FOOT ROT DISEASE OF BLACK PEPPER (*PIPER NIGRUM* L.)

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Foot rot (Quick wilt) is the major disease affecting black pepper (*Piper nigrum* L.) causing severe crop loss, thus limiting pepper production in all pepper growing tracts of the world. The fluctuations in production and consequent changes in market prices have been partly attributed to the crop loss incurred due to foot rot. The problem has been reviewed previously by Muller (1936) Holliday and Mowat (1963) and Nambiar and Sarma (1977).

History and distribution of the disease.

The first report of sudden collapse and death of the pepper vines came from Lampung (Indonesia) in 1885. It was Muller (1936) who identified the causal agent as *Phytophthora* sp. and named it as *P. palmivora* var. *piperina*. In Sarawak (Malaysia) the disease was reported in 1941 (Newman, 1941; Thompson, 1941) and the severe out-break occurred in 1952 (Miller, 1953). In India the report on the incidence of root diseases of black pepper dates back to 1902 (Menon 1949) when Barber (1902, 1903, 1905) and later Butler (1906, 1918) investigated the disease in Wynad (Kerala); however these investigations were inconclusive. Although *Phytophthora* sp. isolation was reported from black pepper in Mysore area (Venkata Rao, 1929) the first authentic record of *Phytophthora* wilt of black pepper in Kerala came from Samraj and Jose (1966) who adopted Muller's identification of *Phytophthora*. The disease was also reported from Puerto Rico (Gregory, Almeyda and Theis, 1960), Brazil (Holliday, 1965, Albuquerque, 1966, Alconero *et al.*, 1972), Jamaica (Leather, 1967) and Thailand (Tsao and Tummakate, 1977). Involvement of *P. palmivora* in the large scale deaths of pepper vines in Sambirano river in the north western part of Malagaican of Malagasy Republic has been reported (de Waard, 1979).

Crop losses

The disease is soil borne, associated with high soil moisture and spreads through soil water. It is more destructive in areas of monoculture as in Sarawak. In India Samaraj and Jose (1966) recorded vine death up to 20% in Cannanore District (Kerala) while Nambiar and Sarma (1977) recorded 25-30% loss in some gardens in Cannanore and Calicut districts. A similar loss was recorded in Sarawak (Robertson, 1955). In Sarawak during 1953-56 the pepper loss was about 7000 tons amounting to £ 1.7 million (Holliday and Mowat, 1963). Vine death of about 10% was redcorded in West Borneo (Leefmans, 1934.) An out break of foot rot occurred during 1967-68 in Lampung area destroying 40-50% of pepper area (de Waard, 1979). The overall loss due to foot rot in major pepper growing countries of the world, when estimated at 3-5% loss of the total planted area, would amount to US $ 4.5-7.5 million per annum (de Waard, 1979).

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Symptoms

There is a general similarity of the disease symptoms in all pepper growing countries. All parts of the plant are susceptible and as such exclusive root rot, collar rot, aerial vine death, leaf infection or spike infection either alone or in different combinations may occur. Foliar infection is not fatal as compared to collar and root rot.

(i) **Foliar infection** : Direct infection of the foliage often occurs apart from foliar symptoms expressed as a result of collar and root rot. Leaf infections generally appear in the lower region of the bush, and might be due to soil splashing during heavy rains. However the authors observed leaf infection even at 3-4 m height of the bush in some plantations in Kerala and Karnataka. These are in conformity with the observations of Turner (1969b). Leaf infection can start from any part of the lamina and appears as water-soaked lesion with smooth or fimbriate margins, which advance rapidly. The mature lesion will be about 0.5 cm or more and dark, some times covering up to half of the lamina. They are either uniformly smooth or may show concentric zonations. Muller (1936) failed to observe the zonate pattern in lesions which were reported from Sarawak (Holliday and Mowat 1963). Turner (1969b) observed that the different types of lesions reflected different conditions of incubations. Under continuous humid conditions fimbriate lesions develop and, when wet and dry conditions alternate, zonate pattern results. Irrespective of the type of lesions heavy defoliation occurs due to leaf infection. Immature leaves are highly susceptible than mature ones and the lower surfaces of leaf is more susceptible than upper surface (Turner 1969b).

