Chapter 2

REVIEW OF LITERATURE
Black pepper (*Piper nigrum* L.) an important spice crop always suffers due to a deadly disease – *Phytophthora* foot rot wherever grown in India and other countries. There is need to understand many factors responsible for the disease cause, development and spread. However, several attempts have been made to tackle the disease by many means like, cultural, biological, chemical and combination of these methods.

In this direction many attempts have been made to review the work on these aspects particularly on *Phytophthora capsici*. However, the literature pertaining to other related species of *Phytophthora* which are of relevance to some aspects under the present investigation has also been made and it is as under.

### 2.1. 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 in Karnataka 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.
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).

### 2.2. **Survey and Crop Loss**

Survey is essential for the identification of varietal variation in black pepper cultivars on the incidence of *Phytophthora* foot rot disease (Amma et al., 2001).

The problem of spike shedding due to foot rot disease incidence done through survey in Thrissur area of Kerala, specially on panniyur variety (Geetha and Nair, 1989). *Phytophthora* pathogen can also cause damage to collateral hosts in black pepper areas (Manmohandas and Abicheeran, 1985). A simple method was developed for indexing *Phytophthora* and nematode infection in black pepper (Jose Abraham et al., 1996). The survey gives first hand information to develop management strategies in black pepper disease (Menon, 1949). Survey in black pepper is necessary to know the varietal variations in the susceptibility for leaf infection due to *Phytophthora* (Nair et al., 1988).
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 per cent 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). Heavy loss of pepper crop due to wilt disease has also been recorded from Uttar Kannada (Sastry, 1982) and Shimoga (Dutta, 1984) districts of Karnataka state.

2.3. Disease Symptoms

Nambiar and Sarma (1977) reported the infection due to species of *Phytophthora* on all parts of black pepper vine and thus described exclusive root rot, collar rot, aerial vine death and leaf and spike berry infection either singly or in different combinations. Spike infection resulting in its shedding is another common symptom of aerial infection. Usually the lesion develops at the distal end of the spike and then spreads towards the stalk. Occasionally, a few berries only show infection in spikes.

Muller (1936) described lesions with grey centres surrounded by alternating dark and light brown zones with peripheral water soaked margins on black pepper leaves due to *Phytophthora* infection. According to him the zonations occurred in alternate wet and dry weather, but not in continuous wet conditions. Holliday and Mowat (1963) reported uniform brown lesions with fimbriate margins on the leaves. Leaf infection resulted in heavy defoliation.
The first visible symptom in case of collar infection was appearance of light yellow interveinal chlorosis in the upper leaves. In advanced cases whole foliage turned yellow leaf shredding. Thus, infected region appeared wet, discoloured, slimy to touch and in advanced stage emitted foul smell. Infection in collar region progressed towards the underground stem then to the root system and caused its rotting (Holliday and Mowat, 1963; Nambiar and Sarma, 1977).

There are reports of independent root infection, although in majority root rot is followed collar rot in case of both root rot and collar rot, the syndrome includes foliar yellowing and flaccidity, defoliation, breaking of tender stems at nodal region and spike shedding. The symptoms of the black pepper wilt have also been described by Sastry (1982), Anandaraj et al. (1988) and Subramanian (1993). The symptoms of foliar yellowing, falling of leaves, wilting and root rot infection were described in outbreak of foot rot of black pepper (Matsuda et al., 1996). Since the fungus is soil-borne, an integrated management involving phytosanitation, chemical and biological control along with host resistance has been recommended (Ramachandran et al., 1990a; Ramachandran et al., 1990b; Sarma et al., 1991).

In addition to a favourable weather, other factors such as crop phenology and cultural operations also affect the inoculum production and disease spread. In various Phytophthora diseases such as black pod disease of cocoa, fruit rot of areca nut, pigeon pea blight and aerial infections in black pepper, etc. The secondary spread of inoculum depends upon rain splashes (Gregory, 1974; Anandaraj, 1982; Ramachandran et al., 1990; Chauhan and Singh, 1991). Soil and infected plant debris in plantations are the main source of inoculum (Nambiar and Sarma, 1982; Sastry, 1982).
Chapter 2

Review of Literature

Biology and Epidemiology of Phytophthora spp.

2.4. Biology

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 for the host. According to Alizadeh and Tsao (1985), light plays an important role in the production of sporangia and *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, 1976). 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 (1991) reported that, maximum zoospore germination at pH 7.5 in dark in *P. dreschleri*, oospore formation was high within 36 hours at 25°C.

