Phytophthora foot rot of black pepper

Y. R. Sharma and M. Anandaraj

Reprinted from the book :

Management of Threatening Plant Diseases of National Importance

Malhotra Publishing House

New Delhi

Phytophthora foot rot of black pepper

Y.R. Sarma and M. Anandaraj
Indian Institute of Spices Research, Calicut-673 012

Black pepper, (*Piper nigrum* L), the 'King of Spices' is an important commercial crop which fetches about Rs. 226 crore per annum as export earnings to the country. It is grown in an area of 183400 ha producing 46100 tonnes per annum. It is a perennial climber, native of Western Ghats of India and has spread to other countries like Indonesia, Malaysia, Sri Lanka, Vietnam, China and Thailand. Out of 17 diseases reported (Sarma *et al.*, 1991), *Phytophthora* foot rot has been identified as major production constraint not only in India but also in other parts of the world where the crop is grown (Holliday and Mowat, 1963; Sarma and Nambiar, 1982). The present status of the disease among the member countries of International Pepper Community (IPC) has been reviewed recently (Duarte and Albuquerque, 1991; Sarma *et al.*, 1992; Manohara *et al.*, 1992; Kueh and Sim 1992; Sarma and Anandaraj, 1994).

CROP LOSS

On a global scale, the crop losses have been estimated around $4.5-7.5 million due to foot rot (deWaard, 1979). About 25-30% vine death has been reported in Kerala (Nambiar and Sarma, 1977). Annual crop loss of 905 and 119 tonnes of black pepper due to 9.4% and 3.7% vine death has been reported in Cannanore and Calicut districts in Kerala (Balakrishnan *et al.*, 1986; Anandaraj *et al.*, 1989).

ETIOLOGY

The disease was first reported in India as early as 1902 (Barber, 1902; Butler 1906). Even though isolation of *Phytophthora* sp. in black pepper was reported from Karnataka (Venkata Rao, 1929), the authentic report that it is caused by *Phytophthora* came from Samraj and Jose, (1966) who adopted *P. parasitica* var. *piperina* (Muller, 1936) as the species involved. Its taxonomic position remained controversial for quite sometime, naming it as *P. palmivora* (Holliday and

Mowat, 1963), as an atypical strain of *P. palmivora* (Turner, 1969) and as *P. palmivora* MF4 (Stamps *et al.*, 1990; Sarma *et al.*, 1982; Tsao *et al.*, 1985). However, it is now resolved that *Phytophthora* of black pepper as *P. capsici* Leonian emend A. Alizadeh and P H Tsao (Tsao, 1991).

P. capsici of black pepper shows considerable variation in its morphology. Ontogeny of sporangiophore is distinctly umbellate and occasionally irregular. Sporangial shape varies from obovoid, fusiform to pyriform with a long tapered base, caducus with an L/B ratio ranging from 1.7-2.7. They are heterothallic which predominantly belong to A1 mating type (Sarma *et al.*, 1982, 1991). However, both A1 and A2 type have been reported (Sastry, 1982). Based on the isozyme analysis, two distinct types of *P. capsici* as CAP1 and CAP2 have been identified (Oudemans and Coffey, 1991). The organism grows profusely on carrot agar at temperature range of 25-28°C and is also known to produce toxic metabolites in culture (Sarma *et al.*, 1991).

The fungus is soil borne and the disease has two important phases, viz., aerial phase and soil phase (Sarma *et al.*, 1991). All the parts of black pepper are susceptible to *Phytophthora.*

Aerial phase

Fast advancing dark brown lesions on leaves with a fimbriate margin and rotting of aerial portions of stems and spikes result in varying degrees of defoliation and spike shedding causing reduction in the bush size.

Soil phase

Feeder root infection in early stages goes unnoticed but with advancement of disease with greater root loss, foliar yellowing is observed. The disease further spreads from the feeder roots to the thicker roots, ultimately culminating in foot rot leading to death of the vine (Anandaraj *et al.*, 1991, 1994). Occasionally, sudden death or 'quick wilt' is noticed when infection occurs at collar or foot independently or when infection reaches collar through runner shoots. Although the foliar infection and root infection are noticed independently, their combined infection in a single garden or in a vine are not uncommon. The combined root infection caused by two plant parasitic nematodes, viz., *Radopholus similis, Meloidogyne incognita* and *P. capsici* either alone or in combination leads to slow decline resulting in decreased vigour and productivity of the vine gradually leading to the death of the vine (Ramana *et al.*, 1990; Anandaraj *et al.*, 1994).

