INTRODUCTION
1.1. About Pepper Plant

Black pepper (*Piper nigrum* L.) is a perennial, glabrous, woody climbing vine. It is monoecious with male and female flowers in the same spikelet. This has originated from the tropical evergreen rain forests of the Western Ghats of south western India which is commonly known as Malabar coasts of Kerala in olden times. The whole dried matured berries from the perennial vine most widely traded as important spice. Considering its importance in the international trade, black pepper is often referred to as “King of spices” which is also popularly known as “black gold”.

It belongs to the family Piperaceae and the genus *Piper*. It requires the support of either living trees or non-living standards. It is being grown as mixed crop in coffee, arecanut and coconut plantations or as a single crop on silver trees. But, it comes up well in coffee based plantations as the supporting forest trees provide grip to the growing vines and also as a single crop on silver trees (Fig. 1).

Pepper has a dimorphic branching system; the upward growing shoot orthotropic shoot is manopodia in growth and lateral fruiting branches - plagiotropic shoots which has sympodial mode of growth. In addition to these two types of branches, it also produces runner shoots at the base and hanging shoots which are being used as propagating materials.
Fig. 1. Healthy pepper vine in coffee plantation
The spike is leaf opposed and is the modified terminal bud the growth is further continued by the axillary bud. Leaves are simple, alternate and variable in size and to some extent in shape also. Considerable variation exists among various cultivars for leaf features.

Pepper plants usually start flowering by the second or third year of planting. Flowers are borne on independent spikes, which vary in length from 3 to 20 cm among cultivars. Flowers are mostly hermaphrodite, small, borne on axils or fleshy bracts, perianth absent, stamens two-small on either side of the ovary. Anther small with two sacs, ovary globose, 1-celled and 1-ovuled. Fruit is sessile globose drupe often called as berry (Fig. 1). The exocarp turns red when ripe (Fig. 1). Embryo is minute. Ripe seeds germinate in 35-50 days. Cultivated types have a somatic chromosome number of $2n = 52$ (Anon., 2001a).

1.2. Area, production and productivity

The crop is presently cultivated in India, Indonesia, China, Cambodia, Brazil, Mexico, Malaysia, Madagascar, Thailand, Srilanka and Vietnam on an area of 3.75 lakh hectares with a production of 19.4 million tonnes and a productivity of 1,071 kg/ha (Anon., 2000). Among these countries, India being the land of spices, it continues to be the leading producer, consumer and exporter. The crop is being cultivated in the states of Kerala, Karnataka, and Tamil Nadu and to a certain extent in Andhra Pradesh, Orissa, West Bengal, Maharashtra, Pondicherry, Goa, North Eastern states and Andaman and Nicobar Islands over an area of 2.4 lakh hectares with an annual production of over 73,348 tonnes with a productivity of 314 kg/ha. Out of the total production, about 60 percent (42,100 tonnes) is exported to various countries with an earning
of Rs 865 crores, which accounts to 46.5% among all spices (Tamil Selvam and Premaja, 2006). More than 95% of the area and production is in Kerala (Thankamani and Kandiannan, 2001). But in Karnataka, this crop is being grown on a total area of 29,000 ha with a production of 20-25 thousand tonnes and a productivity of 224 kg/ha. But it is being grown mainly in malnad districts like Kodagu (3547 ha), Hassan (2705 ha) and Chickmagalur (2474 ha) in coffee based plantations covering 83.93% of total area (10397 ha) in malnad regions of Karnataka (Anon., 2005).

1.3. **Major Malnad regions of Karnataka**

Based on rainfall pattern, topography, soil characteristics, climate in general and cropping pattern, Karnataka State has been grouped into 10 distinct agro-climatic zones (Fig. 2). Among 10 zones, hill zone No. 9 is also called malnad zone having distinct agro-climatic feature with rolling topography of mountains reaching a height of 1500 to 1800 above MSL and deep valleys. The general malnad is slightly more than that of plateau with hills receive larger amount of rainfall and are forested and support one of the largest plantation economics in the country.

