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Fungal communities of symptomless bark of tropical trees

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Abstract

The fungi associated with the bark (phellophytes) of fifteen dicotyledonous tree species of a dry thorn, dry deciduous and a stunted montane evergreen forest of the Western Ghats, southern India, were studied. The species diversity of the phellophytes was higher for the montane evergreen forest when compared with dry thorn and dry deciduous forests. Although many fungal species were present in the bark of different tree species, most of them had a low frequency of isolation and only a few were isolated with high frequencies. Species of *Phoma* and *Phomopsis*, *Fusarium* and *Paecilomyces* and sterile forms EGS1 and EGS3 were isolated with high frequency from dry thorn, dry deciduous and a stunted montane evergreen forest respectively. The dry thorn and dry deciduous forests, which are more arid and fire-prone, shared more phellophyte species than the dry deciduous and montane evergreen forests. The phellophyte assemblages of the different forests were distinct while those of six tree species of a family from one forest showed a high overlap. It appears that the environment, rather than the tree species, determines the phellophyte assemblage in these forests.

Key words – bark fungi – fungal diversity – phellophytes – tropical forests

Introduction

Various ecological groups of fungi establish associations with different tissues of trees such as the mycorrhiza in the roots, the endophytes inside the leaf and roots, the epiphyllous fungi on the leaf surface, and the pathogenic fungi in different organs. Among the endophytes, those that infect leaves have been studied for their diversity (eg. Suryanarayanan et al. 2011a) and technological potential (Suryanarayanan et al. 2009a, Verma et al. 2009, Suryanarayanan et al. 2012). However, there are very few studies on endophytes which reside in the outer barks of trees. Termed phellophytes by Kowalski & Kehr (1992), these fungi are associated with the healthy outer bark of trees (Cotter & Blanchard 1982) and in some instances, increase the fitness of their tree hosts by protecting them against diseases (Webber 1981). Phellophytes of some temperate trees including *Acer saccharum* f. *schneckii* (Kliejunas & Kuntz 1974) and *Fagus grandifolia* (Cotter & Blanchard 1982), *Alnus* species (Fisher & Petrini 1990), *Fagus sylvatica* (Danti et al. 2002) and a few tropical angiosperms (Suryanarayanan & Rajagopal 2000, Kamiyama et al. 2009, Suryanarayanan et al.

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2009b) have been studied. To our knowledge, there is no report on the diversity and distribution of phellophytes in tropical forests. The aim of the present study was to compare the phellophyte assemblages of several dicotyledonous tree species growing in different tropical forests to understand the diversity and distribution pattern of these fungi. We compared the phellophyte assemblages of 45 angiosperm tree species belonging to 23 dicotyledonous families and growing in three different types of tropical forests in the Western Ghats, southern India.

