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Endophytic Fungal Diversity in Tropical and Subtropical Plants

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ABSTRACT

Endophytic fungi are an interesting group of microorganisms associated with the healthy tissues of plants. Endophytic fungal diversity is higher in tropical and subtropical plants than other climatic zones. Most of the reports available on bioactive product formation by endophytic fungi are also from tropical and subtropical climate. Rapid destruction of plants from this region needs special attention to protect endophytic diversity.

Key words: Biodiversity, endophyte, fungi, tropical plant

INTRODUCTION

Tropical and subtropical rainforests are found nearer to north or south of the equator. They are common in Asia, Australia, Africa, South America, Central America, Mexico and on many of the Pacific Islands (Fig. 1). Within the World Wildlife Fund's biome classification, tropical rainforests are considered a type of tropical wet forest and may also be referred to as lowland equatorial evergreen rainforest. Minimum normal annual rainfall between 1,750 mm (69 in) and 2,000 mL (79 in) occurs in this climate region. Mean monthly temperatures exceed 18°C (64°F) during all months of the year. Rainforests are home to half of all the living animal and plant species on the planet. Tropical rain forests are called the world's largest pharmacy because over one-quarter of modern medicines originate from its plants.

Tropical and temperate rainforests are the most biologically diverse terrestrial ecosystems on earth. The most threatened of these spots cover only 1.44% of the land's surface, yet they harbor more than 60% of the world's terrestrial biodiversity (Mittermeier *et al.*, 1999). It is expected that areas of high plant endemicity also possess specific endophytes that may have evolved with the endemic plant species (Strobel, 2002a, b). Tropical rainforests are most active in evolutionary race to survive. Competition is great, resources are limited and selection pressure is at its peak. This gives rise to a high probability that rainforests are a source of novel molecular structures and biologically active compounds (Redell and Gordon, 2000). Bills *et al.* (2002) described a metabolic distinction between tropical and temperate endophytes through statistical data which compares the number of bioactive natural products isolated from endophytes of tropical regions to the number of those isolated from endophytes of temperate origin.

The most common usage of the term endophyte for organisms whose infections are internal and inconspicuous and in which the infected host tissues are at least transiently symptomless, is equally applicable to bacterial prokaryotes and fungal eukaryotes. Taken literally, the word endophyte means in the plant (endon = within, phyton = plant). Endophytes include an assemblage of microorganisms with different life history strategies: those that, following an endophytic growth phase, grow saprophytically on dead or senescing tissue, avirulent microorganisms, incidentals, but also latent pathogens and virulent pathogens at early stages of infection (Bacon and White, 2000; Suriyanarayanan *et al.*, 2009). Communities of endophytes inhabiting a particular host may be

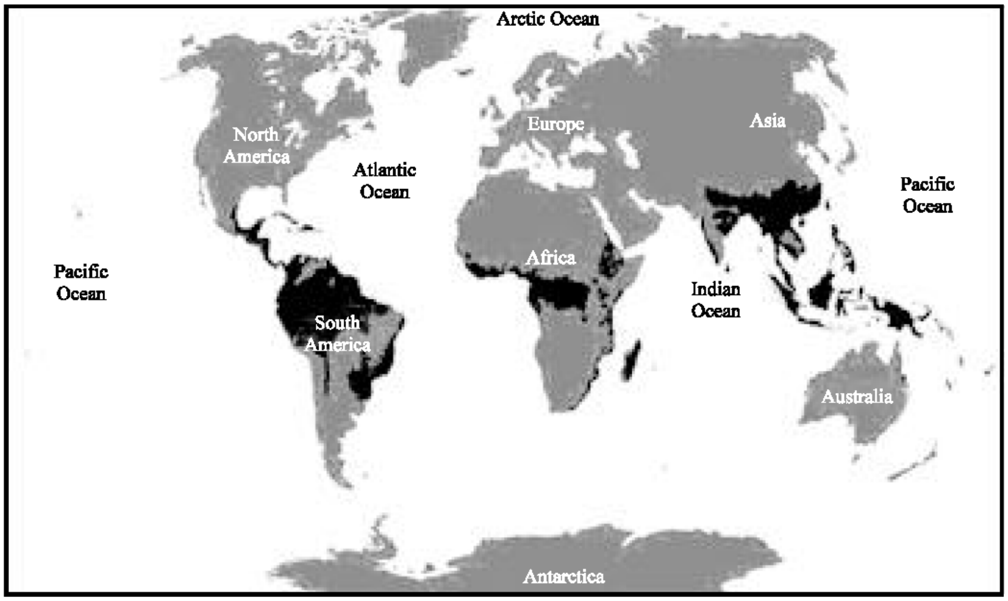

Fig. 1: Tropical and subtropical rain forest (black areas in the map)

