Review of literature
Fungi are the second largest group after insects and key component of tropical ecosystems throughout world. They are ubiquitous with diverse habitats ranging from psychrophilic to thermophilic and remarkably play a vital role in every ecosystem. Being heterotrophic, they are usually saprophytes and parasites. During evolution when plants colonized the land successfully, fungi developed different types of relationship with them. The group ‘endophytes’ form one of these associations and their existence have been traced in the fossil records suggesting that endophyte-host association may have evolved from the time of emergence of first higher plants on earth (Rodriguez & Redman 1997; Strobel 2003).

2.1. Definition

During course of time, the term endophyte has been defined in various ways by different workers. De Barry (1866) coined the term ‘endophyte’ to detect fungi that reside within host tissues from epiphytes. Carroll (1986) used it for those organisms that cause asymptomatic infections within plant tissues, excluding pathogenic and mycorrhizal fungi. Petrini (1991) expanded Carroll’s definition to include all the organisms that colonize a plant without causing apparent harm to the host at any time in their life cycle. However, he included invisible pathogens in this category. Wilson (1995) further expanded it and included both fungi and bacteria, which for all or part of their life cycle invade living plants and cause asymptomatic infections entirely within tissues but cause no disease. Later on, all microorganisms residing inside plants without producing visible symptoms were categorized as endophytes (Azevedo et al. 2000). According to Stone et al. (2000), the term ‘endophyte’ is an all-encompassing topographical term which includes all organisms that during a variable period of their life occupy the living tissues of their hosts without any symptom. However, Bacon & White (2000) more precisely defined that an endophytic fungus lives in a mycelial form in biological association with the living plant, at least for some period.

Although, by definition, endophytes do not cause disease in their hosts, they are obligatory heterotrophic and are often congeneric with a taxonomically diverse range of fungal pathogens. Primarily, fungal endophytes are considered asymptomatic fungi characteristically found in aerial plant tissues (Clay 1990). The majority of plant species
examined to date harbor endophytic fungi inside aerial tissues becoming a vital component of terrestrial plant communities (Arnold and Herre 2003; Gonthier et al. 2006). Fungal endophytes were considered to be among the least-known groups of plant-associated fungi, particularly diverse ascomycetes that grow asymptotically within aerial plant tissues such as leaves and stems (Wilson 1995; Kowalski & Kehr 1996).

Endophytes were first distinguished from epiphyllous fungi by De Bary (1887) and first characterized in depth from north-temperate Poaceous member by Sampson (1933). Subsequently, endophytes have been differentiated from pathogenic fungi on the basis of asymptomatic growth under different conditions (Verhoeff 1974) and from mycorrhizal fungi, on the basis of taxonomy (Bills & Polishook 1991) and tissue-specificity (Carlile & Watkinson 1989; Agrios 1997).

2.2. Major Groups of Endophytic Fungi

According to Stone et al. (2000) endophytic microbes in relation to their plant organ belong to distinct classes. Major groups are as follows: 1) Endophytic Clavicipitaceae, 2) Fungal endophytes of dicots, 3) Endophytic fungi, 4) Other systemic fungal endophytes, 5) Fungal endophytes of lichens, 6) Endophytic fungi of bryophytes and ferns, 7) Endophytic fungi of tree bark, 8) Fungal endophytes of xylem, 9) Fungal endophytes of roots, 10) Fungal endophytes of galls and cysts, 11) Prokaryotic endophytes of plants (includes endophytic bacteria and actinomycetes). Such ubiquitous endophytes dominated their assemblages of distinct hosts suggesting that certain genera of fungi are well adapted to make an endophytic way of life (Bills et al. 2004).

2.3. Diversity and Distribution of Endophytic Fungi

There has been increasing interest in systematics, evolutionary biology, ecology and applied research of endophytic fungi. This ranges from biological control to bioprospecting based on pioneering work done by different workers worldwide on this cryptic guild of fungi (Spurr & Welty 1975; Carroll & Carroll 1978; Petrini 1986, Stone 1986; Sieber 1989; Johnson & Whitney 1989; Rodrigues & Samuels 1990; Espinosa-Garcia & Langenheim 1990; Stierle et al. 1993; Arnold 2007; Backman & Sikora 2008). Studies on methods of detection, taxonomy, species composition, distribution, biological, ecological and physiological aspects of endophytes of woody plants in Europe and North America had been extensively carried out by Carroll (1995), Petrini (1986, 1996) and
Bills (1996). In addition, interactions and mutualistic symbiosis between endophytes and host plants had also been studied in detail (Saikkonen et al. 1998; Clay & Schardl 2002).