The deeply dissected edges of the Ghats with their deeps gorges, waterfalls river capture and the water sheds, interlacing with dense evergreen and semi-evergreen forest constitute the core of malnad. The northern part of the regions are the lower elevation (450 to 600 above MSL) compared to Southern parts (900 to 1500 above MSL) with vertical zonation in other characteristics from the valley plains to the terraced slopes towards the hill crests. This is other distinctive and differentiating landscape characteristics of malnad (Anon., 1992).
Fig. 2. Karnataka map showing malnad regions in hill zone
1.4. Pepper as Medicinal Value

Pepper is mainly used as spice and in medicines. It is one of the most important ingredients of many drugs in Indian system of medicines. It is pungent and acridic, hot, rubefacient, carminative and germicidal, and promotes salivation, increases digestive power, cures cough, cardiac diseases, etc. (Anon., 2001b).

1.5. Cultivation Aspects

It is cultivated as monocrop by live stakes, home gardens, mixed crops in coffee, areca and coconut plantations. It grows up well between 20° north and 20° south equators from the sea level up to 1500 above MSL with well drained loamy soil rich in organic matter. It requires an ideal condition - a warm humid tropical climate with a physiography of undulating hill slope up to 1-3% and with an annual rainfall of 200-300 cm having temperature ranges from 10-40°C with a relative humidity of 60-95% at soil pH of 4.5 to 6.0 (Anon., 2000). About 1000-1200 vines per hectare are planted with 3x3 m spacing. Rooted cuttings with 3 nodes are used for planting during June to July and mature spikes became ready for harvest during January to February.

1.6. Different Cultivars of Black Pepper

Domestication of black pepper started thousands of years back. Today in our country over 100 and odd cultivars and land races of black pepper are known to exist. The most popular among are Karimunda, Aimpiriyan, Kottanadan, Balan Kotta, Neelamundi, Narayakodi, Kuthiravally, Arakkulammunda, Kalluvally, Chumala and Malligesara and recently an high
yielding hybrids are Panniyur (1 to 7 series), Sreekara, Shubhakara, Panchami, Pournami and Palode-2 have been released in addition to two other hybrids like HP-105 and HP-813. Collection of over 3,000 accessions of black pepper related species and inter-cultivar hybrids are available at the Indian Institute of Spices Research, Calicut, Kerala (Anon., 2001) and none of these are free from foot rot disease. But recently *Piper colubrinum*, a related exotic species of *Piper* was identified as resistant to *Phytophthora* foot rot, nematode and pollu beetle and P-24, a black pepper line developed from an open pollinated progeny of Perambramundi, was identified to be tolerant to *Phytophthora capsici* and among the other *Phytophthora* tolerant lines identified are P-107, P-339, C-847, C-1090, P-1534, C-1095, Coll. 1041 and HP-780 and also had a high yielding potential.

1.7. **Global Loss due to Foot Rot Disease**

Though India is having a larger area as compared to other pepper growing countries, productivity is much lower (305 kg/ha). But the annual crop loss due to *Phytophthora* foot rot on a global scale is estimated to be around $4.5 to 7.5 millions which still remains a challenge to all black pepper research workers (Rajan and Sarma, 2000) The reasons for low productivity are the continuous cultivation of poor yielding vines, existence of senile and unproductive vines, losses due to pest, disease and drought, inadequate supply of quality planting materials, non-adoption of appropriate agronomic practices, poor transfer of technology and price fluctuations.

1.8. **List of Pepper Diseases reported in India**

Since crop loss due to pests and diseases identified as one of the major constraints (Sarma *et al.*, 1994). Black pepper in India is affected by 17 diseases
due to fungi, bacteria, phytoplasma, plant parasitic nematodes and a phanerogamic parasite. (Annexure-1) Among 17 diseases, foot rot (quick wilt) and slow decline (slow wilt) are the most important diseases, because they cause severe economic losses (Sarma et al., 1991, 1992, 1996; Anandaraj and Sarma, 1994). But foot rot disease has also been identified as major productivity constraint in other countries like Indonesia (Manohara et al., 1992), Malaysia (Kueh and Sim, 1992) and Brazil (Duarte and Albuquerque, 1991). *Phytophthora* foot rot infection in black pepper occurs on all parts of the vine and the expression of symptoms depends upon the site of infection and extent of damage (Anandaraj et al., 1991). The whole symptom of vine is broadly classified into aerial infection, collar infection and root infection. Based on the types of infection, soil and aerial phase were recognized (Sarma et al., 1988). In the soil phase, collar infection results in sudden collapse of the vine, while feeder root infection leads to slow decline.