EPIDEMIOLOGY

Infected plant debris in the soil and infected dried up vines in the gardens appear to be the primary source of inoculum. Being a wet weather pathogen, the activity of *Phytophthora* is associated with moisture regimes both in the soil and aerial portions of the vine. Disease is monsoon bound which starts during May-

June period with the onset of South-West monsoon and continues up to August and later during North-East monsoon during September - October. The build up of soil moisture levels with early showers during May results in new flush development leading to considerable increase in tender foliage which are highly prone to infection. The same condition would also trigger extensive root proliferation, coinciding with the build up of *Phytophthora* propagules in the soil, thus creating highly conducive conditions for disease development.

Aerial phase

Due to soil splashes, the tender runner shoots spreading on the ground or the tender leaves at the base of the vine are the first to get infected showing rotting of shoots or dark brown lesions on the leaves with fast advancing margins. In the presence of free moisture, these lesions sporulate abundantly. Due to intermittant showers, the infection gradually spreads from the lower to the upper regions, in a hopping manner in ladder like fashion through rain splashes (Ramachandran *et al.*, 1990). Infection also spreads through water channels in areca-pepper or coconut-pepper mixed cropping system (Sarma *et al.*, 1991).

Foliar infections though occur both in pure plantation and also in mixed plantation, they are often noticed in areca-pepper or coconut- pepper mixed cropping system (Sarma *el al.*, 1991, 1992). This might be because of the conducive microclimatic condition that prevail under the canopy. Rainfall, number of rainy days, and relative humidity had a positive correlation, whereas temperature and sunshine hours had a negative correlation. Foliar infection in an arecanut based cropping system showed increasing phase of disease development when daily rainfall of 15.8-23mm, 81-99% relative humidity, 22.7-29.6°C temperature and 2.8-3.5 hours of sunshine per day prevailed (Ramachandran *et al.*, 1988). Similar observations were reported by Unnikrishnan Nair *et al.*, (1988) and Mammootty *et al.* (1991).

Soil Phase

The soil inoculum levels decreased from the base of vine with increase in distance and depth (Ramachandran *et al.*, 1986). The distribution of *Phytophthora* inoculum in soil in relation to disease incidence in black pepper has been reported (Sastry and Hegde, 1982). Root infection being under ground remains unnoticed and foliar yellowing symptom would appear only after sufficient degeneration of root system. The effect of age on root infection studied under field simulated microplot conditions clearly brought out that root infection at advanced stages would lead to foot rot leading to vine death (Anandaraj *et al.*, 1994).

Disease spread

Being a wet weather pathogen, it is precise in its requirements for growth and sporulation. The organism sporulates abundantly and releases zoospores in a drop of water. Soil splash or rain splash is the main mode of spread of foliar infection, and soil water and root contact appear to be the mode of spread of root infections. Disease spread in a centrifugal fashion from the focus of infection has been reported (Nambiar and Sarma, 1982). Slugs act as carriers of inoculum in spread of the disease in a bush during rainy season and termites act as passive carriers of soil inoculum on the standard of the bush during off season (Sarma and Nambiar, 1982). The role of termites and snails in spreading the inoculum of *P. palmivora* and *P. cinnamomi* has been reported (Turner, 1967; Keast and Walsh, 1979).

Unlike the foliar infection noticed during South-West monsoon period during intermittent rain, root infection would continue even up to November because of soil moisture regimes that would persist. Root loss to root regeneration ratio appears to be the deciding factor of the health and productivity of the vine (Sarma and Nambiar, 1982). In spite of degeneration of root system, the vines sustain with available soil moisture during October-December period. The vine death noticed during March-April, the dry period of the year, might be due to depleted soil moisture levels and degenerated root system which is unable to sustain the vine. The soil water relations on the host physiology and water balance in relation to infection need indepth study to develop effective disease management strategies. In Kerala and Karnataka crops like coconut, arecanut, cacao, rubber, pepper and cardamom which are infected by *Phytophthora* form the major components of the cropping system. The possibility of cross infection appears high (Santhakumari, 1987). However, the studies so far carried out indicated that *P. capsici* is the only pathogen so far identified on black pepper and the same has not been recorded on other crops mentioned except in cacao where it is reported from Idukky district of Kerala (Chowdappa *et al.,* 1993). However, involvement of more than one *Phytophthora* on black pepper cannot be ruled out. The correct identity of the *Phytophthora* spp. involved becomes important for any effective disease management strategy.

DISEASE MANAGEMENT

Black pepper is grown as a pure crop and also as a mixed crop in arecanut, coconut and coffee plantation. As such, the management practices vary slightly since the microclimatic conditions differ in the cropping systems. Besides the combined infection of plant parasitic nematodes, viz, *R. similis* and *M. incognita* and *Phytophthora* are common in arecanut and coconut when black pepper is mixcropped, since all these are susceptible to nematodal infection. Hence, a holistic approach in disease management has been stressed (Sarma *et al.,* 1992).

