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Occurrence, Distribution and Bioactive Potential of Mangrove Fungal Endophytes: An Appraisal

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ABSTRACT

Around 30 different mangrove species have been screened for fungal endophytes from different geographical locations that have revealed that the genera of fungi isolated from terrestrial plants are also present in the mangroves, especially, *Phomopsis*, *Phyllosticta*, *Sporormiella,* etc. Species belonging to mangrove *Rhizophora* from different geographical locations, have been studied for fungal endophytes. Mangrove fungal endophytes have been studied for the production of bioactive compounds, which has resulted in recording of a wide array of compounds having antibiofilm, anticancer, antimicrobial, antioxidant, antiviral and insecticidal activities. An appraisal has been presented on these aspects in this paper.

Key words: Endophytes, bioactive compounds, mangroves, *Rhizophora*

INTRODUCTION

Fungal endophytes colonize living plant tissues and cause asymptomatic infections entirely within plant tissues. They are ubiquitously present, and have been recorded from algae, pteridophytes, gymnosperms and angiosperm members (Carroll and Carroll, 1978; Wilson, 1995; Swatzell *et al*., 1996; Suryanarayanan *et al*., 2002; Flewelling *et al*., 2013; Zhang *et al*., 2013). Most of the fungal endophytes belong to Ascomycetous or Mitosporic fungi (Petrini, 1986). *Phomopsis* and *Phyllosticta* are frequently isolated as endophytes and are called as “almost exclusive” endophytes (Bills and Polishook, 1992). *Chaetomium*, *Sordaria*, *Sporormiella,* etc. belonging to Ascomycetous fungi have been reported as endophytes from several hosts (Stone *et al*., 2004), although species belonging to these genera are known to be coprophilous. *Alternaria*, *Aureobasidium* and *Cladosporium* that are known to occur in the phylloplane have also been reported as endophytes. Sterile forms have been isolated as endophytes from many hosts and for such fungi culture characteristics such as growth rate, colony morphology and pigmentation are used to differentiate them (Bills and Polishook, 1994). Also, molecular techniques are being used, such as rDNA sequencing, to assign some of the sterile endophytes to major clades within the Ascomycetous fungi (Dubos *et al*., 1999).

Endophytes are considered plant mutualists as they receive nutrition and protection from the host plants while the host plant may benefit from enhanced competitive ability (Saikkonen *et al*., 1998). Several beneficial features have frequently been reported including drought acclimation (Eerens *et al*., 1998; Cheplick *et al*., 2000), improved resistance to insect pests (Akello *et al*., 2007), enhanced tolerance to stressful factors such as heavy metal presence (Monnet *et al*., 2001; Lodewyckx *et al*., 2002) and high salinity (Waller *et al*., 2005).

Investigations on endophyte assemblages have shown that a large number of fungal taxa can be isolated from a single host species, however, only one or a few fungal species dominate in a host plant. Further, some endophytes appear to be specific to their host. Sun *et al*. (2012) studied three plant species viz., *Betula platyphylla* (*Betulaceae*), *Quercus liaotungensis* (*Fagaceae*) and *Ulmus macrocarpa* (*Ulmaceae*) and reported that 15 species of endophytes showed significant host preference. Endophytic fungi are increasingly recognized as a group of organisms that are likely to be the sources of new metabolites useful to mankind (Pimental *et al*., 2011) and more than 20,000 bioactive metabolites of microbial origin were known by the end of 2002 (Bérdy, 2005).

Bioactive compounds obtained from endophytes include novel antibiotics, antimycotics, immunosuppressants, and anticancer compounds (Strobel *et al*., 2004). Different chemical classes of secondary metabolites viz., terpenoids, polyketides, flavonoids and lignans are known to be produced by endophytes. Investigation of single species of endophyte, *Neotyphodium typhnium* resulted in identification of a number of compounds, suggesting that number of secondary metabolites remain to be discovered from less explored or unexplored endophytes (Mousa *and Raizada*, 2013). Further, Suryanarayanan *et al*. (2009) noted that out of the 150 endophyte isolates studied for bioactive compounds using different bioassays, certain genera such as *Alternaria, Chaetomium, Colletotrichum, Curvularia, Nigrospora* and *Xylaria* were more promising than other genera as producers of bioactive compounds.

Occurrence and distribution of fungal Endophytes from Mangroves

Mangrove forests form a dynamic transition zone between terrestrial and marine habitats extending along the highly biodiverse tropical and subtropical coastlines (Bandaranayake, 2002; Debbab *et al*., 2013), forming an unique ecosystem. Mangroves world over include 54 species including major and minor components (Tomlinson, 1986) and among these around 30 species have been screened for fungal endophytes (**Table 1**). The interest to study mangrove endophytes, especially foliar endophytes, is due to the fact that mangrove leaves form one of the unusual habitats for colonization by fungi as the latter are exposed to high salt concentration in the leaf tissues. Thus, mangrove endophytes are being studied for getting more insight into their diversity and bioactive potential, as they reside in a special niche.