Sudden death of black pepper vine was reported in Wynad region of Kerala as early as 1902 (Menon, 1949) and was investigated by Barber (1905) and later by Butler (1918). Though *Phytophthora* isolation from black pepper was reported earlier (Venkata Rao, 1929), the first authentic report was by Samraj and Jose (1966) who established the pathogenicity. Since then the problem was referred as “Quick wilt” disease of pepper based on sudden wilting and death of vine (Fig. 3). However, the terminology of the disease has been changed to *Phytophthora* foot rot since 1988 (Nair and Sarma, 1988).
Fig. 3. Dead vine due to foot rot disease
Foot rot is the most destructive disease prevalent in all pepper growing tracts of India and takes a heavy toll of the crop. The losses are so heavy that farmer gets disheartened and abandons the crop. The disease is known in Kerala, Karnataka, Tamil Nadu states and recently in Assam state (Sarkar et al., 1985). But detailed investigations on this disease were carried out only since then (Sarma and Nambiar, 1982).

1.9. Crop Loss due to Foot Rot Disease

Precise crop loss figures due to this disease are lacking. However, about 20-30% of the vine death has been recorded in Cannanore and Calicut districts (Samraj and Jose, 1966; Nambiar and Sarma, 1977). Crop loss survey conducted for three years (1982-1984) in Calicut and two years (1985-86) in Cannanore districts of Kerala has shown that the foot rot incidence is 3.7 and 9.4% causing vine death of about 1,88,947 and 1,016,425 amounting to an annual loss of 119 and 905 metric tones of black pepper in Calicut and Cannonore districts of Kerala respectively (Balakrishnan et al., 1986). However, the loss estimation reports from the states of Karnataka are lacking. Hence, it is dealt with immense importance to estimate economic loss due to catastrophic disease and to locate hot spots of Phytophthora malady on black pepper in malnad regions of Karnataka.

1.10. Symptomatology

Detailed symptomatology of the disease has been described (Sarma and Nambiar, 1982). The fungus infects all parts of black pepper vine. Cropping pattern and the micro-climatic conditions appears to be the deciding factors for the type of infection.
1.10.1. Foliar infection

Infection on the leaves starts as water soaked lesions and rapidly expands in to large dark brown spots with a fimbriate margin. The leaf spot of many sizes may remain uniformly dark or they may show concentric zonation with a grayish centre. Tender leaves are more susceptible than matured leaves. Infection is noticed on the spikes resulting is spike shedding. Similarly infection is also noticed on tender to woody stems as dark wet spots and later rotting sets in causing dieback symptoms. Foliar infection is more serious in Areca pepper mixed cropping system because of the conducive micro-climate and it is prevalent in pure plantations also. Foliar infection leads to varying degrees of defoliation of leaves depending on the severity of the disease. Rarely it leads to death of vine.

1.10.2. Collar infection

Collar and root infections are fatal and the infected vine succumbs in 10-20 days and hence, the often locally used term “Quick wilt”. Collar and root infections go unnoticed until foliar yellowing is noticed. Infection starts as wet slimy dark patch on the collar (foot) and rotting occurs as the disease progresses. Vascular discoloration in the stems is noticed beyond the point of infection. The collar infection progress upwards and also downwards. The collar infected vines shows foliar yellowing, flaccidity of leaves, defoliation and breaking of stem at the nodal regions and severe spike shedding occurs.
1.10.3. Root infection

Eventhough infection progresses form collar region to root region exclusive root infections are also noticed. The foliar symptoms will be similar to collar infections. The studies carried out recently under simulated field conditions clearly established that feeder root infection leads to collar rot and subsequent death of vine. The collar rot is possibly the culmination of cumulative root infection starting from the feeder root system over a period of 2-3 years even though exclusive collar rot is common.