2.5. Epidemiology

Epidemiology of aerial phase of Phytophthora infections in black pepper has been studied in greater detail. Weather dependence of foliar infection and conditions which favour spread of the disease in black pepper-coffee mixed cropping system have been reported. There were also attempts to co-relate the occurrence of foot rot with weather factors (Nambiar and Sarma 1982, Ramachandran *et al.*, 1988, 1990; Unnikrishnan *et al.*, 1988). The pathogen has been reported to survive in the infected plant debris upto 19 months in studies using black pepper leaves and castor seeds as baits (Kueh 1986; Kasim and
Prayitno, 1979; Liyang and Wheeler, 1991; Dutta, 1984; Dutta et al., 1984; Sastry, 1982; Sastry and Hegde, 1982, 1987a, 1987b). There are also reports of occurrence of both $A^1$ and $A^2$ mating types and production of oospores (Dutta, 1984; Dutta et al., 1986; Sastry and Hegde, 1982, 1987; Santhakumari, 1987). The progeny of oospores resulting from $A^1$ and $A^2$ mating type was reported to be more virulent than the parental types (Santhakumari, 1987). However, there are contradicting reports on the formation of hybrid progenies and oospores are reported to be produced by one parent by the induction of the other mating type through hormonal regulation (Ko, 1988). A detailed account of the concepts of homothallism, heterothallism and interspecific hybridization in *Phytophthora* is dealt by Savage et al. (1968) and biochemical evidence for the absence of interspecific hybridization is provided by Chang and Ko (1993).

*Phytophthora* infections are classified into 3 types (Schwinn, 1983) namely,

i) Foliar which includes leaves as in potato and fruits as in cocoa,

ii) Locally systemic but not vascular and spread up to the stem from crown or roots as in tobacco,

iii) Roots - hypocotyls of many hosts by *P. cinnamomi* and *P. cactorum*. *Phytophthora* infections on black pepper belongs to the first 2 categories as it affects all parts of the vine. The occurrence of infections confined to the wet monsoon period and soil is the main source of primary inoculum. The distribution of inoculum decreased with increasing depth and distance from the infected vine (Turner, 1969; Kueh and Khew, 1982; Ramachandran et al., 1986). Soil-borne *Phytophthora* spp. survive in plant debris in the form of chlamydospores and also as resting mycelia (Zentmyer, 1967). The survival of pathogens is affected by interaction of several biotic and abiotic factors in the soil.
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 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 continuous 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 propagules 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).

2.6. 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 lesions on leaves. The lesions are gray centres 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 coloured 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 unfavourable 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 to September (Oliveira and Pereira, 1983). Tip of the spikes get discoloured due to infection and later the entire spike get darkened and fall. Tender berries also get infected. Occasionally pathogen spread from foliar region to root system through stem resulted in heavy defoliation and death (Holliday and Mowat, 1963). 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 and 1992). This might be because of the conducive microclimatic condition that prevails under the canopy.

Epidemiology of the aerial phase of the disease is well understood than the soil phase. Weather dependence of the disease and the factors favouring the disease spread in black pepper areca nut mixed cropping system has been reported. The factors identified were temperature range of 22.7-29.6°C, sunshine hours 2.8-3.5 ha/day, rainfall 15.8 to 23.0 mm/day and relative humidity of
81-99% (Ramachandran et al., 1988). The spread of foliar infection from the runner shoots to other parts of the canopy and to the adjacent vines was found to be through the rain splashes.

2.7. Soil phase

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 death of vine as the pathogen enters 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 micro plot 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., 1989a). Runner shoots or stolon 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 of *Piper beetle* due to *P. parasitica* var. *piperina* obtained at the range of 20 to 24°C (Selvaraj et al., 1973). According to Maiti and Sen (1982) the foot rot of beetle vine observed at less than 22°C. But Venkata Rao et al. (1969) reported that, betel vine wilt appeared continuous day temperature attained minimum at 23°C and rainfall has not influenced on diseased incidence. Selvaraj et al. (1973) reported that wilt disease of beetle vine was severe at the soil temperature ranged from 20 to 24°C. Pal and Grewal (1976) reported that, the maximum number of sporangia were noticed at 25 to 30°C and pH range of 6 to 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 beetle vine was occurred when there was of 6 mm 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 (Agarwal, 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 \textit{P. infestans} (Mont) de Bary. Bambawale et al. (1991) reported that, in Punjab (India) the late blight of potato due to \textit{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 unprotected by fungicides.

Reuse of rain water could encourage the spread of \textit{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 favoured stem rot of citrus root stocks by \textit{P. citrophthora} (Sulistryowati and Keane, 1992). Chlamydospores and oospore production of \textit{P. cactorum} was noticed at 4°C within 20 days (Darmono and Parke, 1990).