Spike infection results in their heavy shedding. The infection occurs at stalk portion resulting in its necorosis which progresses along the floral axis. Occasionally berries also get infected. Aerial infection of the stem occurs at any point of the vine, even at a height of 2-3 M. The infected region turns dark due to wet rot. The foliage of the infected twig turns yellow and drops off. The rotting progresses both upwards, and downwards and often results in die-back.

(ii) **Collar and root rot infection** : The infection of collar and root goes undetected until the appearance of foliar yellowing. Infection occurs either at the collar or just above or below the soil level. The infected portion appears slightly dark at the point of attack. When the cortex of the affected portion is chopped off, it shows the healthy yellow patch followed by a necrotic area. The vasculature of such infected stems turns darker. Vascular discolouration up to 0.5 m beyond the point of infection has been observed in many cases but not consistently (Nambiar and Sarma 1977). With progress of the disease the cortex gets disintegrated and peeled off. The rotting progresses further into soft medullary tissues leaving the xylem strands loosened. The infection of the collar gradually progresses downwards and spreads to the root system. Occasionally one vertical half of the stem alone is involved in the infection leaving the other half normal. A careful study is needed further to understand the mechanism underlying such type of rotting. In some bushes a single vine dies leaving the adjacent vine on the same standard unaffected. The general absence of foot rot in young vines might be due to disease escape rather than to juvenile resistance, since young vines succumb when inoculated artificially.

Apart from collar rot infections which spread to the roots, exclusive root infection occurs. The infection generally starts on tender lateral roots and progresses towards the mature root reaching finally the underground stem. Random infections at irregular intervals on the lateral roots are also seen, possibly due to the fungal invasion at some injured points. The number of roots affected and the extent of rotting determine the speed of death of the infected vine (Muller, 1936; Holliday and Mowat, 1963; Nambiar and Sarma, 1977). In general the affected vine may succumb within 15 to 45 days after infection depending upon the severity of the damage of the affected parts.

Intervenal chlorosis is the first foliar symptom of root and collar rot. Foliar yellowing, flaccidity, defoliation, breaking off of the stems at nodal regions and spike shedding are the general aerial symptoms noticed in the case of root rot and collar rot. Holliday and Mowat (1963) reported that cultivation of pepper in mounds favoured root rot infection. Both collar and root rot infection are common in India, where mound cultivation is not the practice. While collar infection is more common in slopy lands, root rot is common in the plains on level lands.

Isolation of organism

Holliday and Mowat (1963) reported successful isolation of *Phytophthora* from fresh lesions of foot rot affected stems and roots of black pepper using plain agar medium. Isolation from the tissues of advanced stage of infection were always negative. Turner (1964) reported successful isolation from the soil using apple bait technique. The authors experienced difficulty in isolation of *Phytophthora* both from infected tissues and soil using apple, castor seed, cacao pod and pepper leaf disc baits. This might be due to quick colonisation of infected tissues by saprophytic bacteria, *Fusarium*, *Rhizoctonia* and *Pythium* sp.. The authors were successful in selective isolation of *Phytophthora* from foot rot affected tissues and from soil with pepper leaf disc baits using PVPH medium of Tsao and Guy (1977).

Taxonomy and biology of the causal organism

Except in Brazil where *Fusarium solani* var. *piperi* appeared to be the major causal agent of foot rot (Albuquerque, 1961), *P. palmivora* has been identified as the causal agent of foot rot of black pepper in all other countries. Recently *P. capsici* has been reported from Indonesia (Kasim, 1978; de Waard, 1979).