ubiquitous, or have what is frequently referred to as host specificity (Carroll, 1988; Petrini, 1996; Stone *et al.*, 2000).

Since, the number of plant species in the world is so great, creative and imaginative strategies must be used to quickly narrow the search for endophytes displaying bioactivity (Mittermeier *et al.*, 1999). A specific rationale for the collection of each plant for endophyte isolation and natural-product discovery was proposed by Strobel and Daisy (2003). Hypotheses govern this plant selection strategy are as follows: (1) Plants from unique environmental settings, especially those with an unusual biology and possessing novel strategies for survival are seriously considered for study. (2) Plants that have an ethnobotanical history (use by indigenous peoples) that are related to the specific uses or applications of interest are selected for study. (3) Plants that are endemic, that have an unusual longevity, or that have occupied a certain ancient land mass, such as Gonwanaland, are also more likely to lodge endophytes with active natural products than other plants. (4) Plants growing in areas of great biodiversity also have the prospect of housing endophytes with great biodiversity. All of these selection strategies are applicable to plants of tropical and subtropical rain forests for endophyte isolation.

Tropical fungal endophytes: As tropical and subtropical climate harbor most of the worlds plants diversity so endophytic diversity in this climatic zone is also higher as almost all vascular plant species examined to date are found to posses endophytic bacteria and fungi (Firakova *et al.*, 2007). The majority of undescribed fungal diversity lies within the tropical plant-associated fungi, yet the diversity and ecological role of endophytes in tropical angiosperms are almost entirely unexplored (Hawksworth, 1993; Rodrigues and Petrini, 1997). Endophytic fungal diversity has been studied essentially in the leaves, stems, petioles, barks and roots of many angiosperm taxa of the tropics (Table 1). Arnold *et al.* (2000) recovered 3000 fungal strains representing more than 418 morphospecies in the leaf tissue from two distantly related understory tree species of *Heisteria concinna* (Olacaceae) and *Ouratea lucens* (Ochnaceae) at Barro Colorado Island,