The environment plays a significant role in spread and dispersal of plant pathogens. Based on the extent of spread and severity, the epidemics are frequent to occur. Various workers have studied the epidemiology of \textit{Phytophthora capsici} causing foot rot of black pepper.

\textit{Phytophthora} is exacting in its ecological requirements for its growth, sporulation and infection. Micro-climateological factors under different cropping systems would determine the type of infection, in a given locality. The precise methods of detection of the disease specially root infection in its very early stage are pending areas in \textit{Phytophthora} research.
Soil and infected plant debris in plantation serve as main source of inoculum (Nambiar and Sarma, 1982; Sastry, 1982). The studies on spatial distribution of fungus propagules showed abundant inoculum upto 30 cm from base and upper layers of soil. The inoculum level decreased with increase in depth and distance from base of the vine. In areca - pepper mixed cropping system, high rainfall (>3000mm) and microclimatic conditions like relative humidity (84 to 89%), low temperature (22.2 to 29.6°C) and shorter sunshine hours (2.8 to 3.5 h/day) favoured the disease increase (Ramachandran et al., 1988). Positive correlation was established between the weather parameters and disease development.

2.8. Disease Spread

In case of foliar infection both vertical and lateral spread was noticed due to rain splashes (Ramachandran et al., 1990). The pre-monsoon showers favour the gradual build up of inoculum. Applie (1952) found that field inoculations with infested oat inoculum were most effective under conditions of ample soil moisture. Lucas (1965) reported that high moisture favoured the growth of Phytophthora nicotiana Broeda de Hann var. nicotina in soil. Zentmyer and Mircetich (1966) reported that under conditions of high soil moisture, the persistence of Phytophthora cinnamomi R and was for long period by invading dead organic matter. Reeves (1975) reported that production of sporangia and zoospores by Phytophthora cinnamomi was more under low water suction pressure.

Splash spread of the disease was reported by Nambiar and Sarma (1982). The termite and slugs as passive carriers of inoculum and movement of
inoculum through soil water was observed by Sarma et al. (1981). In foot rot disease, root rot infection starts with isolated patches subsequently spreads in a centrifugal fashion was reported. It was opined that *Phytophthora* from arecanut, rubber, cocoa, coconut and cardamom serve as collateral hosts for black pepper infection (Das and Abicheeran, 1985).

The studies on pepper wilt in Northern Iraq revealed the complex infection of *P. capsici*, *Fusarium* and *Rhizoctonia* resulting in complete death of plants (Rahim and Shariff, 1995). Sarkar et al. (1985) reported that wilt of black pepper was caused mainly due to *Phytophthora palmivora* var. *pipera* with associated organism identified as *Fusarium*, *Colletotrichum* and *Diplodia* spp.

### 2.9. Integrated Disease Management (IDM)

Integrated management is the harmonious blending of various methods in proper sequence and timing so as to create least harmful effects on man and environment. The various components of integrated management are eco-friendly, economically feasible and compatible.

Conceptually, Integrated Disease Management (IDM) or Integrated Pest Management (IPM) involves the selection, integration and implementations of control based on predicted economic, ecological and sociological constraints. This technology therefore, seeks maximum use of naturally occurring controls including weather, disease agents, native as well as introduced antagonists.

In these cases, the ultimate disease control is brought about by direct inhibition of the pathogen as well as by increased microbial antagonism. Therefore, it is generally indicated as integrated control (Baker and Cook, 1974).
Curl et al. (1976) observed that combined application of penta chloro nitro benzene (PCNB) with *Trichoderma harzianum* Rifori. effectively controlled *Rhizoctonia solani* Kuhn. than *Trichoderma harzianum* alone in cotton seedling disease in greenhouse studies. Henis et al. (1978) opined that integration of PCNB (4μg/g of soil) with *Trichoderma harzianum* effectively brought down the population of *Rhizoctonia solani* causing damping off in radish. Lewis and Papavizas (1981) obtained field control of root rot of cucumber and crown rot of pepper by integration of chlorothalonil and metalaxyl respecting with *Trichoderma harzianum*.

Chandra (1984) observed that integration of both chemical and biological measures has synergistic effect on control of damping off in sugar beet. Mukhopadhyay et al. (1986) and Mukhopadhyay and Chaturvedi (1986) also obtained successful control of damping-off of tobacco and brinjal by integrating *Trichoderma* and metalaxyl. Subramanian (1993) observed integrated application of metalaxyl + neem cake + *Trichoderma* found effective on *Phytophthora capsici* causing wilt of black pepper. The application of neem cake (1 kg/ha) + Phorate (30 g/vine) + Bordeaux mixture + Akomin (0.04%) found very effective in *Phytophthora* disease of black pepper (Anon., 1997). The combined application of *Trichoderma harzianum* + Akomin significantly brought down the populations of *Phytophthora* causing foot rot of black pepper (Anon., 1997).