Tropical and temperate rainforests are considered as most biologically diverse terrestrial ecosystems on earth (Mittermeier et al. 1999). The endophytic fungi from healthy aerial tissues are mostly documented from conifers (Petrini & Fisher 1986; Guo et al. 2004; Wang et al. 2007; Hormazabal & Piontelli 2009) and grasses (Bacon et al. 1977; Waller et al. 1983; Clay 1988). Further, fungal endophytes have also been reported from marine algae (Cubit 1974; Hawksworth 1988), lichens (Li et al. 2007), mosses and ferns (Schulz et al. 1993; Fisher 1996), palms (Rodrigues 1994; Frohlich & Hyde 1999), liverworts (Boullard 1988) and pteridophytes (Dhargalkar & Bhat 2009). It is evident from the literature that endophytes are largely confined to gymnosperms in temperate regions (Bernstein & Carroll 1977; Petrini & Fisher 1988; Boddy & Griffith 1989; Guo et al. 2004). It is agreed that endophytic fungal diversity peaks in tropical forests where woody angiosperm diversity is also higher (Lodge et al. 1996; Arnold 2001; Gamboa & Bayman 2001; Banerjee 2011). Most studies on endophytes have been carried out in the Northern hemisphere (Petrini 1986; Boddy & Griffith 1989; Petrini 1991) and subtropical regions like Argentina (Bertoni & Cabral 1988; Cabral et al. 1993) and New Zealand (Latch et al. 1984; Philipson 1989). Petrini & Dreyfuss (1981) and Dreyfuss & Petrini (1984) reported diversity of endophytic fungi from tropical host plants which belonged to family Araceae, Bromeliaceae and Orchidaceae from French Guiana, Brazil and Columbia (South America). Subsequently, the endophytic assemblages of tropical palm tree were largely studied by Rodrigues & Samuels (1990) and Rodrigues (1994, 1996). Bills & Pollishook (1994), Fisher et al. (1995) and Rodrigues & Dias (1996) also studied the endophytic assemblages of some tropical tree species. Besides, a few studies on endophytes from the tropics include those from Bermuda (Southcott & Johnson 1997), Hong Kong (Brown et al. 1998), Brazil (Rodrigues & Samuels 1999), Barro Colorado Island, Panama (Arnold et al. 2000), Thailand (Bussaban et al. 2001; Photita et al. 2001) and Guyana (Cannon & Simmons 2002).

When compared to other tropical countries, studies on the diversity of endophytic fungi in India are extremely meager though India has rich plant diversity of about 17,527 angiosperm and 67 gymnosperm species (Karthykeyan 2009; Annon. 2009). Although, studies on endophytes have been carried out since two decades, only around 120 host plants belonging to 75 families have been screened for their endophytic assemblages.
In India, studies of endophytic fungi have been focused on tree species (Suryanarayanan et al. 2002, 2003; Raviraja 2005; Tejesvi et al. 2005, 2006; Gond et al. 2007; Kharwar et al. 2008, 2009), mangroves (Suryanarayanan et al. 1998; Suryanarayanan & Kumaresan 2000; Maria & Sridhar 2003), palms (Girivasan & Suryanarayanan 2004) and grasses (Govindu & Thirumalachar 1961, 1963, 1973). Different tissue types, viz. cotyledons, seed coats, stems (Gond et al. 2007), leaves (Rajagopal & Suryanarayanan, 2000; Kumaresan & Suryanarayanan 2002; Suryanarayanan et al. 2002) and petiole (Singh et al. 2005, 2009) were screened to isolate endophytes. Although, endophytes from roots were considered differently, attempts were made to isolate root endophytes from different hosts (Suryanarayanan and Vijaykrishna 2001; Ananda & Sridhar 2002; Seena & Sridhar 2004).