Based on the epidemiological investigations and crop phenological observations, an integrated disease management strategy involving cultural, chemical, biocontrol methods coupled with host resistance has been evolved (Ramachandran *et al.,* 1991; Sarma *et al.,* 1994).

Cultural practices

Phytosanitation

High inoculum levels of the pathogen in soil due to the presence of disease affected vines in garden, necessitates or adoption of strict phytosanitary measures involving removal of infected vines along with root systems and burning off. Maintenance of a green cover and pruning off the runner shoots or the branches adjacent to the ground level has been recommended to reduce chances of foliar infection due to soil or rain splash. Shade regulation during May-June by lopping off the branches of the live standards, minimum tillage practices and provision of good drainage are some of the recommended cultural practices.

Agronomic aspects

Very little is known on the effects of nutrition, irrigation, its frequency and population density of black pepper both in pure and mixed cropping system on *Phytophthora* infection. Disease is noticed both in pure crop and mixed cropping systems. Though pepper is raised as rainfed crop with the change of agroecological condition, it appears to be imperative to resort to irrigation for the sustainance of the crop. Effect of organic soil amendments and consequent microbiological changes that affect *Phytophthora* population is receiving attention. Application of neem cake at 1 kg/vine has been recommended to check *Phytophthora* and nematodes (Sarma *et al.*, 1991). Water and methanolic extracts of *P. colubrinum*, *Chromolaena odorata* and neem were found inhibitory to *Phytophthora* at its different phases of development (Anon., 1995). Their utility in isolation of biomolecules effective against *P. capsici* and also as organic soil amendments need to be explored.

Nursery hygiene

In view of the soil borne nature of the disease, greater precaution need be exerted to maintain nursery hygiene to ensure disease free rooted cutting for a better establishment in the field and longevity (Sarma *et al.*, 1987, 1992). Thorough cleaning of three node cuttings with a jet of water and treating the same with either Metalaxyl-Mancozeb (100 ppm of Metalaxyl) or Carbendazium (0.2%) for 30 min is recommended. To ensure better growth and profuse root development, rapid multiplication method is recommended (Sivaraman, 1992). Incorporation of VAM propagules and biocontrol agents like *Trichoderma* and *Gliocladium* in solarised nursery mixture is being popularised.

Chemical control

In view of the season bound nature of the disease and lack of early detection method for root infections, fixed schedules of fungicide application is the recommended strategy. Copper fungicides because of their high toxicity were found highly effective in reducing the disease. Based on field trials, prophylactic application of Bordeaux paste to the collar once, foliar spray and soil drench with Bordeaux mixture(1%) once as a pre-monsoon during May-June and again during July-August as a post-monsoon treatment were found effective (Sasikumaran *et al.*, 1981). The practice of application of Bordeaux paste to the collar is discontinued as the collar infection is the culmination of the root rot in foot rot. This package of Bordeaux spray and Copper oxychloride drenching has been adopted in about 1 lakh ha in Kerala with the assistance of Central Government.

In view of the heavy rainfall and consequent leaching losses of the protectant/ contact fungicides, the use of systemic fungicides like Phenylamides and Phosphonates specific to Oomycetes were tried. The efficacy of Metalaxyl and Fosetyl Al, both *in vitro* and *in vivo* in reducing *Phytophthora* infection was established and were found superior to Bordeaux mixture (Ramachandran and Sarma, 1990). In view of the reported development of resistance in *Phytophthora* to Metalaxyl, as an antiresistant strategy, commercial formulation of Metalaxyl - Mancozeb mixture was used both as a foliar spray and soil drench. The fungicide residue level in pepper were below 0.8ppm when Metalaxyl at 100pm was used thrice during May-August period (Sarma *et al.*, 1992). Because of the prohibitive cost these are not popular. Metalaxyl was found compatible with insectcides like Quinalphos and Endosulfan used against pollu beetle; and its activity was synergistic indicating its potential in integrated pest and disease management (Ramachandran and Sarma, 1988, 1990). Recent studies indicated the efficacy of Potassium phosphonate both as a foliar spray and soil drench in checking *Phytophthora* infections (Anon., 1995).