Hegde and Anahosur (1998) reported that 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. Nursery 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 greenhouse. Henis et al. (1978) obtained greenhouse control of *R. solani* damping off of radish by integration of PCNB (4 µg/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. Mukhopadhyay 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 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 \textit{P. cactorum}. They reported that the integration of fungicides (metalaxyl, fosetyl-Al, mancozeb, copper+sulphur and captan), along with \textit{Enterobacter aerogenes} applied as soil drench and trunk drench reduced the infection. Utkhede and Smith (1991) reported that, metalaxyl along with \textit{E. aerogenes} significantly reduced the \textit{P. cactorum} in apple orchards. Raicu and Stan (1976) discussed the feasibility of controlling the \textit{P. parasitica (nicotianae)} infection in tomato by integrating the chemical and cultural methods.

2.9.1. Cultural Methods

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 longivity in black pepper against \textit{P. capsici} (Sarma \textit{et al.}, 1987, 1992). Incorporation of bio-control agents in solarised nursery mixture is being popularised (Sarma and Anandaraj, 1988). 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 the infected leaves and twigs to avoid the spread of foot rot disease of black pepper in the fields.

Maintenance of optimum soil drainage is always advocated to reduce incidence and spread of the soil borne disease, but that is not always practised by
nursery men or landscapers. Minor levels of infection become severe under poorly drained conditions. Usually, this leads to the use of chemicals to prevent or slow down the disease. Biological strategies are in their infancy except for the use of some potting mixes with claimed suppressiveness to diseases caused by *Phytophthora* spp. and other pathogens.

Certain solitary attempts have been made to manage *Phytophthora* foot rot disease either through chemicals or cultural and biological means. The review reports on various aspects of management include cultural (Sarma *et al.*, 1988), amendments (Sadanandan *et al.*, 1990), antagonists (Dutta, 1984; Anandaraj *et al.*, 1995), prophylactic measures with chemicals and bio-agents (Sarma, 1985; Subramanian, 1993) and resistant / tolerant cultures (Sarma *et al.*, 1982). However, these various methods have shown the effective management of the disease when applied alone or in combination, but the integration of these various methods with traditional knowledge to arrive at effective economic package is the pending area of research.

Sastry and Hegde (1988) reported the importance of burning of the infected leaves and twigs to avoid the spread of foot rot disease of black pepper in the fields.

Thareja *et al.* (1989) emphasized the need 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 splash dispersal of *P. nicotianae* var. *parasitica* inoculum.
2.9.2. Chemical Methods

In general copper fungicides have been reported to be highly inhibitory to phythiaceous fungi. Bordeaux mixture - a contact fungicide has been recommended to use against the foot rot of beetle vine and black pepper by many workers (Dastur, 1927, 1935; Uppal, 1931; Asthana, 1947; Subramaniyan and Venkata Rao, 1970; Narasimhan 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) is the recommended package (Sasikumaran et al., 1981; Mammooty et al., 1991; Ramachandran et al., 1990). Foot rot incidence was significantly reduced with the Bordeaux mixture pasting on foot region and spraying and drenching (Nair et al., 1993). Harper (1974) reported that soil drenching with cuprous oxide reduced the number of dying plants in the field over a 5 months period. Applications of Bordeaux mixture alone and their combinations with copper oxychloride and metalaxyl found significant effect on disease control (Malebennur et al., 1991). In an in vitro assay Sastry (1982) reported that, 1% Bordeaux mixture inhibited the growth and sporulation of 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 formulation tested (Bordeaux mixture, DM - 45, Blitox 50WP, Brestanol and Dithane Z 78), Bordeaux mixture was found very effective on control of late blight pathogen (Navase and Dhande, 1982). Fungicides tested
against *P. parasitica*, the foot rot pathogen of betel vine, 1% Bordeaux mixture was found most effective on controlling of the disease (Raj *et al.*, 1973). Ayyavoo and Samiyapan (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 copper oxy chloride (COC) (0.25%) and dexan (0.5%) - (Narasimhan *et al.*, 1976). Reddy and Mohan (1984) reported that out of 24 fungicides tested for their bio-efficacy on controlling black pod of cocoa, copper fungicides tested for their bio-efficacy on controlling black pod of cocoa and copper fungicides performed best. Application of COC at 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 phytotoxin production it was suggested that apply fosetyl-Al 14 days earlier than the application of copper fungicides and it could reduce the phytotoxin production in hosts.