In recent times taxonomy of *Phytophthora* in general and *P. palmivora* in particular received a greater attention with respect to the sporangial morphology, caducity and chromosome type (Tsao, 1977a; Griffin, 1977; Kaosiri, Zentmyer and Erwin, 1978; Brasier and Griffin, 1979). Turner (1969b) referred isolates from *Piper betle* and *P. nigrum* as atypical strains of *P. palmivora*. Waterhouse (1974) recognised black pepper isolates (BP) as atypical (Piper form) of *P. palmivora* which differed from morphological forms 1 and 2. The sporangia of black pepper isolates are ovoid, obovoid, pyriform or fusi-form which are caducous with long occluded pedicels. However isolates from Sarawak were reported to be non-caducous with no pedicel (Holliday and Mowat, 1963). The black pepper isolates from Thailand showed unique sporangial morphology in that they are highly caducous with long pedicels, with biseptate sporangia and umbellate type of

sporangial arrangement. The sporangia with tapered base showed L. B. ratio of 2.5 and that with rounded base 1.8. Further the isolates from Malaysia, Central America and Africa had similar morphology as that of Thai isolates and are considered to be Morphological from 4 (MF 4) of *P. palmivora* (Tsao and Tummakate, 1977). Caducity of black pepper isolates was influenced considerably by the medium. Studies on length of the pedicel in 4 isolates showed a range from 37.3 to 73.4 (AL-Hedaithy and Tsao, 1979a, 1979b). Idosu and Zentmyer (1978) opined that BP isolates are similar to MF4 of *P. palmivora* of cacao. The isolates from Thailand probably have chromosome number n = 9-12 (Brasier and Medeiros, 1978). According to Brasier and Griffin (1979) the BP isolates from Sarawak, Thailand and Peurto Rico showed petalloid type of colonies with dense aerial mycelium, sporangia with shallow papilla with base tapered towards the stalk, with long occluded pedicels and are similar to MF4 of *P. palmivora* and opined that it should be given a species status.

The fungus grew luxuriantly at 25-28°C on oats agar (Turner, 1969b) and growth was absent at 35°C. Sporulation was maximum at pH 6.0 and absent at PH 3.0 (Turner 1969a). Zoosporangial germination in sporulating discs in water was noticed even at 20-24°C; however when cold shock was given at 10°C for 15-20 min, the germination was enhanced (Sarma and Nambiar, unpublished). Turner (1962) reported oospore formation in BP isolates of Sarawak when the cultures were stored for 2-3 months. Homothallic oospore formation in single A1 or A2 compatible types in 3 out of 7 BP isolates was noticed when aged inoculum of about 12 months old, was plated on oats agar (Tsao, 1979). Ageing of the cuture appears to have direct relation to sex organ formation. Holliday and Mowat (1963) obtained oospore formation when BP isolates of Sarawak were paired with *Phytophthora palmivora* isolates from cacao or *Citrus reticulata*. The authors observed the oospore formation in BP isolates when paired with *P. palmivora* isolates from cacao or rubber. When two compatible types of BP isolates inoculated on pepper leaves and incubated at 20°C in dark, oospore formation was noticed and was absent at 30°C (Brasier, 1969a; 1969b). Brasier opined that oospore formation was likely to occur in nature, though rarely and their production was confined to woody tissues or debris, which were protected from light. *Trichoderma viridae* stimulated oospore formation in *P. palmivora* in BP isolates (Brasier, 1972). Presence of both A1 and A2 compatible types was noticed in BP isolates in Sarawak (Brasier, 1978). Formation of oospores by *Phytophthora* in response to *Trichoderma* has been hypothesised as a defense response to potential antagonist or competitor and is important from the point of survival of the fungus. The *Trichoderma* effect was confined to A2 mating types and the stimulus was volatile in nature. Out of 4 BP isolates tested 3 showed mixed response to "Trichoderma effect" (Brasier, 1975, 1978). Oogonia in BP isolates were morphologically similar to 'S' chromosome (MFI) type, often oval, and on carrot agar golden coloured and turned dark when treated with acetorcein (Brasier and Griffin, 1979.)