Biocontrol

The potential of biocontrol agents in the management of soil-borne diseases of spice crops has been reviewed (Sarma *et al.*, 1996). The presence of *Phytophthora* in soils of Silent valley of Western Ghats in Kerala, where black pepper occurs in wild and remained healthy, indicated the biological balance and possible coexistant evolution of black pepper and *Phytophthora.* The rhizosphere soils of black pepper in Silent valley and also in other black pepper plantations yielded *Trichoderma* spp. *Gliocladium virens* and also fluorescent pseudomonads. Highly antagonistic isolates of *T. harzianum, T.hamatum* and *G.virens* which were found efficient in root rot suppression are now under large scale field evaluation in black pepper plantations of Kerala, Karnataka and Andhra Pradesh. Incidentally, the biocontrol agents are compatible with Metalaxyl and Potassium phosphonates and can be used in the integrated disease management (IDM) programme. Since copper fungicides are toxic to *Trichoderma* and *Gliocladium,* there is a necessity to evolve copper tolerant efficient, disease suppressive strain of *Trichoderma* and *Gliocladium* to evolve IDM stratagies. The association of vesicular arbuscular mycorrhiza (VAM) with root system of black pepper received attention in recent years (Anandaraj *et al.*, 1993). Disease suppressive activity of *Glomus fasciculatum* on *P. capsici, R.similis* and *M.incognita* has been established (Anandaraj *et al.*, 1993). Incorporation of *Trichoderma* and *Gliocladium* and VAM ensures disease free planting material and is the strategy adopted at present (Sarma *et al.*, 1994). Disease suppressive soils for *P. cinnanomi* have been reported (Broadbent and Baker, 1974) and needs to be explored in black pepper soils.

Disease resistance

High degree of resistance has not been identified for *Phytophthora* in black pepper, but few tolerant cultivars were identified (Sarma *et al.*, 1992). Monoculture of highly susceptible but productive cultivars like Karimunda appear to be the main reason for the large scale vine death. Pepper being vegetatively propagated, the available variations might have been locked up unexploited. To overcome this, open pollinated seedling progenies (OP) from number of cultivars were subjected to mass screening with *P. capsici.* Promising selections were further multiplied, subjected to stem inoculation and the tolerant lines selected were field tested in hot spot area of disease. High degree of resistance so far has not been identified but few productive field tolerant types like P24, P339, P1534, (OP) HP780 (hybrid) and cultivars ACC 1047, ACC1095, ACC347 have been identified. Cultivation of a mixture of tolerant varieties has been the suggested strategy of disease management (Sarma and Anandaraj, 1992). The present conventional breeding programmes with major aim of development of resistance need be intensified since it is possible to obtain resistant genotypes through transgressive seggregation of recombination (Sarma *et al.*, 1991).

Piper colubrinum highly resistant to *P.capsici* has been used successfully as a root stock (Gasking and Almeyda, 1959; Albuquerque, 1968) but due to graft incompatibility, breakdown of the graft union has been reported (Alconero *et al.*, 1972). The lateral fruiting branch of black pepper as scions grafted onto root stock of *P.colubrinum* remained healthy for more than four years at IISR, Calicut. This calls for a detailed study on the scion root stock of the grafts of *P.nigrum* and *P.colubrinum* to standardise long lasting graft union. The ploidy level of *P.nigrum* is 2n=52 or more and that of *P.colubrinum* is 2n=26. Inducing tetraploidy in *P.colubrinum* with 52 chromosomes and using it as a root stock for better compatibility in grafting needs to be explored. *P. colubrinum* is less tolerant to drought and susceptible to mealy bugs and hence limitations.

Biotechnological approaches to induce host resistance

In the absence of high degree of host resistance in the available germplasm and to overcome the long time consuming breeding cycles, the option of biotechnological approaches appear attractive. The importance of biotechnological approaches in inducing resistance in black pepper has been stressed

(Sarma and Ramadasan, 1990; Sarma *et al.*, 1992). *P.colubrinum*, a South American type with its multiple resitance to *P.capsici, R.similis, M.incognita* and pollu beetle is an ideal candidate for this approach. However, identification of genes responsible for resistance and transferring the same to black pepper through recombinant DNA technology, electroporation or through biolistics is one of the available avenues and are being persued. Studies on induction of variation through somaclones, *in vitro* screening of callus of cultivars of black pepper with toxins of *P.capsici* and protoplasts fusion are in progress. Techniques have been standardised for callus induction and regeneration, protoplast isolation and induction of friable callus for cell suspension cultures (Shaji *et al.*, 1995) for *in vitro* screening. The initial screening of somaclones with *P.capsici* has shown clear indication of high degree of variability for disease reaction.

The importance of both technical and social factors that affect the disease management have been identified (Sarma *et al.*, 1994). Soil borne nature of the disease, suceptibility of all parts of the plants, prolonged climatically conducive conditions for the disease development, monoculture of highly susceptible cultivars like Karimunda, lack of high degree of host resistance and non-availability of disease free planting materials are some of the technical problems. Predominance of poor and marginal farmers with poor financial resources, lack of community approaches, poor price stability and inadequate extension machinery are some of the social factors that contribute to the non implementation of effective disease management programmes.

In a recent review on the disease management of soil-borne *Phytophthoras*, prospects of disease control in foot rot of black pepper have been expressed as bleak in view of the above mentioned technical and social factors (Coffey, 1991). However, the present envisaged strategy of integrated disease management involving nursery hygiene, cultural, chemical, biocontrol programmes coupled with host resistance and implementing the same through a community approach is the only viable strategy to effectively manage this important disease problem.

