixture is resorted to only as a post-symptom application. Some of the epidemiological aspects of the *Phytophthora* diseases in black pepper are discussed here in the context of chemical control. The points raised may be of relevance in view of the availability of systemic fungicides for the control of *Phytophthora* diseases.

Early detection of the disease

An early detection of the disease in a garden is very much important, because, apart from being easy to control, the measures adapted will be highly effective at this stage both in cost and efficacy. Our studies have revealed that the infections first appear on the tender leaves and succulent stems of the runner shoots that emerge at the base of the vines following the pre-monsoon showers (Ramachandran, Sarma and Anandaraj, 1990). The first visible symptoms of infection were noticed two to three weeks after the onset of monsoon and after about 249 to 318 mm of rainfall (Ramachandran, et al., 1988). These infections on the runner shoots serve as a warning and also as an early indication of the presence of the pathogen in the garden in an active state. Because of profuse sporulation on the affected leaves and stems, these early infections serve as a potential source of inoculum for the secondary spread of the infection. An early detection followed by prompt hygeinic practices like removal of infected shoots and fungicide application to the soil results in good control of the disease. Wilting of vines due to collar/root infection is seen mostly towards end of the monsoon in August and September, when it is too late and difficult to save the vines. Studies are to be conducted to know the exact time of root infection and the connected external symptoms. Through isolation the presence of the pathogen can be confirmed but an early symptom will serve as a better indicator to the farmer for identification of the disease.

Effect of flushing and foliar application of fungicides

It is often noticed in the field that the infections occur on tender foliage that is produced after the premonsoon spray with Bordeaux mixture. This is because premonsoon showers trigger the production of new foliage and spikes which will continue up to August depending on the monsoon pattern. Hence, a single application of any contact fungicide fails to protect the foliage produced later. In fact a majority of the tender and the most susceptible leaves is left unprotected.

Our studies on the rate of flushing conducted during 1986 have shown that the ratio of new leaves to that of old leaves present at the beginning of the season reaches its maximum by the last week of June in case of Panniyur-1 and first week of July in Karimunda. After this the rate of production of new leaves comes down. Bordeaux mixture spraying in such cases before these dates doesn't ensure protection to most of the foliage unless the spraying is repeated at frequent intervals. Thus the first spraying should be timed to coincide with maximum emergence of new foliage which depends on the premonsoon showers.

Progression of foliar infection and the relevance of second application of Bordeaux mixture

Our studies have shown that the foliar infection shows a rapid decrease after the first fortnight of August. According to the present recommendation Bordeaux mixture is sprayed on to foliage before the onset of Northeast monsoon in August-September period. Eventhough wilting due to root and collar infection is seen during this period, the infection would have occurred quite early when the climate was highly favourable to the pathogen. So the second foliar application with Bordeaux mixture is relevant only when foliar infection continues due to prolonged monsoon.

Due to various reasons somehow the existing chemical control schedule with copper fungicides is not widely practiced inspite of pepper being a high value crop and also serious losses caused by the disease. It was found that only about 10% of the farmers adopt chemical control methods that too mostly as a post symptom application. In view of the different aspects already discussed in this paper, it calls for an urgent need to formulate a flexible and need based application schedule taking into consideration the available information on epidemiology of the disease and efficacy of systemic fungicides. Since highly effective systemic fungicides are available for the control of *Phytophthora*, the cost effectiveness of these chemicals can be enhanced if they are applied at the critical periods of the disease to obtain maximum control possible.

Thus the cultural, chemical and biological methods including host resistance will further strengthen our strategies of managing *Phytophthora* infection in black pepper.

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