According to Rao (1985), single spray of 1% Bordeaux mixture in combination with 0.5% Zinc Sulphate was effective throughout the rainy season and decreased the incidence of rotting by *P. nicotianae* var. *parasitica* to 5.6 to 6.8%, compared with 97.5 to 6.8%, compared with 97.5 to 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% 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 70's. Since then, the information on these chemicals was 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 (acylanlanines) introduced during 70's (Urech et al., 1977), having 4 sub-classes (Cohen and Coffey, 1986) namely acylanlanines, 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 fungus and 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), 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 MZ-72WP, followed by Aliette-80WP, Dithane M-45 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 5 systemic fungicides viz. metalaxyl, fosetyl-Al, ethazole, propamocarb and oxyadixyl for their bioefficacies on different phases of *P. palmivora* (MF4) and the field evaluation of first 3 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 (Vasilakkakis 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. controphtthora* and *P. capsici* was completely inhibited by metalaxyl at 25 ppm and *P. palmivora* at 50 ppm. Lethal concentrations of metalaxyl for *P. catrophthora* and *P. palmivora* was reported at 75 ppm. (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 greenhouse trial Garibaldi and Timietti (1980), reported that metalaxyl at 50 g/plant used as soil drench, 2 days before inoculation protected the plants throughout the trial ridomil applied as a single soil drench containing 0.25 μg/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 greenhouse 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. dreschieri* 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. dreschieri* by metalaxyl (Chauhan and Sigh, 1987; Bisht et al., 1988; Agrawal, 1987; Singh and Chauhan, 1992; Kannaiyan and Nene, 1984). Ramraj and Vidyasekaran (1983) reported that metalaxyl inhibited the production of pectic enzymes by *P. parasitica* var. *piperina* in *Piper* beetle. Root tissue of wilted beetle
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 100 ppm metalaxyl could give effective control of
*P. parasitica* var. *nicotianae* infection in tobacco (Bhatt and Patel, 1989).
*P. palmivora* infection in cocoa fields could be controlled effectively by metalaxyl
(Mc Gregor, 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*. *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 50 μg/litre of metalaxyl (Farin et al 1981). Root rot of rough
lemon due to *P. nicotianae* var. *parasitica* could control by soil drenching of
metalaxyl and upto 1000 ppm it was not phytotoxic to 2 years old rough lemon
seedlings (Lee and Wicks, 1982). Utkhede (1984) reported that soil drenching
with metalaxyl mancozeb application around the base of naturally tree,
prevented the further spread of *P. cactorum* in apple trees.

Out of 11 fungicides tested for their bio-efficacies, metalaxyl and alliete
(fosetyl aluminium) completely inactivated the mycelium of *P. cactorum* in the
soil within 2 days and completely inhabited 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. cactorium*. Soil drenched with metalaxyl prevented the infection of apple trees in greenhouse *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, whereas 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 and Guest, 1984). Antifungal activity of phosphorous acid has 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 (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 0.1 \( \mu g/ml \) (Dolan and Coffey, 1988). Oospores and chlamydospore production of *P. cinnamomi* inhibited at higher concentration-50 ppm. (Coffey and Joseph, 1985). Coffey and Joseph (1985) and Dolan and Coffey (1988) emphasized the selective interference with key biosynthesis events on zoosporangia production by *Phytophthora*.

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

Ramachandran *et al.* (1988) opined that in the field evaluation of five systemic fungicides, metalaxyl was highly effective in suppressing soil population of *P. palmivora*. The several reports on other effective fungicides tested both *in vitro* and *in vivo* against *Phytophthora capsici* are metalaxyl, metalaxyl - ziram, fosetyl-Al and Carbamate (Ramachandran and Sarma, 1989; Ramachandran *et al.*, 1990). Root feeding with metalaxyl + mancozeb (0.2%) has
given better control of *Phytophthora* foot rot of black pepper in Dominican Republic (Matsuda *et al.*, 1996).