Some studies have also highlighted ecological factors which affect the diversity of endophytes. Relationship between geographic locations and seasons has been studied (Rajagopal & Suryanarayanan 2000; Suryanarayanan & Thennarasan 2004; Mahesh et al. 2005; Verma et al. 2006). Occurrence and distribution of foliar endophytes of four different types of tropical forests found in India, viz. dry thorn forest, dry deciduous forest, moist deciduous forest and semi-evergreen forest of Western Ghats of Southern India were studied by Suryanarayanan et al. (2002). They studied twenty tree species for their endophyte assemblages and concluded that though the tropical trees were endophyte rich, overall endophytic diversity of the entire plant community was not exceptional. Subsequently, Suryanarayanan et al. (2003) compared the distribution, diversity and host recurrence in twenty-four tree species belonging to 17 families of two dry tropical forests of the Nilgiri Biosphere Reserve. They identified two groups of fungi in both the forests, one group consisting of ubiquitous forms dominating the endophyte assemblages of various hosts and second were represented by the less frequent forms. This study suggests that dry tropical forests are not hyper-diverse with reference to endophytes. It is required to identify generalists/ubiquitous endophytes prior to extrapolating the data to calculate global fungal diversity. In another study Murali et al. (2007) studied foliar fungal endophytes of fifteen tree species from tropical dry thorn forest and tropical dry deciduous forest in Madumalai Wildlife Sanctuary, Nilgiri Biosphere Reserve, Southern India. They observed that isolation frequencies of cultural endophytes increased for both forest types during wet season.
2.4. Fungal Grass Endophytes

Fungal endophytes consist of three basic ecological groups: i) mycorrhizal fungi, ii) balancious or ‘grass endophytes’ and iii) non-balancious endophytes (Schulz & Boyle 2005). Grass endophytes are estimated to occur in 20-30% of grass species, which can play important ecological roles in plant communities (Leuchtmann 1992; Clay & Holah 1999). It has been reported that these are systemic and often mutualistic for cold season grasses especially in sub-family Pooideae (Clay 1996). The mycotoxins and different other classes of alkaloids produced by grass endophytes are reported to enhance resistance to herbivores (Clay & Schardl 2002). Besides, these fungi play a vital role in host-fungal interactions like drought resistance (Elmi & West 1995), efficient nutrient uptake (Malinowski et al. 2000) and also tend to improve competitive ability of their host plant even in absence of herbivory (Marks et al. 1991; Clay et al. 1993). White & Morgan-Jones (1987) studied morphological and physical adaptations of Balansieae and evolution of grass endophytes. Reports on incidence and distribution of grass endophytes in tropical countries are fragmentary. In India Balansia andropogonis Syd. & E.J. Butler (grass endophyte) from Andropogon aciculatus Retz. was first reported by Sydow in 1914. Although information on distribution of grass endophytes was inadequate till 1961, several grass endophytes were reported by Govindu & Thirumalachar (1961, 1963 & 1973). Janardhanan and Ahmad (1997) reported Balansia and its anamorphic state Ephelis from various grasses found in Indian states of Bihar, Uttar Pradesh, Karnataka and Tamil Nadu.

2.5. Fungal Endophytes from Medicinal Plants

Now a days, studies on endophytes of medicinal plants have been given due attention as they tend to produce natural products beneficial for a human being. Apart from isolating potential strains from medicinal plants, diversity studies also focuses on different aspects of ecology. Although association of endophytes with tropical tree species has been studied by various workers, knowledge on comprehensive diversity of endophytic fungi from medicinal plants is scanty. A number of medicinal plants have been screened in other regions of world for endophytes (Stierle et al. 1993; Strobel & Daisy 2003; Suthep et al. 2004; Li et al. 2005).

Terminalia arjuna Wight & Arn., an important ethno pharmacological plant extensively used in ayurvedic medicines to treat heart ailments in India were studied for
their endophytic fungal assemblages of inner bark and twigs (Tejesvi et al. 2005). Further, bark of other six plants of riparian vegetation of Mysore, Nanjungud and Srirangatna of Southern India was studied by Tejesvi et al. (2006) and reported that distribution and density of some endophytic taxa was higher in inner bark as compared to twigs. In another study by Gond et al. (2007), endophytic fungal community was studied from different parts of Aegle marmelos (L.) Correa (Rutaceae) collected from Varanasi, India which showed that endophytic assemblages differed in bark, leaf and root.

