Chapter 3

REVIEW OF LITERATURE

3.1. A brief history of Tea- its origin and dispersion

Tea \( \textit{Camellia sinensis} \) (L.) O. Kuntze is one of the World’s most popular beverages. The word tea originated from the Amoy pronounciation of the Chinese word t’ě, while cha was derived from Cantonese (Harler, 1964). Tea was first mentioned in a Chinese dictionary published in 350 B.C. The first detailed reference to this beverage was made in the 4th century when Kien-Lung described its medicinal properties and methods of preparation (Eden, 1976). The taxonomic status of tea plant was described by Kempfer (1712) in detail under the generic name \textit{thaeae}, a Latinized Chinese as well as Japanese name. Linnaeus, in his \textit{Species Plantarum} (1753) used the name \textit{Theae sinensis} for the tea plant, and described the ornamental species as \textit{Camellia japonica}. The generic name \textit{Camellia} was given after George Joseph Kamel, a German missionary in Phillipines (1661 to 1706), who wrote on the plants of Asia. Robert Sweet (1818) united both the genera \textit{Theae} and \textit{Camellia} into one genus \textit{Camellia}. In Sixth International Botanical Congress held at Amsterdam in 1935, \textit{Camellia} was finally adopted as the correct name for the genus (Bezbarua, 1999).

Like many other crop plants, it is believed that tea originated somewhere in north China, probably in central Mongolia. From these it migrated southwards to central China. Tea was used as early as 3500 B.C. in China, mainly as a medicinal drink. Later, with time it became a common beverage. With the spread of Buddhism, tea was introduced to Japan around 600 A.D. Despite its extensive use in China and later in Japan, tea drinking did not spread to other parts of the World until about the middle of the seventeenth century. The opening of a sea route to India and the East by the Portuguese in 1497 facilitated large scale trading between Europe and the Orient. The Dutch introduced tea in Europe in the year 1610 A.D. (Barua, 1989).
Various authors (Watt, 1908; Vavilov, 1926; Baildon, 1877; Cohen Stuart, 1918; KINGDONWARD, 1950; Purseglove, 1963) have discussed the origin of the cultivated varieties of tea. However, due to non-availability of a pure wild population representative of the form genera from which the cultivated population of diverse morphological characters originated, controversy still exists as to the real place of origin of tea (Bezbaruah, 1999).

A number of expeditions were undertaken by Capt. Kingdonward during the first part of 19th century for a few decades into upper Indo-China, north Burma, Southern Tibet and the hilly areas of north-eastern India especially Assam, in search of true wild tea populations. Kingdonward (1950) concluded from his extensive exploration as well as from other evidences that there may be two centres of origin and dispersal of different kinds of tea. According to him, tea probably originated in a primary centre somewhere in Mongolian plateau, about 60° N or further North of it, which was dispersed along two axes associated with glaciations from that region. It was further assumed that one of the axes, probably of assamica and cambodiensis had a southern migration, again dispersed from a secondary centre somewhere near the junction of the borders between India, Burma, China and Tibet. From the geographical evidence of the distribution of tea, dispersal from the secondary centre in three different directions along the sources of the three great rivers, Yang-Tse, Mekong and Brahmaputra was suggested (Bezbaruah, 1999).

As there is no evidence that the three varieties had a common origin, Kingdonward (1950) put forward his views that the prototype from which these varieties originated might have something different, probably unlike the present tea. Barua (1989) opined that in the absence of facts on the origin of tea, Kingdonward’s interpretation still holds good.

Even if ‘China’ variety originated in the north, the “assamica” variety known to the people of north-east India and northern Burma since the pre-historic times and ‘cambodiensis’ known from south east Asia for a long time, could not have thrived in the harsh climate of the region of primary centre through to the secondary centre. Bezbaruah (1999) suggested that with the dispersal of ‘China’ variety towards southern region of Yunnan province, it might have hybridized with related species and
/or genera resulting in the dispersal of ‘assamica’ variety, which further dispersed to northern Burma and north-east India by the migratory people.

The ‘cambodiensis’ might have evolved similarly by hybridization and had south easternly dispersal. There is no evidence of ‘cambodiensis’ genome in ‘assamica’ population. It was introduced in north-east India only in the beginning of 19th century (Bezbaruah, 1999).

3.2. Tea in India

India has been producing tea commercially for over 150 yrs. The discovery of wild tea plants in upper Assam in 1823 by Mr. C.A. Bruce and thereby his active participation in the establishment of tea plantation in Sadiya with the Assam variety of tea in the early years of the 18th century marked an epoch in the making of tea in India (Bora and Deka, 1999).

India produced 780 million kg. in 1996 of tea from an area of about 434 thousand hectares spreaded over north and south India. The average has been 1776 kg/hac in 1996 (Bora and Deka, 1999) of the two major tea growing regions of India. North East India alone covers about 341 sq. Km total area under tea in the country. More than 76.1 % of the country’s total production comes from this region (Tea Statistics, Tea Board in India, 1996). Out of the national production of 780 million kg North East India alone produces 597 million kg and South India produces about 180 million kg of tea from about 88 thousand hectare area. South India’s contribution from 20 % of the total area is about 24% of the production. Tea is a labour intensive industry, utilizing (in India and Sri Lanka) on an average 650 man days per hectare per year (Jain, 1999).

Tea is one of India’s major export commodity, contributing over seven percent gross earning in foreign exchange. Indian tea has its demand in the International market and are presently being exported at Azerbaijan, Kazakhstan, Russia, Ukrain, Uzbekistan, Afghanistan, Australia, Canada, Jordon, Libya, Muscat, Netherland, Pakistan, Poland, Saudi Arabia, South Africa, UK, USA and many other countries of the World (Annon, 1997).
Although India has maintained its position as the largest producer of tea in the World, it has been fast losing its superiority in global production (Bora and Deka, 1999). India’s share in World tea production dropped from 38.9 % in 1971 to 29.90 %, while the share of China and East African countries (Kenya, Uganda, Tanzania and Malawi) increased significantly.

3.3. **Tea in Barak valley**

The history of tea in Barak valley (the then Cachar district of Assam) can be traced back to 1855 when tea was discovered to grow wild in South of the Barak. By 1856 tea companies were established. Considerable increased in plantations was achieved by 1860 (Chakraborty, 1995).

The first tea in this valley was planted in 1856 in Mauza Barsangan on the low spurs running from the Barail range to the Barak. In 1869, only 24, 151 acres of areas were under tea in Cachar, yielding somewhat over 170 1 bs/ acre. By 1898, the area under tea plantation was 62,179 acres yielding about 340 1 bs/ acre (Harler, 1928).

Cachar showed an increase of 180 % in total production during the last 40 yrs. 19.28 million kg in 1951 and 41.35 million kg in 1990 (Chakraborty, 1995). At present Cachar produces 53,807 million kg of tea from the 36,827 hac area. The productivity of tea per kg per hac being 14.16 (Tea statistics, Tea board, India, 1996) as against 1809 kg in North East India and 2050 kg in South India. In the light of the envisaged production target of 1000 million kg for India as a whole and 750 million kg for North East India by the turn of the Country, Cachar has to produce 57 million kg made tea by 2000 AD., if it has to retained its 7.6 % share of North East production (Chakraborty, 1995). Cachar has almost achieved the target but with the fluctuation of production in some years, when it is affected by abiotic stress (i.e. drought) and biotic stress (caused by Red spider mite, *Helopeltis*, Black rot disease and Red rust).
3.4. About the diseases of tea

Diseases of Tea

Tea is prone to many diseases during its long life span which extends over 60 years. Watt and Mann (1903) was the first to give a comprehensive account on the pests and diseases of tea in their memorable book “Pests and Blights of Tea Plants” where they enumerated only a dozen diseases, though they mentioned type of disease appeared to be growing in number and virulence every season. Mann and Hutchinson (1904) described some tea specific diseases. Petch (1923) described several fungal parasitic on tea and brought out a comprehensive book on “Fungi and diseases in Plants” from Ceylon. Butler and Bisby (1937) reported 30 species of fungi on tea from India. Besides these treatises, many regional works are also available from India (Tunstall, 1930), Sri Lanka (Gadd, 1949), East Asia (Goodchild, 1952), Mauritius (Ramlogun, 1971), Japan (Hamaya, 1981), Peoples Republic of China (Sudoi and Langat, 1992; Tzong Mao Chen and Shin Funchen, 1982), which describes in detail about the fungi and alga associated with tea plants.