*Phytophthora capsici* has been identified as the causal agent of foot rot disease and it is being a wet weather pathogen, is active only during the wet monsoon season and remain dormant during the inter monsoonal dry period. It is reported that contaminated soil and the fungus infected plant debris in plantations are the main source of inoculum (*Nambiar and Sarma, 1982; Sastry, 1982*) for a period of 19 months (*Kueh, 1979; Kasim *et al.*, 1987)

1.10.4. Pre-disposing factors

However, the role of various epidemiological factors such as high rainfall, number of rainy days low temperature, high relative humidity favours the disease development. In addition to favourable weather, other factors such as crop phenology and cultural operations are also affect the inoculum production and disease spread. In various *Phytophthora* diseases such as black pod of cocoa, fruit rot of areca nut, pigeon pea blight and the aerial infection of black pepper, etc. The secondary spread of inoculum depends upon rain splash (*Gregory, 1974; Anandaraj, 1982; Ramachandran *et al.*, 1990; Chauhan and Singh, 1991*). The secondary spread of inoculum and disease severity is reported to be reduced by
the growth of weeds in the plots which prevents soil splashes (Anandaraj et al., 1989a; Ramachandran et al., 1991). Further there is need to study the role of weather parameters in a particular geographical area to understand the influence and disease limitation and spread so as to establish a stable relationship between temporal and spatial distributions of pathogenic agents and their subsequent influence on disease spread. So that it is easy to formulate management strategies for foot rot disease.

1.10.5. Management strategies

Certain solitary attempts have been made to manage Phytophthora foot rot disease either through chemicals or cultural and biological means. The review report on various aspects of management includes cultural (Sarma et al., 1988), amendments (Sadanandan et al., 1990), antagonists (Dutta, 1984; Anandaraj et al., 1995), prophylactic measures with chemicals and bioagents (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. An increasing number of planters apply prophylactic treatments of metalaxyl or fosetyl-Al to control Phytophthora disease either alone or alternatively. However, the problem of pathogen resistance to fungicides and its residual toxicity, effect on beneficial agents concern major areas of thinking in the effective and eco-friendly management. Fungicide treatments supplemented by various organic amendments may significantly affect the soil borne diseases, but the effect may depend on the kind and state of decomposition (Linderman, 1989).
Chapter 1

Introduction

Novel approaches using biological agents currently known to have efficacy against Phytophthora may offer better possibilities for long term control than using only chemicals. Approaches using natural soil borne microorganisms are both intellectually and environmentally appealing (Sharma et al., 1995). The present environmental concern on pesticide use make it imperative that systems that offer a more scientific basis for integrated disease management (IDM) systems are examined. Perhaps lower level of chemicals can be used in combination with biological agents (Wills, 1989).

For the majority of Phytophthora problems, effective control practices have been much slower to evolve. In most instances, however, suitable germplasm has been slow due to time frames of 15 to 20 years needed to evaluate resistance in such perennial crops. Thus, in the management of Phytophthora, there has been an increasing awareness in the last decade of the need to develop integrated control approaches for disease management (Coffey, 1987; Pegg and Whiley, 1987; Schmitthenner, 1985). The major components of integrated control include hygiene and sanitation, cultural and biological control, use of tolerant root stocks and fungicides, biological control which may already be an important component (Pegg and Whiley, 1987) of some practices, remains the "cindrella" of integrated control. Since black pepper is almost exclusively a small holder's crop and consequently financial resources are meager to allow technology transfer and low prices for commodity, discourage changes in traditional farm practices (Dewaard, 1986). Keeping these points in view, the present investigation was formulated with the following specific objectives.
1.10.6. Objectives for Study

1. To undertake survey for the identification of foot rot hot spots of black pepper in major malnad regions of Karnataka.

2. To estimate actual and avoidable loss due to foot rot disease.

3. To study the epidemiological parameters responsible for disease severity and spread.

4. To develop suitable and sustainable management practices for the disease.