

# Root Endophytic Fungi: Research Update

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## Abstract

Fungal endophytes are group of microorganisms that reside asymptotically within the healthy living tissue. Root endophytic fungi like dark septate endophytes (DSE), *Piriformospora indica* and *Trichoderma* show mutualistic association with many plant species. The endophytes are known to produce a diverse group of secondary metabolites, extracellular enzymes, antibiotics, antifungal, anticancer agents that can be used as therapeutic drugs, agrochemicals or in industries. Plants associated with fungal endophytes play an important role in the survival of plants in extreme stressed condition. This review focuses on the functions of fungal root endophytes, their relationship with host plant, tolerance to abiotic stress and secondary metabolites production against various pathogens.

**Keywords:** Fungal Endophytes, Plant Growth Promoting Fungus, Secondary Metabolites, *Piriformospora indica*, Dark Septate Endophyte, Arbuscular Mycorrhizal (AM)

## 1. Introduction

The term endophyte was coined by the German phytopathologist Heinrich Anton De Bary in 1884, and is used to define fungi or bacteria occurring inside plant tissues without showing disease in the host plant (Wilson 1995). In contrast to others like epiphytes and mycorrhiza, endophytes reside within leaves, bark, stems and roots of the plant whereas mycorrhiza only colonizes the roots of the host plant (Saikkonen et al. 1998). Root endophytes harbor an

important component of microbial community that is different from above ground plant tissue (Addy et al. 2005), but as common as mycorrhizal fungi that reside below the ground (Weishampel and Bedford 2006). They differ from mycorrhizal fungi in morphology, development and nutrient transfer (Brundrett 2004). Brundrett and Kendrick (1988) stated that endophytic fungi living in the old roots as Glomerocycete can service for more than years even after the collapse of arbuscules. Fungal endophytes are the microorganisms that reside inside the plant tissue that can be roots, leaves or stem. They basically fall in ascomycota and basidiomycota groups (Arnold and Lutzoni 2007; Selosse et al. 2009). Endophytic fungi are plant mutualists and show various benefits to the host plant, for example abiotic stress tolerance (Redman et al. 2002), resistance to pathogens and disease (Benhamou and Garand 2001) and the production of secondary metabolites (Schulz et al. 1995). There are more than one million species of endophytic fungi associated with plants worldwide that can provide a variety of secondary bioactive products such as alkaloid, benzopyranones, flavanoids, phenols, phytochemicals and anticancer agents (Aly et al. 2010; Kharwar et al. 2011; Kusari and Spiteller 2012b). Endophytic fungi promote plant growth through auxin (IAA) (Zou and Tan 1999), phosphate solubilization (Malla et al. 2004; Wakelin et al. 2004) and siderophore production (Costa and Loper 1994).

Fungal root endophytes involve diverse group of fungi. Some specific examples are Dark septate endophytes (DSE), *Trichoderma*, *Piriformospora indica*, that are known to be true root endophytes. This review focuses on the functions of fungal root endophytes, their relationship with host plant, and secondary metabolites production against various pathogens.

### 1.1 Dark Septate Endophyte

Dark septate endophyte (DSE) is a ubiquitous group of ascomycete's fungi that may function as saprophytes or mutualistic. Kohn and Stasovski (1990) found that these fungi can survive in cold and stressed environment than AM fungi. DSE differ from other group of fungi because of their septate and melanised hyphae (Yu et al. 2001). DSE produces conidia with microsclerotia in plant roots. It has been found that these groups of fungi uses inorganic form of nitrogen that in turn benefits the host plant for nutrient uptake (Upson et al. 2009; Newsham 2011). They are frequently observed in cortex, epidermis as well on root surface. Sieve elements of roots of *Atriplex canescens* were predominately colonized with the hyaline hyphae and non-pigmented fungal structure (Barrow and Aaltonen 2001). They have been reported from many plants and habitat worldwide. *Phialocephala fortinii* (Wang and Wilcox 1985) has a broad host and geographical range (Ahlick and Sieber 1996) mostly dominated in Europe and western Canada. *Phialocephala dimorphospora*, *Phialocephala fortinii*, *Phialocephala finlandia* forms association with the root of alpine ericoid. Colonization by this fungus has a unique characteristic; hence they are sometimes termed as ericoid mycorrhizae. Other than ericoid host's *P. fortinii* and mycelium radices atrovirens (MRA) also colonizes the roots of *Fagus sylvatica*, *Pinus sylvestris*, *Phialocephala resinosa*, *Phialocephala contorta* and various alpine perennials (Ahlick and Sieber 1996). Colonization of roots with dark septate endophyte increases the growth of the plant (Read and Haselwandter 1981).