Among the mangroves screened *Rhizophora apiculata* and *R. mucronata* have been studied for endophytes from 5 different regions, each (**Tables 1** and **2**), suggesting that, these are most widely studied plant species with respect to endophytes when compared with other mangroves. Suryanarayanan *et al*. (1998) for the first time studied the fungal endophytes from *Rhizophora apiculata* and *R. mucronata* mangroves. The seasonal occurrence of endophytes in these two mangrove

Table 1. List of mangrove plants studied for the occurrence of fungal endophytes

Location	Mangrove species studied	Dominant/Frequent[@] endophytes	Reference
Pichavaram, Tamil Nadu, India	*Rhizophora apiculata* and *R. mucronata*	*Phyllosticta* sp. (MG 90), *Sporormiella minima*	Suryanarayanan *et al*. (1998); Kumaresan *et al*. (2002)
Pichavaram, Tamil Nadu, India	*Aegiceras corniculatum, Avicennia marina, A. officinalis, Bruguiera cylindrica, Ceriops decandra, Excoecaria agallocha* and *Lumnitzera racemosa*	*Colletotrichum gloeosporioides, Glomerella* sp. *Paecilomyces* sp., *Phoma* sp., *Phomospsis* sp., *Phyllosticta* sp. and *Sporormiella minima*	Kumaresan and Suryanarayanan (2001)
Udyavara (Karnataka) on the west coast of India	*Acanthus ilicifolius**, *Avicennia officinalis, Rhizophora mucronata* and *Sonneratia caseolaris*	*Aspergillus* sp., *Cylindrocarpon* sp. and *Cytospora abietis*	Ananda and Sridhar (2002)
Mai Po Nature Reserve, Hong Kong	*Kandelia candel*	*Phomopsis* sp., *Pestalotiopsis* sp., *Guignardia* sp., and *Xylaria* sp.	Pang *et al*. (2008)
Nethravathi mangrove, southwest coast of India	*Canavalia cathartica*	*Aspergillus niger*, *A. flavus, Penicillium chrysogenum* and *Fusarium oxysporum*	Anita and Sridhar (2009)
Chanthaburi Province, Prachuap Khiri Khan Province and Ranong Province) in Thailand	*Acanthus ilicifolius**, *Avicennia alba*, *Ceriops decandra, Lumnitzera littorea, Rhizophora apiculata*, *R. mucronata*, *Sonneratia alba, Xylocarpus granatum* and *X. moluccensis*	Species of *Cladosporium, Colletotrichum, Phomopsis, Phyllosticta* and *Xylaria*	Chaeprasert *et al*. (2010)
Dong Zhai Gang, Hainan Province, China	*Ceriops tagal*, *Rhizophora apiculata*, *R. stylosa* and *Bruguiera sexangula* var. *rhynchopetala*	Species of *Pestalotiopsis* and *Phomopsis*	Xing and Guo (2011)
South coast of China	*Sonneratia apetala, S. caseolaris*, *S. hainanensis*, *S. ovata* and *S. paracaseolaris*	Species of *Cytospora, Diaporthe, Fusarium, Glomerella, Mycosphaerella, Phoma, Phomopsis* and *Stemphylium*	Xing *et al*. (2011)
Itamaracá Island, Brazil	*Avicennia schaueriana, Laguncularia racemosa* and *Rhizophora mangle*	*Colletotrichum gloeosporioides, Glomerella cingulata* and *Guignardia* sp.	Costa *et al*. (2012)
Cananeia mangrove forest Bertioga mangrove forest Sao Paulo, Brazil	*Avicennia schaueriana Laguncularia racemosa* and *Rhizophora mangle*	Species of *Diaporthe, Colletotrichum, Fusarium, Trichoderma* and *Xylaria*	de Souza Sebastianes *et al*. (2013)

[@] Only sporulating forms included
* *Acanthus ilicifolius* is considered as mangrove associate (Tomlinson, 1986).