In India, studies on endophytic fungi associated with Azadirachta indica A. Juss. (ver. Neem), a well known medicinal plant have been carried out by various workers (Rajagopal & Suryanarayanan 2000; Singh et al. 2006; Kharwar et al. 2009). In most cases, endophytes were recovered from aerial parts of plant. Qualitative and quantitative changes in diversity were found in endophytic mycoflora of Neem from different regions and plant parts. However, most of the studies support the hypothesis that qualitative and quantitative endophytic diversity increases with precipitation. Similarly endophytes of leaf, stem and root tissues of Catharanthus roseus collected from two different ecosystems in North India were isolated and studied in detail by Kharwar et al. (2008). It suggests fungal host and tissue specificity and little variation in their species richness.

Banerjee et al. (2006, 2009) studied endophytes of three medicinal plants of Lamiaceae (Ocimum sanctum Linn, O. bacilicum L. and Leucas aspera (Willd) Link and Vitex negundo L. (Verbenaceae), respectively. Krishnamurthy et al. (2008) studied nine medicinal herbs for fungal communities from Bhandra River Project, Malnad region, Southern India during wet and dry seasons. They found ubiquitous forms with some host specific species. In their study, colonization frequency of fungal species varied significantly between two seasons. Naik et al. (2008) studied endophytic diversity from 15 shrubby medicinal plants growing in Malnad region, Southern India and isolated significantly more number of isolates during the winter season than monsoon and summer seasons.

2.6. Fungal Endophytes from Mangroves and Halophytes (Sea Grasses)

Mangrove forests are biodiversity hotspots for marine fungi which constitute second largest ecological group of marine fungi (Sridhar 2004; Shearer et al. 2007; Jones et al. 2009). There are few studies on endophytes from halophytic plants of temperate region (Petrini & Fisher 1986; Pelaez et al. 1998). There appears to be no published report on
fungal endophytes of marine angiosperms, although a few mangrove trees and terrestrial halophytes have been studied for their endophyte assemblages from coastlines of Pacific and Atlantic Ocean (Xing et al. 2010; Schmit & Shearer 2004). Although, endophytic fungi of mangrove plants received little attention in India, a few reports are available on their ecological aspects. Suryanarayanan et al. (1998) studied foliar fungal endophytes from two species of *Rhizophora*. Subsequently, Suryanarayanan & Kumaresan (2000) studied fungal endophytes of four mangrove plants, viz. *Acanthus ilicifolius* Linn. (Acanthaceae), *Arthrocnemum indicum* (Willd.) Moq., *Suaeda maritima* (L.) Dumort. (Chenopodiaceae) and *Sesuvium portulacastrum* (L.) L. (Aizoaceae) and speculated that tropical halophytes can also harbor diverse taxa of endophytic fungi. *Halophila ovalis* (R. Br.) Hook. F. (Hydrocharitaceae), a sea grass collected from Coromandel Coast of India was examined for endophytes by Devarajan et al. (2002). Kumaresan et al. (2002) studied endophytes of 8 different mangrove plants, viz. *Aegiceras corniculatum* (L.) Blanco (Myrsinaceae), *Avicennia marina* (Forsk.) Vierh., *A. officinalis* L. (Avicenniaceae), *Bruguiera cylindrica* (L.) Blume, *Ceriops decandra* (Griff.) Ding Hou, *Rhizophora mucronata* Lamareck ex Poiret (Rhizophoraceae), *Excoecaria agallocha* L. (Euphorbiaceae) and *Lumnitzera racemosa* Willd. (Combretaceae) from the Pichavaram mangrove forest, Tamil Nadu, India. They also studied the endophytic assemblages of *Rhizophora apiculata* Blume and its parasite *Dendrophthoe falcata* (L. F.) Etting (Kumaresan et al. 2002). The results show some degree of host-recurrence among mangrove endophytes. Apart from host, some degrees of tissue recurrence exemplified by endophytes in different tissues of *R. apiculata* were also recorded. These results indicate that endophytes occupy different niches within mangrove ecosystem, thereby avoiding competition. The result of studies on mangrove community differs from other tropical plant communities and succession (understory or stratification) is not observed.

