REVIEW OF LITERATURE

Rajan P.P “Approaches towards the integrated disease management of phytophthora infection of black pepper (Piper nigrum L.)” Thesis. Department of Botany, University of Calicut, 1999
REVIEW OF LITERATURE
Phytophthora foot rot of black pepper, earlier known as "Quick wilt" (Nair and Sarma, 1988) caused by a soil borne fungus Phytophthora capsici (= P. palmivora- MF1) (Stamps et al, 1990; Sarma et al, 1982; Tsao et al., 1985) is a serious pathogen and a major concern for the farming community in all the pepper growing countries including India. Status of this important malady on black pepper is reviewed.

HISTORY AND DISTRIBUTION:
In India, the disease was known as early as in 1902 when severe vine deaths were noticed in Wynad region of erstwhile Madras state (Menon, 1949). Later it was investigated by Barber (1902, 1903 & 1905) and Butler (1906 & 1918) but the investigations were inconclusive and the etiology remained unresolved. The difficulties in isolation of Phytophthora in earlier days in the absence of selective media (Tsao and Guy, 1977) might have been the major factor in correct diagnosis of the causal agent. Although Phytophthora in black pepper was recorded during 1929 (Venkata Rao, 1929) the first authentic record of wilt of black pepper due to Phytophthora in India was in 1966 (Samraj and Jose, 1966) from Kerala. In Karnataka the disease was noticed in 1929 (Venkata Rao, 1929).

This disease was very serious and destructive in nature in Indonesia a century ago (Muller, 1936; Soepartono, 1953). In Malaysia, the disease was reported as “sudden death” in 1929 (Holl, 1929). Due to the serious outbreak, the research was initiated on the problem in Malaysia during 1952 (Robertson, 1953). Later Phytophthora was isolated from diseased pepper vines and was named as P. palmivora (Holliday and Mowat, 1957; Holliday, 1960; Holliday and Mowat, 1963). This disease has also been reported from Brazil (Holliday, 1965), Jamaica (Leather, 1967), Thailand (Tsao and Tummakate, 1977) and Malagasy Republic (de Waard, 1979). Recently, the disease has been observed in severe form in Uttar Kannada and Shimoga districts of Karnataka state, India (Sastry, 1982; Hegde, 1983; Dutta, 1984; Hegde and Hegde, 1987)
ECONOMIC IMPORTANCE

In India, Samraj and Jose (1966) recorded the death of pepper vines upto 20 percent and Nambiar and Sarma (1977) reported that, 20 - 30% crop loss in Cannanore and Calicut districts of Kerala. Crop loss survey conducted for three years (1982 - 1984) in Calicut, including Wynad and two years (1985 - 1986) in Cannanore districts of Kerala, has shown that foot rot incidence is causing vine deaths of about 1,88,947 (3.7%) and 10,16,425 (9.4%) amounting to an annual loss of 119 and 905 metric tones of black pepper in Calicut and Cannanore districts respectively (Balakrishnan et al., 1986; Anandaraj et al., 1988b). In Indonesia, up to 20% crop loss has been reported due to this disease (Sitepu and Kasim, 1988).

In Sarawak (1953 - 56), the loss was about 7000 tones amounting to £17 million (Holliday and Mowat, 1963). Ten percent death of vine was reported from West Borneo (Leafman, 1934) due to this disease. In Lampung, an outbreak of foot rot occurred during 1967 - 68, which destroyed 40 - 50% of pepper crop (de Waard, 1979). The overall loss due to this disease in all pepper growing countries was estimated to be $ 4.5 - 7.5 million per annum (de Waard, 1979). This disease appeared in severe form during 1978 in Karnataka state of south India (Dutta, 1984; Sastry and Hegde, 1991).

BIOLOGY AND EPIDEMIOLOGY OF PHYTOPHTHORA

BIOLOGY OF PHYTOPHTHORA

Kasim, 1978 reported that, the *P. capsici* zoospores get encysted within 2 hours at 5 - 10°C and 35 - 50°C. Maximum germination of zoospores and germ tube growth was noticed at 30°C and least was at 10 and 45°C. In *P. capsici*, thermal death point was high, ranging from 45 - 47°C and this temperature was very critical temperature for the host. According to Alizadeh and Tsao (1985), light plays and important role in the production of sporangia in *P. capsici*. In dark sporangial production was less and they were not easily dislodged from pedicel.
Optimum growth of *P. dreschleri* var *cajani* was obtained at 30°C, pH 6.5 in Mehrotra's medium (Pal and Grewal, 1976b). Singh and Chauhan (1988) reported that, temperature has got a vital role in the germination of zoospores of *P. dreschleri* f. sp. *cajani*. Chauhan and Singh (1991a), reported that, maximum zoospore germination of *P. dreschleri* f.sp *cajani* noted at pH 7.5 in dark. In *P. dreschleri*, oospore formation was high within 36 hours at 25°C (Singh and Chauhan, 1988).

**EPIDEMIOLOGY**

Although the speciation of *Phytophthora* infecting black pepper remained controversial, its taxonomic status as *P. capsici*, Leonian (amend Alizadeh and Tsao, 1983) has been resolved (Tsao et al., 1985). The fungus is soil borne and all the parts of black pepper are prone to infection. Infected plant debris in the soil and infected dried up vines in the gardens appear to be the primary source of inoculum. Since *Phytophthora* being a wet weather pathogen, the activity of the pathogen is association with moisture regimes both in the soil and aerial portions of the vine. Disease starts in the field during the South - West monsoon and continues up to August and later during North - West monsoon during September - October. During the early showers, new tender foliage and tender roots, are highly prone to infection. The early showers and consequent soil moisture would trigger extensive root proliferation, coinciding with the build up of *Phytophthora* propogules in the soil, thus creating highly conducive conditions for disease development. The disease has two important phases, viz; aerial and soil phase (Sarma et al., 1991).

**AERIAL PHASE**

Due to soil splashes, the tender runner shoots spreading on the ground and the tender leaves at the base of the vine are the first to contact infection, resulting in rotting of shoots or dark brown lesions on the leaves with fast advancing margins. In the presence of free moisture on the leaves, these lesions sporulate abundantly. Due to the intermittent showers, the infection gradually spreads from the lower to the upper regions of the bush, 'hopping' in a 'ladder' like fashion through rain splashes (Ramachandran et al., 1990). In early investigations, Muller (1936) described the appearance of symptoms as concentric lesion
development on leaves. The lesions are gray centers surrounded by alternating dark and light brown zones with peripheral water soaked margins. The zonation appeared due to the prevalence of intermittent wet and dry weather. If wet condition prolonged, no concentric rings appeared. Presence of fimbriate margin at outer, peripheral side of the lesion had been found to be characteristic (Holliday and Mowat, 1963).

In inoculated leaves, symptoms appeared within 24 hours as pale colored water soaked lesions. Lesions coalesced, expanded rapidly, covering the large areas of the lamina. Time taken for lesion development varied from 24 - 48 hours, depending upon the maturity of the leaves. Faster defoliation occurred under low temperature (20 - 24°C) and high relative humidity (90 - 97%). If unfavorable weather prevails there may be concentric zonations (Nambiar and Sarma, 1977). The infected leaves shed prematurely before the entire lamina is covered by the spots. Spike infection is very common in rainy season - July - September (Oliveira and Pereira, 1983). Tip of the spikes get discolored due to infection (Holliday and Mowat, 1963) and later the entire spike get darkened and fall. Tender berries also get infected. Occasionally, a few berries only showed infection in a spike (Nambiar and Sarma, 1977). Pathogen spread from foliar region to root system through stem resulted in heavy defoliation and death (Holliday and Mowat, 1963; Nambiar and Sarma, 1977). Foliage 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 et al., 1991&1992). This might be because of the conducive microclimatic condition that prevail under the canopy.