Toxin

The pathogen being a necrotroph, primarily colonises the parenchymatous tissues of cortical region and brings about their disintegration and creates a condition similar to that under water stress resulting in death of the vine. Typical vascular browning is noticed in the stems and roots of affected vines. The fact that vascular browning is noticed beyond

the point of infection suggests the possible involvement of toxemia in disease syndrome. Incidentally Lee(1973) reported toxin production by BP isolates and it was related to virulence. He used toxin as a marker to screen pepper varieties for foot rot resistance. Keen *et al.* (1975) reported the presence of mycolaminarins and B-1 glucans in the mycelium of *P. cinnamomi*, *P. palmivora* and *P. megasperma* var. *sojae* and they were phytotoxic to soybean, cacao and tomato shoots. The authors found that cell free culture filtrates from BP isolates of *P. palmivora* could induce vascular browning and flaccidity of leaves in cut shoots of pepper (Anonymous, 1977a).

Spread

Flow of surface water and root contact between healthy and infected plants appear to be the primary mode of disease spread. In hilly terrain, the vines in the valley get infected early and the infection spreads gradually, more downwards, supporting the view that spread is mainly through soil and water. In the plains, infection occurs in a sporadic manner and spreads to the adjacent vines. The spread is rapid in neglected plantations with infected vines around.

We studied the spread of the disease in an arecanut plantation having pepper as an intercrop and observed that within two years, about 250 vines died. Regular irrigation as well as cultivation in the gardens could have aided the quick spread of the pathogen. Incidentally the authors could isolate *Phytophthora* from drainage water in some arecanut gardens intercropped with pepper where foot rot incidence was noticed in Sirsi area of Karnataka. Role of irrigation water in causation and spread of disease in betel vine plantations has been reported (Singh and Chand, 1973).

The rate of spread appears to be much more rapid in Sarawak, and it has been ascribed to the prevalence of continuous wet seasons coupled with application of large amounts of organic fertilizers and bare soil cultivation without any weed growth. Movement of farm personnel from diseased to healthy gardens and usage of same farm implements in these gardens also help in disease spread (Holliday and Mowat, 1963). They have proposed that the grass cover and weed growth in Indian pepper plantations may be impeding the spread of the pathogen.

Vines of all age groups are infected under field conditions. However, the incidence is less common in vines during the first three years after planting and maximum incidence is noticed after the first five years.

Muller (1936) and Holliday and Mowat (1963) have suggested that infection of leaves in the lower region of the bush might be due to rain splash only. Turner(1969b) observed that number of leaves exhibiting leaf lesions was more at lower heights of the vines than at the top and felt that heavy rainfall and wind could contribute to aerial spread of the disease. Aerial transmission of zoospores of *P. palmivora* has been reported in coconut (Briton-Jones, 1940), rubber (Chee, Lim and Wastie, 1967) and cacao (Thorold, 1952).

Many agents aid the dispersal of the zoospores of *Phytophthora* (Turner, 1964, 1967). *Phytophthora* has been recovered from the faeces of the giant African snail, *Achatina fulica*, which often feeds on infected foliage. He opined that this might serve as an effective

mode of spread during the hotter months of the year. Spores of *Phytophthora* have been isolated from the ant runs of *Crematogaster* (Turner, 1972). The ants carry the spores with soil while constructing tunnels on posts supporting pepper vines and thus spread the spores. The authors isolated *Phytophthora* from the soil deposited by termites on the live standards in a few infected bushes. This perhaps suggests the possible passive spread of the disease propagules during off season. Viable chlamydospores of *P. cinnamomi* have been found in the intestinal tracts of termites (*Nasutitermis exitiousus*) and faeces of two species of forest birds indigenous to West Australia Jarrah forests and thus serving as vectors of the pathogen (Keast and Walsh, 1979). Studies are warranted on various biological agents as disease carriers and these are of epidemiological importance for a better understanding of the disease spread during off season.

Climatic factors

The disease incidence is generally high during the South-West monsoon (June-September), in Kerala, India when rainfall (2270-2990 mm) and relative humidity (91-99%) are high and minimum temperature (19-23°) is low. In Sarawak, maximum disease incidence was observed during October-March when the mean maximum and minimum temperatures are about 26°C and 21°C. The mean rainfall during the period is 318-653 mm and daily mean sunshine 4.3 hr (Holliday and Mowat, 1963). The pathogen was successfully isolated in 60% of cases during October-March, but only in 43% during the dry months (April-September). Sarawak does not have a long dry season as the west coast of India has. On overcast days with low mean sunshine hours and heavy rainfall, the temperatures generally fall, and such conditions are conducive for spore release.