Kumaresan & Suryanarayanan (2002) studied leaves of different age of *R. apiculata* (a halophyte) showing role of endophytes in litter degradation of tropical mangrove plant communities. They concluded that endophytic species produce cell wall enzymes such as pectate transeliminase, pectinase and protease that degrade leaf litter. Ananda & Sridhar (2002) studied the diversity of endophytic fungi in roots of mangrove species of west coast region of India. Further, Maria & Sridhar (2003) studied two halophytes, *Acanthus ilicifolius* Linn., *Acrostichum aureum* L. from the west coast mangrove habitats of India and observed high endophyte species richness and diversity in stems and roots of *A. ilicifolius* and *A. aureum*, respectively.
Although, endophytic fungi have been recovered from almost all aerial tissues, there are limited reports on their organ and tissue specificity. Carroll et al. (1977) first suggested the tissue specificity and mentioned that endophytes most frequently colonize petiole rather than other distal portion of needles. Sieber (1985) demonstrated organ specificity of endophytic fungi from wheat plant for the first time. Subsequently, it was reported on *Picea abies* L., Norway spruce and white fir (Sieber 1988 & 1989). The endophytic fungi of *Alnus glutinosa* (L.) Gaertn. showed some organ specificity where aquatic and terrestrial roots were colonized by two different populations (Fisher et al. 1991). Petrini et al. (1992) reported organ specificity of endophytic fungi due to adaptation to particular micro-ecological and physiological conditions (microcosm) present in a particular organ. The tissue specificity exhibited by endophytes is also reported as a result of their adaptation to different physiological conditions in plants (Rodrigues & Samuels 1999). However, other studies also confirmed certain degree of tissue specificity in endophytes (Fisher & Petrini 1990; Frohlich et al. 2000; Wang & Guo 2007).

Apart from organ and tissue specificity, review of literature reveals that these fungi show significant host specificity, similar to other groups like rust, smut and mycorrhizal fungi (Petrini 1986; Fisher & Petrini 1990). Petrini (1985) observed endophytic communities colonizing distinct Ericaceous plants at same site and later noted host specificity at family level (Petrini 1986). Petrini and Fisher (1988) studied host specificity of endophytic fungal communities from *Pinus sylvestris* L. and *Fagus sylvatica* L. growing at same site. In subsequent years, independent studies on different host plants confirmed that each plant species harbors specific endophytic community (Sieber & Hugentobler 1987; Sieber et al. 1991).

There have been several reports from independent studies in India on organ, tissue and host specificity. Suryanarayanan & Vijaykrishna (2001) studied tissue specificity in endophytes of *Ficus benghalensis* Linn.. Further, Raviraja (2005) screened five different medicinal plant species, viz. *Adhatoda zeylanica* Medik., *Bauhinia phoenicea* Heyne ex Wight & Arn., *Callicarpa tomentosa* Murr., *Clerodendron serratum* (Linn.) Moon and *Lobelia nicotinifolia* Heyne. collected from Kudremukh range in Western Ghats of India for their endophytic association and confirmed host and tissue specificity of endophytic fungi. Nalini et al. (2005) studied a medicinal plant, *Crataeva magna* (Lour.) DC. from constituting riparian vegetation in Karnataka (Southern India) and reported bark
specificity in endophytes. Tejesvi et al. (2006) studied host specificity of fungal endophytic assemblages from six ethnopharmaceutically important trees. In another study, endophytic fungi were host specific in *Cuscuta reflexa* Roxb. and its 7 angiosperm hosts (Suryanarayanan et al. 2000).

2.8. Fungal Endophytes recovered as New to Science

Endophytes constitute a major portion of the undescribed fungal diversity. A large part of work carried out on endophytic fungi is based on diversity studies whereas, only some studies report their practical biotechnological applications. However, attempts for searching taxonomic novelty in endophytic taxa are comparatively less, partly due to unavailability of appropriate expertise in fundamental systematics. Rodrigues & Samuels (1990) described a new species *Idriella licualae* K.F. Rodrigues & Samuels from a tropical palm tree, *Licuala ramsayi* (F. Muell.) Dom occurring in rainforests of Queensland. Subsequently in 1992, they described three new species of *Idriella* (*I. euterpes* K.F. Rodrigues & Samuels, *I. asaicola* K.F. Rodrigues & Samuels and *I. amazonica* K.F. Rodrigues & Samuels) from *Euterpe oleracea* in Brazilian Amazon forest. Liu et al. (2007) described *Colletotrichum yunnanense* Xiao Ying Liu & W.P. Wu as an endophytic species isolated from *Buxus* sp. from China. *Penicillium coffeaee* Peterson et al. was described as a new endophyte from *Coffea arabica* L., collected in Hawaii by Peterson et al. (2005). Similarly, *Ceratopycnidium baccharidicola* M.D. Bertoni & Cabral (Bertoni & Cabral 1991) from Argentina and *Preussia mediterranea* Arenal, Platas & Peláez (Sporormiaceae) from Mediterranean region (Arenal et al. 2007) were also described as new endophytes.