SOIL PHASE

The soil inoculum level 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, it remains unnoticed and foliar yellowing symptom would appear only after sufficient degeneration of root system. During monsoon, the pathogen build up enhances the rotting of feeder root system leading to vine death. Pathogen enters.
the main roots through the feeder root system. When feeder roots decayed, vine starts showing the initial symptoms as yellowing of leaves. The effect of age on root infection, studied under field stimulated microplot conditions clearly brought out that root infection at advanced stages would lead to foot rot leading to vine death (Anandaraj et al., 1994). When the pathogen attack on collar region through the roots, light yellow interveinal chlorosis observed, especially on the upper leaves. This is due to the poor absorption of nutrients and water from the soil. Gradually the whole foliage turned yellow. Even if a portion of root system is healthy, the plant survives with reduced canopy. Rate of root regeneration and root infection determines the speed of decline and death of the vines. After the monsoon, if root system is not enough to support the vine, the vine collapses with wilting and drying of leaves observed (Anandaraj et al., 1988a). Runner shoots or stolons which spreads on the ground from mother plant also play a major role in disease spreading. The creeping stolons get infected and infection advances to the root system later to collar region. Once collar region get infected, the entire vine wilts and defoliation occurs without yellowing (Anandaraj et al., 1988a).

Severe infection on *Piper betle* due to *P. parasitica var piperina* obtained at the range of 20 - 24°C (Selvaraj et al. 1973). According to Maiti and Sen (1982) the foot rot of betle vine observed at less than 22°C. But Venkata Rao et al. (1969) reported that, betle vine wilt appeared continuous day temperature attained minimum at 23°C, and rain fall has not influenced on disease incidence. Selvaraj et al. (1973) reported that, wilt disease of betle vine was severe at the soil temperature ranged from 20 to 24°C. Pal and Grewal (1976b) reported that, the maximum number of sporangia were noticed at 25 - 30°C and pH range of 6 - 6.5. Lucas (1965) reported that *Phytophthora nicotianae var nicotianae* in tobacco prefer high soil moisture for its growth, but according to Apple (1952) ample moisture was good enough to cause the disease on host. Upto 35% crop loss on betel vine was occurred when there was of 6mm. or above daily rainfall in three districts of West Bengal, India (Maiti and Sen, 1982).

Zentmyer and Mircetich (1966) reported that, *P. cinnamomi* can survive a long time in the
soil under high moisture level. The percentage of rainy days had significant positive correlation with infection index and increase in lesion size of *Phytophthora dreschleri* f. sp *cajani* and it was positively correlated with the mortality of plants (Agrawal and Khare, 1987). Singh and Chauhan, 1985 emphasized the importance of drainage in the field and reported that disease incidence due to *P. dreschleri* f. sp *cajani* was sever in the field where the water accumulation was more during the rainy season.

Phukan and Baruah (1989a), published that at 20°C and at 100% RH was suitable for the growth of *P. infestans* (Mont) de Bary. Bambawale *et al.* (1991) reported that, in Punjab (India) the late blight of potato due to *P. infestans* occurred at less than 20°C temperature and 80% RH and there was no correlation with rain where dew appeared to be the alternate source of moisture. According to Russell (1969), the ample rain in winter season had devastating effect on the potato crop which were exposed to high humidity and un protected by fungicides.

Reuse of rain water could encourage the spread of *P. cinnamomi* (Brawne, 1987). Liyanage *et al.* (1983) reported that, a small quantity of water on the surface of rubber pods were enough for proliferation and dissemination of sporangia.

Both high soil salinity and increased water content favored stem rot of citrus root stocks by *P. citrophthora* (Sulistyowati and Keane, 1992). Chlamydospores and oospore production of *P. cactorum* was noticed at 4°C within 20 days (Darmono and Parke, 1990).

**ISOLATION OF PHYTOPHTHORA**

*Phytophthora capsici*, the causal organism of foot rot disease of black pepper can be isolated from infected regions. Due to the high phenol content present in root and collar region, the isolation is difficult compared to leaves (Sarma and Nambiar, 1982). Before the discovery of selective medium, the successful isolation was made by using plane agar medium (Holliday and Mowat, 1963). Infected roots and hardy stems, infected materials
kept for leaching in running water for 24 hours (Sarma and Nambiar, 1982) and isolation made successfully by using CMA-PVPH medium (Tsao and Guy, 1977). Addition of 100ppm. of nystatin and 200ppm. ampicillin to rye B agar medium suppressed the fungal and bacterial contaminants and better isolation was made (Sato and Kato, 1993).

Isolation of *Phytophthora capsici* was made from soil by using different baits. Black pepper leaves (Muller, 1936, Kueh and Khew, 1982), black pepper leaf discs (Ramachandran *et al.*, 1986), apples (Holliday and Mowat, 1963), castor seeds (Narasimhan and Ramakrishnan, 1969 and Sastry, 1982), root pieces of *Colocasia esculenta* (Satyaprasad and Rama Rao, 1980), leaf lets of *Albizia falcataria* (Anandaraj and Sarma, 1990) were used. A number of baiting techniques and selective media to isolate and quantify *Phytophthora* from soil have been developed (Tsao, 1983, Dhingra and Sinclair, 1985). A number of selective media containing antibacterial antibiotic and selective antifungal agents have been tried for isolation of *Phytophthora* from soil and plant tissues (Eckert and Tsao, 1960; Kuhlman and Hendrix, 1965; Flowers and Hendrix, 1969; Tsao and Ocana, 1969; Sneh, 1972; Fujisawa and Masago, 1975; Masago *et al.*, 1977; Tsao and Guy, 1977).

**PATHOGENICITY**

Zoospore suspension has been used by several workers to establish the pathogenicity of *Phytophthora* spp. on their respective hosts (Turner, 1967; Mehrotra, 1972; Kroll and Elide, 1981; Mc Donald and Duniway, 1978; Sastry, 1982; Dutta, 1984; Cho *et al.*, 1987). *Phytophthora cinnamomi* zoospores suspension has used as main source of inoculum (Zentmyer, 1980). It was reported that $5 \times 10^2$ zoospores were good enough to cause infection on black pepper (Freire and Bridge, 1985).

**QUANTIFICATION OF PHYTOPHTHORA IN SOIL**

Various species of *Phytophthora* which cause foot rot and root rot of black pepper, black pod of cocoa and black shank of tobacco are generally isolated from the upper soil horizons and it was believed that soil borne inoculum is most important in causing disease.
epiphytotics (Thorold, 1955; Holliday and Mowat, 1963; Okaisabor, 1971; Onesirosan, 1971; Flowers and Hendrix, 1972; Nambiar and Sarma, 1977). In addition, the inoculum levels of several soil borne species of *Phytophthora* and *Pythium* and infection of several hosts were correlated (Mitchell, 1978). Presence of pathogen at above horizon is more likely to cause early disease out break (Cho *et al.*, 1987) and quantity of inoculum in soil becomes important (Luz and Mitchell, 1994).

A number of selective media and baiting techniques were employed by several researchers for the quantitative estimation of different *Phytophthora* species from soil (Tsao, 1983; Dhingra and Sinclair, 1985). Tsao (1960) used a serial dilution end point method for estimating the disease potentials of *Phytophthora citrophthora*. According to Duncun (1976), the most probable number analysis (MPN) with the baiting technique allowed comparisons between inoculum levels of different plots or treatments. Sastry (1982), found a direct relation between the percentage of baits colonized by *P. palmivora* and inoculum level in the soil.

**CULTURAL PRACTICES**

In view of soil borne nature of the disease, greater precaution need be exerted to maintain nursery hygiene to ensure disease free rooted cuttings for the better establishment in the field and longevity in black pepper against *P. capsici* (*Sarma et al.*, 1987 & 1992). Incorporation of biocontrol agents in solarised nursery mixture is being popularised (*Sarma* and *Anandaraj*, 1998). To reduce the inoculum levels of pathogen in the field, removal of affected vines along with root system and burning off and also maintenance of green cover in the field and pruning off the runner shoots of branches adjacent to the ground level has been emphasized to reduce the chances of foliar infection due to soil and rain splash (*Sarma* and *Anandaraj*, 1998). *Sastry* and *Hegde* (1988) reported the importance of burning off of infected leaves and twigs to avoid the spread of foot rot disease of black pepper in the fields. *Thareja et al.*, (1989) emphasized the importance of drainage system in tomato fields and also reported that, maximum infection was noticed in the area where direct contact of plants
with soil or near the ground, due to the splash dispersal of \textit{P.nicotianae} var \textit{parasitica} inoculum.