REFERENCES

Albuquerque, F.C. (1968). *Piper colubrinum*, a grafting rootstock for *Piper nigrum*, resistant to diseases caused by *Phytophthora palmivora* and *Fusarium solani* f.sp., *piperi* (in Spanish). *Psqul. Agropecu. Bras.* 3: 141-145.

Alconero, R., Albuquerque, F.C., Almeyda, N. and Santiago, A.G. (1972). Phytophthora foot rot of black pepper in Brazil and Puerto Rico, *Phytopathology* 62: 144-148.

Anandaraj, M., Jose Abraham and Balakrishnan, R. (1989). Crop loss due to foot rot disease of black pepper. *Indian Phytopath.* 42: 473-476.

Anandaraj, M., Ramana, K.V. and Sarma, Y.R. (1993). Suppressive effects of VAM on pathogens of black pepper - A component of Western Ghats forest ecosystem. Abstract : In IUFRO *Symposium*, 23-26 November 1993. Kerala, Forest Research Institute, Peechi, Kerala, India.

Anandaraj M., Ramachandran, N. and Sarma, Y.R. (1991). Epidemiology of foot rot disease of black pepper (*Piper nigrum* L.) in India. In *Diseases of Black pepper - Proceedings of the*

International Pepper Community Workshop on Black Pepper Diseases. 27-79 October, Goa, India (Eds., Sarma, Y.R. and Premkumar, T.). pp 114-135, National Research Centre for Spices Calicut, Kerala, India.

Anandaraj, M., Sarma, Y.R. and Ramachandran, N. (1994). *Phytophthora* root rot of black pepper in relation to age of the host and its culmination in foot rot. *Indian Phytopath.* **47**: 203-206.

Anonymous (1995). Annual Report for 1994-95. Indian Institute of Spices Research, Calicut, Kerala.

Balakrishnan, R., Anandaraj, M., Nambiar, K.K.N., Sarma, Y.R., Brahma, R.N. and Geroge, M.V. (1986). Estimates on the extent of loss due to quick wilt disease of black pepper (*Piper nigrum* L.) in Calicut district of Kerala. *J. Plant Crops* **14**: 15-18.

Barber, C.A. (1902). Ann. Rep. for 1901-1902. Dep. Agric., Madras.

Broadbent, P. and Baker, K.F.(1974). Behaviour of *Phytophthora cinnamomi* is soils suppressive and conducive to root rot. *Aust. J. Agric. Res.* **25**: 121-137.

Butler, E.J. (1906). The wilt disease of pigeon pea and pepper. *Agric. J. India* **1**: 25.

Chowdappa, P., Chandramohanan, R, and Ramanujam, B. (1993). Occurrence of *Phytophthora capsici* on cocoa in Kerala. *Indian Phytopath.* **48**: 92-93.

Coffey, M.D. (1991). Strategies for the integrated control of soil borne *Phytophthora* species. In *Phytophthora* (Eds., Lucas, J., Shattock, R.C., Shaw, D S. and Cooke, L.R.). pp 411-434. Cambridge University Press, Cambridge, U.K.

deWaard, P.W.F. (1979). Evaluation of the results of research on eradication of *Phytophthora* foot rot of black pepper *(Pipper nigrum* L). Circulated during the First Meeting of the Pepper Community Permanent Panel on Techno-economic Studies. 31 January - 4 February 1979. Cochin, India. pp 1-47.

Duarte, M.L.R. and Albuquerque, F.C. (1991). *Fusarium* disease of black pepper in Brazil. In *Disease of Black pepper-Proceedings of the International Pepper Community Workshop on Black Pepper Diseases-27-29* October 1988, Goa, India. (Eds., Sarma, Y.R. and Premkumar, T.) pp 39-54. National Research Centre for Spices, Calicut, Kerala, India.

Gasking, M.H. and Almeyda, N. (1968). Growth of *Piper nigrum* L. on root stock of other *Piper* species. Proc. XVI Annual Meeting of the Carribean Region. Proc. *Amer. Soc. Hort. Sci.* **12**: 55-60.

Holliday, P. and Mowat, W.P. (1963). Foot rot of *Piper nigrum* L. *(Phytophthora palmivora)* Phytopath. paper No. 5: 62 pp. Commonwealth Mycol. Inst., Kew, Surrey.

Keast, D. and Walsh, L.G. (1979). Passage and survival of chlamydospores of *Phytophthora cinnamomi* Rands, the causal agent of forest dieback disease through the gastrointestinal tracts of termites and wild birds. *Appl. Environ. Microbial.* **37**: 661-664.