Table 1: Some fungal endophytes isolated from tropical and subtropical plants

Endophytic fungi	Source plant	References
Acremonium acremonium	*Crataeva magna, Azadirachta indica, Hollarrhena antidysenterica, Butea monosperma*	Tejesvi *et al.* (2006)
Acremonium strictum	*B. monosperma*	Tejesvi *et al.* (2006)
Allescheriella crocea	*Avicennia officinalis*	Ananda and Sridhar (2002)
Alternaria alternata	*Aegle marmelos*	Gond *et al.* (2007)
Alternaria longipes	*Callicarpa tomentosa*	Raviraja (2005)
Alternaria sp.	*Vitex negundo, Leucas aspera*	Banerjee *et al.* (2006, 2009b)
Aposphaeria sp.	*C. magna*	Tejesvi *et al.* (2006), Nalini *et al.* (2005)
Arthrinum sp.	*Cinchona lederiana*	Maehara *et al.* (2009)
Arthrobotrys conoides	*C. magna*	Tejesvi *et al.* (2006), Nalini *et al.* (2005)
Ascochyta rabei	*C. magna*	Tejesvi *et al.* (2006)
Ascotricha chartarum	*Rhizophora mucronata*	Ananda and Sridhar (2002)
Aspergillus fumigatus	*Aegle marmelos*	Gond *et al.* (2007)
Aspergillus niger	*A. marmelos*	Gond *et al.* (2007)
Aspergillus sp.	*Acanthus ilicifolius, A. officinalis, R. mucronata, Sonneratia caseolaris, Adhatoda zeylanica, Bauhinia phoenicea, Callicarpa tomentosa, Clerodendrum serratum, Lobelia nicotinifolia, Vitex negundo*	Ananda and Sridhar (2002), Raviraja (2005), Banerjee *et al.* (2006), Banerjee *et al.* (2009b)
Aspergillus versicolor	*Coffea arabica*	Sette *et al.* (2006)
Asteromella andrewsii	*B. monosperma*	Tejesvi *et al.* (2006
Aureobasidium sp.	*V. negundo; O. sanctum*	Banerjee *et al.* (2006), Banerjee *et al.* (2009b)
Bispora sp.	*A. ilicifolius*	Ananda and Sridhar (2002)
Botryodiplodia theobromae	*T. arjuna, H. antidyscenterica*	Tejesvi *et al.* (2006)
Calcarisporium arbuscula	*B. monosperma*	Tejesvi *et al.* (2006)
Chaetomium crispatum	*H. antidyscenterica*	Tejesvi *et al.* (2006)
Chaetomium globosum	*T. arjuna, H. antidyscenterica, C. magna, C. tomentosa, V. negundo, A. marmelos*	Tejesvi *et al.* (2006), Raviraja (2005), Raviraja *et al.* (2006), Gond *et al.* (2007)
Chaetomium spirale	*A. zeylanica, C. tomentosa, C. serratum*	Raviraja (2005)
Chloridium sp.	*T. arjuna*	Tejesvi *et al.* (2005, 2006)
Cirrenalia pygmea	*R. mucronata*	Ananda and Sridhar (2002)
Cladosporium acaciicola	*H. antidyscenterica, A. indica*	Tejesvi *et al.* (2006)
Cladosporium cladosporioides	*T. arjuna, A. indica, C. arabica, A. marmelos*	Tejesvi *et al.* (2006), Sette *et al.* (2006), Gond *et al.* (2007)
Cladosporium oxysporum	*A. officinalis*	Ananda and Sridhar (2002)
Cladosporium psoraleae	*R. mucronata*	Ananda and Sridhar (2002)
Cladosporium sp.	*C. Arabica, V. negundo, S. caseolaris*	Banerjee *et al.* (2006), Sette *et al.* (2006), Ananda and Sridhar (2002)
Cladosporium sphaerospermum	*C. arabica*	Sette *et al.* (2006)
Cladosporium sp.	*T. arjuna*	Tejesvi *et al.* (2006)
Cochlonema sp.	*T. arjuna*	Tejesvi *et al.* (2006)
Cochlonema verrucosum	*C. magna, A. indica*	Tejesvi *et al.* (2006)
Colletotrichum sp.	*Theobroma cacao, Leucas aspera*	Arnold *et al.* (2003), Banerjee *et al.* (2009b)