\section*{CHEMICAL CONTROL}

In general copper fungicides have been reported to be highly inhibitory to pythiaceous fungi. Bordeaux mixture - a contact fungicide has been recommended to use against the foot rot of betel vine and black pepper by many workers (Dastur, 1927 & 1935; Uppal, 1931; Asthana, 1947; Subramaniyan and Venkata Rao, 1970; Narasimhan \textit{et al.}, 1976; Nair and Sasikumaran, 1991).

In black pepper, spraying the foliage with Bordeaux mixture, drenching the soil - around the base of the vines with Bordeaux mixture or copper oxychloride and application of Bordeaux paste to the collar region during May - June (pre-monsoon) and repeating the spraying and drenching again during August - September (post - monsoon) is the recommended package (Sasikumaran \textit{et al.}, 1981; Mammootty \textit{et al.}, 1991; Ramachandran \textit{et al.}, 1990). Foot rot incidence was significantly reduced with the Bordeaux mixture pasting on foot region and spraying and drenching (Nair \textit{et al.}, 1993). Harper (1974) reported that, soil drenching with cuprous oxide reduced the number of dying plants in the field over a five months period. Application of Bordeaux mixture alone and their combinations with copper oxychloride and metalaxyl found significant effect on disease control (Malebennur \textit{et al.}, 1991). In an \textit{in vitro} assay Sastry (1982) reported that, 1\% Bordeaux mixture inhibited the growth and sporulation of \textit{P.meadii}, the capsule rot pathogen of cardamom. Bordeaux mixture (1\%) spraying twice in June and August gave good control on capsule rot of cardamom (Nambiar and Sarma, 1977).

Out of 5 fungicide formulations tested (Bordeaux mixture, DM-45, Blitox 50, Brestanol and Dithane Z78), Bordeaux mixture was found very effective on control of late blight pathogen (Navase and Dhande, 1982). Fungicides tested against \textit{P.parasitica}, the foot rot pathogen of
betal vine, 1% Bordeaux mixture was found most effective on controlling of the disease (Raj et al., 1973). Ayyavoo and Samiyappan (1984) reported that, application of Bordeaux mixture 0.1% or 1% was good enough to control the foot rot incidence of betel vine in the field. Drenching the soil with Bordeaux mixture at monthly intervals gave effective control and increased yield, followed by COC (0.25%) and dexan (0.5%) - (Narasimhan et al., 1976). Reddy and Mohan (1984) reported that, out of 24 fungicides tested for their bioefficacy on controlling black pod of cocoa and copper fungicides performed best. Application of COC @ 3 applications per year could control the black pod pathogen (Figueiredo and Lellis, 1980).

Sonoda et al. (1990), found that the production of phytotoxin was induced in citrus due to the application of copper fungicides. To overcome the problem of phytoalexin production it was suggested that, apply fosetyl Al 14 days earlier than the application of copper fungicides and it could reduced the phytotoxin production in hosts.

According to Rao (1985), single spray of 1% BM in combination with 0.5% Zinc sulphate was effective throughout the rainy season and decreased the incidence of rotting by *P.nicotianae var parastitica* to 5.6 - 6.8%, compared with 97.5 - 100% in unsprayed fruits of coorg mandarin. It was also reported that application of 1% Bordeaux mixture alone could not able to control the disease effectively. Sarkar et al. (1985) reported that, *P.palmivora* infection was reduced up to 82.15% by the application of 1% Bordeaux mixture in bell pepper.

Systemic fungicides for the control of Oomycetes fungi were developed in sixties. Chloroneb was introduced in 1967 was the first fungicide to show selective toxicity to Oomycetes (Bruin and Edgington, 1983). In 1969, etridiazole (Anon, 1966) was introduced mainly for the control of soil borne species of *Phytophthora, Pythium* and other fungi affecting turf grass, vegetables, fruits, cotton, ground nut and ornamentals. The chemical control of disease caused by Oomycetous fungi had taken a new turn with the introduction of highly
effective chemicals against them in mid seventies. Since then, the information on these chemicals were reviewed by many workers (Schwinn, 1979; Straub and Hubele, 1980; Schwinn, 1983; Bruin and Edgington, 1983; Schwinn and Urech, 1986; Cohen and Coffey, 1986; Schwinn and Staub, 1987). Phenylamides (acylanalines) introduced during seventies (Urech et al, 1977), having four sub classes (Cohen and Coffey, 1986) namely acylanalines, bytyrolactones, thiobutyrolactones and oxazolidinones constitute one of the important groups of fungicides. Detailed investigations have been carried out on the effect of metalaxyl, Methyl D, L - N - (2,6 - dimethyl phenyl) - N - (2' methoxy acetyl) alaninate, a systemic fungicide to control the Phytophthora infections on various crops. Metalaxyl is reported to inhibit both protein and nucleic acid synthesis (Fisher and Hayes, 1982) besides reducing nuclear division. According to Fisher and Hayes (1982) respiration, wall synthesis and membrane permeability remained unaltered in treated mycelia of Phytophthora nicotianae, P.palmivora and Pythium ultimum. As metabolites of the fungicides were not seen in both the fungus and the in medium, metalaxyl is believed to be the primary toxic agent and it is reported to reduce the uptake of labelled uridine and thiamine into RNA and DNA. Hence Fisher and Hayes (1984) concluded that matalaxyl might inhibit RNA polymerase. Ramachandran et al. (1988), conducted an extensive study on the effect of metalaxyl on different species of Phytophthora affecting on plantation crops. In green house and field trials, Kasim (1986) could get good control on foot rot incidence of black pepper by using Ridomil, followed by Alliette, Dithane M45, and Delsene MX 200. Sastry and Hegde (1987) reported that, foliar spray with metalaxyl gave good control on foliar infection of black pepper due to P.capsici. Ramachandran and Sarma (1985) studied the efficacy of 3 systemic fungicides against the foot rot pathogen of black pepper and reported that ridomil (metalaxyl) treated plants showed least root necrosis and no death was noticed followed by Terrazole and Alliette.

Ramachandran and Sarma (1985) evaluated five systemic fungicides viz; metalaxyl, fosetyl-Al, ethazole, propamocarb and oxyadixyl for their bio-efficacies on different phases of 'P.palmivora' (MF₄) and the field evaluation of first three fungicides. From in vitro assays, it was reported that ethazole and metalaxyl were the most toxic to the growth of fungal
mycelium. On sporulation, ethazole followed by metalaxyl, fosetyl Al and oxadixyl were effective. Among three fungicides tested in the field, metalaxyl gave good control of the disease and suppressed *P. palmivora* population.

Spraying and drenching of black pepper with ridomil at 0.08%, 2 weeks before and after inoculation gave good control on *Phytophthora* infection (Kueh, 1984). Effective control on black shank of tobacco due to *P. parasitica* Dastur var. *nicotianae* Tucker (Vasilakakis *et al.*, 1979), and *P. infestans* on tomato plants by metalaxyl was reported (Cohen *et al.*, 1979). According to Edgington *et al.*, (1980), metalaxyl was effective against *Pythium* and *Phytophthora*.

Mycelial growth of *P. citrophthora* and *P. capsici* was completely inhibited by metalaxyl at 25ppm, and *P. palmivora* at 50ppm. Lethal concentrations of metalaxyl for *P. citrophthora* and *P. palmivora* was reported as 75ppm. (Campelo *et al.*, 1984). Extensive work has been done on the action of metalaxyl on *P. infestans* De Bary, the late blight pathogen of potato (Mantecon and Escande, 1985; Berggren, 1985; Kozlovski and Suprun, 1989; Cohen and Samoucha, 1989; Easton and Nagle, 1985; Tedle, 1985).