Kueh, T.K. and Sim, S.L. (1992). Etiology and control of *Phytophthora* foot rot of black pepper in Sarawak, Malaysia. In *Proceedings International Workshop on Black Pepper Disease,* Bander Lampug, Indonesia 3-5 December 1991 (Eds. Wahid, P., Sitepu, D., Deciyanto, S. and Suparman, U.) pp 155-164. Agency For Agricultural Research and Development Research Institute for Spice and Medicinal Crops. Bogor. Indonesia.

Mammootty, K.P., Manmohandas, T.P., Sasikumaran, S., Unnikrishnan Nair, P.K. and Abicheeran. (1991). Some aspects on epidemiology of foot rot (quick wilt) disease of black pepper *(Piper nigrum* L.) In *Diseases of Black Pepper-Proceedings of the International Pepper Community Workshop on Black Pepper Disease* 27-29 October 1988., Goa, India (Eds., Y.R. Sarma and T. Premkumar). pp 102-113. National Research Centre for Spices, Calicut, Kerala, India.

Manohara, D., Kasim, R. and Sitepu, D. (1992). Current research status of foot rot disease in Indonesia. In *Proceedings International workshop on Black Pepper Diseases.* Bander Lampung, Indonesia 3-5 December 1991. (Eds., Wahid, P., Sitepu, D., Deciyanto, S. and Superman, U.). pp 144-154. Agency for Agricultural Research and Development, Research Institute for Spice and Medicinal crops, Bogor, Indonesia.

Muller, H.R.A. (1936). The *Phytophthora* foot rot of pepper. *(Piper nigrum* L.) in the Dutch East Indies (in Dutch), Meded. *Inst. Pl. Ziekt., Batavia.* No. 88, 73pp.

Nambiar, K.K.N. and Sarma, Y.R. (1977). Wilt diseases of black pepper *J. Plant Crops* 5: 92-103.

Nambiar, K.K.N. and Sarma, Y.R. (1982). Some aspects of epidemiology of foot rot of black pepper. In *Phytophthora Diseases of Tropical Cultivated Plants - Proc. of the Workshop on Phytophthora Diseases of Tropical Cultivated Plants* (Ed., Nambiar, K.K.N.). pp 225-232. Central Plantation Crops Research Institute, Kasaragod, Kerala, India.

Oudemans, P. and Coffey, M.D. (1991). A revised systematics of twelve papillate *Phytophthora* species based on isozyme analysis. *Mycol. Res.* 95: 1025-1046.

Ramachandran, N. and Sarma, Y.R. (1988). Fungitoxic effects of endosulfan and quinalphos on *Phytophthora palmivora* the root rot pathogen of black pepper. Tests of Agrochemical and Cultivars No. 9. *Ann. appl. Biol.* 112 (Supplement): 26-27.

Ramachandran, N. and Sarma, Y.R. (1990). Bioefficacy of systemic fungicides against *Phytophthora* in black pepper *(Piper nigrum* L.) *J. Plant. Crops* (Supplement) 20 : 78-84.

Ramachandran, N., Sarma, Y.R. and Anandaraj, M. (1990). Vertical progression and spread of *Phytophthora* leaf infection in arecanut - black pepper mixed cropping system. *Indian Phytopath.* 43: 414-419.

Ramachandran, N., Sarma, Y.R. and Anandaraj, M. (1991). Management of *Phytophthora* infections in black pepper. In *Diseases of Black Pepper. Proceedings of the International Pepper Community Workshop on Black Pepper Diseases.* 27-29 October 1988, Goa, India (Eds., Sarma, Y.R. and Premkumar, T.). pp 158-174. National Research Centre for Spices, Calicut, Kerala, India.

Ramachandran, N., Sarma, Y.R. and Nambiar, K.K.N. (1986). Spatial distribution of '*Phytophthora palmivora*' MF4 in the root zones of *Piper nigrum. Indian Phytopath.* 39: 414-417.

Ramana, K.V., Sarma, Y.R. and Mohandas, C. (1990). Slow decline of black pepper *(Piper nigrum* L.) and role of plant parasitic nematodes and *Phytophthora capsici* in the disease complex. *J. Plant Crops* (Supplement) 20 : 65-68.

Samraj, J. and Jose, P.C. (1966). A *Phytophthora* wilt of pepper. *Sci. & Cult.* 32: 90-92.

Santhakumari, P. (1987). *Studies on Phytophthora Diseases of Plantatioin Crops.* Ph.D. thesis, University of Agricultural Sciences, Dharwad, 139p.

Sarma, Y.R. and Anandaraj, M. (1992). Disease management in black pepper - Present scenario and future thrust. In *Black Pepper and Cardamom - Problems and Prospects* (Eds., Sarma, Y.R., Devasahayam, S. and Anandaraj, M.), pp. 35-38. Indian Scieity for Spices and National Research Centre for Spices, Calicut, Kerala.