Tunstall (1942) described specific diseases of Tea and Tunstall and Sarmah (1947) described the stem diseases. Different aspects of tea diseases have also been discussed by Agnihotrudu (1963), Satyanarana and Barua (1975). Agnihotrudu (1963) reported 389 species of fungi on tea, out of which over 190 occur in Northeast India. A few more species has been added by Chandra Mouli and Ravi Kumar (1988); Rattan and Pawsay (1981). A number of fungal pathogens causes foliar diseases of tea, some of which cause serious damage to the existence of the tea plantations.

The pest and disease causes about 10-15 % crop loss every year. Watt (1989) was perhaps the first to give a comprehensive account on the pest and disease of tea. Mann (1901) and Hutchinson (1904) and Tunstall (1942) described specific disease of tea, and Tunstall and Sarmah (1947) described the stem diseases. Different aspects of tea diseases have also been discussed by Agnihotrudu (1963). Agnihotrudu (1963) reported 385 species of fungi from tea. Agnihotrudu (1964) reported a total of 209 genera comprising 385 species of fungi representing all major groups of the disease causing organisms. Satyanarayana and Baruah (1975) also reported the same. Of the total disease reported 74 genera are fungi, 17 nematodes, 5 bacteria and one each a
virus and a parasitic alga (Chandramouli, 1995). Organized cultivation of tea was initiated in India around 1836 with the opening of few tea gardens under two tea companies in Assam. Today it is cultivated in about 0.37 million hectares in Northeast India producing 556.6 million kg tea. Tea cultivation in Cachar however, was initiated around 1850’s by the Britishers. At the moment Cachar produces about 44 million kgs of tea from 35,000 ha area under tea cultivation. As it is a perennial crop, it becomes a happy hunting ground for the disease causing organisms and since the beginning of tea plantations, disease problems were found to be integral part of tea plant, which is under monoculture for over 150 years in the North East including Barak valley of Assam (Dutta, 1989; Dutta and Barthakur, 1991).

3.4.1 Foliar Diseases

The foliar disease of tea are extremely important economically as even slight damage to the tea leaves reduces the quality and quantity of tea production. Black rot is a major disease of tea capable of causing a significant depreciation in the yield and quality in India (Banerjee, 1993). Black rot diseases of tea was recognized for the first time in 1914, in a garden of Surma valley and the first serious outbreak recorded as such in upper Assam took place in a garden in the Lakhimpur district in 1918. It is a widespread disease and is found to occur in all the tea growing areas. The name black rot was originally given to the fungus in Ceylon. It has also been adopted in North East India (Tunstall et al., 1917).

_Pestalotiopsis_ has always been considered to be a weak parasite and of minor importance in different crops and is being managed by manipulating existing cultural practices (Bilgrami et al., 1979). This pathogen has been recorded on a wide variety of hosts, mostly on their leaves, fruits and in the rhizosphere (Bilgrami et al., 1979). Early studies indicated that _Pestalotiopsis_ sp is ubiquitous in distribution, occurring on wide range of substrate. Many of them are saprobes (Wu et al., 1982), while others are pathogenic on a wide range of hosts causing various diseases including stem canker, necrotic lesions on leaf, seed and root rots in different hosts (Madar et al., 1991; Yuan 1996; Yuan and Mohammed 1999; Vujanovic et al., 2000; Whingra et al., 2002, 2003). Grey blight disease of tea caused by _Pestalotiopsis_ sp. has been reported from all the tea growing countries of the world. Though the disease appears
on bare stalk and young shoots as well, the disease generally affects mature leaves (Baby et al., 2006). After the extensive mechanized harvesting had been brought into practice, this disease gained more importance. The mechanized harvesting practice weakened the bushes and also provided sites for infection by this pathogen (Sanjay et al., 2008). In Assam, blister blight was first reported in 1968 as having been prevalent for 10 yrs. It attracted little attention till the fungus responsible moved in 1908 out of Assam valley and caused a severe attack in Darjeeling (Eden, 1976), Sarmah (1960) indicated that the fungus probably thrives on wild tea in the Himalayan forests hill and the spores are carried down to the plains by wind. At present it is still a major problem of Darjeeling (Ghosh Hazra, 1991). Blister blight (Exobasidium vexans Massee) by far is the most important leaf disease, known to occur in almost all the tea growing areas in India, Sri Lanka and Japan. In Japan and Taiwan, tea leaves are also affected by reticular blight caused by E. reticulatum Ito and Sawada (Dutta, 1995; Chandra Mouli, 1999).

The leaf spot caused by Cercospora theae (Cav.) Breda de Hann. has been occasionally found to be severe in Japan (Hamaya, 1981). Anthracnose (Gleosporium theae-sinensis Miyake) is a serious leaf disease in Japan. In Taiwan and China, though widely distributed, this is not so severe. A type of black rot caused by Ceretobasidium species has also been reported from Japan (Chandra Mouli, 1999). Leaf scab caused by Elsinoe theae and sooty mould (Meliola species and Capnodium theae Boed) occur commonly but neither of them are considered to be serious problem. Certain other foliar fungi such as Piggotia theae, Hendusonia theicola, Phoma theicola, Cladosporium species, Phyllosticta species, Discoria species, Septoria species are reported by Petch (1923).

The order Trentepohliales is a group of subaerial green algae widespread in regions with humid climate and growing on rocks, buildings, tree bark, leaves, stem and fruits (Printz, 1939; Chapman 1984 and Gartner 1995). Due to the production of carotenoid pigments, they form yellow, orange or red coating on the surfaces on which they occur. Some species are endophytic or parasitic whereas others grow in close association with fungi, forming lichens (Uyenco, 1965; Chapman and Good, 1983; Chapman and Waters, 2001). Red rust causes serious die-back of the stem of young tea during its formative years. In Cachar district of Assam, it was one of the most
serious causes of decline and closure of old tea gardens (Tunstall, 1940). Sarmah (1960) observed that the spores of red rust are common almost throughout the year and mostly come from collateral hosts which are abundant. Red rust has been reckoned as one of the most problematic secondary disease of tea in NE India (Agnihothrudu, 1963). Red rust caused by *Cephaleuros parasiticus* (Karst.), a parasitic green alga and birds eye spot (*Cercospora theae* Car and Caurzi) occur in tea in several tea growing countries. Ten-fifteenth percent crop loss due to the disease was recorded in Assam and the predisposing cause was observed to be bad drainage system (Satyanarayana and Baruah, 1983).

The fungi *Colletotrichum* was established in 1831 by Corda (1831), for fungi characterized by hyaline, curved, fusion conidia and setose acervuli. Diseases caused by *Colletotrichum* species occur on a wide range of plant species and have been recorded Worldwide (Derbyshire *et al.*, 1978). *Colletotrichum camelliae* Mass is reported to cause brown blight in tea in India (Sarma, 1960) and Africa (Rattan, 1992).

**3.4.2 Stem Diseases**

Among the stem diseases, wood rot is reported from India, Sri Lanka and Kenya. Collar canker (*Phomopsis theae* Petch) and dieback (*Leptothyrium theae* Petch) are frequently reported from India and Sri Lanka. Collar canker is also reported from Kenya. The branch canker (*Macrophomina theicola* Petch) apart from India, Sri Lanka, Indonesia and Taiwan is also known to occur in Kenya and Malawi. Thorny stem blight (*Tunstallia aculiata* (Petch) Agnihothrudu) is reported Worldwide (Chandra Mouli, 1999).