plants showed that more number of isolates were there during rainy season. Further, sterile forms were one of the dominant groups and have been a challenge in the studies on fungal endophytes. Studies on foliar fungal endophytes of seven species of mangroves from estuarine mangrove forest in south India showed that different fungi dominated the assemblages of the mangrove species thus, suggesting occurrence of selection mechanism which distributes different fungal endophytes in different mangroves (Kumaresan and Suryanarayanan, 2001). Similarly, Xing *et al*. (2011) recovered a total of 39 distinct endophytic species of which *Cytospora*, *Diaporthe*, *Fusarium*, *Glomerella, Mycosphaerella*, *Phoma*, *Phomopsis* and *Stemphylium* were the dominant fungal taxa and the dominant species differed according to host and tissue type. In the endophyte assemblages of *Rhizophora mangle*, *Avicennia schaueriana* and *Laguncularia racemosa* trees inhabiting two mangroves in the state of São Paulo, Brazil the most frequent endophytes were *Diaporthe, Colletotrichum, Fusarium, Trichoderma* and *Xylaria* (de Souza Sebastianes *et al*., 2013). Chaeprasert *et al*. (2010) studied the endophytes of mangrove species from Thailand and recorded *Phyllosticta* to be the most frequently isolated fungus from the mangrove plants. The common fungal endophyte genera were *Cladosporium*, *Colletotrichum*, *Phomopsis* and *Xylaria*. Xing and Guo (2011) studied four members of *Rhizophoraceae* and obtained two hundred and ninety-five isolates belonging to 38 taxa among which *Pestalotiopsis* and *Phomopsis* were the most frequent endophytes. Costa *et al*. (2012) studied three mangrove species and recorded *Glomerella cingulata* from all the three host species. Dominant sporulating fungi present in *Kandelia candel* were *Phomopsis* sp., *Pestalotiopsis* sp., *Guignardia* sp. and *Xylaria* sp., which are cosmopolitan and common endophytic species (Pang *et al*., 2008).

Phyllosticta is known to occur as endophyte in a number of plant species including mangroves. Pandey *et al*. (2003) studied the ITS-RFLP and ITS sequence of *Phyllosticta* from different tropical tree species including *Phyllosticta* sp. from *Rhizophora* and placed all of them under a single species viz., *Phyllosticta capitalensis*. Now, *Phyllosticta capitalensis* is known to occur as an endophyte with a worldwide distribution occurring in about 70 plant families (Wikee *et al*., 2013).

Mangrove Endophytes as Potential Source of Bioactive Compounds

Mangrove fungi constitute the second largest ecological group of the marine fungi (Hyde, 1990), and many of them may produce a wide variety of metabolites that are structurally unique and pharmacologically active such as anti-tumor, anti-biotic, anti-HIV, and so on (in Wang *et al*., 2014). But, these fungi, especially mangrove fungal endophytes, are an untapped reservoir of novel chemical and biological diversity, which is poorly investigated but are a dependable source of bioactive and chemically novel compounds with potential for exploitation in medical, agricultural and industrial areas (Yuan *et al*., 2005; Baby Joseph and Mini Priya, 2011). Debbab *et al*. (2013) opined that mangrove-derived endophytic fungi contribute to mangrove adaptation to their extreme habitat, and in addition prove to be promising sources and amazing array of bioactivities.

A number of studies are being carried out to understand and exploit the various bioactive compounds obtained from mangrove fungal endophytes with wide range of activities including cytotoxic, antibiofilm, antimicrobial, antioxidant and antiviral activities (**Table 2**). Wang *et al*. (2015) showed that mangrove endophytic fungus *Alternaria* sp. produced cyclopentenone derivative and fischexanthone that exhibited inhibitory activity against *Fusarium graminearum*, and xanthone derivative exhibited antifungal activity against both *Colletotrichum musae* and *Fusarium graminearum*, suggesting that these compounds can be used for the development of antifungal agents. Xu (2015) compiled the various natural products from mangrove-associated microbes over three years (January 2011December 2013) and found that phenols and lactones were produced by more than 50 taxa of microbes. Studies on antimalarial natural products from Chinese mangrove endophytes showed that a novel compound Dicerandrol-D from *Diaporthe* sp. (strain CY-5188) showed favourable bioactive profile (Calcul *et al*., 2013). *Aspergillus* and *Penicillium* have also been reported as endophytes from different host plants (Vega and Posada, 2006; Shaaban *et al*., 2013) . Abraham *et al*. (2015) recorded species of *Aspergillus* from *Rhizophora mucronata*, and these endophytes showed insecticidal activity (**Table 1**). Further, Kumaresan and Suryanarayanan (2002) studied the fungal endophytes of young, mature and senescent leaves of *Rhizophora apiculata* and showed that a species of