### 1.2 Trichoderma Species

*Trichoderma* species is considered as a major component of soil biodiversity that is mostly associated with plant roots. However, recent studies have revealed that *Trichoderma* species is not only associated with plant roots but they also persist above ground tissues (Evans et al. 2003; Bailey et al. 2006). *Trichoderma* species has been widely used as a biocontrol agent against soil borne pathogens (Whipps 2001). Various toxic compounds (e.g., the antibiotics gliotoxin, gliovirin) and extracellular enzymes are released by *Trichoderma* species to kill fungal pathogen that penetrate and utilize host nutrients (Lorito et al. 1996). Interaction of arbuscular mycorrhiza with *Trichoderma* shows synergistic effect on plant growth through a wide range mechanism. The use of *Trichoderma* species as biotrophic decomposer and as endophyte makes it an important tool for agricultural and natural ecosystems (Harman et al. 2004). Some *Trichoderma* isolates enhances plant growth and reduce damage against nematode damage (Meyer et al. 2001). The genus *Trichoderma* produces a wide range of metabolites, plant growth regulators (ciclonerodiol), antibiotics (anthraquinone), antifungal (phenolic compounds), antitumor agents and immune modulatory compounds (harzianodiona) that expand the use of this organism commercially (Supothina et al. 2007, Xiao-Yan et al. 2006).

### 1.3 *Piriformospora* Species

*Piriformospora* spp. (Verma et al. 1998) is a root endophytic fungus discovered from Thar Desert of India, belongs to family basidiomycetes (Verma et al. 1999; Pham et al. 2004) that colonize the root cortex of many plant species. Like Arbuscular mycorrhizal fungi, *Piriformospora indica* and *Sebacina vermifera*, (Basidiomycota, Sebaciniales) has a broad spectrum against soil born fungal pathogens, promotes plant growth and induces resistance against various insects/pests (Varma et al. 2013).

Basiewicz et al. (2012) have described a new species of *Piriformospora williamsii* and have established its phylogenetic relationship with other members of Sebaciniales. Recent study reported 25 Mb genome of *P. indica* (Zuccaro et al. 2009, 2011). The main features of *P. indica* genome sequence include 50.68 % GC content, 4.68 % repeat rate, 11,769 protein-coding genes, 5.16 average exons per gene, gene density of 471(number of gene per Mb), 867 secreted proteins, 386 small secreted proteins (SSP), 3,134 unique gene models, 197 unique SSP and 58 tRNA genes. This breakthrough research is the first in-depth genomic study that describes a mutualistic symbiont with a biphasic lifestyle through extensive comparative analysis of the *P. indica* genome with other Basidiomycota and Ascomycota fungi that have diverse lifestyle strategies identified features typically associated with both, biotrophism and saprotrophism. The tightly controlled expression of the lifestyle- associated gene that sets during the onset of the symbiosis was revealed by microarray analysis that argues for a biphasic root colonisation strategy of *P. indica*.

This root interacting fungus forms asexual chlamydospores and can easily be grown on various medium (Pham et al. 2004; Prasad et al. 2005). The chlamydospores occur as typical pyriform. *P. indica* readily colonizes the *Arabidopsis thaliana* and increases the yield and salt tolerance in barley plant (Oelmüller et al. 2009; Varma et al. 2013). The fungus uses unidentified signaling pathway to protect its host from pathogen and induces systemic resistance (Waller et

al. 2005; Serfling et al. 2007). Plants infected with *P. indica* results in higher yield, early flowering and seed production and increase fresh weight (Varma et al. 2013; Prasad et al. 2013). Tolerance to abiotic stress was induced in *Arabidopsis thaliana*; overall growth and biomass production was achieved in herbaceous mono- and dicots, medicinal plants, and other important crops (Verma et al. 1999).