Tunstall and Sarmah (1947) listed *Poria hypobrunnea* Petch as a commonly occurring disease associated with the decay or dead woody tissues in NE India. *Phomopsis theae* which causes collar canker and *Macrophomina theicola* produces stem canker. These are important diseases that could inflict heavy economic loss. *Leptothyrium theae* is reported only from Sri Lanka (Gadd, 1949) and India (Venkata Ram, 1960). Species of *Nectria* and *Septobasidium* occur only on woody branches (Tunstall and Sarmah, 1947). Similarly, the pathogen causing thorny stem blight (*Tunstallia*
aculiata) and wood rot (Hypoxylon species) inhabits old stem portions of the tea bushes, and can cripple the bush frame once it establishes in the stem tissue (Venkata Ram, 1974). Horschair blight disease caused by Marasmias equicrinis, common in Japan, Sri Lanka and India, has recently been reported from Taiwan (Hu, 1984). The disease is mild and does not pose serious problem.

### 3.4.3 Root Diseases

Butler (1918) observed that the root diseases in tea are known to originate from parasites within the roots of the plants in natural vegetation and as such they constitute a major problem of tea cultivation.

Root diseases are a common feature wherever tea is grown on land which has previously been under jungle. This is attributed to the presence of tree stumps that are left behind while clearing the jungle and which serve as a source of infection for long periods. Root diseases spread slowly and since their effects are not immediately visible, they are able to secure a firm hold on the tea bushes before their presence is detected and control measures adopted. Their importance in reducing crop is nevertheless great not only because they cause death of the entire bush, but also because of the long time taken before the bushes that are replaced come into production.

The above ground symptoms of all the root diseases are similar. They are always associated with water shortage, but they also occur at times when the soil is not deficient of water. If a whole bush or part of it suddenly dries up and dies with all its leaves attached, it is almost a case of root disease. The leaves often turn a coppery brown and stay attached to the branches for a few days before they fall off. The roots of the bushes should be dug up and examined carefully for the identification of the disease (Sarmah, 1960).

In old tea the chief source of infection lies in the stumps of shade trees. Numerous secondary infections can occur as a result of accidental dispersal of infected material. In addition, infections can also take place by means of wind-borne spores. When the disease is at an advance stage, fructifications of the causative fungus frequently
develop on the affected stumps of tea. The spores released from these fructifications settle and germinate on freshly cut shade tree stumps and the fungus ramifies through the tissues and invades the entire root system. The fungus then spreads from the roots of these shade tree stumps to neighbouring tea roots. Instances of direct infection of tea by wind borne spores are very rare (Dey, 2001).

Unlike other diseases, root diseases are difficult to control as by the time their presence is detected, it is too late. Therefore, attention must be focused on preventing the spread of the disease to healthy plants once its presence has been detected. The first step is to remove all the dead or dying bushes as soon as they are detected, with all their roots and burn them on the spot, irrespective of the cause of death. Under no circumstances the stump should be left in the ground or below ground. Any jungle or shade tree stump in the diseased patch must also be dug up and burnt, and its lateral roots should be traced and pulled out as far as possible. No roots, living or dead and no woody material which might become a food base for pathogens should be left in the soil.

In order to stop the spread of the root diseases, it is not sufficient to remove the visibly affected bush, because, by the time it is diagnosed, adjacent bushes, though not showing symptoms, may already be infected. It is advisable, therefore, to remove healthy looking bushes surrounding the infected patches for examination until two rows of healthy bushes have been removed.

**Primary Root Diseases**

Primary root disease is one in which the fungus attack itself is the direct cause of death of the bush. Even the most vigorous and healthy bushes may be attacked and killed. The common symptom of primary root diseases are wilting and dying of foliage, but the withered leaves remain attach to the branches for sometime and then, they drop off. Sometimes, a patch of tea infected by a primary root disease may be recognized by the presence of a dead branch or branches on the side adjoining the focal centre, which is near a completely dead bush or a vacancy. Primary root disease may kill one to nine bushes depending on the spacing and planting arrangement, at a time in any patch (Sarmah, 1960).
Primary root diseases are very common in tea plantations raised after clearing natural growth and therefore all the cases have the legacy of the jungle. They generally spread through soil or by root contact. When an apparently healthy tea bush dies suddenly, with the withered and dried leaves remaining attached to the bushes, the most usual cause of death is primary root disease. A bush may also be killed completely by a secondary root disease, so it is important to ascertain the casual agent before replacing it with a fill. It is essential to be able to recognize the difference between the common, primary and secondary root diseases. If every death is attributed to attack of primary disease, it may result in unnecessary removal of a healthy bush. On the other hand, if a primary disease is mistaken for a secondary one and no uprooting is done, the dead bush may spread infection to its neighbor and ultimately severe loss may occur. Descriptions of some primary root diseases are given below:

**Brown root rot disease (Fomes lamoensis (Murr.) Sacc. and Trott.)**

It is commonly prevalent in low elevation tea growing areas particularly in hilly region. Petch describes the disease as the earliest known root disease of tea. It is prevalent in all the tea growing areas of Sri Lanka but seldom causes any serious trouble. The progress of the disease is usually slow and, although the fungus produces external mycelium it does not appear to spread to any appreciable distance through the soil. Apparently the disease passes from one bush to another along the roots which happen to be in contact. The organism causing brown root rot gains entry through the roots. Infection also occur by infected material coming into contact with the healthy plants (Satyanarayana, 1979). The disease is more common on tea in sandy soil and characteristic feature of brown root rot is the presence of brown mycelium on the root surface to which soil, sand and stone particles remain encrusted (Bannerjee, 1993). The mycelium cannot be easily knocked or washed off. The mycelium of the fungus acts like a cement and binds the soil to the roots. The mycelium can be seen as tawny brown threads often collected into woolly masses between the soil particles. In old cases, these masses of mycelium acquire a black, hard covering, sometimes with a brown powdery outer layer. When the bark is removed, there is usually a layer of white or brownish mycelium on the surface of the wood. The wood rarely shows much evidence of decay, especially if the bush has been dug up as soon as it was dead, but in advanced cases it is permeated with yellow brown sheets which assumes
a honeycomb structure and appear as a network of lines and the wood is cut. At this stage the wood of the diseased root becomes soft, spongy and crumbling under slight pressure. Since infection spreads mostly through diseased root materials, dead tea bushes and stumps of felled jungle or shade trees are potential sources of the disease. The disease development is rapid and once established, it spreads to adjacent plants through root-to-root contact. After removal of the diseased plant, the pathogen can survive in debris remaining in the soil for more than 10 years (Sarmah, 1960).

**Charcoal Stump Rot (Ustulina zonata (Lev.) Sacc.)**

Generally lightning is the predisposing factor for this disease. The disease is capable of causing sudden death of the bushes. W fan shaped patches of mycelium on the wood surface below the bark, the wood is transverse by typical double black line carbonaceous brittle fructifications at the collar region are the symptoms of attack. Charcoal stump rot is the most common of all the root diseases of tea in NE India. It was also reported from South India and Ceylon on tea and a large number of alternate hosts are also recorded. In South India, it is invariably seen on areas affected by lightning (Satyanarayana, 1979). The organism, is soil borne and enter the tea plant through roots. Infection also occurs through wound in thick branches by air borne spores. On the collar region of the affected tea bush, the fungus produces black, hard effuse fructifications which is wavy on the surface (Satyanarayana, 1980).

The disease is sometimes more difficult to identify than the other root diseases because roots attacked by *Ustulina* have no visible mycelium on the surface. But if the bark is removed, large white or brownish-white, fan shaped patches of mycelium are found overlying the wood. The fans may frequently be fused to form a thin continuous sheet, but the fan structure is usually recognizable. The wood is often hard and permeated by black sheets which appear as black lines when they are cut. Such lines are found in wood killed by other fungi also, but in the case of *Ustulina* the lines are duplicated as if drawn with a faulty nib which draws two parallel lines simultaneously. Fructifications are produced in abundance on dead *Grevillea* and *Albizzia* stumps and frequently at the collar of diseased tea bushes. They are somewhat ovoid in shape and initially thin and plate like, grayish white in colour and
dotted with black spots. When old, they are charcoal black and brittle and hence the name “Charcoal Stump Rot” for the disease (Sarmah, 1960).