Methods

Trees of a tropical dry thorn forest, dry deciduous forest and tropical stunted montane evergreen forest of the Nilgiri Biosphere Reserve (11° 32' and 11° 43' N, 76° 22' and 76° 45' E and 980 m), southern India, were studied for their phellophyte assemblages. The dry thorn forest receives a mean annual rainfall of 800 ± 65 mm and lies in the rain shadow of the Nilgiri Mountains. Maximum rainfall occurs between April and June, and in August. Members of Fabaceae dominate here (Suresh et al. 1999). The dry deciduous forest occupies a major portion of sanctuary and receives about 900-1500 mm rainfall per annum. The dominant plant species include *Anogeissus latifolia, Terminalia crenulata, Tectona grandis, Kydia calycina* and *Helictres isora* (Suresh et al. 1999). The montane evergreen forests are interspersed with grasslands and are dominated by members of the families Lauraceae, Rubiaceae, Myrtaceae and Euphorbiaceae. The mean annual rainfall is 1300-2500 mm (Suresh & Sukumar 1999). Fifteen dicot tree species growing in each of the three forests were sampled for their phellophytes (bark fungi) (Table 1). For each tree, 150 bark segments of approximately 0.5 cm^2 size (obtained from healthy bark pieces collected from 5-8 feet above soil level) were surface sterilized by serially dipping in 75% ethanol for 60 s, 4% NaOCl for 180 s and 75% ethanol for 30 s (Fisher et al. 1993). Ten bark segments were plated on potato dextrose agar medium (amended with chloramphenicol 150 mg L^{-1}) in Petri dishes (9 cm dia). The Petri dishes with the tissue segments were sealed with Parafilm and incubated in a light chamber (8 h light: 16 h dark cycle) for 30 d at 26 °C. The agar plates were periodically observed for fungal growth from the tissues. The fungi were identified using standard identification protocols. Fungi which failed to sporulate were given codes based characters such as colony morphology, texture and margin (Suryanarayanan et al. 1998). The following representative cultures from this study have been deposited with Institute of Microbial Technology, Chandigarh (IMTECH) - *Penicillium* sp. 1 (accession no. 8664), *Trichoderma* sp. 1 (8662), *Fusarium* sp. 1 (8666), *Botrytis cinerea* (8659), *Periconia* sp. 1 (8663) and National Fungal culture Collection of India, Pune (NFCCI) - *Curvularia clavata* (10334).

Statistical analysis

Fisher's α was used to estimate species diversity since it is a better discriminator and is not unduly affected by the abundance of the most common species (Taylor 1978). Rarefaction analysis was used to estimate the number of species captured by a constant number of isolates. The Correspondence Analysis and the Bray-Curtis measure of distance was calculated according to Ludwig & Reynolds (1988). The density of colonization and isolation frequency was calculated as follows.

$$\text{Density of colonization (DC\%)} = \frac{\text{Total number of isolates in each forest}}{\text{Total number of segments}} \times 100$$

$$\text{Isolation frequency (IF\%)} = \frac{\text{Total number of isolates in particular species}}{\text{Total number of segments in one or two or all the forests}} \times 100$$