## 2. Functions of Fungal Root Endophytes

### 2.1 Plant Growth Promoting Properties

From the past few decades' agrochemicals are been used by producers for crop protection, use of this has led to negative impact on crop yield as it increases the resistance of pathogen to antimicrobial agents (Gerhardson 2002). Presently, biological agents are more popular than chemical pesticides; in this concern plant growth promoting activity of root endophytic fungi has the capacity to develop sustainable systems in plant growth (Shoebitz et al. 2009). Plant growth promoting endophytes stimulate growth of plants by solubilization of nutrients, production of growth regulating hormones, siderophore, antibiotics, chitinase and cyanide (Pal et al. 2001).

Crop productivity is mainly affected by different stress factors for e.g. high alkaline soil contains high amount of ions that reduces the nitrogen fixation. These adverse conditions reduce the water absorption by plants and induce metabolic changes and decrease the growth rate (Joseph et al. 2007). In such type of soil use of endophytic fungi plays a major role as stress-tolerating organisms. Root endophytic PGPF are those that reside in the roots of the host plants and are beneficial for its host. (Table 2,3). PGPF are crop specific and their significance on plant is limited because of variation in climate and soil inconsistency (Khalid et al. 2004, Wu et al. 2005). Plant growth promoting traits of endophytic fungi are phosphate solubilisation; IAA production for e.g. *Trichoderma virens* produces the auxin related compounds and increases the growth and development of *A. thaliana* (Cornejo et al. 2009), ammonia and salicylic production, siderophore, HCN production and tolerance to heavy metals. Other factors are also responsible for its effect on PGPF activities i.e., soil type, nutrient, moisture content and organic matter (De Freitas and Germida 1992).

PGPF has been used as biocontrol agent as it cooperatively decreases the pest and pathogens and it is one of the biological and effective approaches to control soil pathogens (Ramamoorthy et al. 2001).

Table 2. Functions of root endophytic fungi on growth of the plant

Fungi	Host	Effect on plant	Reference
<i>Cryptosporiopsis</i> spp	<i>Larix decidua</i>	Increased root length	Schulz et al. 2002
<i>Periconia macrospinoso</i>	<i>Brassica campestris</i>	Increased root growth	Shin et al. 2005
<i>Phialocephala fortinii</i>	<i>Rhododendron</i> spp	Increased root biomass phosphorus intake	Vohnik et al. 2005

<i>Piriformospora indica</i>	<i>Zea mays</i> , <i>Nicotiana tobaccum</i> , <i>Bacopa monniera</i> , <i>Artemisia annua</i>	Increased growth and early rooting in tobacco calli	Varma et al. 1999; 2012
	<i>Spilanthes calva</i> , <i>Withania somnifera</i>	Increased overall growth and yield, number of flowers and fruits	Rai et al. 2001

Table 3. Functions of root endophytic fungi in host resistance to pathogens

Fungi	Host	Pathogen	Effect on host	Reference
<i>Piriformospora indica</i>	<i>Orzya sativa</i>	<i>Fusarium culmorum</i> , <i>Cochliobolus sativus</i>	Significant improvement in biomass in infected plants	Waller et al. 2005
DSE taxon LtVb3	<i>Brassica campestris</i>	<i>Verticillium longisporum</i>	Symptoms reduced by 90%	Narisawa et al. 2004
<i>Phialocephala fortinii</i>	<i>Solanum melongena</i>	<i>Verticillium dahliae</i>	Decreased symptoms of pathogen	Narisawa et al. 2004
<i>Fusarium oxysporum</i>	<i>Lycopersicum esculentum</i>	<i>Melioidogyne incognita</i>	Reduced infection through release of antimicrobial compounds by 60%	Hallman and Sikora 1994,1996
<i>Acremonium strictum</i>	<i>Lycopersicum esculentum</i>	<i>Helicoverpa armigera</i>	Decreased development of pupae and larva	Jallow et al. 2004
<i>Acremonium alternatum</i>	<i>Brassica oleracia</i> var. <i>gemmifera</i>	<i>Plutella xlostlla</i>	Decreased growth rate of larva	Raps and Vidal 1998