*Ustulina* usually attacks tea by spreading to its roots from the roots of decaying stumps. Its prevalence is due to the felling of shade trees like *Grevillea robusta* and *Albizia moluccana* without prior ring-barking and leaving the stumps of decay on the site. Very often diseased or dead bushes are found in the vicinity of decaying stumps. In some instances, a row of dead bushes can be traced along the course of a lateral root. Unlike *Poria* the fungus cannot pass from one bush to another unless the roots are in close contact. The disease therefore occurs most frequently on solitary bushes (Satyanarayana, 1979).

**Root splitting disease (Armillaria mellea (Vahl ex Fries) Kummer)**

Root splitting disease is the most devastating primary root rot disease occurring at high altitudes. It was recorded and diagnosed from Sikkim and later from other gardens in Darjeeling (Satyanarayana et al., 1980). This disease is identified by cracks on the bark; compact white fungal growth crevices; thick layer of mycelium between the leaves and the wood and the presence of thin root like or shoe lace like rhizomorphs which are either black or brown in colour. The fungus can withstand adverse conditions and when conditions are favourable spreads freely through the soil. Fruiting body of the fungus is rarely seen.

**Black root rot disease (Rosellinia arcurata Petch)**

Black root rot is one of the predominant root rot disease of tea plant, it is caused by the fungus *Rosellinia arcurata* Petch considered as serious primary root disease in India as well as NE India (Chandra Mouli, 1999). This disease is characterized by black wooly mycelia growth on the bark of the infected root and collar region with the presence of radiating ‘stars’ of white mycelium between the bark and the wood. Black lead shot like bodies are sometimes seen on the collar. The mycelium grows freely through the surface soil and organic matter. The spread of the disease is very rapid in damp weather.
Red root rot disease (*Poria hypolateritia* Berk)

Red root rot disease is the most common and destructive, affecting the tea bush. It also affects coffee. The mycelium of the fungus in early stages of infection is of white strands and it later attains bright red colour from which the red root rot is derived. The mycelia strands fuse with one another to form a sheet in advanced stage of infection and the mycelial shoots, becomes dark almost black in colour. The affected root is invariably encrusted with soil and stones. When such roots are washed in water vigorously rubbing and held under light, the characteristic light red mycelium can be seen. Affected roots lose weight and become spongy. As the symptoms on host are manifested slowly, it is difficult to diagnose the disease in the early stages. It makes about 2-5 years for the plant to succumb to this malady. Symptoms of leaf yellowing, unthriftiness and lack of vigorous growth can be noticed among the young plants invaded by this pathogen. Most frequently infection occurs by direct contact of diseased material with the roots of the plants (Sarmah, 1960).

**Xylaria root disease** (*Xylaria* species Roger)

The occurrence of this disease was first identified in 1971. Affected tea roots were covered by typical, black ribbon like, compact strands of fungal hyphae. The growth of mycelium is superficial and the affect of the fungal growth on the host tissue is confined more or less to the bark of the roots. The disease occurs in isolated patches and high casualty is noticed soon after drought.

**Secondary root diseases**

Secondary root diseases are those in which the fungus generally seen association with the root is only of secondary importance, the prime cause of bush decline being something else. The fungus in this case invades the roots, which are already weakened by other factors and perhaps accelerate the death of the infected plant. The causes of secondary infection may be a mechanical injury to the plant, droughty condition, lack of drainage or hail storm or lightning. One has to study the symptoms carefully to decide whether the pathogen entered after occurrence of the pre-disposing factor or not. The following are some of the common secondary root diseases of tea.
Diplodia root rot disease (*Botryodipodia theobromae* Pat.)

Diplodia root rot disease though very common infects root only when the soil temperature is high (Venkata Ram, 1960) and the root starch reserves are depleted (Gadd, 1949; Petch, 1923; Venkata Ram 1960). It is due to continuous hard plucking and pruning the bushes after a rush crop. Prolonged drought and a severe attack of pest and diseases may also be the cause of the attack. The common symptom of diplodia root disease is root surface covered with small groups of greyish black to coal black hairy cushions, giving a sooty appearance. Other symptoms are weak appearance of frame and presence of unhealthy leaves, failure of the bushes to recover after pruning. New shoots after pruning may also exhibit dieback (Venkata Ram, 1960).

Violet root rot (*Sphaerostibe repens* B. and Br.)

Violet root rot is a disease of tea bushes and occurs due to the attack of a parasitic fungus on roots *Sphaerostibe repens* and very common in North-east India. It mainly occurs in water logging conditions. The characteristic symptom of this disease is that the leaves turn yellowish and the fresh green colour of the leaf is lost. As the condition becomes aggravated the bushes began to die in a specific fashion, the leaves drop off in fresh state without withering and dying. Violet, blue-black patches can be observed in roots on examination. The most characteristic feature of the disease is the sour rancid vinegar like smell of the roots (Sarmah, 1960). It is found most commonly on heavy soils particularly where there is flooding, back feeding of drains, collapsing or blockage of drains; poor soil aeration also favours the disease occurrence. Large scale death of the bushes have been observed in the low lying area of Barak Valley, where the bushes are growing under waterlogged condition. Large number of the bushes are found to be affected, when the waterlogged / partially water logged areas are uprooted for replanting.
3.5 Chemical control

The use of chemical sprays, dusts or seed treatment for protecting plants from ravages of pathogens is not an innovation of the 20th century. The early agriculturists did try to control plant diseases by utilizing chemicals and fungicides. The first recorded mention of plant disease control is in the writings of the Greek poet, Homer (1000 BC), who mentions sulphur, which is still in use. Also, the Roman patriot, Cato (200 BC), mentioned the fumigation of trees with bitumen and sulphur. The first landmark in the control of fungal diseases of plants was the discovery by Anton de Bary that the causal agents of many plant diseases are fungi. The development of these fungi rapidly followed this discovery. Pierre Alexis Millardet (1885) showed that the downy mildew of grapes could be controlled by a mixture of copper sulphate and lime. The Bordeaux mixture was used both in Europe and mixture was followed by lime sulphurs in the late 19th century, and formalin, copper carbonate dusts and organomercurials (1913) as seed treatments.

There is an enormous amount of literature available on the chemicals used for disease control (Vyas, 1983; Grover, 1986; Nene and Thapaliyal, 1993; Mehta, 1971; Sbragia, 1975; Dekker, 1976; Siegel and Sisler, 1977; Thompson, 1993).

Takaya (1976) reported the usefulness of thiophenate- methyl and benomyl against black rot in Japan. Similarly, Thiophanate-methyl and benomyl are found to be effective against brown blight (Hamaya, 1981) disease of tea. The antifungal activity of hexaconazole and propiconazole has been reported to be the result of their ability to inhibit ergosterol biosynthesis in fungi (Anonymous, 1985; Arulpragasam et al., 1987; Agnihothrudu and Chandra Mouli, 1990 and Dutta et al., 1992). Harsh et al., (1987) reported the effectiveness of Bavistin at 0.1% concentration and Dithane M45 at 0.3% concentration against Pestalotiopsis versicolor, which causes foliar disease in Diospyros melanoxylon Roxb. The earlier reports of Wajid et al., (1986) in Cercospora nicotianae of FCV tobacco and Reddy et al., (1992) in burley tobacco nursery opined effectiveness of Carbendazim at 0.04 %. Copper fungicides are the chemicals most commonly used to control olive leaf spot in New Zealand olive groves and have been showed to be effective in controlling olive leaf spot in California olive groves (Teviotdale et al., 1989). Laboratory screening of some
selected systemic fungicides was done by a modified slide germination technique (Dutta and Debnath, 1990). Sujan Singh et al., (1991) revealed that in laboratory tests, of 5 fungicides tested (Captan, Dithane M-45 [mancozeb], Captanol, Blitox [copper fungicides] and Bavistin [carbendazim]). Bavistin at 0.05% and Dithane M-45 at 0.25% was effective against P. adjuncta. The mixture of cymoxanil and mancozeb was consistently found to be the most effective fungicide against crucifer downy mildew (Brophy et al., 1992). Dutta et al., (1992) reported the inhibition in the germination and germ tube growth of Exobasidium vexans spores by seven fungicides (Propiconazole, Hexaconazole, Myclobutanil, Nickel chloride, Tridemorph, Copper oxychloride) in vitro condition. Subsequent field applications of the said fungicides also gave excellent control of the disease. Hexaconazole at 50 μg/ml gave excellent control of both white rust and powdery mildew. The mixtures of hexaconazole with captan (1:17.5) and with mancozeb (1:28) were also highly effective in controlling white rust on chrysanthemum (Lam et al., 1993).