Although most of the newly described species are largely mitosporic fungi, there are few reports on new ascomycetous species. A new ascomycetes genus, *Edenia* with *E. gomezpompae* González et al. as type species was reported from *Callicarpa acuminata* Kunth collected in Mexico (Gonzalez et al. 2007). Jacob & Bhat (2000) described two new endophytic conidial fungi, *Kumbhamaya indica* Jacob & Bhat and *Gonatobotryum bimorphosporum* Jacob & Bhat from India. Later on *Echinosphaeria pteridis* S. Dharg. & Bhat and its anamorph *Vermiculariopsiella pteridis* have been described as endophytes of a pteridophyte by Dhargalkar & Bhat (2009). Singh et al. (2005, 2009) studied endophytic assemblages of two medicinal plants collected in India and described two
species, viz., *Gnomoniella pongamiae* from *Pongamia pinnata* and *Thielavia icacinacearum* from *Nothapodytes nimmoniana*.

### 2.9. Biotechnological Potential of Fungal Endophytes

About 4000 secondary metabolites of fungal origin were described as biologically active (Dreyfuss & Chapela 1994). Endophytes are now considered as an untapped resource for producing valuable natural products offering potential for medical, agricultural, and/or industrial exploitation (Tan & Zou 2001; Zhang *et al.* 2006; Pupo *et al.* 2006; Suryanarayanan *et al.* 2009). Natural products from fungal endophytes have been reported to exhibit a broad spectrum of biological activity and are grouped into various categories, including alkaloids, steroids, terpenoids, isocoumarins, quinones, phenylpropanoids, lignans, phenol and phenolic acids, aliphatic metabolites, lactones, etc. Moreover, reports on the secondary metabolites from endophytic fungi of different hosts have been on the rise from all over the world (Table 1). Several natural compounds are now known to have antiviral, anticancer, antioxidants, insecticidal, antidiabetic, immunosuppressive properties etc. (Strobel & Daisy 2003).

Recent review on the production of volatile organic compounds (VOCs) by endophytic fungi from rain forests with different use in agriculture has opened a new path in environment friendly disease control and further confirmed that endophytes are an abundant and reliable source of natural products. Recently wide range of bioactivities of volatile organic compounds produced by endophyte, *Muscodor albus* Worapong, Strobel & W.M. Hess and *M. roseus* Worapong, Strobel & W.M. Hess were demonstrated in controlling plant pathogenic fungi (Strobel *et al.* 2001; Stinson *et al.* 2003) and nematodes (Riga *et al.* 2008). Lacey & Neven (2006) reported fumigation ability of *M. albus* to control potato tuber moth (PTM), *Phthorimaea operculella* a serious pest of stored potato in many countries. Another *M. albus* strain GBA was recently isolated from *Ginkgo biloba* L. (family Ginkgoaceae) collected in Newport, RI, USA which inhibited and killed certain test microbes via production of mixture of volatiles (Banerjee *et al.* 2010). Daisy *et al.* (2002) showed the potential of Naphthalene, as an insect repellent by a related fungus *Muscodor vitigenus*. The antibiotic effect of *M. albus* against microbes pathogenic to human is also reported (Strobel *et al.* 2001). Most recently a *Coryne* sp. (Strain- NRRL 50072) designated as anamorphic form of an *Ascocoryne* sp. was found to produce hydrocarbon derivative (Strobel *et al.* 2010).
However, these reports demonstrate the potential and wide acceptance of antibiotic effects of VOCs producing endophytic fungi for their utilization in agriculture and medicine. It was also suggested that antibiotic effects of volatiles produced by endophytes may be used as alternatives for many of the chemicals scheduled to be phased out, e.g. methyl bromide.