## 2.2 Mechanism to Control Phytopathogens

### 2.2.1 Siderophore Production

Iron is a crucial element for microbial growth and mostly it is unavailable to microbes because inorganic iron is extremely insoluble and less in concentration in soil. For iron sequestration many microbes release the iron binding low molecular weight substances called as siderophores, which has the ability to bind with  $Fe^{3+}$ . This bound iron becomes soluble and transport into the microbial cell and increase its growth (Saharan and Nehra 2011).

### 2.2.2 Enzyme Production

Hydrolytic enzymes secreted by endophytes can lyse the cell wall of fungal pathogens but not the plant cell wall, and by this it prevents the attack of phytopathogens. Host plants which colonized by endophytes have more vigour because of secretion of phytohormones i.e., cytokines, auxins (Robinson et al. 1998) and help in the absorption of minerals like nitrogen (Lyons et al. 1990) and phosphorus (Malinowski et al. 1999).

### 2.3 Abiotic Stress Tolerance

Agriculture is mostly prone to abiotic and biotic stresses, crop yield gets adversely affected as the stress condition increases either due to natural or anthropogenic factors and it may become one of the reasons for productivity limitation. Unfavourable condition like high temperature; elevated CO<sub>2</sub>, droughts, extreme rainfall, floods, cold waves, global warming etc. cause a negative impact on crops and results in economic losses.

Many genes are involved for adaptation of microbes in stressed environmental conditions (Srivastava et al. 2008). Under extreme environmental condition many microbes possess different mechanisms i.e., metabolic process like involvement of enzymatic activities and membrane stability at high temperature and salinity (Madigan 1999). In tropical and subtropical areas the major problem is high soil temperature for crop production and fungal colonization. Response of all the organisms is by induction of synthesis of specific proteins known as heat shock proteins (HSPs). These HSPs are composed of chaperons (such as GroEL, DnaK, DnaJ, GroES, ClpB, ClpA, ClpX,) and small form of heat shock proteins (HSPs and proteases). The role of chaperons is proper folding and alignment of denatured proteins and proteases that are useful in degradation of irreversible damaged proteins (Munchbach et al. 1999). This has been proved that microbes play a significant role in plant protection by stress management mechanisms; unique properties of stress tolerance, ubiquity, and genetic diversity and now new methods are being employed for their deployment in agriculture. Many reports are also there for AM symbiosis, which improve the plant resistance in drought condition by alteration of plant physiology and metabolic activities, expression of genes (Ruiz-Lozano and Azcon 2000) and dehydration tolerance (Allen and Boosalis 1983).

Wu and Xia (2006) demonstrated that induction of *Glomus versiforme* enhanced the osmotic adjustment in citrus plants under drought condition by increasing the concentration of non-structural carbohydrates, Ca, Mg and K. Under water deficient condition ascorbate and glutathione plays an important role in protection and maintenance of metabolic functions of plants but low concentration of these compounds present in lavender plants shows more drought tolerant. This is because the roots of plant are colonized by *Glomus* sp. strain (Marulanda et al. 2007). Neto and co workers (2006) reported that *A. trifolium* plants inoculated with endophytic fungi showed better tolerance to flood by maintenance of osmotic pressure and proline concentration in plant tissues.

One of the examples of endophytic fungus is *P. indica* that confers the drought tolerance in *A. thaliana* by priming the expression of stress related genes. In arid and semi arid regions soil salinization is a major problem and it is increasing steadily in various part of world (Giri et al. 2003; Al-Karaki 2006). In natural environmental condition plants are colonized by both external and internal endophytic fungi and they are beneficial fungi helpful in improving plant growth and tolerance under stressed condition (Creus et al. 1998). Most of the AM fungi are incorporated with roots of 80% plants. AMF and endophytic fungi naturally occur in saline areas (Hilderbrandt et al. 2001; Yamato et al. 2008), and the most predominant occurrence of *Glomus* species i.e., were *Glomus intraradices*, *G. versiforme* and *G. etunicatum* in severe saline soil of Tabriz plains having electrical conductivity of 162 dS m<sup>-1</sup>.