The ambient temperature plays an important role in the infection process. When the pathogen is inoculated on rooted cuttings, symptoms of root necrosis and foliar yellowing appear in 3-4 days when inoculated plants are incubated at 20-25°C. The symptom expression is delayed when the temperature is 28°C and above (Nambiar and Sarma, 1977). In one year old cuttings, symptoms appeared only after 35 days at 28-30°C. Selvaraj (1966) working on betel vine wilt in Tamil Nadu found that wilt incidence was maximum (100%) at low soil temperature (20-23°C). The incidence of betel vine wilt was maximum during December—January period when the temperatures fall below 23°C (Rao, Vidyasekharan and Narasimhan, 1969).

In pure pepper plantations in India, the disease generally becomes apparent during the south-west monsoon period. In mixed cropping systems such as pepper in arecanut gardens (which are generally irrigated during the dry period), the disease is noticed during the post monsoon period (November-January) also. Since during the winter months, the minimum temperature falls to 16-21°C and soil water content remains high due to frequent irrigations (once in 4-5 days), the microclimatic factors are very congenial for fungal growth, sporulation and zoospore emission.

Soil factors

In India, Nambiar *et al.* (1965) observed heavy incidence of the disease in neglected pepper gardens where inorganic fertilizers were not being applied. Kliejunas and Ko(1974) reported that deficiency of inorganic nutrients contributed to the heavy incidence of Ohia

decline (*Metrosideros collina* (Forst.) Gray subsp. *polymorpha* (Gang.) (Rock) associated with *P. cinnamomi*. Broadbent and Baker (1974) reported that exchangeable Ca, Mg, N and organic matter were high in soils suppressive to root rot of avocado caused by *P. cinnamomi* as compared to soils conducive to the incidence of root rot. Application of super phosphate had a suppressive effect on betel vine wilt in Tamil Nadu (Thyagarajan *et al.*, 1972). Working with quick wilt, Nambiar *et al.* (1965) reported that surface soils in diseased gardens contained lower levels of Ca, Mg, and K with high N. They suggested that if the ratios of K/N, available K/N and $CaO + MgO + K_2O/N$ fell below 1.14, 0.05 and 3.80 respectively, then the area would be prone to the disease. Huber and Watson (1974) found that the type of nitrogenous source also determined disease incidence in several root diseases involving Pythiaceous fungi.

Since the final outcome of root rot and foot rot caused by *Phytophthora* is gradual wilting simulating a stress syndrome, information on the plant and soil water relationships of healthy and diseased plants, and the effect of water potential on the fungus are essential, for a better understanding of the disease etiology and management in black pepper wilt. Although the major pepper crop is rainfed, pepper intercropped in arecanut gardens with regular irrigation, is more vulnerable, and regulation of soil moisture becomes more important to reduce the disease. In a recent study on *Phytophthora* root rot of avocado on water relation, the symptoms were similar to water stress resulting from low xylem pressure potential due to increased resistance to flow in the soil plant system even in well watered soils (Sterne, Kaufmann and Zentmyer, 1978). At present no information is available on soil water relations and the effect of nutrition on the incidence of pepper wilt. Hence such studies are warranted in this line.