Fungicides form one of the major components in the production and supply of food for the ever increasing populations of the world (De Waard *et al.*, 1993). Fungicides developed for the control of oomycetes belong to four major groups (Schwinn, 1983) namely,

Carbamates - prothiocarb and propamocarb

Cyanoacetamide oxime - cymoxanil

Acylalanines - furalaxyl and metalaxyl

Ethyl phosphites - benalaxyl and phosethyl - A1

Among these four groups, acylalanines and phosetyl-Al were found to be very effective against the genus *Phytophthora*. As these fungicides had site specific action, the ear of resistance build up among pathogen population led to the development of fungicidal mixtures. During 1970s mixtures of site specific high resistance fungicides with multisite low resistance risk fungicides were use (Rodriguez-kabana *et al.*, 1977). By 1980s negatively correlated fungicide mixtures were introduced in which each ingredient was capable of controlling pathogen genotypes resistant to other ingredient (Schwinn and Urech, 1986). These mixtures were used as tank mixes or prepacked mixtures. A new strategy in which different fungicides are applied to adjacent plants and diversification of cultivars and fungicides in a crop for the maximising production and minimising resistance build up have been developed (Cohen and Coffey, 1986; Cohen and Levy, 1990). The two way
mixtures have given way for three way mixtures which are reported to be superior than two way mixtures in preventing resistance in pathogens (Staub and Sozzi, 1984). The reported development of resistance to site specific fungicides, the toxicological and ecotoxicological problems and perceptions by the public calls for the judicious use of fungicides as integral part of protection rather than a measure of last resort (De-Waard et al., 1993).

Studies with newer fungicides revealed that the treatment consisting of all cultural practices + 1 kg neem cake + 3g phorate / vine + first spray with 1% Bordeaux mixture + 0.2% Akomin (second) recorded minimum defoliation (6.74%) and foliar yellowing (5.65%) without any death of vines. Studies at Panniyur including standardization of management practices with spraying of 0.2% Akomin followed by spraying and drenching with 1% Bordeaux mixture were found to be effective in checking foot rot disease under different shaded conditions (Anon., 1997). Spraying with 1% Bordeaux mixture drenching with 0.2% copper oxychloride was found effective against Phytophthora foot rot (PFR) of black pepper (Anon., 1996).

2.9.3. Biological Control

Biological control is the use of organisms, gene or gene products to regulate a pathogen and can be used with strategies intended to keep (i) Inoculum density below the economic threshold level, (ii) Retard or exclude infection, (iii) Maximize the plant system for self defence (Cook, 1988). 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 beetle vine *Phytophthora, P. nicotiana 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. nicotiana var piperina*. Sharma and Tiwari (1981) studied the phylloplane microflora infected by *P. infestans* on *Solanum khasiuanaum* 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 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;
Trichoderma spp. are becoming well known for their capacities to control soil borne pathogens. Biological control which may already be an important component (Pegg and Whiley, 1987) of some practices (e.g., mulching, organic amendments) remains the 'Cinderella' of integrated control.

Some successful biological control of soil born pathogens like Sclerotium rolfsii, a causal agent of root rot of several agricultural crops has been achieved (Chet et al., 1979; Elad et al., 1980), but only when applied at relatively high inoculum rates.

Nambiar and Sarma (1977) isolated Trichoderma spp. from the roots of black pepper vines and noted the lysis of mycelium of Phytophthora capsici due to over growth of antagonist. The reviews on Trichoderma spp. as biological agent against betel vine wilt was reviewed by Tiwari and Mehrotra (1968), root rot of avocado (Zentmeyer, 1963, 1967) and of many other Phytophthora diseases have been reviewed by (Baker and Cook 1974). Trichoderma viride was found to protect the host plants against Pythium ultimum Trow (Liu and Vanghan, 1965). Phytophthora splendens Brawn (Bolton, 1978) and Phytophthora aphanidermatum (Odson) Fitzp. (Bolton, 1980).

Roiger and Jeffers (1991) reported evaluation of Trichoderma spp. for biological control of Phytophthora crown and root rot of apple. Isolates of Trichoderma spp. were evaluated with two delivery systems. A viscous suspension of conidia in an aqueous gel was applied to seedling roots or colonized mixture of peat and wheat bran (peat) was added to soil. Isolate T-55
of *Trichoderma virens* in peat bran preparation was found superior to rest of treatments and application of biocontrol agent was better delivery method.

Isolation and identification of micro-organisms antagonistic / hyper parasitic to *Phytophthora capsici* in black pepper plantation of Kerala and Karnataka showed predominance of *Trichoderma viride*, *T. harzianum*, *T. koningii* and *Gliocladium virens* (Anon., 1996). Use of biocontrol agents like *Glomus fasiculatum*, *Trichoderma humatum* and *Gliociadium virens* were found effective against *Phytophthora* foot root of pepper (Anandaraj et al., 1995). Biocontrol studies against foot rot disease revealed that *Trichoderma viride* was found to be effective in controlling wilt disease with incidence (10%). In biocontrol studies of *Phytophthora* foot rot disease, use of antagonistic organism *Trichoderma viride* at 150 g/vine along with 5 kg of FYM was found effective in trials at Sirsi and Paniyur (Anon., 1997). Abd-El-Moity *et al.* (1982) developed selective medium containing fungicide allyl alcohol and the fungicide *Viclozolin* for isolation of *Trichoderma* spp.