In a green house trial Garibaldi and Timietti (1980), reported that metalaxyl @ 50g/plant used as soil drench, 2 days before inoculation protected the plants throughout the trial. Ridomil applied as a single soil drench containing 0.25µg/litre was sufficient to protect the tomato plants from *P. infestans*. Penetration and initial establishment of *P. infestans* in leaves and fruits of tomato was observed, to achieve most efficient control on blight incidence in green house plants and must be treated with chemical either before or within the first 2 days after the inoculation (Cohen *et al.*, 1979). Growth and sporangial germination of *P. dreschleri* f sp. *cajani* was inhibited by the low concentration of metalaxyl. Growth was completely inhibited by at 0.5 µg/ml and sporangial germination at 1 µg/ml. (Chaube *et al.*, 1987). Extensive studies have been carried out on control of *P. dreschleri* by metalaxyl (Chauhan and Singh, 1987; Bisht *et al.*, 1988; Agrawal, 1987; Singh and Chauhan, 1992; Kannaiyan and Nene, 1984)
Ramraj and Vidhyasekaran (1983) reported that metalaxyl inhibited the production of pectic enzymes by *P. parasitica var piperina* in *Piper betle*. Root tissue of wilted betle vine were reported to contain C1 and Cx enzymes, and these enzymes were also produced in cultures of *P. parasitica var piperina*. The Cx production was completely inhibited and inactivated when cultures incubated with etridiazole formulations, which is highly inhibitory to production of C1 enzyme (Ramraj and Vidhyasekaran, 1982).

Soil treatment with 100ppm metalaxyl could give effective control on *P. parasitica var nicotianae* infection in tobacco (Bhatt and Patel, 1989). *P. palmivora* infection in cocoa fields could be controlled effectively by metalaxyl (McGregor, 1982). Metalaxyl or cuprous oxide spray could effectively control the pod rot and canker of cocoa (Holderness, 1992). Low concentrations of metalaxyl was highly inhibitory to mycelial growth, sporangial formation, chlamydospore and oospore formation both in *P. parasitica* and *P. citrophthora* (Farih et al., 1981). *Phytophthora citrophthora*, the causal agent of gummosis of citrus was controlled by soil drenching with metalaxyl and fosetyl aluminium. Stem lesions were reduced by the application of 50μg/litre of metalaxyl (Farih et al., 1981). Root rot of rough lemon due to *P. nicotianae var parasitica* could control by soil drenching of metalaxyl and up to 1000ppm. it was not phytotoxic to 2yrs old rough lemon seedlings (Lee and Wicks, 1982). Utkhede (1984c) reported that soil drenching with metalaxyl mancozeb application around the base of naturally infected trees, prevented the further spread of *P. cactorum* in apple trees.

Out of 11 fungicides tested for their bio-efficacies, metalaxyl and alliette (fosetyl aluminium) completely inactivated the mycelium of *P. cactorum* in the soil within 2 days and completely inhibited the production of sporangia and oospores (Rana and Gupta, 1984). Ellis et al. (1982) reported that, metalaxyl at lower concentration inhibited the growth, sporulation and zoospore germination of apple collar rot pathogen *P. cactorum*. Soil drenched with metalaxyl prevented the infection of apple trees in green house. *P. syringae*, the apple fruit rot fungus was inhibited by metalaxyl in fields (Edney and Chambers, 1981). Significantly effective
control on *P. capsici*, the pepper blight pathogen was noticed by metalaxyl. In an *in vitro* assay, mycelial growth in solid and liquid media and sporangial germination were inhibited even at low concentrations of metalaxyl, where as sporangial germination was inhibited at higher concentrations (Sung and Hwang, 1988). Lee and chung (1989) studied the effect of metalaxyl on growth of *P. capsici*, the fruit rot pathogen red pepper and reported that metalaxyl MZ was more effective on inhibiting the growth of *P. capsici* than alliette F. From pot culture studies Tamietti and Ritucci (1986) reported that, metalaxyl showed much effective and persistent activity against the foot rot pathogen - *P. capsici* - of capsicum.

Recent studies have demonstrated that some simple phosphorous compounds have powerful and selective antifungal properties, with good selective activity against oomycete plant pathogens in higher plants. This compound triggered a resistant reaction in the host (Bompeix *et al.*, 1981 & Guest, 1984). Antifungal activity of phosphorous acid have been proved very early (Thizy *et al.*, 1978). Coffey and Bower, 1984 and Fenn and Coffey, 1984 reported that phosphorous acid compounds showed antifungal activity against oomycete fungi and has little or no activity against the majority of other fungi. Potassium phosphonate was investigated for its antifungal properties against a range of fungi grown on liquid and solid media (Coffey and Bower, 1984; Fenn and Coffey, 1984; Dolan and Coffey, 1988). Phosphonate has got high selectivity against certain *Phytophthora* species (Fenn and Coffey, 1984). Sporangial development of *P. palmivora* was inhibited (EC50) even at 0.1µg/ml. (Dolan and Coffey, 1988). Oospores and chlamydospore production of *P. cinnamomii* inhibited at higher concentration-50ppm. (Coffey and Joseph, 1985). Coffey and Joseph (1985) and Dolan and Coffey (1988) emphasised the selective interference with key biosynthesis events on zoosporangia production by *Phytophthora*.

It is known that phosphorous compounds in plant tissues degrade easily (Piedallu and Jamet, 1985; Saindrenan *et al.*, 1985). Tomato leaves when treated with 400 µg/ml. of phosphonate compound and analyzed after 48 hours contained 14µg/g of ethyl phosphonate and 358 µg/g of phosphonate on fresh weight basis (Fenn and Coffey, 1988). Very low
level of ethyl phosphonate was detected in seedlings treated with potassium phosphonate (Ouimette and Coffey, 1989).

A single pre-planting dip of pine apple sucker was effective against *P.cinnamomi* and *P.parasitica* for 18 months (Rohrbach and Schenck, 1985). In avocado, Darvas *et al.* (1984) and Pegg *et al.*, (1985) reported that, two application with potassium phosphonate as trunk injection could control *P.cinnamomi* and resulted in enhanced growth of host in the following season.

Adams and Conrad (1953) demonstrated that, the microorganisms presented in the soil could oxidize the phosphonates into phosphate. Micoorganisms including bacteria, fungi and actinomycetes can apparently utilize the phosphonate as a phosphorous source (Casida, 1960; Malacinski and Konetzka, 1966).

Dimethomorph or commonly known as acrobat, which was firstly described in 1988 (Albert *et al.*, 1988) was highly effective in the control of downey mildews and diseases caused by different species of *Phytophthora*. Kuhn *et al.* (1989a & b) reported that, dimethomorph is active against *Phytophthora* species *in vitro*, where it inhibits radial growth of mycelium with ED50 values typically in the range of 0.25 - 0.75 micromol. Albert *et al.* (1988) and Kuhn *et al.* (1989a) found that, dimethomorph acts as a fungicide compound and not as a fungistatic compound. Kuhn *et al.* (1991) has conducted an excellent study on its mode of action on different *Phytophthora* species and reported that, the formation of periodic constrictions along treated hyphae with the dimethomorph, producing a beaded morphology, stunting of hyphae and stimulated the formation of short lateral branches. The most important finding was the extensive proliferation and aberrant deposition of cell wall material and which lead to the formation of false septa. Tomat (1992) and Thomas *et al.* (1992) supported the findings of Kuhn *et al.* (1991) reported that, dimethomorph acts on fungus by interfering with the biochemical processes regulating the cell wall formation.

Aureofungin, chemically known as a heptaene compound, produced from streptomycete –
*Streptoverticillium cinnamomeus* var *terricola*. Aureofungin reported to be very effective *in vitro* against *P.palmivora* and *P.citrophthora* (Agarwala and Thirumalachar, 1967; Agarwala and Sharma, 1975; Bedi and Dhalial, 1970; Bedi et al., 1969; Capoor and Marathe, 1970). Its *in vitro* efficacy against *Pythium debaryanum* and *P.myriotylum* was established (Captor and Marathe, 1970). Field efficacy of aureofungin to control of leaf rot of pan due to *P.parasitica* var *piperina* was reported (Chaurasia et al., 1973).

Aureofungin was also reported to be effective against *Phytophthora* diseases viz; fruit rot of guava (Sohi, 1975), citrus gummosis (Desai et al., 1966) and abnormal leaf fall of rubber (KAU, 1976). Seed dip of rhizomes in 100ppm aureofungin solution before planting them in the field was found effective against rhizome rot of ginger caused by *Pythium debaryanum* (Haware et al., 1973).