Dutta (1994) conducted field experiment on the systemic fungicides against the blister blight, black rot and red锈 diseases of tea and observed good control of blister blight in triazole and morpholine compounds treated bushes compared to copper fungicides treated bushes. Black rot was successfully controlled with systemic fungicides, Tridemorph and Carbendazim followed by Cyproconazole and Hexaconazole. Red rust disease of tea under the field conditions was best controlled with Carbendazim and Tridemorph. Devanathan et al., (1995) reported mancozeb as most effective chemical against Alternaria solani. Various workers have reported that Bavistin (Carbendazim), Tilt 250 EC, Cupravit and Dithane M-45 (Mancozeb) performed best against Pestalotia palmarum in vitro (Kundalkar et al. 1991; Joshi and Raut 1992; Selvan et al. 1993; Saw and Raut 1995; Khalequzzaman et al. 1998; Islam 2001). The contact fungicide, captan was reported to be consistently effective in inhibiting spore germination in Rhizopus oryzae, which causes storage rot of potato (Amadioha 1996). Tebuconazole significantly decreased lesion expansion rate in early blight of potato caused by Alternaria solani (Shtienberg et al., 1996).

The relative efficacy of carbendazim in the control of various diseases is well known (Srivastav and Mishra, 2008; Hesse and Hiepko, 1974). Commercial formulation of saaf- a combination of Carbendazim and dithiocarbamates was first time used at
different concentrations has been confirmed by Mishra and Sinha (1999) and Manibhushanrao et al., (1979). Benyon et al., (1999) have tested the ability of an image analysis routine to differentiate spores of eleven allergenic fungal genera using analysis based on seven basic and up to 17 more complex features, extracted from digitized images. Fungal spores of *Alternaria, Cladosporium, Fusarium, Aspergillus, Penicillium, Botrytis, Epicoccum, Exserohilum, Ustilago, Corrimus* and *Psilocybe* were examined in a series of experiments designed to differentiate between spores at the genus and species level.

Pre-infectional application of tebuconazole was superior to application carried out post-infection of *Fusarium culmorum* in Wheat (Homdork, 2000).

Kamla Uniyal et al., (2001) revealed that, Dithane M-45 and Redomil were effective in controlling leaf blight disease of poplar caused by *Phyllosticta adjuncta*. However, a high EC50 value of 34.1 mg/litre for this chemical was also reported for conidial germination of *Phaeomoniella chlamydospora* (Jaspers 2001).

The inhibitory effect of Carbendazim has also been reported for chickpea blight pathogen, *Ascochyta rabiei* (Demirci et al., 2003).

Spray programmes of the novel fungicides azoxystrobin, cyprodinil, kresoxim-methyl, tebuconazole and pyrimethanil were as effective, or more so, than the standard treatments (chlorothalonil, vinclozolin) used by growers for controlling Smoulder, which is the most widespread foliar disease of narcissus (*Narcissus* cultivars) caused by *Botrytis narcissicola* (O’Neil et al., 2004). Similarly, the performance of Dithane M45 against *Pestalotia palmarum*, the causal agent of leaf spot of Betelnut, was poor under *in vitro* tests (Islam et al. 2004).

Of the fungicides tested, kresoxim-methyl and captan were the most effective in preventing conidium germination of *Spilocaea oelagina*, the fungus that causes olive leaf spot at low concentrations, with EC50 values of 0.002 and 0.003g/ml, respectively, carbendazim was effective (EC50=0.005 g/ml).The two copper-containing fungicides, copper hydroxide and copper sulphate, were ineffective for preventing conidium germination (Obanor et al., 2005). Hundekar et al., (2005) also reported effectivenesss of Carbendazin in bidi tobacco. Premkumar et al., 2005
published the latest recommendations on the control of blister blight and grey blight in tea, using chemicals such as Carbendazim, Hexaconazole, Prpiconazole and tridemorph, Copral 50% WP (Copper oxychloride) and Cabriotop 38% WG (Pyraclostrobin + Metiram) were the most effective fungicides against Phyllosticta sp. followed by Nimrod 25% EC.

Gopinath et al., 2006 reported that application of propiconazole at 0.1% caused a dramatic reduction of disease incidence of chilli anthracnose by 70% when compared to difenoconazole at 0.05% (58%) and carbendazim at 0.1% (44%). Best results on in vitro fungal growth reduction of Armillaria mellea causing white root rot of grapevine were obtained with the four azoles tested, in particular with cyproconazole and hexaconazole, achieving 67-72% mycelial growth inhibition at the lowest dose (Aguin et al., 2006). Complete inhibition of Pestalotiopsis mangiferae colony growth at the lowest concentration (0.11%) of Carbendazim was reported by Pandey et al. (2006). Ponmurugan et al., (2006) evaluated copper oxychloride, copper hydroxide, Mancozeb, Bordeaux mixture, baycon, calixin, hexaconazole and bavistin against Phomopsis theae causing collar canker disease in tea and reported that carbendazim was found to be the most effective in suppressing the growth followed by Mancozeb.

Mancozeb @ 0.25 per cent completely inhibited the growth of Exserohilum turcicum causing Turcicum leaf blight of maize (Harlapur et al., 2007). Bhanumathi et al., (2007) screened seven fungicides against Pestalotiopsis sp and found that Bavistin and Roko were proven to be effective against it at the concentrations of 50, 100 and 150 mg/l.

The systemic fungicides thiophanate methyl and carbendazim at 0.05% were most effective, followed by the contact fungicides mancozeb (dithane M45) and copper oxychloride (COC) at 0.3% against grey blight disease of tea (Sanjay et al., 2008). Epoxiconazole, epoxiconazole+pyraclostrobin and tebuconazole presented protective, curative and antisporeulating effects against the pathogen against eucalypt leaf spot caused by Quambalaria eucalypti (Ferreira et al., 2008).

Bhat et al., 2010 reported that amongst all the 8 systemic fungicides (Carbendazim, Propiconazole, Tridemefon, Thiophanate methyl, Tridemorph, Hexaconazole,
Difenconazole, Fosetyl AL) screened at 250, 500, 750 and 1000 ppm concentrations were capable of inhibiting the growth of the pathogen i.e. *Lasiodiplodia theobromae*. Carbendazim was most effective and produced 100 percent inhibition at all the concentrations used. Among the five combinations tested, Carbendazim+Coper oxychloride, Mancozeb+Carbendazim (Saaf) and iprodin +Carbendazim (Quintal) gave 100 percent inhibition at all the concentrations tested. Carbendazim either alone or in combination completely inhibited the growth of *L. theobromae*. Shamarao *et al.*, 2010 reported the effective management of frog eye spot with new molecules hexaconazole at 0.1 % (25.5 percent disease index) or propiconazole at 0.1 % (23.7 PDI) exhibited significant superiority over untreated check (42.9 PDI) and per se performance with positive check Carbendazim (23.3 PDI) in both individual years and pooled basis. Bavistin was found to slow down the growth (16.0 %) of *Phytophthora cinnamomi* at 100 ppm concentration in vitro (Singh *et al.*, 2010). Arunakumara *et al.*, 2010 reported the effective control of early blight of tomato by using the fungicidal application of mancozeb (0.2 %) or propiconazole (0.1 %).