Endophytes are gaining importance because of their enormous potential to produce bioactive compounds. One of the crucial aspects for a successful natural product-based drug discovery program is the selection of natural source. The discovery of ‘taxol’ (generic name: paclitaxel), a potent anticancer drug from endophytic fungus, *Taxomyces andreanae* of yew plant *Taxus brevifolia* Nutt. attracted world’s attention on drug discovery and increased their relevance (Stierle *et al.* 1993). In fact, discovery of ‘taxol’, has opened a new possibility of cheaper and more widely available product via industrial fermentation. The amount of taxol so far produced by most endophytic fungi is relatively small when compared with the produce from trees. However, the short generation time and high growth rate of fungi make it worthwhile to examine these species for production of valuable drugs.

Later, several endophytes were reported as taxol producers, viz. *Pestalotiopsis microspora* (Speg.) Bat. & Peres, *Pestalotiopsis guepini* (Desm.) Steyaert, *Periconia* sp., *Sporormia minima* Auersw., *Trichotheccium* sp. *Seimatoantlerium nepalense* Bashyal *et al.*, *S. tepuiense* Strobel *et al.*, *Stegolerium kukenani* Strobel *et al.*, *Tubercularia* sp., *Pestalotta* sp., *Fusarium* sp., *Alternaria* sp., *Pithomyces* sp., *Monochaetia* sp. which were isolated from yew as well as other plants (Strobel *et al.* 1996; Strobel *et al.* 1997; Bashyal *et al.* 1999; Li *et al.* 1998; Strobel *et al.* 2001; Wang *et al.* 2000; Shrestha *et al.* 2001). In India, attempts were made to isolate taxol with potent cytotoxic action from two endophytes, viz. *Colletotrichum gloeosporioides* and *Bartalinia robillardoides* Tassi isolated from *Justicia gendarussa* Burm F. and *Aegle marmelos*, respectively (Gangadevi & Muthumary 2008).

The representatives of genus *Pestalotiopsis* have been considered as the most common endophytes from rainforest (Nag Raj 1993). Many bioactive secondary metabolites were also reported from species of *Pestalotiopsis* (Strobel *et al.* 1996; Lee *et al.* 1996; Li *et al.* 2001; Pulici *et al.* 1996). Similarly, Gangadevi *et al.* (2008) and Gangadevi & Muthumary (2009) have reported taxol production from endophyte, *Pestalotiopsis terminaliae* G.P. Agarwal & Hasija (*Terminalia arjuna*) and *P. pauciseta* (Sacc.) Y.X. Chen (*Cardiospermum helicacabum* Linn.), respectively.
Camptothecin was isolated from various plant species such as *Camptotheca acuminata* Decaisn, *Ophiorrhiza mungos* Linn., *Ervatoma hyneana* (Wall.) Cooke and *Nothapodytes foetida* (Amna et al. 2006; Rehman 2009). Puri et al. (2005) reported Camptothecin from an unidentified endophyte from inner bark of plant *Nothapodytes foetida* (*N. nimmoniana*) from Western coast of India. Amna et al. (2006) also reported Camptothecin (CPT) from an endophyte *Entrophospora infrequens* (I.R. Hall) R.N. Ames & R.W. Schneid. isolated from inner bark of *N. foetida* growing in Jammu and Mahabaleshwar regions of India.
<table>
<thead>
<tr>
<th>Host Plant</th>
<th>Endophytic Fungi</th>
<th>Compound</th>
<th>Activity</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Species</td>
<td>Genus/Species</td>
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<td><em>Xylopia aromatica</em></td>
<td><em>Periconia atropurpurea</em></td>
<td>Periconicin B</td>
<td>Teles et al. 2006. 67:2686–2690.</td>
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<tr>
<td><em>Urospermum picroides</em></td>
<td><em>Ampelomyces</em> sp.</td>
<td>macrosporin-7-O-sulfate, 3-O-methylalaternin-7-O-sulfate, amelopyrone, desmethyldiaportinol, desmethyldichlorodiaportin, and ampelanol</td>
<td>Amal et al. 2008. <em>Phytochemistry</em> 69:1716–1725.</td>
<td></td>
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</table>

The table lists various species and their associated compounds, along with the biological activities and references for each entry. The table also includes the species' antifungal and antitumor activities.
2.10. Antimicrobial Activities of Fungal Endophytes