**BIOLOGICAL CONTROL**

The potential of biocontrol of plant pathogens has been reviewed excellently (Garret, 1965; Baker and Cook, 1974; Cook and Baker, 1983; Baker, 1987 & 1992). Biological control is the use of organisms, genes or gene products to regulate a pathogen and can be used with strategies intended to keep (1) inoculum density below an economic threshold level (2) retard or exclude infection (3) maximize the plant's system for self defence (Cook, 1988). The mechanism of biocontrols on plant pathogens have been reviewed extensively and the main mechanisms identified are antibiosis, lysis, competition and mycoparasitism. (Cook and Baker, 1983; Papavizas and Lumsden, 1982).

Several toxic metabolites are produced by antagonists against pathogens *in vitro* and in soil (Wright, 1956). Many researchers dealing with *Trichoderma* noticed that hyphae of the antagonists parasitize on the hyphae of pathogens brought about several morphological changes viz; coiling, haustoria, disorganization of host cell contents and penetration of the host (Cook and Baker, 1983). It is reported that, cell wall degrading enzymes such as mycolytic enzymes being produced by many biocontrol agents (Cook and Baker, 1983).
Studies on biocontrol of plant pathogens have started during the early period of 20th century. First paper on biological control was published in 1926 (Sanford, 1926), on microbial and soil factors affecting the pathogenicity of *Actinomyces scabies* on potato.

In India, Mehrotra *et al.* (1990) and Mehrotra (1992) reviewed the biocontrol strategy for the control of *Phytophthora* disease of various crops with special emphasis on betle vine *Phytophthora, P.nicotianae var piperina*. Tiwari and Mehrotra (1974) studied the colonization ability of *Trichoderma viride* and *Aspergillus terreus* on infected root and petiole sections of *P.betle* in fumigated soil and reported that, *T.viride* population was increased in fumigated soil and gave better control against *P. nicotianae var piperina*. Sharma and Tiwari (1981) studied the phylloplane microflora infected by *P.infestans* on *Solanum khasianum*, and reported that, healthy leaves had more number of microorganisms than diseased leaves. Halsall (1982) studied the microorganisms in suppressive soil of eucalyptus forest. Suppressive soil from wet sclerophyll eucalyptus forest in Tallaganda, NSW, contained more actinomycetes than conducive soil. All *Streptomyces* isolates isolated from suppressive soil showed antagonistic activity against *P.cinnamomi* and *P.cryptogea*.

Duvenhage *et al.* (1991) isolated antagonistic microorganisms from suppressive soil from avocado plantation. Out of 48 soils studied, 12 found suppressive in nature and had more actinomycetes, bacteria and fungal populations. Out of 50 microbes evaluated 5 bacteria, 4 fungi and 6 actinomycetes were found significant in reducing root rot of avocado caused by *P.cinnamomi*. Broadbent and Baker (1974) studied the suppressiveness of avocado soil. Disease suppressive soil showed higher populations of bacteria and actinomycetes. Mycelial growth and sporangial formation was poor in suppressive soil compared to disease conducive soil.

Among the many potential antagonistic soil inhabitants, members of the genus *Trichoderma* have been studied extensively (Dennis and Webster, 1971; Papavizas, 1982; Wood and Tvet, 1955; Boosalis, 1964; Baker, 1968; Baker and Cook, 1974; Cook, 1977).
Gliocladium roseum was reported antagonistic to *P. palmivora*, and it colonized on sporangia and chlamydospores of the pathogen (Lim and Chan, 1986). Their light microscopic studies, SEM and TEM investigations showed that process of parasitism as coiling, penetration and proliferation of the mycoparasite within the host spores followed by destruction of host cytoplasm. Out of 96 fungi, 174 actinomycetes and 576 bacterial isolates isolated from rhizosphere and non-rhizosphere areas of 5 major capsicum growing areas, *Tr. harzianum*, *P. cepacia* and *B. polymyxa* have been sorted out as promising antagonists agents against *P. capsici* (Jee et al., 1988). *Trichoderma* and *Gliocladium* isolates were found to be potential antagonist of *P. cactorum* causing root and crown rots of apple (Smith et al., 1990; Lederer et al., 1992; Orlikowski and Schmidle, 1985; Roiger and Jeffers, 1991). Pasini et al. (1991) tested 62 soil samples for their suppressive nature against *P. cryptogea*, foot rot pathogen of Gerbera and 7 samples were found suppressive and the suppressiveness of soil was correlated with the antagonistic effect of *Trichoderma* spp.

Efficacy of *T. harzianum* against *P. cryptogea* causing foot rot of Gerbera has been reported (Duskova, 1992). Orlikowski (1994) studied the biocidal property of *Trichoderma* and *Gliocladium* spp. against *P. cryptogea* and reported that 10^9 spores of *T. viride* applied to pits 10 days before inoculation with *P. cryptogea*, could control foot rot of Gerbera effectively. *T. harzianum* impregnated on clay granules could control damping off of pineapple seedlings due to *P. cinnamomi* (Kelley, 1976).

Culture filtrates of *G. roseum*, *T. harzianum* and *T. roseum* inhibited the mycelial growth of *P. megasperma* f sp. *glycinea* (Al-Heeti and Sinclair, 1988). In an *in vitro* study, culture filtrates of *Chaetomium globosum*, *G. virens* and *T. viride* were found antagonistic and mycoparasitic to *P. cinnamomi*, *P. cactorum*, *P. fragariae* and *P. nicotianae*. Culture filtrates of *T. viride*, *A. niger* and *A. flavus* suppressed the sporangial formation of *P. parasitica* var *piperina* in Piper betle (Vyas et al., 1981; Chile, 1982). In an *in vitro* assay, culture filtrates of *Myrothecium noridum*, strongly inhibited the growth of *P. nicotianae* var *parasitica*, *P. syringae* and *P. capsici* (Tuset et al., 1990). Antagonistic
property of *Neocosmospora vasiforma* (Von.Arx) Cannon and Howkswork on *P. capsici* (Turhan and Grossmann, 1988). *Penicillium aurantiogriseum* and *Fusarium equiseti* were reported as antagonists against *P. infestans* (Jindal et al., 1988). Krishnakumar et al. (1987) isolated *Penicillium aurantiogriseum*, *T. koningii* and *Mucor hiemalis* from potato phylloplane as antagonists of *P. infestans*.

Bacterial isolates antagonistic to the growth and multiplication of serious soil borne pathogens have been reported (Brown, 1974; Hutchins, 1980; Merriman et al., 1975; Sneh et al., 1977; Utkhede and Rahe, 1980). By using Kings (B) and D4 media, Ryu et al. (1991) isolated 926 rhizosphere bacteria and 63 isolates were found antagonistic to *P. capsici*. Galindo (1992) studied the efficacy of *Pseudomonas fluorescens* isolates against *P. palmivora*, *in vitro* and *in vivo* and reported that it was more effective than copper oxychloride and chlorothalonil. The fluctuation of bacteria depends on RH and rainfall. *Pseudomonas cepacia*, *Bacillus polymyxa* and *Bacillus sp.* were found effective against *P. nicotianae* and *P. capsici* (Cho, 1987).

Antagonistic effect of bacterial isolates on *P. cactorum* were studied extensively (Utkhede, 1984a&b; Utkhede and Gouce, 1983; Marchi and Utkhede, 1994; Utkhede and Smith, 1993). *In vitro* efficacy of *Rhizobium* sp. was studied on *Fusarium* spp., *Pyrenochaeta terrestris*, *Colletotrichum destructum*, *P. cactorum* and *Coniothyrium* sp. (Drapeau et al., 1973). Gupta and Utkhede (1987) studied the nutritional requirements of antagonistic bacteria *Enterobacter aerogenes* and *Bacillus subtilis* and they found that addition of (NH₄)H₂PO₄ increased the production of antagonistic substances. Results indicated that use of N and P fertilizer increased the production of antifungal substances by the agonistic bacteria in soil.

For better antagonistic effects against *P. cactorum*, the temperature and pH requirements were 14 - 21°C and 3 - 5 for *E. aerogenes* and 21 - 28°C and 5 - 8 for *B. subtilis* respectively. Optimum growth in sterilized soil was observed at 18°C for *E. aerogenes* and 25°C for *B. subtilis*. Fosetyl did help in bacterial multiplication at lower temperature and
metalaxyl at higher temperature. Light and electron microscopic studies conducted by Malajczuk et al. (1977) reported that, Pseudomonas spp., Bacillus spp. and Streptomyces spp. lysed the hyphae and inhibited the production of zoospores and its release of P.cinnamomi in soil.