The harmful impact of salinity is not on the host plants but also on endophytic fungi; it can alter



the colonization capacity, growth of hyphae and germination of spores of fungi. Many reports are there on the effect of salinity on fungi (Jahromi et al. 2008). Percentage of root colonization by fungi decreases as the concentration of NaCl increases in soil (Giri et al. 2007; Sheng et al. 2008) indicating salinity inhibits the fungi colonization and arbuscular mycorrhiza formation (Sheng et al. 2008). Juniper and Abbott (2006) showed that spore germination of fungi is delayed rather than prevented. In synthetic media, the number of spores' produced by *Glomus intraradices* decreases as the medium contains the different concentration of salts. This reduction suggests that if salinity continuous there can be decline in colonization percentage by reducing the capacity of inoculums (spores). Abiotic stress results into series of physiological, morphological, molecular and biochemical changes in plants and adversely growth and productivity.

Mainly clavicipitaceous endophytic fungi colonize the tissues and provide the beneficial effects on host plants by increasing the resistance to pathogens and stressed conditions (Kuldau and Bacon 2008). Habitat specific adaptation also supported by *F. culmorum*, *C. protuberate* and *C. magna* endophytes. *F. culmorum* confers salt but not heat or disease tolerance; *C. protuberata* confers heat but not disease or salt tolerance; and *C. magna* confers disease but not heat or salt tolerance (Rodriguez et al. 2008). For e.g. in the geothermal soils of Yellowstone National Park, *Dichanthelium lanuginosum* plant is heavily colonized by one of the dominant endophyte i.e. *Curvularia protuberate*. This endophyte confers the heat tolerance to the host plant and when they are separated from one another none of them survive alone when exposed to temperature >38 °C (Redman et al. 2002). These endophytes symbiotically tolerates the stress conform the evolutionary dynamics plays differently in various habitats and confer the stress tolerance to plants (Table 4).

Table 4. Some examples of fungal endophytes that conferred abiotic stress tolerance

Fungal endophytes	Abiotic stress	Host Plants	References
<i>Neotyphodium</i> spp	Drought	<i>Festuca pratensis</i> , <i>Perennial Ryegrass</i> , <i>Festuca arizonica</i>	Malinowski et al. 1997 Barker et al. 1997 Morse et al. 2002
<i>Curvularia protuberate</i>	Heat	<i>Dichanthelium lanuginosum</i>	Redman et al. 2002
<i>Curvularia protuberate</i> (Cp4666D)	Drought	<i>Dichanthelium lanuginosum</i>	Rodriguez et al. 2008
<i>Curvularia</i> spp	Heat/Drought	<i>Lycopersicum esculentum</i>	Rodriguez and Redman 2008
<i>Fusarium culmorum</i> (Fc18)	Drought	<i>Leymus mollis</i> , <i>Oryza sativa</i> , <i>Lycopersicum, esculentum</i>	Rodriguez et al. 2008
<i>Fusarium culmorum</i> (FcRed1)	Salinity	<i>Leymus mollis</i> , <i>Oryza sativa</i> , <i>Lycopersicum esculentum</i> , <i>Dichanthelium lanuginosum</i>	Rodriguez et al. 2008
<i>Colletotrichum</i> spp	Drought	<i>Lycopersicum esculentum</i>	Rodriguez et al. 2004
<i>Fusarium</i> spp <i>Alternaria</i> spp	Heat/Drought	<i>Lycopersicum esculentum</i>	Rodriguez and Redman 2008
<i>Piriformospora indica</i>	Salinity	<i>Hordeum vulgare</i>	Waller et al. 2005

Previous studies documented that stress tolerance by fungal endophytes in host plant plays an important role in the survival of plants in extreme stressed condition (Rodriguez et al. 2004).