Endophytes are rich source of natural products displaying broad spectrum of biological activities. Many endophytic fungi are known to produce antimicrobial substances. The crude extracts from culture broths of endophytic fungi have shown antimicrobial activity against pathogenic fungi, bacteria and yeasts, cytotoxic activity on human cell line, anti-Herpes simplex virus type 1 activity (anti-HSV) and antimalarial activity against protozoan *Plasmodium falciparum* (Rodrigues *et al.* 2000; Huang *et al.* 2001; Lie *et al.* 2001; Corrado & Rodrigues 2004; Wiyakrutta *et al.* 2004). Although there are numerous studies on antimicrobial activity of endophytic fungi isolated from different geographical locations (Yang *et al.* 1994; Liu *et al.* 2001; Li *et al.* 2005; Wang *et al.* 2007; Phongpaichit *et al.* 2007; Zhang *et al.* 2009; Hormazabal & Piontelli 2009), there are scanty reports from different ecological settings in India (Maria *et al.* 2005; Raviraja *et al.* 2006; Tejesvi *et al.* 2007). Maria *et al.* (2005) studied antifungal and antibacterial activities of 14 endophytic fungi isolated from two mangrove plants, viz. *Acanthus ilicifolius* and *Acrostichum aureum* L. and indicated that many endophytes of mangrove plants are likely to possess novel metabolites. Raviraja *et al.* (2006) checked antimicrobial potential of 15 endophytes of leaf, stem and bark from eight medicinally important plant hosts from Western Ghats of India. Partially purified extracts of *Alternaria* sp., *Nigrospora oryzae* and *Papulospora* sp. exhibited considerable antimicrobial activity against selected bacteria and fungi.

Tejesvi *et al.* (2007) screened *Pestalotiopsis* strains from medicinally important plants, *Azadirachta indica*, *Holarrhena antidysenterica* (Roxb. ex Fleming) Wall., *Terminalia arjuna* and *T. chebula* Retz. for their antifungal activity and concluded that species of *Pestalotiopsis* can be explored for bioactive antifungals for better management of fungal pathogens. Mohanta *et al.* (2008) studied antimicrobial potential of endophytic fungi inhabiting three ethnomedicinal plants of Simplipal Biosphere Reserve, India. In the study, 60 fungal endophytes belonging to 14 genera were tested for their antimicrobial potential.

Kharwar *et al.* (2009) reported the production of Javanicin under liquid and solid media culture conditions from the endophytic *Chloridium* sp. of *Azadirachta indica*. This highly functionalized Naphthaquinone exhibits strong antibacterial activity against *Pseudomonas* spp., representing pathogens of both humans and plants. Similarly, 16 endophytes from *Eucalyptus citriodora* Hook. were tested for their antagonistic activities.
against human and plant pathogenic fungi (Kharwar et al. 2010). Mahapatra & Banerjee (2010) had evaluated endophytes of petiole, bark and leaf isolated from *Alstonia scholaris* (L.) R.Br. for their antibacterial activity and noted *Curvularia* sp., *Aspergillus* sp. and an unidentified fungus shows significant activity.

2.11. Genetic Diversity of Fungal Endophytes

Endophytic microorganisms are a huge reservoir of genetic diversity, and a valuable source for the discovery of novel bioactive secondary metabolites. Pandey et al. (2003) examined genetic variation using ITS-RFLP (Restriction Fragment Length Polymorphism) technique among endophytic isolates of *Phyllosticta capitalensis* Henn obtained from different tropical trees from Mudumalai Wildlife Sanctuary, Western Ghats. They could not find variation among *P. capitalensis* isolates and suggested that it is a ubiquitous foliar endophyte affecting different tree hosts from different families and habitats. In another study carried out by Murali et al. (2006) on eleven isolates of *Phomopsis* species obtained from teak trees sampled in dry and moist deciduous forests of Nilgiri Biosphere reserve, all eleven isolates formed two groups based on ITS sequences. The authors also found that the fungus is not host specific.

The genetic diversity of fungal endophytes in root, bark and twigs of four medicinally important plants, *Azadirachta indica*, *Holarrhena antidysenterica*, *Terminalia arjuna* and *T. chebula* collected from river banks of Southern India was examined by Tejesvi et al. (2007). The genetic diversity of thirty isolates of *Pestalotiopsis* and two isolates of *Bartalinia robillardoides* obtained from different hosts and places were analyzed by Randomly Amplified Polymorphic DNA. They found the lack of specificity in *Pestalotiopsis* spp. to its hosts and the locations. The observation of this study was further supported by phylogenetic analysis of *Pestalotiopsis* spp. (Tejesvi et al. 2009).