Sarma, Y.R. and Anandaraj, M. (1994). Present status of *Phytophthora* foot rot of black pepper in India. National Group Meetings on *Phytophthora* Diseases of Horticultural Crops. 21-23 September 1994, Calicut, Kerala, pp 8-10 (Abstr.)

Sarma, Y.R., Anandaraj, M. and Ramachandran, N. (1992). Recent advances on *Phytophthora* foot rot research in India and the need for holistic approach. In *Proceedings International Workshop on Black Pepper Diseases,* Bandar Lampung, Indonesia. (Eds., Wahid, P., Sitepu, D., Deciyanto, S. and Suparman, U.). pp 133-143. Agency for Agricultural Research and Development, Research Institute for Spice and Medicinal Crops, Bogor - Indonesia.

Sarma, Y.R., Anandaraj, M. and Ramachandran, N.(1994). Strategies of disease management in *Phytophthora* caused plant diseases. Abstracts of papers, *National Group Meeting on Phytophthora Diseases of Horticultural Crops.* pp 37-39. 21-23 September 1994, Calicut, Kerala.

Sarma Y.R., Anandaraj, M. and Ramana, K.V. (1991). Tips on control of *Phytophthora* foot rot and slow decline disease of black pepper. National Research Centre for Spices, Calicut, 673 012, Kerala.

Sarma, Y.R., Anandaraj, M. and Rajan, P.P. (1994). *Phytophthora*- A threat to black pepper - Present status and future stretagies of disease management. *Spice India* 7 : 10 - 13.

Sarma, Y.R., Anandaraj, M. and Ramana, K.V. (1993). Managemenat of *Phytophthora* foot rot (quick wilt) and slow decline diseases of black pepper. *Spice India* 6 : 8 - 10.

Sarma, Y.R., Anandaraj, M. and Venugopal, M.N. (1996).Biological control of diseases of spices " In *Status of Biocontrol Diseases and Pest Management in Spice Crops*" Indian Institute of Spices Research, Calicut, Kerala.

Sarma, Y.R. and Nambiar, K.K.N. (1982). Foot rot disease of black pepper (*Piper nigrum* L.). In *Phytophthora Diseases of Tropical Cultivated Plants-Proceedings of the Workshop. Phytophthora Disease of Tropical Cultivated.* plants (Ed. Nambiar, K.K.N.), pp 209-224. Central Plantatiton Crops Research Institute, Kasaragod, India.

Sarma, Y.R., Nambiar, K.K.N. and Nair, M.K. (1982). Screening of black pepper, *Piper nigrum* L. and *Piper* spp. against *Phytophthora palmivora*. In *Phytophthora Diseases of Tropical Cultivated Plants- Proc. of the Workshop on Phytophthora Disease of Tropical Cultivated Plants* (Ed., Nambiar, K.K.N.). pp 242-247. Central Plantation Crops Research Institute, Kasaragod.

Sarma, Y.R., Premkumar, T., Ramana, K.V., Ramachandran, N and Anandaraj, M.(1987). Disease and pest management in black pepper nurseries. *Indian Cocoa Arecanut and Spices J.* 11: 45-49.

Sarma, Y.R. and Ramadasan, A. (1990). Scope of bio-technology in disease management in spice crops. A review. In *Genetic Engineering and Tissue Culture for Crop Pest and Diseases Management.* Vol. I (Ed., Vidhyasekaran, P.), pp 10-11. Tamil Nadu Agricultural University, Coimbatore, 641 003.

Sarma, Y.R., Ramachandran, N. and Anandaraj, M. (1988). Integrated disease management of 'quick wilt' (foot rot) of black pepper caused by *Phytophthora palmivora* MF4. *J.Coffee Research,* (Suppliment) 18 : 68-72.

Sarma Y.R., Ramachandran, N. and Anandaraj, M. (1991). Black pepper diseases in India. In *Diseases of Black pepper - Proceedings of the International Pepper Community Workshop on Black Pepper Diseases.* Goa. India (Eds., Sarma, Y.R. and Premkumar, T.). pp 55-101. National Research Centre for Spices, Calicut, Kerala, India.

Sarma, Y.R., Ramachandran, N., Anandaraj, M. and Ramana, K.V.(1988). Disease management in black pepper. *Indian Cocoa, Arecanut* and *Spices J.* 11: 123-127.

Sarma, Y.R., Ramachandran N and Nambiar, K.K.N. (1981). Sources of inoculum of *Phytophthora palmivora* of black pepper (*Piper nigrum* L) in disease spread and the importance of morphology of the fungus. *Third International Symposium on Plant Pathology,* New Delhi, December 14-18, 1981. Indian Phytopathological Society, IARI, New Delhi, India. 59pp. (Abstr.).