Rose Bengal and Penta Chloro Nitro Benzene (PCNB) were used together with captan as the basic antimicrobial agents for developing a semi-selective medium for the quantitative isolation of *Trichoderma* from soil (Elad and Chet, 1983). A new semi-selective medium with either rosebengal or PCNB has also been described for isolation of *Trichoderma* spp. (Papavizas, 1982). Another *Trichoderma* medium (TME) with or without benomyl, gave good results with soil that did not contain *Mucor* and *Rhizopus* (Abd-El-Moity *et al.*, 1982; Papavizas, 1982). It was further improved with addition of alkylayal polyethylene alcohol (Papavizas and Lumsden, 1982) and used effectively in enumeration of rhizosphere microflora.


*Trichoderma* spp. represent most thoroughly and widely studied fungus that show antagonistic activity towards soil borne plant pathogens. Some successful biological control of soil borne plant pathogen like *Sclerotium rolfsii* a casual agent of root rot of several agricultural crops has been achieved (Chet *et al.*, 1979; Elad *et al.*, 1980) but only when applied at relatively high inoculum

*Trichoderma harzianum* has shown potential to control diseases caused by *Fusarium* spp. Thus, strain of T-35 of *T. harzianum* controlled *Fusarium* wilt of cotton and melons caused by *F. oxysporum* sp. *vasinfectum* and *Fusarium oxysporium* sp. *melonis* respectively (Kemf and Wolf, 1989). Control of *Fusarium* seedlings blight in wheat caused by *Fusarium culmorum* by *Trichoderma harzianum* under natural condition was reported by Sivan and Chet (1986).

Sangeetha and Jayarajan (1993) used different substrates like rice bran, wheat bran, peat soil, farm yard manure (FYM) and rice bran and reported that FYM and wheat bran are the best substrates for the mass multiplication of *Trichoderma* spp. Shamarao *et al.* (1997) used six different organic substrates and oil cakes for the mass production of *Trichoderma*, among which FYM and dung, pongamia cake, neem cake supported maximum colonization of biocontrol agent and reported as best substrates for mass multiplication of *Trichoderma* native isolates from *Fusarium* infected banana gardens. The development of a stable, cost effective and easy to apply biocontrol formulations is critical for the biological control of plant pathogens with introduced antagonists (Lisanky, 1985).

There are four different techniques for the application of *Trichoderma* spp. as biocontrol agents. They are Broadcast; *Trichoderma* preparations are broadcasted on surface and incorporated in to infested soil, furrows; preparation put in to pathogen infested soil in planting furrow, root zone; *Trichoderma*
inoculated in to root zone by mixing before transplanting seedlings in a infested soil and seed coating; seeds coated with *Trichoderma* spores using an adhesive. Each method has been shown to be effective in field, in their own area of application, however, broadcasting is being rarely used. Gel seedling or fluid drilling a technique by which pregerminated seeds are extruded into soil in a fluid matrix also has been used as delivery system for biological control agents (Conway *et al.*, 1982; Fischer *et al.*, 1983; Hadar *et al.*, 1984).

Addition of *Trichoderma harzianum*, *Arachimolius* and *Aspergillus flavus* with suitable organic substance in September or March followed by an application of substrate alone in May before sowing gave satisfactory control of root rot of cotton (Akhtar *et al.*, 1982). Sarma *et al.* (1995) reported soil application of VAM and *Trichoderma* spp. *G. virens* found as effective delivery system in bio control of *Phytophthora capsici* causing foot rot of black pepper under green house studies and observational trials.

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. It is reported that, cell wall degrading enzymes such as mycolytic enzymes being produced by many biocontrol agents (Cook and Baker, 1983).

Out of 96 fungi, 174 actinomycetes and 576 bacterial isolates isolated from rhizosphere and non-rhizosphere areas of 5 major capsicum growing areas. *T. harzianum*, *Pseudomonas cepacia* and *Bacillus 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). *T. harzianum* impregnated on clay granules could control damping-off of pineapple seedlings due to *P. cinnamomi* (Kelley, 1976).

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. Ricard (1981), mass multiplied and commercialized the *Trichoderma* and *Glicocladium* as mycofungicide for field application.