Table 1: Continued

Endophytic fungi	Source plant	References
Cortnespora sp.	*A. marmelos*	Gond *et al.* (2007)
Curvularia clavata	*A. zeylanica, B. phoenicea, C. tomentosa*	Raviraja (2005)
Curvularia lunata	*A. indica, A. zeylanica, B. phoenicea, C. tomentosa, A. marmelos*	Tejesvi *et al.* (2006), Raviraja (2005), Gond *et al.* (2007)
Curvularia pallescens	*C. tomentosa*	Raviraja (2005)
Cylindrocarpon sp.	*A. ilicifolius, A. officinalis*	Ananda and Sridhar (2002)
Cytospora abietis	*S. caseolaris*	Ananda and Sridhar (2002)
Dactylaria purpurella	*A. ilicifolius*	Ananda and Sridhar (2002)
Diaporthe ambigua	*Coffea robusta*	Sette *et al.* (2006)
Diaporthe sp.	*C. lederiana*	Maehara *et al.* (2009)
Dicyma sp.	*R. mucronata*	Ananda and Sridhar (2002)
Dithiorella sp.	*C. magna*	Tejesvi *et al.* (2006)
Drechslera ellisii	*A. marmelos*	Gond *et al.* (2007)
Emericella sp.	*A. marmelos*	Gond *et al.* (2007)
Exserohilum rostratum	*Stemona* sp.	Sappapan *et al.* (2008)
Fusariella obstipa	*R. mucronata*	Ananda and Sridhar (2002)
Fusarium chlamydosporum	*A. ilicifolius, R. mucronata, C. magna, A. indica*	Ananda and Sridhar (2002), Tejesvi *et al.* (2006)
Fusarium graminearum	*H. antidyscenterica*	Tejesvi *et al.* (2006)
Fusarium oxysporum	*C. magna, A. indica, C. rabica, C. robusta, B. phoenicea, C. serratum, L. nicotinifolia, A. marmelos, A. ilicifolius, A. officinalis, R. mucronata*	Ananda and Sridhar (2002), Tejesvi *et al.* (2006), Sette *et al.* (2006), Raviraja (2005), Gond *et al.* (2007)
Fusarium roseum	*A. marmelos*	Gond *et al.* (2007)
Fusarium solani	*C. magna, A. indica, B. monosperma*	Tejesvi *et al.* (2006)
Fusarium sp.	*V. negundo, T. cacao, Oscimum sanctum, L. aspera*	Banerjee *et al.* (2006, 2009b), Arnold *et al.* (2003)
Fusarium verticilloides	*H. antidyscenterica, C. magna, A. indica*	Tejesvi *et al.* (2006)
Fusarium verticilloides var. subglutinans	*C. magna, A. indica*	Tejesvi *et al.* (2006)
Gliocladium delequescens	*T. arjuna, C. magna*	Tejesvi *et al.* (2006), Tejesvi *et al.* (2005)
Gliomastix sp.	*A. indica*	Tejesvi *et al.* (2006)
Glomerella cingulata	*C. robusta, Garcinia mangostana*	Sette *et al.* (2006), *Sim et al.* (2010)
Gongronella butleri	*C. robusta*	Sette *et al.* (2006)
Guignardia camelliae	*Garcinia parvifolia*	Sim *et al.* (2010)
Guignardia endophyllicola	*C. arabica*	Sette *et al.* (2006)
Hansfordia sp.	*C. magna*	Tejesvi *et al.* (2006)
Haplosporella acaciae	*S. caseolaris*	Ananda and Sridhar (2002)
Heterosporium terrestre	*S. caseolaris*	Ananda and Sridhar (2002)
Humicola fuscoatra	*T. arjuna, H. antidyscenterica*	Tejesvi *et al.* (2006)
Hyalopus sp.	*Ocimum sanctum, O. bacilicum*	Mahapatra and Banerjee (2009), Banerjee *et al.* (2009b)
Hypocrea virens	*G. parvifolia*	Sim *et al.* (2010)
Lulworthia grandispora	*S. caseolaris*	Ananda and Sridhar (2002)
Lulworthia sp.	*A. officinalis*	Ananda and Sridhar (2002)
Memnoniella sp.	*T. arjuna*	Tejesvi *et al.* (2006)
Mixotrichum chartarum	*C. tomentosa*	Raviraja (2005)
Monochaetia sp.	Not mentioned	Li *et al.* (2001)
Monocillium sp.	*T. arjuna*	Tejesvi *et al.* (2006)