For e.g. Class II type of endophytes confers the heat tolerance to plants in geothermal soils (Redman et al. 2002), extent of colonization by endophytes directly related to the resistance to pathogens of host plant (Arnold et al. 2003) and endophyte can confer drought tolerance to many host plants (Waller et al. 2005). Endophytes colonized plants express different range of adaptations to biotic and abiotic stress condition i.e., drought (West 1994), mineral imbalance (Malinowski et al. 1997) and soil acidity (Malinowski and Belesky 1999).

#### 2.4 Natural Products from Root Endophytes

The endophytic fungi associated with the roots of the plant can produce natural active secondary metabolites that have many industrial and agriculture applications. Endophytes are known to produce various metabolites such as antibacterial, anticancer, antifungal, antiviral and immunosuppressant compounds e.g. paclitaxel, torreyanic acid, etc. which can be used in various field of medicine. Isolation and characterization of endophytic fungi for their use in medicine and industry depends upon the environmental as well as on host endophyte relationship. Since last one decade number of bioactive compounds have been isolated and characterized from root endophytic fungi, which belongs to groups like phenolics, quinones, flavonoids, terpenoids, xanthenes and other biological active compound (Tan and Zou 2001; Gunatilaka 2006; Zhang et al. 2006). Various pathways like polyketide, isoprenoid, and amino acid derivation synthesize these secondary metabolites. Strobel et al. (1996) discovered that paclitaxel was produced by *Pestalotiopsis microspora*, isolated from *Taxus wallichiana*. *Muscodoralbus* (Strobel et al. 2001) isolated from *Cinnamom zeylanicum* produces an antifungal compound that has proved lethal to *Aspergillus fumigates* and *Candida albicans* (Woropong et al. 2001). Myco-diesel hydrocarbons from endophyte *Gliocladium roseum* can be used as an alternative source for bio-diesels (Strobel et al. 2008). *Gliocladium catenulatum* endophyte isolated from *Theobroma cacao* is used as a biocontrol agent against *Crinipellis perniciosus* Witches Broom disease of the Cacao tree (Rubini et al. 2005). *Aspergillus fumigates* isolated from twigs of the *Juniperus communis*, produces deoxypodophyllotoxin that has anticancer and antiviral activity. Taxol, a powerful anti cancer drug is produced by an endophytic fungi *Taxus brevifolia* Nutt (Strobel et al. 1993). Endophytic fungi *Pestalotiopsis microspora* has been used for the isolation of antioxidant metabolites such as Pestacin and Isopestacin. Grass-associated endophytes such as *Epichloë* and *Neotyphodium* species have been detected with alkaloids.

A number of antifungal products are produced from endophytes. Griseofulvin was first reported from endophyte *Abies holophylla* that was used as an antifungal against plant pathogen. Griseofulvin and dechloro griseofulvin isolated from *Xylaria* species have shown high antifungal activity against *Magnaporthe grisea*, *Puccinia recondite* and *Blumeria graminis* f. sp. *Hordei* (Park et al. 2005). Endophytes are known to produce many antiviral agents. Cytonic acid A and B isolated from *Cytonaema* sp. act as an inhibitor for human cytomegalovirus (hCMV) protease (Jensen and Roulund 2004).

Kusari et al. (2009) demonstrated one of the examples of horizontal transfer of genes from host to endophyte. *Aspergillus fumigatus fresenius* was isolated from the twigs of *Juniperus communis* L. *Horstmann*, which is a producer of deoxypodophyllotoxin that is known for anti



therapeutically properties like antitumor, antiviral, and anti-inflammatory activities. Pimentel et al. (2011) reported that bioactive compounds produced by endophytes could be use in biotransformation process. Biotransformation of grandisin to tetrahydrofuran by *Phomopsis* species is a promising method for the production of metabolites by these endophytes. Biotransformation has also been reported from endophytic fungus isolated from *Aphelandra tetragona* roots (Zikmundová et al. 2002). These endophytic fungi are able to mimic mammalian metabolism through various reactions of biotransformation (Borges et al. 2007).