Turnbull et al. (1992) reported that Pseudomonas cepacia reduced the root rot caused by P.cinnamomi. Myatt et al. (1993) screened 1000 bacterial isolates in vitro and in vivo against Phytophthora root rot pathogen of chick pea. They reported that 31 isolates out of 1000 delayed or limited the decay of chick pea seedlings disease in pasteurized soil. The most effective isolates included P.cepacia (7 strains) and P.fluorescens (2 strains).

Several actinomycetes have been isolated and tested against soil borne plant pathogens. Lee et al. (1990) studied the activity of Streptomyces parvullus against P.capsici. The active compound responsible for the antagonistic activity was purified by ion-exchange, adsorption and gel-permeation and partial column chromatography techniques and identified as polyoxin. Ahn and Hwang (1992) isolated actinomycetes antagonists to P.capsici from rhizosphere soil of 6 capsicum growing areas. Actinomycetes, antagonistic to P.meadii, causing fruit rot of rubber, were isolated from soils of rubber growing areas and reported that soil samples had more antagonistic actinomycetes (Kochuthresiamma et al., 1988).

Treatment of tomato seedlings with culture filtrates of Streptomyces aurantiacus, S. griseus and S. longissimus, before sowing reduced the infection due to Fusarium oxysporum and P.parasitica (Tsintasadze and Tsilosani, 1973). Chung and Hong (1991) studied the action of two strains of Streptomyces sp. (Strain11 &20) on Fusarium oxysporum f sp. vasinfectum and P.nicotiae var.parasitica and they reported that the culture filtrates of actinomycetes lysed the mycelia and inhibited the spore germination.

Verticillium tenerum a saprophytic fungus, proved its antagonistic ability against the foot rot pathogen of black pepper, P.capsici (Rajan and Sarma, 1997) and as hyper parsite on Rhizoctonia solani (Turhan, 1990).
The role of VAM in nutrient uptake, growth promotion, tolerance to biotic and abiotic stress in crop plants has been reviewed (Sieverding, 1991). The association of VAM with root system of black pepper and the growth promoting activities was reported (Manjunath and Bagyaraj, 1982; Bopaiah and Khader, 1982). Role of VAM and *Trichoderma* on *Phytophthora* root rot suppression in black pepper nurseries has been proved (Anandaraj and Sarma 1994; Sarma *et al.*, 1996). Nambiar and Sarma (1979) isolated *Trichoderma* spp. from the roots of healthy black pepper vines and also noted the lysis of mycelium of black pepper isolate of *Phytophthora* when the *Trichoderma* sp. over grown on the test fungus.

**MASS MULTIPLICATION AND DELIVERY SYSTEM OF TRICHODERMA AND GLIOCLADIUM**

Apart from isolation and identification of potential biocontrol agents, their mass multiplication and delivery systems are important for the successful exploitation of biocontrols. Different solid media for the mass production of *Trichoderma* and *Gliocladium* have frequently been used (Davet *et al.*, 1981; Elad *et al.*, 1980a; Elad *et al.*, 1980b). Use of different carrier media were tried by many workers, bark pellets (Sundheim, 1977), wheat bran plus peat (Sivan *et al.*, 1984), barley grains (Abd-El Moity and Shatla, 1981). Composted hard wood bark was used for multiplication of *Trichoderma* and *Gliocladium* (Hoitink, 1980; Nelson and Hoitink, 1983; Nelson *et al.*, 1983). Ricard (1981), mass multiplied and commercialized the *Trichoderma* and *Gliocladium* as mycofungicide for field application. Hunt *et al.* (1971), tried motor oil for *Trichoderma* formulation and successfully inoculated on pine stumps during tree cutting.

Growth media for liquid formulation included such as inexpensive products like glucose, starch, hydrolyzed corn and soy products, whey and molasses (Kenney and Couch, 1981). Use of inexpensive liquid media such as molasses and brewers yeast to produce viable inocula of *Trichoderma* and *Gliocladium* with a deep tank fermentor system for large scale industrial production has been emphasized recently (Papavizas *et al.*, 1985).
formulation of *Trichoderma* and *Gliocladium* was prepared by air drying the fungal mats, grinding them and diluting the powder with the commercially available pyrax as a carrier (Papavizas, 1984). Lewis and Papavizas (1984) refined the techniques of incorporation of antagonistic fungi in nutrient carrier (bran) with alginate to provide a food base in intimate contact with the antagonist.


**ESTABLISHMENT AND PROLIFERATION OF FUNGAL ANTAGONISTS IN SOIL**

Locke *et al.* (1984) got excellent control of Fusarium wilt of chrysanthemum by the addition of conidial suspension of *T. viride* as soil mix. The biocontrol agent, *T. viride* was applied as conidia @10⁴ conidia/cm² to the pasturized (at 82°C for two hours) soil mix, which helped in rapid colonization of antagonist in soil mix and prevented the reinvasion of the pathogen. Lewis and Papavizas (1984) described that, *Trichoderma* and *Gliocladium* and other potential antagonistic fungi proliferated abundantly in various natural soils when added as young mycelia in intimate contact with a food base (sterile moist bran inoculated with conidia and allowed to incubate for one to three days before addition to soil), but not as conidia with or without bran. Proliferation (upto 10⁶ fold) and subsequent establishment in
soil depended on inoculum age and how it is added in relation to food base. Lewis and Papavizas (1984) reported that, alginate pellets containing fermentor biomass preparations of *Trichoderma* and *Gliocladium*, in a food base (bran) stimulated the great increase in population. Dry formulation of *Trichoderma* and *Gliocladium* by fermentation technique appeared to proliferate greatly. The conidial number was increased in soil from $5 \times 10^5$ to $6-7 \times 10^6$ per gram of soil (Papavizas *et al.*, 1984). The unique ability of young hyphae but not conidia of *Trichoderma* and *Gliocladium* to proliferate from thoroughly colonized substrate or from alginate pellets might be due to their insensitivity to fungistasis.

**EFFECT OF ORGANIC SOIL AMENDMENTS**

Addition of soil amendments into soil may alter the soil microbial population. Zentmyer (1963) noted that, addition of alfalfa and cotton waste (gin trash) increased the soil microorganisms and suppressed the *P.cinnamomi* Rands. infection in avocado root. On contrary Jeyarajan *et al.* (1987) reported that addition of neem and neem products reduced the fungi, bacteria and actinomycetes population in the soil and suppressed the *P.capsici* infection on betel vine. Tsao and Oster (1981) studied the effect of urea and chicken manure on *Phytophthora*, they reported that the formation of ammonia and nitrous acid from amendments, found toxic to the fungus. Nam *et al.* (1988) reported that amendments with 5-10% of arrow roots, leaf tissue, rice polish and wheat bran stimulated the growth of *Capsicum annum* and its inhibitory effect on growth of *P.capsici in vitro*. They also reported that, application of organic amendments together with antagonists greatly enhanced the disease suppressive effect. Crown rot of capsicum due to *P.capsici* reduced significantly by addition of 10% compost of sewage sludge and survival of pathogen was not affected by compost but it enhanced the total microbial population which suppressed the activity of pathogen (Lumsden *et al.*, 1983). Singh and Vyas (1984) studied the effect of 5 oil cakes viz, *Brassica compestris* L., *Linum usitatissimum* L., *Ricinus communis* L., *Azadirachta indica* Juss. and *Madhura indica* Gmel. on *P.parasitica* var *nicotianae* and they found that mustard oil cake was fungi toxic causing up to 51.2% inhibition.
Inhibitory effect of soil amendments on *P. cinnamomi* was studied by several workers (Hoitink *et al.*, 1977; Rosas Romero *et al.*, 1986; Sivasithamparam 1981; Nesbitt *et al.*, 1979). Spencer and Benson (1982) studied the effect of pine bark, hard wood bark compost and peat amendment on lupin root rot by different *Phytophthora* species. Huang (1991) obtained very good control on *Phytophthora* blight of cucumber, *Pythium* damping off, club root rot of crucifers (*Plasmodiophora brassica*) and *Fusarium* wilt of water melon by using a S-H mixture consisted of 4.4% bagasse, 8.4% rice husk, 4.25% oyster shell powder, 8.25% urea, 1.04% potassium nitrate, 13.16% calcium sulphate and 60.5% mineral ash (slag). Enhancing effect of organic amendments on antagonistic organisms were emphasized by Linderman (1989). Stover (1962) and Hubber & Watson (1970) emphasized the effect of organic amendments and green manures in the control of soil borne plants pathogens.