Dutta *et al.*, (2011) reported Saaf (Carbendazim 12 %+ Mancozeb 63 %) was the most effective fungicide against *Rhizoctonia solani* which registered a cent - percent inhibition even at 10 ppm concentration followed by Carbendazim exhibiting 95.5 percent inhibition at 10 ppm, 97.7 percent at 25 ppm and 100 percent inhibition at 50, 100, 200 and 500 ppm. Saha *et al.*, (2011) recorded maximum disease reduction of brown spot of rice with the maximum dose of 1000 ml/ha of Carbendazim manifesting the minimum percent disease index i.e. 12.70 which corresponds to 51.89 % decrease of disease over control.

Morang *et al.*, (2012) reported the effectiveness of propiconazole and hexaconazole over bavistin and cktino in inhibiting the growth of brown root rot causing pathogen, *Fomes lamoensis in vitro*. The results of Khalifa *et al.*, (2012) indicates that the fungi, obtained from diseased tomato, were sensitive to fungicide tetraconazole (according to the EC 50 values) i.e. 0.73 and 1.67 μg /ml for *A. alternata* and *F. solani*, respectively. Vitavax was also found as the best fungicide followed by Quintal and Saaf against the test fungus i.e. *Drechslera bicolor* causing leaf blight of bell pepper (Kuldeep *et al.*, 2012).
The fungicides, Calixin (Tridemorph 80EC) @ 0.3% showed 100 per cent inhibition of *Thielaviopsis paradoxa* over control whereas Ridomil MZ-72, Blitox-50 and Bavistin showed 92.00, 91.55 and 91.44 per cent inhibition respectively, over control after 144h of incubation (Chakrabarty *et al*., 2013).

Excessive use of chemical pesticide has posed serious problems of environmental contamination by entering the food chain. Apart from this, the resistance of pests to these chemicals is known to increase over time (Burgese and Hussey, 1971). Fungicidal protection is the prime strategy in the control of plant diseases (Maloy, 1993). In tea variety of fungicides with different modes of action is being used for the control of leaf diseases such as blister blight (Dutta, 1994), grey blight, brown blight, red rust and anthracnose (Muraleedharan and Chen, 1997). According to Horikawa (1986), 12 to 31 fungicides registered in Japan were found to be effective in grey blight of tea. Differences in the occurrence of resistant isolates to benzimidazole fungicides between *Pestalotiopsis theae* and *Pestalotiopsis longiseta* was demonstrated in Japan (Oniki *et al*., 1986). Protectant fungicides are used as prophylactic chemicals, as they act outside the plant prior to infection by the pathogen.

### 3.6 Plant extracts

Weeds compete with the crops for different environmental resources and either inhibit or stimulate the crop growth by releasing substances (allelochemicals) into the growing environment (Alam and Islam, 2002). Inhibitory or stimulatory effect of weeds on the growth of crops depends upon the concentration of allelochemicals, which inhibit the growth of some crops at certain concentrations, may stimulate the growth of the same or different crops at lower concentration (Narwal, 2004). The chemicals involved in allelopathic interactions are present in virtually all the plant parts including leaves, stems, fruits, roots, rhizomes, buds and seeds (Alam *et al*., 2001; Weston and Duke, 2003; Qin *et al*., 2006; Rudrappa *et al*., 2007). Different weed species differ widely in their ability to produce allelopathic effects (Hamayun *et al*., 2005). Different parts of same weed also differ in their ability to produce allelopathic effects on the germination and growth of crop plants. Some parts are more inhibitory compared to others (Ferguson and Rathinasabapathi, 2003; Tanveer *et
A number of studies have shown that allelochemicals released into the soil from residues of weeds, affects the growth of crop plants (Qasem and Foy, 2001; Kobayashi, 2004; Kong et al., 2006; Kumar et al., 2009). Furthermore, many allelopathic plants incorporated in soil are known to inhibit the growth of other plants (Rajashekhara et al., 2007). Besides competing for moisture, nutrients, and light, weeds can also affect a crop’s growth by releasing allelochemicals into the growing environment (Rice 1984; Kim and Shin 1998; Kadioglue et al., 2005).

Leaf extract of *I. carnea* was the most efficient one, followed by this of *E. citriodora*, with respect to *in vitro* inhibition of *B. fabae* mycelial growth. This may be attributed to the secondary metabolites present in the plant (e.g., phenolic, alkaloids, flavonoids and terpenoids), which could adversely influence the growth of the pathogen and its subsequent development (Cown, 1999). Some plants antagonise the growth and/or development of others by releasing some chemical compounds (Jadhav et al., 1997). Aqueous extract of some plants inhibit seedling growth (Lydon, et al., 1997); root and shoot growth (Athanassova, 1996); germination (Pratley et al., 1996); and induce mortality of plants (Eyini, et al., 1996).

All plant parts of the weed including leaf, stem, root, and fruit have allelopathic potential (Mahmood et al., 1999; Alam and Islam 2002; Tinnin and Muller 2006). However, various parts of weeds show different behavior in exerting their allelopathic effects on crops (Veenapani, 2004). Weeds also exert allelopathic effects on crop seed germination and growth by releasing water-soluble compounds into the soil (Singh et al., 2005; Batish et al., 2007). Allelopathic effects of different weeds on wheat and chickpea crops have been reported in the literature (Mishra et al., 2004; Shukla et al., 2003; Kadioglue et al., 2005; Singh et al., 2005). Results showed that ethanol and aqueous extracts of *Allium sativum*. L., *Datura metel*. L., *Dryopteris filix-mas*. (L.) Schott, *Zingiber officinale*. Rosc., *Smilax zeylanica*. L., *Azadirachta indica*. A. Joss. and *Curcuma longa*. L. recorded 100% inhibition of spore germination of the pathogens *Pestalotiopsis theae*. (Saw.) Stey., *Colletotrichum camelliae*. Mess., *Curvularia eragrostidis*. (P. Hennings) Meyer, and *Botryodiplodia theobromae*. Patouillard (Saha et al., 2005).

It was found that water extracts from fresh and dry biomass of *Amaranthus retroflexus*, *Chenopodium album*, *Erigeron canadensis* and *Solanum nigrum* had an
inhibitory effect on seed germination of *Glycine max*, *Pisum sativum* and *Vicia sativa*, the inhibition rate for the extracts from fresh biomass varying from 28.8 to 81.5% and for the extracts from dry weed biomass it was from 26.8 to 89.2% (Marinov-Serafinov Plamen, 2010).

Leaf extract had a greater inhibitory effect compared to other extracts. Water extracts from the root, stem, leaf, and fruit of *E. helioscopia* resulted in the reduction in seed germination (chickpea and lentil only) and germination index but the leaf extract increased the mean germination time in all the test crops (Tanveer et al., 2010).

Radicle length was more sensitive to extract source of *Brassica nigra* L. compared to seed germination or hypocotyl length of *Avena fatua* L. (Turk, 2003). Chickpea seed germination was inhibited by the extracts of *Solamum nigrum* L., *Chenopodium album* L., and *Matricaria chamomilla* L. (10%, 20% and 22.5%, respectively) at the end of 21 days of incubation period (Kadioglu, 2005). Germination and seedling growth of *Triticum aestivum*, *Cicer arietinum*, *L. culinaris* was significantly reduced by the leaf extract of *Ficus indica* and *Plumbago plebejum* (Raza et al., 2013).

Leachates from plants have been shown to suppress seed germination and vegetative growth, and early seedling growth (Babu and Kandasamy, 1997; Dhawan and Gupta, 1996); and decrease in radicle growth (Casado, 1995). Rice et al., (1981) showed that phytotoxicity from a crop might be from indirect effects of micro-organisms and direct toxic actions. Aqueous extract of some plants inhibit seedling growth (Lydon, et al 1997); root and shoot growth (Athanassova, 1996); germination (Pratley, et al, 1996); and induce mortality of plants (Eyini et al., 1996). Schon and Einhellig (1980) demonstrated that incorporation of dried sunflower leaf material into the soil; treatment with aqueous extract, root exudates and leaf leachates inhibited germination and growth of sorghum grain (*Sorghum bicolor*).