Table 2 Bioactive potential of mangrove endophytes

Endophyte	Host plant and Location	Activity	Reference
Alternaria chlamydospora, Aspergillus spp., *Cumulospora marina, Nigrospora oryzae, Pestalotiopsis* sp. and Sterile form (MA 1)	*Acrostichum aureum, Acanthus ilicifolius*, Nethravathi mangrove, southwest coast of India	Antimicrobial activity	Maria *et al.* (2005)
Xylaria sp. (#2508)	*Avicennia marina,* South China Sea coast	L-calcium channel blocking activity	Wu *et al.* (2005)
Sporothrix sp.	*Kandelia candel*, South China	Acetylcholine esterase inhibitor	Wen *et al.* (2009)
Acremonium sp., *Diaporthe* sp., *Hypoxylon* sp., *Pestalotiopsis* sp., *Phomopsis* sp., and *Xylaria cubensis*	*Aegiceras corniculatum, Avicennia alba, A. officinalis, Bruguiera gymnorrhiza, B. parviflora, Lumnitzera littorea, Rhizophora apiculata, R. mucronata, Sonneratia caseolaris, Scyphiphora hydrophyllacea, Xylocarpus granatum* and *X. moluccensis*, Satun, Songkhla, Surat Thani and Trang provinces in Thailand	Antimicrobial activity	Buatong *et al.* (2011)
Nigrospora sp.	*Kandelia candel,* South China Sea	Antitumour and antimicrobial activity	Xia *et al.* (2011)
Penicillium chrysogenum (MTCC 5108)	*Porteresia coarctata,* Chorao Island, Mandovi estuary, Goa, India	Antibacterial activity	Devi *et al.* (2012)
Corynespora cassiicola	*Laguncularia racemosa,* China	Protein kinase inhibitor	Ebrahim *et al.* (2012)
Fusarium oxysporum	*Rhizophora annamalayana*, Vellar Estuary, Tamil Nadu, India	Taxol – anticancer compound	Elavarasi *et al.* (2012)
Aspergillus flavus	*Avicennia officianlis, Kandelia candel, Excoecaria agallocha* and *Rhizophora mucronata,* Chorao, Goa, India	Antioxidant property	Ravindran *et al.* (2012)
Xylaria sp. BL321	*Acanthus ilicifolius*, Yangjiang, Guangdong, China	Cytotoxicity activity	Song *et al.* (2012)
Aspergillus flavipes	*Acanthus ilicifolius*, Daya Bay, Shenzhen City, Guangdong Province, China	Antibiofilm activity	Bai *et al.* (2014)
Acremonium strictum	*Rhizophora apiculata, I*sland of CatBa, Vietnam	Cytotoxic and antibacterial activity	Hammerschmidt *et al.* (2014)
Trichoderma sp. Xy24	*Xylocarpus granatum,* Sanya district, Hainan Province of China	Antiviral activity	Zhang *et al.* (2014)
Penicillium sp. GD6	*Bruguiera gymnorrhiza,* Zhanjiang, China	Penibruguieramine A- a Pyrrolizidine Alkaloid	Zhou *et al.* (2014a)
Stemphylium sp. 33231	*Brguiera sexangula* var. *rhynchopetala*, South China Sea	Antibacterial activity	Zhou *et al.* (2014b)
Aspergillus oryzae, *A. tamarii*, *A. versicolor* and *Emericella nidulans*	*Rhizophora mucronata,* Prof. Dr. Sedyatmo Angke Kapuk Mangrove Rehabilitation and Ecotourism, Jakarta, Indonesia	Insecticidal activity	Abraham *et al.* (2015)
Penicillium aurantiogriseum	*Hibiscus tiliaceus*, South China Sea	Aldose reductase inhibitor	Ma *et al.* (2015)
Penicillium brocae MA-231	*Avicennia marina,* Hainan Island of China	Antimicrobial activity	Meng *et al.* (2015)
Penicillium sp. FJ-1	*Avicennia marina,* Zhangpu county – Fujian province, China	Antifungal activity	Song *et al.* (2015)
Aspergillus sp. 16-5C	*Sonneretia apetala*, South China	*Mycobacterium tuberculosis* protein tyrosine phosphatase B inhibitor	Xiao *et al.* (2015)

Glomerella produced six different extracellular enzymes, suggesting that endophytes are suitable candidates for industrial enzyme production.

CONCLUSION

A number of mangrove plants have been screened for fungal endophytes from different geographical locations, but the species composition appears to be similar to the terrestrial plant species as 'almost exclusive' endophytes viz., *Phomopsis* and *Phyllosticta* occur in mangroves too and these endophytes are quite dominant in some of the mangrove plants. Though similar to terrestrial plants, mangrove endophytes are known to produce a vast array of bioactive compounds, probably due to the fact that they are exposed to harsh microenvironments including salinity. This has led to resurgence in the study of mangrove endophytes giving us more insight into the biology of this group of organisms.

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