**EFFECT OF PLANT EXTRACTS**

Smale *et al.* (1964) have carried out a survey of green plants showing antifungal properties against fungi and bacteria. Chamount and Jolivet (1978), have tested 100 extracts of vegetable origin against seven plant pathogenic fungi and reported that *Fusarium oxysporum* and *P. cinnamomi* were most resistant to the action of these plant extracts. Chamount (1979) tested aqueous extracts of eight flowering plants against 51 fungi and found that *Phytophthora* and *Pythium* were among the most resistant ones. Singh (1972) tested 10 plant extracts on plant pathogens. Whitefield *et al.* (1981) reported, the root extract of *Acacia pulchella* R.Br. showed high inhibitory effects on growth, sporangial production, sporangial germination and zoospore germination of *P. cinnamomi* Rands. They characterized the volatile compounds responsible for inhibitory action as 2 & 3 methyl butanol, hexanol, pentanol, 2, 3 methylbutanol, 4-methyl acetophenone and carbon disulphide.

Pathak and Dixit (1984) studied the antifungal and antimicrobial activity of essential oils extracted from *Glossocardia bosvallia* DC, and reported that it showed good antifungal action against *P. parasitica*. Gennari *et al.* (1987) emphasized the activity of parthenolide.
extracted from *Tanacetum vulgare* on *P. capsici*. Chauhan and Singh (1991b) conducted a study on activity of 5 plant extracts on *P. dreschleri f.sp. cajani*, and reported the feasibility of garlic and onion extracts in fields to control the pigeon pea wilt. Johri *et al.* (1994) reported that, the use of *Ammi majus* extracts to control the *P. palmivora* in betel vine. Wagner and Flores (1994) studied the effect of Taxol and related compounds obtained from *Taxus* spp. on several fungi, their study showed that the extracts got good inhibitory effect on growth of *Phytophthora* spp., *Pythium* and *Rhizoctonia solani*. Gerrettson *et al.* (1976) found that growth and pathogenicity of *P. cinnamomi* were inhibited by the bark extract of *Pinus radiata* D.Don.

Vasyukova *et al.* (1977) found that, both deltozid and deltonin (second saponins from the rhizome of deltoid yam) were inhibitory to zoospore of *P. infestans*. Leaf extract of six plant species were tried against *P. palmivora* and found that *Xylia xylocarpe* (Rosb.) Taub. was the most effective one (Hegde, 1983).

Ajoene, a compound derived from garlic (*Allium sativum* L.) was found highly inhibitory to *P. dreschleri f.sp. cajani* (Singh *et al.*, 1992). Zoospore germination of *P. dreschleri f.sp. cajani* was found inhibited by the extracts of garlic and onion at 5,000 and 10,000 ppm. respectively (Chauhan and Singh, 1991b). Zuberi (1987) reported the antifungal activity of garlic on *Aspergillus flavus* spores. A clear zone of inhibition was noted in garlic extract treated plates. Kohlos *et al.* (1993) reported the antifungal action of garlic on *Inonotus obliquus*. Antimicrobial activity of garlic has been well established by many workers (Rees *et al.*, 1993; Hughes and Lawson, 1991; Dalaha and Garagust, 1985; Jain, 1993; Weber *et al.*, 1993; Dhaliwal and Dhaliwal, 1971). Compound responsible for antimicrobial activity of garlic has been isolated, purified and identified as allicin (di allyl thiosulphinate) (Barone and Tansey, 1977). Later on Pandy *et al.* (1990) Yoshida *et al.* (1987) and Singh *et al.* (1990 & 1992) have isolated a compound called ajoene from garlic extract, which showed high inhibitory action against fungi.

Ernest Guenther (1978), has well documented the major constituents of mustard (*Brassica*
REVIE\' OF LITERATURE

*compestris* L.) and he reported that, allyl isothiocyanide is the principal constituent of mustard oil and this compound showed high antimicrobial properties.

**COMPATIBILITY OF BIOCONTROLS WITH GROCHEMICALS**

Integrated disease management (IDM) has become more relevant in the present crop protection strategies and biocontrol has become very important component, especially soil borne plant pathogens. Hence the compatibility of biocontrol agents with fungicides received considerable attention in recent years.

Fungicide application into soil will distort the existing equilibrium of microorganisms in the soil. Due to the fungicides, some get killed and some may over come the situation. Organisms escaped tend to multiply and proliferate in the soil. The biological equilibrium will change better for worse (Martin, 1950). Saprophytic soil fungi influence survival/pathogenicity of soil borne pathogens by competition, antagonism or parasitism (Warcup, 1951; Weindling *et al*., 1950). Soil application of metalaxyl to control avocado root rot enhanced the suppression of *P. cinnamomi* disease without affecting its biological antagonists (Malajczuk *et al*., 1983). Chandra and Bollen (1961) demonstrated that soil application of nabam (100ppm.) and mylone (150ppm.) significantly reduced the number of fungal propagules in the soil. Corden and Young (1965) studied the effect of Vapam, metasol, mylone and nabam on soil fungi and found that a drastic reduction in the number of fungal propagules in the treated soil compared to untreated soil. Waksman and Starkey (1923) reported that fungal colonies developing on plates from fungicide treated soil represented relatively few species as compared to those in untreated soils. Quantitative studies revealed that certain genera like *Aspergillus*, *Penicillium*, *Fusarium* and *Trichoderma* became abundant in most of the treated soils. It was noted that indigenous of introduced *Trichoderma* sp. have greater tolerance to most of the broad spectrum fungicides and greater colonizing capacity than other soil competitors (Munnecke, 1972). Richardson (1954) demonstrated that *Trichoderma* and *Penicillium* in thiram treated soil have constantly better survivability and multiplication. Davet (1981) confirmed from his work.
that, *Trichoderma harzianum* has got beneficial effect in thiram treated soil. Spores of *T. hamatum*, *T. harzianum* and *T. viride* isolates can tolerate exposure to methamsodium in dilution up to 350 μg active ingredient when incorporated along with the fumigant and applied (Lewis and Papavizas, 1984).

Metalaxyl was reported non-toxic to *T. harzianum*, *in vitro*, in contrast benimidazole fungicides. Benomyl strongly inhibited the growth of *Trichoderma* spp. in culture even at the concentration of 0.5 mg/litre. Captan, chlorothalonil, chloroneb and PCNB were not inhibitory to *Trichoderma* (Abd El moity *et al.*, 1982). Papavizas (1981) demonstrated the compatibility of metalaxyl with *T. harzianum* by the infusion of pea seeds with this fungicide before planting, with conidia of *T. harzianum*, which improved the survival of conidia and even increased the CFU in the rhizosphere compared to rhizosphere of plants where seed covered with conidia only.

Casida (1960), Malacinski and Konetzka (1966) demonstrated the effect of potassium phosphonate on disease suppression and its effect on other soil microorganisms. They reported that, different soil microorganisms including bacteria and actinomycetes can apparently utilize phosphonate as phosphorus source. Wongwathanarat and Sivasithamparam (1991) reported that, potassium phosphonate has got no negative effect on beneficial microorganisms in soil and it is compatible with *T. harzianum*. Rajan and Sarma (1997) proved the compatibility of potassium phosphonate with eight species of *Trichoderma* in an *in vitro* study even at 1200 ppm.

The population of different group of bacteria are generally altered by fungicide application in soil. They are reduced in number for a period, then multiply rapidly, usually the numbers exceeding those in untreated soil. Part of the rise in number might be due to decomposition of the chemical (Mattews, 1924). After reaching a maximum, bacterial numbers fall towards those of untreated soil (Waksman and Starkey, 1923). The fall is some times very slow taking over a year. Treatment of cotton seeds with Agrosan GN had increased the bacterial population in the rhizosphere of cotton seedlings (Pugashetty and Rangaswami, 1969) for
the first seven days. An initial increase in bacterial population in Dithane-M45 and captan treated soil has been reported by several workers (Agnihotri, 1971; Balasubramanian, et al., 1973; Cram and Vaarteya, 1957; Domsch, 1959). All concentrations (2.5, 5, 10 and 20ppm.) of aretan and lower concentrations of bavistin (5 to 20ppm.) stimulated bacterial counts (Sinha, et al 1979a & 1980b).