Amadioha (1998), Owolade and Osikanlu (1999) and Adejumo et al., (2000) reported the efficacy of extracts from *Carica papaya*, *Artemessia ciliate*, *Chromolaena odorata*, among other extracts in reducing the mycelial growth of *Erysiphe cichoracearum*, *Collectotrichum capsici* and *Protomycopsis phaseoli*, the results were comparable favourably with the chemical pesticides Benlate and Ridomil.
Enikuomehin, O.A. (2005) reported that extracts of *Chromolaena odorata* and *Aspilia africana* substantially reduced the number of infected leaves and number of lesions on the foliage, and curtailed disease development, which in turn, protected flowers and capsules from infection by Cercospora leaf spot causing organism. Seeds from the plots sprayed with the extracts of *A. africana* and *C. odorata* also had significantly (*p* < 0.05) lower fungal infection (range: 4.50 to 8.75%) compared to unsprayed plots (10.25 to 13.5%).

Among the different extracts 20% of *Azardiachat indica* was found to be most effective followed by *Rheum emodi, Eucalyptus globulus, Artemesia annua* and *Ocimum sanctum* against *Fusarium solani* f. sp. melongenae causing wilt disease in brinjal (Babu Joseph, 2008).

The results showed that all the tested concentrations of the plant extracts of leaves of *Carica papaya, Chromolaena odorata* and *Acalypha ciliata* (10, 20 and 30%), significantly (*p*<0.05) reduced the mycelial growth of the fungi *Aspergillus niger, Botryodiplodia theobromae, Fusarium solani* and *Penicilium* sp in vitro (Ebele Martina Ilondu, 2011).

Hemraj Vashist, (2012) reported that the extracts of *Albizia lebbeck, Cleistanthus collinus, Emblica officinalis, Eucalyptus deglupta, Eupatorium odoratum, Oxalis corniculata* and *Hevea brasiliensis* were reported to exhibit highest zone of inhibition (>11mm) against *Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus, Bacillus cereus, Vibrio cholerae* and *Candida albicans*. The extracts of *Butea frondosais, Melastoma malabathricum, Terminalia Arjuna, and Lycopodium japonicum* were reported to show moderate activity (8 to 11mm) against all the tested microorganisms. The use of bio fungicides of plant origin has been suggested by some workers as alternative to the use of chemicals in order to counter the potential hazards and pollution problems associated with the use of synthetic chemicals (Amadioha, 2000; Chiejina, 2006).
Chiejina et al., (2013) reported that the inhibitory effects of Chromolaena odorata extracts at 20, 40 and 60 mg/ml were greater than those of Moringa oleifera on Aspergillus niger, Fusarium oxysporum and Mucor micheli.

3.7 Biological control

The exploitation of phylloplane fungi for the control of pathogens as demonstrated in this study has therefore further expanded the frontier of research into finding affordable, easy to mass production in culture, non-toxic to humans, non-pathogenic to host and effective at low concentration mycofungicides (Istwange, 2006).

Biocontrol fungi (BCF) are agents that control plant diseases. These are beneficial organisms that reduce the negative effects of plant pathogens and promote positive responses in the plant. They do not control diseases and in addition have other benefits, including amelioration of intrinsic physiological stresses in seeds and alleviation of abiotic stresses. They can also improve photosynthetic efficiency, especially in plants. There are several soil fungi which also increase nitrogen use efficiency in plants. Biological control involves the use of beneficial microorganisms to attack and control plant pathogens, and the diseases they cause. It is an environmentally acceptable approach to disease management. Among the fungal biocontrol agents, Trichoderma sp have acquired much importance (Papavizas, 1985; Chet, 1987; Sreenivasaprasad et al., 1990).

Several mechanisms are involved to control plant diseases, some are due to mycoparasitism, production of antibiotics and competitions for nutrients in the rhizosphere (Chet, 1987; Harman, 2007; Harman et al., 2004; Vinale et al., 2008). During the process of mycoparasitism, the fungi first locates the target hyphae by proling with constitutively produced cell wall degrading enzymes (CWDEs) coupled with very sensitive detection of cell wall fragments released from the target fungi (Harman et al., 2004; Viterbo et al., 2002; Zeilinger et al., 1999). Expression of fungitoxic CWDEs is induced, and these diffuse towards the target fungi and attack even before physical contact (Brunner et al., 2003; Viterbo et al., 2002; Zeilinger et al., 1999). This detection stimulates and increases the directional growth towards the
target fungus. Once the fungi come into contact, the BCF attach and may coil around and form appressoria on the surface of the host (Inber et al., 1996). Enzymes and antibiotic substances produced kill and/or degrade the target hyphae and permit penetration of the BCF. Both the enzymes and antibiotic are strongly antifungal and are synergistic in their action (Chet et al., 1998; Howell, 1998; Lorito, 1998; Schirmbock et al., 1994). Most of the BCF can produce gibberellins as part of modulation of plant defenses in the roots (Schafer et al., 2009). Other mechanisms are employed by the plant to restrict the growth of this fungus in the roots and recent studies implicate a β-glucosidase, PYK 10 and perhaps germins in this process (Schafer et al., 2009; Sherameti et al., 2008) as well as Salicylic acid (Stein et al., 2008). When inside plant roots, fungi have access to plant nutrients which allow them to proliferate. Moreover they significantly enhance the root growth in many cases (Druege et al., 2007; Harman, 2000; Harman et al., 2008; Harman et al., 2004; Peskan-Berghoefer, 2004; Vadassery, 2008) thus providing more niches for growth of the fungi. The plants benefit from this relationship through increased root and shoot growth, increased macro and micronutrient uptake and protection from the diseases (Gosal et al., 2007; Harman, 2000; Harman and Donzelli, 2001; Harman et al., 2004; Serfling et al., 2007; Sherameti et al., 2005; Singh et al., 2000; Yedidia et al., 2001). It also increases percentage of germination and rates of germination of seeds (Barazami et al., 2005; Bjorkman et al., 1998; Chang et al., 1986). Application of BCF led to increase in dry matter content, starch, total and soluble sugars and reduction in sugar content in the leaves of different plants (Adams and De-Lij, 2007; Lamba et al., 2008; Shoresh and Harman, 2008). More importantly, the effect of BCF on plant growth has a long duration and this even lasts for the entire life of annual plants (Barazani et al., 2005; Harman, 2000; Harman, 1991; Harman et al., 2004; Waller et al., 2005). The interaction of BCF with plant results inreprograming plant transcriptome and proteome (Alfano et al., 2007; Marra et al., 2006; Schafer et al., 2009; Segarra, 2007; Shoresh and Harman, 2008; Waller et al., 2008).

To reduce the use of pesticides, biological control method has been considered as more natural and environmentally acceptable approach (Bagwan, 2010). Several species of *Trichoderma* are well documented mycoparasites and have been used successfully against certain pathogenic fungi. *Trichoderma* strains are the key antagonists for the ecofriendly management of plant diseases. Significant growth

*Trichoderma* sp are not only among the most commonly isolated soil fungi, but are also potential biocontrol agents, especially against pathogenic fungi (Dluzniewska, 2003) such as *Macrophomina phaseolina* (Adekunle *et al.*, 2001), *Rhizoctonia solani* and *Phytophthora* species (Howell, 1982). On tea plantations *Trichoderma* sp are used as biocontrol agents against primary and secondary root diseases (Chandra Mouli, 1992), Collar canker caused by *Phomopsis theae* (Ponmurugan *et al.*, 2007) and some stem diseases. Morang *et al.*, (2013) reported the potentiality of *Trichoderma viride* and *T. citrinoviride* showing highest antagonism against *Fomes lamoensis* (a tea root pathogen) followed by *A. niger*, *Penicillium* sp.

### 3.8 Crop productivity

The presence of antifungal compounds, in higher plants, has long been recognised as an important factor in disease resistance (Mahadevan, 1982). Such compounds, being biodegradable and selective in their toxicity, are considered valuable for controlling some plant diseases (Singh and Dwivedi, 1987). In addition, plant extracts might have inhibitors to enzymes from the invading pathogen, and the effects of different phenolic compounds on the germination and growth of many fungal pathogens have been reported by Ismail *et al.*, (1987).