Sarma, Y.R., Ramachandran, N. and Nambiar K.K.N. (1982). Morphology of black pepper *Phytophthora* isolates from India. In *Phytophthora Diseases of Tropical Cultivated Plants - Proc. of the Workshop on Phytophthora Diseases of Tropical Cultivated Plants,* 1980 (Ed. Nambiar, K.K.N.), pp 232-236. Central Plantation Crops Research Institute, Kasaragod, Kerala, India.

Sasikumaran, S., Mammootty, K.P., Abicheeran and Sukumara Pillai, V.(1981). Field trials for the control of quick wilt (foot rot) disease of pepper - *Third International Symposium on Plant Pathology,* December 14-18, 1981, New Delhi. 128 pp (Abstr.).

Sastry, M.N.L. (1982). *Studies on Species of Phytophthora Affecting Plantation Crops in Karnataka With Special Reference to Koleroga of Arecanut and Wilt of Black Pepper.* Ph.D thesis, University of Agricultural Sciences, Bangalore, College of Agriculture, Dharwad, 188pp.

Sastry, M.N.L and Hegde, R.K. (1982). Distribution of *Phytophthora palmivora* (Butler). Butler in North Kanara soils and its role in wilt of pepper. In *Phytophthora Diseases of Tropical Cultivated Plants - Proc. of the Workshop on Phytophthora Diseases of Tropical Cultivated Plants* 19-23 September 1980 (Ed., Nambiar, K.K.N.). pp. 237-241. Central Plantation Crops Research Institute, Kasaragod, India, 284 pp.

Philip Shaji, Bindu, M.R,.Anandaraj, M.and Sarma, Y.R. (1995a) Variability in callus induction and regeneration among the cultivars of black pepper (*Piper nigrum* L.) *All India Symposium on Plant Tissue culture* June 1995. 23-25 CFTRI, Mysore. pp 30-31. (Abstr.).

Philip Shaji, Bindu, M.R,.Anandaraj, M.and Sarma, Y.R. Protoplast isolation and Micro callus development from the leaves of black pepper (*Piper nigrum* L.) (Communicated to *Plant Cell Reports*).

Philip Shaji, Bindu, M.R,.Anandaraj, M.and Sarma, Y.R. (1995b). Induction of friable callus and regeneration in black pepper (*Piper nigrum* L.) *National Seminar on Biotechnology for Rural and Industrial Development.* 22-23 Dec., 1995. Gulberga University, Gulbarga, Karnataka. pp 18-19. (Abstr.).

Sivaraman, K. (1992). Large scale production of quality planting material of black pepper. 68-72pp. In *Black Pepper and cardamom - Problems and Prospects* (Eds Sarma, Y.R., Devasahayam, S. and Anandaraj, M.). pp 68-72. Indian Society for Spices, National Research Centre for Spices Calicut, Kerala.

Stamps, D.J., Waterhouse, G.M., Newhook, F.J. and Hall, G.S.(1990). *Revised Tabular Key to the Species of the Phytophthora*, CAB International Mycological Institute, Kew, London.

Tsao, P.H.(1991). The identities nomenclature and taxonomy of *Phytophthora* isolates from black pepper. In *Diseases of Black Pepper-Proceedings of the International Pepper Community Workshop on Black Pepper Diseases.* 27-29 October 1988. Goa, India. (Eds., Sarma, Y.R. and Premkumar, T.). pp 185-211. National Research Centre for Spices, Calicut, Kerala, India.

Tsao, P.H., Sarma, Y.R., Kasim, R., Mustika, I. and Kueh, T.K.(1985). Variation in *Phytophthora palmivora* MF4 (*P.capsici*) isolates from black pepper in India, Indonesia and Malaysia. *Phytopathology* 75: 1315 (Abstr.)

Turner, G.J. (1967). Snail transmission of species of *Phytophthora* with special reference to foot rot of *Piper nigrum. Trans. Brit. mycol. Soc.* 50:251-258.

Turner, G.J. (1969). Leaf lesions associated with foot rot of *Piper nigrum* and *P. betle* caused by *Phytophthora palmivora*, *Trans. Brit. mycol. Soc.* 57: 61-65.

Unnikrishnan Nair, P.K., Sasikumaran, S.,Sukumarapillai, V. and Prasad Rao, G.S.L.H.V (1988). Influence of weather on foot rot disease of pepper (*Piper nigrum* L.). In *Agrometeorology of Plantation Crops* (Eds., Prasada Rao, G.S.L.H.V., and Nair, R.R.). pp 98-103. Kerala Agricultural University, Trichur.

Venkata Rao, M.K. (1929). Ann. Rept. for 1927-28 to 1988. Dept. Agric, Mysore.