Table 1: Continued

Endophytic fungi	Source plant	References
Muscodor albus	*Gauzuma ulmifolia, Cinnamomum zeylanicum*	Strobel *et al.* (2007), Worapong *et al.* (2001)
Muscodor roseus	*Grevillea pteridifolia*	Worapong *et al.* (2002)
Myrothecium cinctum	*T. arjuna, H. antidyscenterica*	Tejesvi *et al.* (2006)
Myrothecium verrucaria	*T. arjuna, H. antidyscenterica*	Tejesvi *et al.* (2006)
Nigrospora oryzae	*T. arjuna, A. indica, B. phoenicea, C. tomentosa, A. marmelos*	Tejesvi *et al.* (2005, 2006), Raviraja (2005), Gond *et al.* (2007)
Nigrospora sacchari	*B. phoenicea*	Raviraja (2005)
Nigrospora sp.	*V. negundo*	Banerjee *et al.* (2006)
Oidium sp.	*Terminalia catappa*	Strobel *et al.* (2008)
Paecilomyces varioti	*R. mucronata*	Ananda and Sridhar (2002)
Papulospora sp.	*V. negundo*	Raviraja *et al.* (2006)
Penicillium sp.	*A. zeylanica, B. phoenicea, C. tomentosa, C. serratum, L. nicotinifolia, R. mucronata, A. marmelos, V. negundo*	Raviraja (2005), Gond *et al.* (2007), Banerjee *et al.* (2006), Ananda and Sridhar (2002)
Pestalotia macrotricha	*A. marmelos*	Gond *et al.* (2007)
Pestalotiopsis sp.	*T. arjuna, H. antidyscenterica, A. indica, Terminalia chebula, C. tomentosa*	Tejesvi *et al.* (2005, 2006), Raviraja (2005), Li *et al.* (2001)
Petriella sordida	*A. officinalis*	Ananda and Sridhar (2002)
Phialophora spp.	*T. arjuna*	Tejesvi *et al.* (2006)
Phoma eupyrena	*A. indica*	Tejesvi *et al.* (2006)
Phoma herbarum	*R. mucronata*	Ananda and Sridhar (2002)
Phoma sp.	*A. ilicifolius, R. mucronata, Vitex negundo, G. parvifolia, O. sanctum, L. aspera*	Ananda and Sridhar (2002), Banerjee *et al.* (2006, 2009b), Sim *et al.* (2010)
Phomopsis chimonanthi	*C. robusta*	Sette *et al.* (2006)
Phomopsis loropetali	*C. ledgeriana*	Maehara *et al.* (2009)
Phomopsis pittospori	*A. zeylanica, A. officinalis, R. mucronata*	Raviraja (2005), Ananda and Sridhar (2002)
Phomopsis sp.	*A. officinalis, A. marmelos, G. parvifolia, C. ledgeriana*	Ananda and Sridhar (2002), Gond *et al.* (2007), Sim *et al.* (2010), Maehara *et al.* (2009)
Phyllostica sp.	*A. indica*	Tejesvi *et al.* (2006)
Rhizoctonia sp.	*A. marmelos*	Gond *et al.* (2007)
Schizophyllum commune	*C. lederiana*	Maehara *et al.* (2009)
Sclerotonia sp.	*C. magna*	Nalini *et al.* (2005)
Scopulariopsis brevicaulis	*C. arabica*	Sette *et al.* (2006)
Sordaria destruens	*H. antidyscenterica*	Tejesvi *et al.* (2006)
Spicaria sp.	*L. aspera*	Banerjee *et al.* (2009b)
Sporothrix sp.	*C. magna*	Tejesvi *et al.* (2006)
Stemphylium sp.	*T. arjuna, L. aspera*	Tejesvi *et al.* (2006), Banerjee *et al.* (2009a)
Stenella agalis	*A. marmelos*	Gond *et al.* (2007)
Talaromyces sp.	*C. arabica*	Sette *et al.*, (2006)
Tharoopama trina	*C. magna*	Tejesvi *et al.* (2006)
Thielaviopsis sp.	*B. phoenicea*	Raviraja (2005)
Trichocladium alopallonellum	*R. mucronata*	Ananda and Sridhar (2002)

Table 1: Continued

Endophytic fungi	Source plant	References
Trichocladium asperum	*A. zeylanica*	Raviraja (2005)
Trichoderma harzianum	*T. arjuna, H. antidyscenterica, C. magna, C. arabica*	Tejesvi *et al.* (2006), Sette *et al.* (2006)
Trichoderma koningi	*C. serratum, L. nicotinifolia, Madhuka nerifolia*	Raviraja (2005), Raviraja *et al.* (2006)
Trichoderma sp.	*C. robusta, V. negundo, O. sanctum, A. indica, T. arjuna, A. marmelos*	Sette *et al.* (2006), Banerjee *et al.* (2006, 2009b), Tejesvi *et al.* (2006) Tejesvi *et al.* (2006), Gond *et al.* (2007)
Trichophyton sp.	*V. negundo*	Banerjee *et al.* (2006)
Tubercularia vulgaris	*T. arjuna*	Tejesvi *et al.* (2006)
Verticillium albo-atrum	*A. indica*	Tejesvi *et al.* (2006)
Verticillium sp.	*A. marmelos, C. magna, A. indica*	Gond *et al.* (2007), Tejesvi *et al.* (2006)
Xylaria sp.	*T. cacao*	Arnold *et al.* (2003)
Zalerion maritimum	*A. ilicifolius, R. mucronata*	Ananda and Sridhar (2002)
Zygosporium masonii	*A. ilicifolius, A. officinalis, R. mucronata*	Ananda and Sridhar (2002)