Contrary reports exist showing reduced population of bacteria following fungicide application. Nauman (1972) observed that vapam, dozomet and allyl alcohol when added to soil inhibited proliferation of bacterial population in the soil. Detrimental effect of worlex to the proliferation of soil bacteria was noticed during the first two week. Potassium phosponate was found compatible with Enterobacter aerogenes (Utkhede and Smith, 1993).

Yatzawa et al. (1960) observed that, allyl alcohol at or 112.5litre/ha. inhibited actinomycetes population. Similar inhibition was observed due to metham (Bollen et al., 1954), indar (Sinha and Singh, 1979), carbendazim (Sinha et al., 1980). Contrary in this, Roslyeky (1980) showed little initial effect on the actinomycete population following worlex application at recommended rates. Pugashetty and Rangaswami (1969) while studying the rhizosphere microflora of cotton seedlings as influenced pre-treatment of cotton seed with agrosan-GN, observed a reduction in the actinomycetes counts in initial stage of plant growth, but not in the later part of the growth. Balasubramanian et al. (1973) reported the compatibility of Dithane M-45 with different antagonistic actinomycetes. An appreciable increase in the population of actinomycetes in soil, treated with aretan has been reported (Hofer, 1958).

Malatozuk et al. (1983) reported that, metalaxyl stimulates the lytic capacities of soil microorganisms, antagonistic to P.cinnamomi. Bailey and Coffey (1985) reported that the composition and levels of microbial populations (bacteria, fungi and actinomycetes) of similar soils either active or inactive in the break down of metalaxyl, did not differ.
EFFECT OF HOST NUTRITION IN RELATION TO DISEASE INCIDENCE

Rhizosphere organisms and pathogens depend on nutrients present at rhizosphere areas for their food. Addition of chemical fertilizers one way or other influence the microbial equilibrium of rhizosphere as well as it may support or suppress the soil borne plant pathogens. The effect of plant nutrient solutions on late blight pathogen was studied extensively (Main and Gallegly, 1964; Borys, 1964). Sawicka (1993) and Rudkiewicz et al. (1983) reported that higher dose of nitrogen (200kg.nitrogen/ha) increased the haulm infection in potato by *P. infestans*. Increased dose of NPK and excessive nitrogen reduced the rishitin concentration related to host resistance in potato tubers, which caused high infection by *P. infestans* (Stroikov et al., 1980). Graded doses of nitrogen and potassium showed increased susceptibility to infection in potato by *P. infestans* (Phukan, 1993). Phukan and Baruah (1989b) reported that increased concentration of potassium showed more susceptibility to *P. infestans*. Inhibitory action of phosphorus against *P. infestans* has been emphasized by Szczotka et al. (1973). Sharma and Sohi (1983) described that higher dose of nitrogen resulted good yield but it enhanced the infection due to *P. nicotianae* in tomato. They also reported that increased phosphorus yielded healthy fruits and less disease incidence. Nema (1990) studied the effect of graded dose of NPK on *Phytophthora parasitica* var *piperina* infection on betle vine and reported that all doses of P and K reduced the disease intensity while N enhanced the disease incidence in the field. Dirks et al. (1980) studied the effect of fertilizer on incidence of *P. megasperma* var *sojae* on soya beans, they reported that increased dose of chemical fertilizer enhanced the disease incidence in the field. Hoitink et al. (1986) reported that nitrogen concentration in the soil support the *Phytophthora* infection in rhododendron. Utkhede (1984d) studied the effect of ammonium sulphate, ammonium nitrate, calcium nitrate, urea and sewage sledge on *P. cactorum* infection of apple and reported that all the amendments enhanced the disease incidence.
HOST RESISTANCE

Host resistance is one of the major components of IDM and with great practical value. The centre of origin of black pepper is Western Ghats of India and it is expected that host resistance for \textit{P.\textit{capsici}} would be available in the center of origin. However high degree of resistance has not been located so far. Muller (1936) reported the black pepper variety Belantung from Indonesia as resistant to foot rot. Indian pepper cultivar Uthirankotta and the Indonesian varieties Djambi and Belantung reported to possess appreciable resistance (Holliday and Mowat, 1963). Ruppel and Almeyda (1965) reported that out of five \textit{Piper} species tested, \textit{P.aduncum L.}, \textit{P.scabrum Sw.}, and \textit{P.treleasanum} Britt. and Wils showed partial resistance. Albuquerque (1968) reported resistance in \textit{Piper colubrinum} Link., \textit{P.obliquum} and Balankotta were found to be resistant (Turner, 1971). In Ghana, \textit{Piper quineese} has been reported to be resistant (Anonimous, 1977). Sarma and Nambiar (1982) screened different \textit{Piper} species against \textit{P.palmivora} (=\textit{P.capsici}) and reported that \textit{P.colubrinum} was apparently resistant. Sarma and Nambiar (1979) tested 40 Indian cultivars including Uthirankotta and 45 wild types adopting root dip inoculation technique and reported that all of them as susceptible. However \textit{Phytophthora} tolerant lines of black pepper have been reported (Sarma \textit{et al.}, 1996). Hegde (1984) conducted screening of seven cultivars in wilt sick plot and could not get a single resistant plant. Dutta (1984) tested the seedlings raised from seeds and cuttings of healthy black pepper vines survived in the badly infected gardens and reported that none of them were resistant.

INTEGRATED DISEASE MANAGEMENT (IDM)

Integrated disease management would be the ideal strategy to tackle the complex and elusive soil borne problems like foot rot of black pepper, since any single approach would be of little consequence to contain the disease. Nursey hygiene, phytosanitation and other cultural practices, chemical, biocontrol measures coupled with host resistance are important components of IDM, that would reduce the pesticide load into the environment. Out of the various components of IDM, biocontrol programmes are of high priority in managing soil
borne plant pathogens. Curl et al. (1976) observed that ineffective amounts (1-2 μg/g soil) of PCNB applied together with *T.harzianum* Rifai controlled *Rhizoctonia solani* Kuhn. more effectively than did *T.harzianum* alone in cotton seedling disease in the green house. Henis et al. (1978) obtained green house control of *R.solani* damping off of radish by integration of PCNB (4μg/g soil) and *T.harzianum*. Lewis and Papavizas (1981) have reported that field control of root rot of cucumber caused by *R.solani* by integration of chlorothalonil with *T.harzianum* and cultural practices. Lewis and Papavizas (1981) obtained field control of root rot of cucumber and crown rot of pepper caused by *P.capsici* by integration of chlorothalonil with metalaxyl respectively with *T.harzianum*. Chandra (1984) reported that integration of both chemical and biological control measures showed a synergistic effect on the control of damping off in sugar beet. Mukhopadyay et al (1986) also obtained successful control of damping off of tobacco and egg plants by application of *Trichoderma* preparation to soil and integrating it with metalaxyl seed treatment. Stankova-Opocenska and Dekker (1970) reported that treatment of cucumber seed with fungicide (6-azauracil) at lower dose resulted in significant increase in the number of bacteria in the rhizosphere and control the damping off of cucumber seedlings caused by *Pythium debaryanum* Hesse.

Sarma et al. (1988) emphasized the importance of integrated disease management of *Phytophthora* infection in black pepper by using cultural, chemical, biological coupled with host resistance. Utkhede and Smith (1993) described the long term effect of chemical and biological treatment on crown rot of apple trees caused by *P.cactorum*. They reported that the integration of fungicides (metalaxyl, fosetyl-Al, mancozeb, copper+sulphur and captafol), along with *Enterobacter aerogenes* applied as soil drench and trunk drench reduced the infection. Utkhede and Smith (1991) reported that, metalaxyl along with *E.aerogenes* significantly reduced the *P.cactorum* in apple orchards. Raicu and Stan (1976) discussed the feasibility of controlling the *P.(nicotianae) parasitica* infection in tomato by integrating the chemical and cultural methods.