Table 5. List of secondary metabolites produced by fungal root endophytes

Fungus	Source	Compound	Activity	Reference
<i>Penicillium expansum</i>	<i>Excoecaria agallocha</i>	Polyphenols, expansols A & B	Cytotoxic	Lu et al. 2010
<i>Curvularia lunata</i>	<i>Niphatcs olemda</i>	Cytoskyrins	Antibacterial, anticancer agent	Brady et al. 2000, Jadulco et al. 2002
<i>Phoma medicaginis</i>	<i>Medicago sativa</i> , <i>Medicago lupulina</i>	Brefeldine A	Antibacterial	Weber et al. 2004b
<i>Phomopsis</i> spp PSU-D15	<i>Garcinia dulcis</i>	Phomoenamides	Antimycobacterial activity	Rukachaisirikul et al. 2008
<i>Muscodora albus</i>	<i>Cinnamomum zeylanicum</i>	Colatile organic compounds	Antifungal, antibacterial	Ezra et al. 2004
<i>Pestelotiopsis microspora</i>	<i>Taxus wallichiana</i>	Paclitaxel	Anticancer	Strobel et al.1996
<i>Chaetomium acuminata</i>	<i>Edenia gomezpompae</i>	Naphthoquinone spiroketal	Allelochemical activity	Macias- Rubalcava et al. 2008
<i>Muscodora vitigenus</i>	<i>Paullinia paullinioides</i>	Naphthalene	Insecticides, antimicrobials, anti helminthics and vermicides	Strobel et al. 2007

### 3. Host Endophyte Relationship

Several theories have been developed to mark the advantages of root endophyte colonization. Two of the most prominent methods are plant (Newsham 2011) and phytohormones production (Schulz and Boyle 2005). The association between host and endophyte depends upon the environmental condition and ranges from mutualistic, neutral or antagonist (Kogel et al. 2006; Moricca and Ragazzi 2008). The interaction is highly variable and transitory (Bacon and Yates 2006). Although transitory association exists; endophytic fungi are known to show various benefits to the host plant like tolerance to abiotic and biotic stress (Schulz and Boyle 2005; Rodriguez and Redman 2008). Schulz et al. (1999) demonstrated that the host endophyte interaction is a balanced antagonist that refers to a state of equilibrium between fungal virulence and plant defences. Although change can occur through an imbalance in flow of nutrients, change in environmental (Moricca and Ragazzi 2008) and stress condition (Halmschlager et al. 1993). Genetic variation plays an important role in host endophyte

interactions. The relationship between host genotype and their lifestyle from mutualistic to parasitic has been shown by some fungal isolates (Unterseher and Schnittler 2010).

Stress tolerance to reactive oxygen species (ROS) produced by endophytes protects the host plant from drought and pathogens. ROS produced by endophytes have increased the production of antioxidant such as phenols and/or flavonoids in endophyte-infected plants. ROS denatures the cell membrane of the plant thus involving influx of nutrients that is radially absorbed by fungal hyphae (White and Torres 2010). Host specificity, selectivity and host preference also plays an important role in host endophyte relationship (Cohen 2006). Endophytic fungi interact with the roots of the plants in several ways depending upon the environment and species involved. For e.g. in tree species the interaction between the fungal root endophytes and plants takes place through the formation of mantle and hartig net. *Phialocephala finlandica* (*C. finlandica*) develops a hartig net by radial elongation that is confined till the epidermis and the mantle to the roots of yellow birch (Wilcox and Wang 1987 b). It has been reported that roots of oak and pine have been colonized with large number of root endophytic fungi (Reininger and Sieber 2012) as well as with AM fungi (Dickie et al. 2001).

#### 4. Conclusion

Root endophytic fungi are the group of microorganisms that reside inside the plant roots and their association varies from mutualistic to pathogenic. *Piriformospora indica* has a broad spectrum of resistance against soil-borne pathogens and promotes plant growth. Endophytic fungi are excellent source of bioactive natural metabolites with broad range of functions and structural diversity therefore it can be used as a bio fertilizer. It also plays an important role in conferring resistance to biotic and abiotic stress conditions. The ease of culturing root endophytic fungi can fulfil the future demands in medical, agriculture and pharmaceutical industries.

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