Survival

Holliday and Mowat (1963) observed that *P. palmivora* from pepper survived for about 15 weeks in naturally infected underground stems. The authors could isolate the fungus from the infected soil stored for 4 months. The pathogen, however, has a low saprophytic ability (Holliday and Mowat, 1963). Survival of *P. palmivora* of rubber for about 32 weeks in soil was reported (Chee, 1973). Brasier (1969a) observed oospore formation *in vitro* when two compatible types of the pathogen were present under congenial conditions of low temperature (20°C), darkness and adequate food supply. Oospore formation has been presumed to occur in nature though rarely, in woody tissue or debris not exposed to light. We have not however been able to notice oospores so far in infected tissues. Holliday and Mowat (1963) also did not observe any fusion organ in nature. Although the survival of the fungus is reported to be for about 15 weeks, the exact mode of survival is not known. Fluorescent labelling techniques with brightners (Tsao, 1970) or fluorescent antibody techniques (Macdonald and Duniway, 1979) might be useful in studies on survival of the fungus, since oospore formation is not noticed in infected tissues. The mode of perennation and population build up of the pathogen during different seasons and under varied soil, water, and temperature regimes are to be studied in depth for developing effective control measures.

Host range

P. palmivora has been recorded to infect 138 species belonging to different families

of angiosperms (Chee, 1969) Turner (1971a) reported that the isolates of *P. palmivora* from pepper in Sarawak were highly host specific and none of the 43 species from 40 genera, belonging to 20 families other than the Piperaceae, was susceptible. Out of 32 *Piper* species tested, 30 species including *P. betle* were susceptible. All the seven *Peperomia* spp. were resistant. Further the leaves of *Lycopersicon esculentum*, *Solanum melongena* and *Vinca rosea* and fruits of *Areca catechu* and *S. melongena* were also occasionally infected under laboratory conditions. The authors found that *P. palmivora* isolates from pepper in Kerala infected roots of *P. betle*, *P. longum*, *P. attenuatum*, cacao pods, tender leaves of rubber, castor, and caused mild rotting of capsules of cardamom. *Phytophthora* isolates from cacao, cardamom, betel vine, palmyrah, oil palm, areca and *Ficus* showed differential reaction on leaves and root system of black pepper. Pepper gardens in the vicinity of rubber plantations usually show heavy incidence of pepper wilt. The information on positive cross inoculation of different *P. palmivora* on pepper, though important, is not of epidemiological significance unless the same strains are isolated from the infected pepper tissues. The pepper isolates examined so far by the authors are distinct from the *P. palmivora* from rubber, cacao, palmyrah and cardamom. Holliday and Mowat (1963) reported that *Phytophthora* isolates from *Colocasia* and cacao did not infect leaves of pepper, while an isolate from citrus did. According to Muller (1936), *Phytophthora* isolate from pepper in Indonesia showed similar characters in culture to those from coconut, rubber, cacao and papaya. Isolates of pathogen from pepper were, however, less virulent to the other host plants than those from the respective hosts.

Role of other associated organisms.

Holliday and Mowat (1963) have often isolated *Rhizoctonia solani* and *R. bataticola* from the roots and stems of pepper. They appear to be the earliest colonisers of *Phytophthora* infected tissues. The present authors have also made similar observations. We have isolated *Pythium* sp. from tender discoloured roots of pepper vines showing foliar yellowing and also from roots of quick wilt affected vines. Incidentally, Holliday and Mowat (1963) have frequently isolated *P. splendans* from small roots of pepper in Sarawak causing damping off in pepper seedlings.

The authors have isolated *Trichoderma* sp. from the roots of healthy pepper vines and also noted lysis of mycelium of BP isolate of *Phytophthora* when *Trichoderma* sp. overgrown over the former in the culture plates. *Trichoderma* as biological control agent of betel vine wilt (Tiwari and Mehrotra, 1968), root rot of avocado (Zentmyer, 1963, 1967) and of many other *Phytophthora* diseases has been reviewed (Baker and Cook, 1974). However the reports of Brasier (1978) regarding the response of *Phytophthora* to *Trichoderma* in oospore formation has been opined as of 'survival value' and needs further investigation on its utility as a biological control agent.

The plant parasitic nematode *Meloidogyne incognita* and *Radopholus similis* are being increasingly observed in pepper plantations. Holliday and Mowat (1963) observed that infestation by *Meloidogyne* sp. did not significantly enhance the susceptibility of pepper vine to foot rot. Selvaraj (1966) also made similar observations on betel vine wilt in Tamil Nadu. However, critical studies of the fungus–nematode interaction (Powell, 1971)

are required to be carried out in the case of pepper under conditions of both pure cropping and mixed cropping.