Mukhopadhyay (1987) has given a list of growth media used for mass multiplication of *Trichoderma* species and tried a mixture of wheat bran, sawdust and tap water to multiply *T. harzianum* and used against damping-off of seedlings of tobacco caused by *Phythium aphanidermatum*. Backman and Rodriguez-Kabana (1975) formulated a diatomaceous earth granule impregnated with a 10 percent molasses solution and was found suitable for growth and delivery of *Trichoderma harzianum*. Kausalya and Jeyarajan (1988) used tapioca ‘hippe’ for mass multiplication of *T. viride* and *T. harzianum*. Padmanabhan and Alexander (1987) used *T. viride* multiplied in sand and sorghum medium for the
control of root rot of sugarcane seedlings caused by *P. graminicolum*. Mukhopadhyay (1986) used sorghum grains substrate for mass multiplication of *T. harzianum*.

Jayarajan *et al.* (1987) reported that addition of neem products reduced the fungi, bacteria and actinomycetes population in the soil and suppressed the *P. capsici* infection on beetle vine. Nam *et al.* (1988) reported that, application of organic amendments together with antagonists greatly enhanced the disease suppressive effect. Singh and Vyas (1984) studied the effect of five oil cakes viz., *Brassica compestris* L., *Linum usitatissimum* L., *Ricinus communis* L., *Azadirachta indica* Juss. and *Madhuca indica* Gmel. on *P. parasitica* var. *nicotianae* and they found that mustard oil cake was fungi toxic causing upto 51.2% inhibition. 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. 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*.

### 2.9.4. Compatibility of chemicals and biological methods

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.

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). 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).

It was noted that indigenous 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 upto 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 benzimidazole fungicides. Benomyl strongly inhibited the growth of *Trichoderma* spp. in culture even at the concentration of 0.5 mg/l. 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 phosphorous source. Wongwatharat 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.

Lokesh *et al.* (2002) reported that black pepper vines treated twice during June and August with potassium phosphonate (Akomin) at 0.3 percent alone as spray (3L/V) and drench (5L/V) or in combination with bioagent (*T. viride*) at 50g/V along with 5 kg FYM to the basin of black pepper vine reduced the disease incidence of foot rot.

2.9.5. Effect of host nutrition in relation to disease incidence

Barnett *et al.* (2003) stated that in Australian dry land cropping systems, soil can become suppressive to disease caused by soil borne pathogen under
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intensive cropping with retention of residues with continuous wheat and wheat
rotated with pasture, peas or medics which is suppressive to root rot disease.

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 (200 kg/ha) increased the foliage 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 beetle 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 soybeans, they reported that increased dose of chemical fertilizer enhanced the disease incidence in the field.
Rajan et al. (2000) stated that integrated approach on disease management has become an imperative to tackle this serious disease. As an eco-friendly approach four-commonly available organic soil amendments namely, coffee pulp, poultry manure, neem cake and FYM, application a minimum root rot was noticed where coffee pulp was applied (10%) followed by neem cake (18.2%) which supports the growth and proliferation of microorganism, water holding capacity of soil, suppression of pathogen population and enhance the root regenerations.

2.9.6. 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 *P. 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 *Piper* species tested, *P. aduncum* L., *P. scabrum* Sw. and *P. treleasamum* Britt and Wils showed partial resistance. Albuquerque (1968) reported resistance in *Piper colubrinum* Link., *P. obliquum* and Balankotta were found to be resistant (Turner, 1971). In Ghana, *Piper quineese* has been reported to be resistant (Anon, 1977). Sarma and Nambiar (1982) screened different *Piper* species against *P. palmivora* (=*P. capsici*) and reported that *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, *Phytophthora* tolerant lines of
black pepper have been reported (Sarma 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.

Kumar et al. (2000) indicated that naturally available agricultural waste is an important component of sustainable disease management. In partially decomposed coirpith and sterilized coconut coirpith, population of *Trichoderma* increased dramatically from $10^4$ Cfu to $10^7$ per gram of coirpith in 10 days. When the coir pith was enriched with coconut water, multiplication of *Trichoderma* increased. Sadanandan and Hamza (2002) stated that application of lime at 3/4 time requirement of soil increased the soil pH and yield of black pepper studies showed that chicken and goat manures are efficient organic sources and are comparable with inorganic NPK fertilizer for increasing yield besides reducing foot rot disease incidence.

Veena and Sarma (2000) reported that uptake and persistence of potassium phosphonate (Akomin) both as foliar spray and soil drench can reduce foliar infection of foot rot disease in black pepper to an extent of 86.4% in days after treatment. Whereas root rot infection can also be suppressed upto 70% after 8 days after treatment. Further studies showed that higher concentration ranging from 3-10 ml/L (1200- 4000 ppm) gives prolonged protection to pepper vines beyond 30 days with out any phytotoxicity as this compound develops host resistance by hardening the cell wall of leaves.