Panama. Reduced leaf damage and loss due to a major pathogen were reported in endophytic fungi associated woody angiosperm. Field surveys in lowland Panama to characterize the diversity, spatial structure and host affinity of natural endophyte infections in the economically important rainforest tree, *Theobroma cacao* (Malvaceae) were done. During this experiment Arnold *et al.* (2003) demonstrate that inoculation of leaf tissues by an assemblage of endophytes frequently isolated from naturally infected, asymptomatic hosts significantly reduces damage by an important foliar pathogen *Phytophthora* sp. Li *et al.* (2001) isolated *Pestalotiopsis* sp. and *Monochaetia* sp. from different plant materials collected in rainsforsts of several countries. They have isolated an antifungal agent, ambuic acid from those fungal endophytes. About 21 filamentous fungi were isolated from the young stems of a rubiaceaceous plant *Cinchona ledgeriana* in West Java, Indonesia (Maehara *et al.*, 2009). The isolates belongs to six genera are *Phomopsis* sp., *Diaporthe* sp., *Schizophyllum* sp., *Penicillium* sp., *Fomitopsis* sp. and *Arthrinium* sp. About 24 endophytic fungi were isolated from *Garcinia mangostana* and *Garcinia parvifolia* plants in Sungai Rengit village, Johar, Malaysia. Isolated endophytes were characterized through internal transcribed spacer (ITS) region sequence analysis (Sim *et al.*, 2010). Gond *et al.* (2007) reported 79 isolates belonging to 21 fungal genera from bark, leaf and root parts of *Aegle marmelos* in Baranasi, India. Most of the fungal isolates belong to hyphomycetes. They have reported a large number of *Alternaria alternate* and *Fusarium roseum* as fungal endophyte among the isolates. Different medicinal plants were screened to isolate fungal endophytes in Western Ghats of India (Raviraja, 2005; Raviraja *et al.*, 2006). *Curvularia* and *Fusarium* were found in maximum number among 18 different endophytic fungal isolates. Tejesvi *et al.* (2006) studied the fungal diversity of some medicinal trees of southern India. They have isolated 48 fungal species from bark samples of *Terminalia arjuna*, *Crataeva magna*, *Azadirachta indica*, *Holarrhena antidysenterica*, *Terminalia chebula* and *Butea monosperma*. Ananda and Sridhar (2002) studied endophytic fungal diversity of mangrove species in west coast of India and reported 35 fungal species including 4 sterile ones. They have reported highest species richness in *Rhizophora mucronata*. Endophyte assemblage was also reported in another mangrove plant *Rhizophora apiculata* by Kumaresan and Suriyanarayanan (2002). Suryanarayanan and Rajagopal (2000) isolated 963 fungi from the bark sample of 10 tropical tree species in southern India. Banerjee *et al.* (2006) isolated different endophytic fungi from *Vitex negundo* in Midnapore, West Bengal, India. Banerjee *et al.* (2009a, b) reported presence of 14 endophytic fungal genera in three medicinal herb *Ocimum sanctum*, *Ocimum bacilicum* and *Leucus aspera*. Sette *et al.* (2006) isolated 39 strains of endophytic fungi from coffee plants in Pindorama, Sao Paulo, Brazil and identified the isolates using ITS region sequence analysis. Sixty-nine fungal species were isolated from the bark of a single *Coprinus caroliniana* tree, which suggest the enormous extent of fungal diversity in a single plant (Bills and Polishook, 1991). One of the potent volatile antibiotic producing fungi *Muscodor albus* was isolated from *Cinnamomum zeylanicum* in a botanical garden in Honduras (Strobel, 2006; Strobel *et al.*, 2007). Other isolates of this fungus have been obtained in rainforests ranging from the upper Amazon countries, to Indonesia, Thailand and Australia (Mitchell *et al.*, 2010; Banerjee *et al.*, 2010).

CONCLUSION

Tropical and subtropical rainforest are most rich in plant diversity so endophytic diversity in this region is highest. Most of the work done till date with endophytic fungi is from the plants of this region. Rapid diminishment of plants from this highly diverse region needs special attention otherwise we will loose a great microbial resource in near future.

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