Kundu and Gaur (1980a, b) have reported increase in yield of cotton and of wheat owing to *Aspergillus* activities. Nagaraju and Najundappa (1996) have also reported increase in yield of cowpea owing to treatment with *Aspergillus*. Subbedar and Padwa (2003) studied the effects of *A. niger* on the soybean and found that the total number of pods present per plant in 20 ppm treated plants were 14, in 40 ppm treated plants, were 28, in 60 ppm treated plants were 10 in the stipulated period (i.e. 62 days), while control was in flowering stage only.
Pre-infectional application of tebuconazole against *Fusarium* wilt of Wheat was found to be superior to application carried out post-infection. Fungicide treatment saved yield, thousand grain weight and kernel numbers per head (Homdork *et al.*, 2000). *C. odorata* extracts and residues incorporated in the soil inhibited the growth and reduced the dry weight of tomato plants (Onwugbuta, 2001).

Treating faba bean plants with plant extracts (*Ipomoea carnea, Cuminum cyminum, Allium sativum* and *Hyoscyamus muticus*) and microbioagents (*Streptomyces exfoliates* and *Trichoderma harzianum*) improved most tested growth criteria as well as plant productivity and seed yield. (Yehia *et al.*, 2004). Wilson *et al.*, (2005) reported that programmes of four to six sprays, using two or three fungicides carbendazim+flusilazole, epoxiconazole, iprodione + thiophanate-methyl, tebuconazole and vinclozolin with different modes of action, applied alternately, reduced smoulder by 35–69% and increased bulb yields by 7–59%.

Subhedar *et al.*, (2006) reported that plants treated with *A. niger* achieved a height of more than 40 cm while the control attained the height of 30 cm in the same period. The results of Ganesan *et al.*, (2007) indicates that the application of the native microorganisms Rhizobium and *Trichoderma harzianum* successfully decreased the stem rot incidence and also increased the growth and yield of the groundnut plants.

The biocontrol agent in crop protection and pest management will have the prospective to enhance crop yield quality and quantity (Oyekanmi *et al.*, 2008).

Martin and Maria (2009) reported that the inoculation with *Azospirillum brasiliense* increased the number of harvested grains of wheat by 6.1% and grain yield by 260 kg ha$^{-1}$ (8.0%).

Arunakumara *et al.*, 2010 reported maximum yield of tomato in plots sprayed with 0.1 \% propiconazole followed by 0.25 \% mancozeb.
The leaf extracts of *Zizyphus jujuba* and *Ipomoea carnea* inhibit the mycelial growth of *Rhizoctonia solani* *in vitro*, and effectively reduce the incidence of sheath blight disease in rice Sateesh *et al.*, 2011.

Fungicide application have been reported to have reduced leaf disease severity and increased yield, kernel weight, test weight, and kernel plumpness, while decreasing dockage and thins of barley crop (Turkington *et al.*, 2012).

The results of Nahunnaro and Tunwari (2012) revealed the effectiveness of plant extracts (*Chromolaena, Allium sativum, Ocimum* and *Jatropha*) and benomyl against Cercospora leaf spot which drastically reduced the intensity of the disease by 7.1% to 8.64% and induced significantly better agronomic traits that increased yield of sesame by 40.7% and 38.22% over the untreated check (548.66kg ha-1 and 551.04 kg ha-1). Results showed that Moringa extract increased growth and yield of tomato in both greenhouse and field. Moringa extract significantly increased above ground dry matter yield (DM), root dry matter weight and plant height for the crop (Mvumi *et al.*, 2012).

Adeyela and Thomas (2013) showed that the highest percentage increase in plant height, number of leaves, number of branches and stem girth (130.6, 865.0, 220.4 and 114.0%, respectively) in *Corchorus olitorius* was found in the untreated *Corchorus, cypermethrin* treated *Corchorus, Azadirachta indica* extract treated *Corchorus*, respectively. The highest percentage increase in shoot weight (71.0%), marketable yield (53.9%) and total biomass (51.5%) was in *Azadirachta indica* treated *Corchorus olitorius*.

### 3.9 Compatibility

The idea of combining biocontrol agents (BCA) with fungicides is for the establishment of desired microbes in the rhizosphere (Papavizas and Lewis, 1981) and on the phyllosphere. Further, the antagonism of BCA was influenced by the addition of fungicides (Kay and Stewart, 1994; Naar and Kecskes, 1999). Earlier reports suggest that biocontrol agents that can tolerate a certain level of concentration of the
fungicides were mixed with agrochemicals, resulting in eradication of diseases (De Cal et al., 1994).

Results on the susceptibility of *Trichoderma* to carbendazim supports the earlier findings on benzimidazole compounds (Ortiz et al., 1996; Viji et al., 1997; Naar and Kecskes, 1998; Silva et al., 1999). Similarly Gowdar et al., (2006) reported maximum inhibition (100%) of *Trichoderma* sp with carbendazim @ 0.1 and 0.2 per cent concentration at 24 hrs incubation followed by 96.88 and 88.44 per cent inhibition at 24 hrs with thiophanate methyl @ 0.1 and 0.2 per cent concentration, respectively. The minimum inhibition (00.00%) of the test fungus was observed with captan @ 0.1 and 0.2 percent concentration at 48 and 72 hrs. and at 72 hrs. in thiram @ 0.1 per cent concentration. Bagwan (2010) reported that thiram, copper oxychloride and Mancozeb at 0.2 % are compatible with *T. harzianum* and *T. viride*. Tapwal et al., (2012) also reported compatibility of *Trichoderma* sp with Dithane, Bavistin and Ridomil at any level of selected concentration (i.e. 50 ppm, 100 ppm, 200 ppm, 300 ppm) and highly insensitive to blue copper and captaf. However, Vyas (1994) stated that under pot culture studies Carbendazim gave an additive effect with *Trichoderma viride* and *T. harzianum* when applied as soil drench against *Rhizoctonia bataticola* causing dry root rot of soybean. Compatibility studies on thiophanatemethyl with *Trichoderma* revealed that the fungicide at lower concentration improved the antagonistic potential of *Trichoderma* spp., which might be due to weakening of the pathogen by the fungicide. Viji et al., (1997) reported that application of fungicide may metabolically weaken the pathogen and make it vulnerable to potent antagonists. The antagonistic potential of biocontrol agents is expressed in terms of enhanced mode of action as increased hyperparasitism activity. Papavizas (1985) observed that application of biocides in sub-lethal doses, *Trichoderma* spp are known to proliferate and produce antibiotics in soil. Kay and Stewart (1994) and Naar and Kecskes (1998) also reported that the tolerant biotypes exhibited greater antagonism with the addition of fungicides.

The results of Mclean (2001) indicate that *T. harzianum* was least sensitive to procymidone and captan and most sensitive to mancozeb, tebuconazole and thiram. Similarly, Sarkar et al., (2010) also reported that hexaconazole to be the most toxic to the growth of *T. harzianum*, followed by propiconazole and triflumizole among the
systemic fungicides tested, at the lowest concentration of 5 ppm. Deepthi (2013) reported that the *Trichoderma* isolate GRHF4 was more compatible with Mancozeb followed by copper oxychloride. Similar results were obtained by Vijayaraghavan and Abraham (2004). They observed that mancozeb was compatible with *Trichoderma* sp. Sarkar et al., 2010, also reported Copper oxychloride and copper hydroxide to be highly compatible with *T. harzianum*.

Anita and Penmurugan, (2011) reported that *Trichoderma atroviride* isolates showed better compatibility and it was able to tolerate the bordeaux mixture, blitox and kocide to a great extent, when compared with calixin, carbendazin and dithane M-45.

Natural chemicals and their use with integrated botanicals is one of the focus for the research workers all over the world (Kiran, 2006). The biocontrol agents in crop protection and pest management will have the prospective to enhance crop yield quality and quantity (Oyekanmi et al.,2008).

Therefore, the potential of the application of *Trichoderma* spp deserve careful attention for biocontrol of tea disease in the tea plantation area will surely enhance the tea productively also.