Resistance

Muller (1936) reported the black pepper variety Belantung from Indonesia as resistant to foot rot. Holliday and Mowat (1963) found the Indian pepper cultivar Uthirankotta and the Indonesian varieties Djambi and Belantung possess appreciable resistance. However, the present authors tested 40 Indian cultivars including Uthirankotta and 45 wild types adopting root dip inoculation technique (Sarma and Nambiar. 1979) and found all of them to be susceptible. Uthirankotta has also been found to be susceptible in Puerto Rico (Alconero *et al.*, 1972) and Sarawak (Turner, 1973a). Turner (1973a) however, found Balancotta to be highly resistant. The observations of differences in reaction of a particular type may be attributed to the differences in virulence of the isolates of the pathogen.

As already reported, Turner (1971a) screend 32 *Piper* species and found that *P. colubrinum* and *P. obliquum* var. *eximum* were resistant. Albuquerque (1968a, b) had earlier reported resistance in *P. colubrinum* in Brazil. In Ghana, *Piper guineense* has been reported to be resistant (Anonymous, 1977b). Ruppel and Almeyda (1965) reported that out of five *Piper* species tested, *P. aduncum, P. scabrum,* and *P. treleasanum* showed partial resistance. Several workers in Puerto Rico, U.K, Brazil, and Malaysia (Sarawak) have successfully grafted *P. nigrum* on to a number of *Piper* spp., both resistant and partially resistant (Gaskins and Almeyda, 1969; Garner and Beakbane, 1968; Albuquerque, 1968a, b; Turner 1973a). However, field establishment has been reported only in the combination involving *P. nigrum* and *P. colubrinum* (Albuquerque, 1968a, b., Gaskins and Almeyda, 1969). Grafts with root stocks of pink form of *P. colubrinum* with 'Kuching' variety as scion, grew much faster as compared to root stocks of green form of *P. colubrinum* and no signs of degeneration of graft union was noticed even after 4 years (de Waard, 1979). In some combinations involving *P. colubrinum* and cultivars like Balancotta, Kalluvalli, and Singpuri, Alconero *et al.* (1972) observed that longitudinal cracks developed at the graft union after a normal growth of four years. The incompatibility of the grafts might be due to anomalous secondary growth and consequent poor callus growth.

Control

Only limited success has been achieved in controlling the disease with fungicides in trials carried out in Malaysia (Sarawak) and India. Holliday and Mowat (1963) reported that heavy doses of a copper oxide (Perenox) reduced the disease incidence slightly when it was forked into the soil in the basins of the vines. Using Actidione was also suggested to control foot rot and root rot of pepper (Lee and Verghese, 1974.) In Indonesia, Harper (1974) recommended copper fungicides against *Phytophthora.* Among the ten different commercial formulations of fungicides tested by the present authors as foliar sprays and soil drenches around the vines, before and after South West monsoon, only Bordeaux mixture spraying and application of Bordeaux paste to the stem from the collar region to a height of about one meter reduced the incidence. In tests against betel vine wilt in India, spraying and drenching the soil with Bordeaux mixture alone checked the disease (Narasimhan *et al,* 1976). None of the 29 chemicals tested by Turner (1973b) was fungicidal,

He opined that concentration-volume-time interaction determined the efficacy of the formulation and soil permeability would be a major factor in penetration. In Sarawak, captafol has been reported to be useful as a soil drench against *P. palmivora* (Anonymous, 1972). We, however, did not find it to be effective. Recently, Noveroske (1975) reported pyroxychlor (Dowco 269) which is known to have basipetal translocation, to be effective against *P. parasitica* in tobacco. But in our *in vitro* studies this fungicide was ineffective even at 2000 ppm concentration. Suppression of root rot of avacado caused by *P. cinnamomi* by alfalfa meal (Zentmyer, 1963), suppression of *P. cinnamomi* and *P. parasitica* in 0.1% urea amended soils (Tsao and Zentmyer 1979) and also suppression of root rot of citrus caused by *P. nicotianae* var. *parasitica* using several organic amendments (Tsao, 1977b) are of greater relevance to the black pepper foot and root rot problem. In view of high rainfall conditions at a stretch for 3-4 months during South West monsoon period in India and consequent leaching off of the soil fungicides applied as a prophylactic measure, greater stress should be on biological control aspects, manipulating microbiological status of the soil suppressive to the pathogen, and thus ensuring a better protection and boosting up the health of the vines. Agronomic practices like earthing up around the vine ensures greater root regeneration, and consequently the health of the vine, since ratio of root regeneration to root degeneration determines the health of the vine (Nambiar and Sarma, 1977). Better drainage conditions helped in reducing the foot and root rot of pepper in Sarawak (de Waard 1979). Lysis of mycelium of *P. cinnamomi* and sporangial abortion was reported when the organic matter of the soil was 50% or more (Nesbitt, Malajczuck and Glenn, 1979).

Holliday and Mowat (1963) and Nambiar and Sarma (1976) have stressed the need for adopting phytosanitary measures under field conditions to reduce the inoculum in soil and thus check the disease. These included isolation of infected plants from the surrounding healthy vines, ensuring better drainage facilities and burning infected pits or drenching them with Bordeaux mixture before replanting. Chemical control measures are meaningless without adequate phytosanitary measures to check the disease spread. Turner's (1969a) observation of complete inhibition of sporulation and disease is theoretically possible in soils with low PH, but it will not be possible to rule out nutritional disorders under such circumstances (de Waard, 1969). In India, where the pepper soils have a PH of 4.5–5.8, Nambiar *et al.* (1965) recorded low K, Mg, and Ca levels in diseased soils and recommended application of lime, magnesium and potassic fertilizers in balanced amounts to prevent the disease.

In the absence of a highly resistant variety to foot rot disease at present (Nair, 1978) an integrated system of disease management involving phytosanitary measures, chemical and biological control methods, combined with efficient agronomic practices that boost up the vigour and health of the vine, are of greater relevance in the present context for tackling this serious scourge of black pepper. While priority should be given to screening wild types of *Piper* spp. for locating resistance to the pathogen, ecological studies on the factors that predispose the vines to infection under different cropping systems and on the possible existence of strainal variations are also to be made. This will enable us to develop an efficient forecasting system to make the control measures more effective and meaningful.

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DISCUSSIONS

T. N. Sreenivasan : What was the height of the graft? Any reference on use of root–stock for pepper?

Answer : About 3-month-old grafts are transplanted in the field. *Piper colubrinum* has been used as a root–stock both in Puerto Rico and Brazil. But the field establishment is poor. Longitudinal cracks developed at the graft union.

F. J. Newhook : How much time a grown up vine takes to express the foliar symptoms such as yellowing, defoliation etc.?

Answer : We have not worked out the time taken to express foliar symptoms in mature vines after inoculation. In rooted cuttings foliar yellowing can be seen in 8-15 days after inoculation.

P. H. Tsao : What type of symptoms you observe with 'Foot rot' disease?

Answer : Type of symptoms depends on the situation in which pepper is grown. When pepper is grown in hilly slopes with good drainage condition, colla rot or foot rot is more common. When pepper is crop-mixed with arecanut, coconut and under high soil moisture and thick shade, root rot symptom is generally prevalent. The leaves start drooping and branches at nodal region break. The whole foliage drops off leaving a bare vine.

P. H. Tsao : Early detection of infection is not possible in perennial crops like citrus, avacado and other tree crops, because after damaging certain amount of root system, then only the infected tree expresses foliar symptoms. In pepper also death may not occur immediately after infection. It may take 6-8 years to express symptoms. If we are able to detect the infection at an early stage, we can prevent the death of the vien.

J. Subbayya : Are the two symptoms, i.e. collar rot and 'foot rot' distinct? Can we save the affected vines by fungicidal treatment?

Answer : Infection of mainstem occurs at the soil level and some times just below the soil level. Collar and foot rot are one and the same. Application of