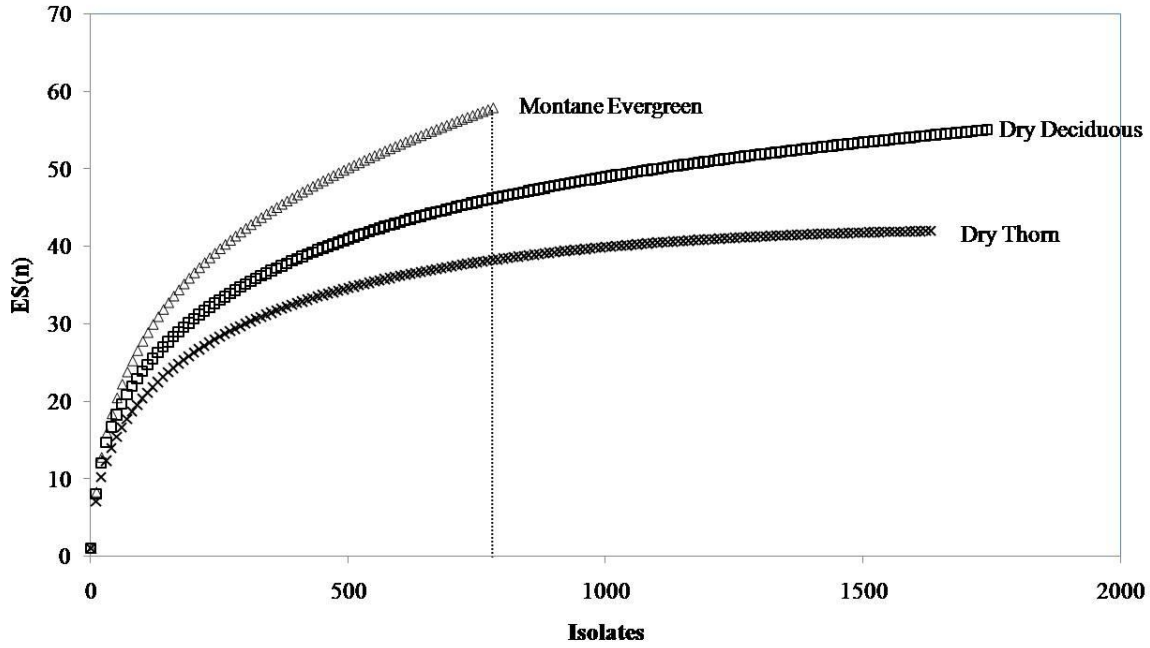

Fig. 1 – Rarefaction curve for the expected number of phellophyte species ES(n) in the different forests studied

Results

The bark of all the trees screened harboured phellophytes. For the same number of bark segments screened, different number of phellophyte isolates and species were obtained for the different forests. The density of colonization was high for dry thorn (73%) and dry deciduous (77%) forests but was low for montane evergreen forest (35%). However the species diversity of the phellophytes was high for montane evergreen forest (Table 2). This was further substantiated by a rarefaction analysis which showed that 781 phellophyte isolates captured 38, 46 and 60 species of fungi in dry thorn, dry deciduous and montane evergreen forests respectively (Fig 1).

In dry thorn forest, *Choloroxylon swietenia* bark had the maximum number of phellophyte species (13) and *Pongamia pinnata* bark had the least number of species (5) [Table 3]. The bark of *Samanea saman* had the maximum number of isolates (165) and that of *Acacia suma* had the minimum number (70). The diversity value for the phellophyte assemblage of this forest ranged from 1.1 in *Pongamia pinnata* to 4.2 in *Acacia suma* (Table 3). Xylariaceous forms had a wide distribution and were isolated from all tree species except from *Samanea saman*. *Torulomyces* sp. and *Phomopsis* sp. were isolated from 11 of the 15 tree species and *Phoma* spp. and *Lasiodiplodia theobromae* were present in 8 and 9 hosts respectively. Some fungi showed uneven distribution; there were 112 and 86 isolates of *Phomopsis* sp. in *Samanea saman* and *Acacia leucophloea* bark respectively and 115 and 80 isolates of *Phoma* sp. 1 in *Cordia wallichii* and *Acacia ferruginea* bark samples respectively. There were 1, 2 and 3 isolates of the sterile form SDT004 in the bark of *Acacia sundra*. The species diversity of the entire phellophyte assemblage of this forest was 7.9 (Table 2). In dry deciduous forest, the barks of *Anogeissus latifolia*, *Careya arborea*, *Kydia calycina* and *Premna tomentosa* harboured the maximum number of phellophyte species while *Terminalia crenulata* bark had the minimum number. The maximum and minimum numbers of isolates were obtained from the barks of *Tectona grandis* and *Lagerstroemia microcarpa* respectively (Table 3). The species diversity of the phellophytes was highest for *Careya arborea* and least for *Terminalia crenulata* (Table 3). The species diversity for the entire assemblage was 10.8 (Table 2). Xylariaceous forms or their anamorphs (*Nodulisporium* spp.) and *Torulomyces* sp. were present in the bark of all tree species and *Phomopsis* sp. could be isolated from all the trees screened excepting from *Cordia wallichii* and *Premna tomentosa*. The bark of ten tree species had *Paecilomyces* sp. and nine tree species harboured *L. theobromae*. *Fusarium* spp. was present in 11

tree species of the 15 screened. With reference to montane evergreen forest, maximum number of phellophyte species was isolated from *Cinnamomum wightii*, *Litsea stocksii*, *Lasianthus venulosus* and the minimum number from *Turpinia nepalensis* (Table 3). The bark of *Turpinia nepalensis* had maximum number of isolates and that of *Psychotria bisulcata* had the minimum number. The diversity index for the phellophytes was high for *Psychotria bisulcata* and low for *Turpinia nepalensis*. Xylariaceous forms and their anamorph (*Nodulisporium* sp.) were present in the barks of all tree species excepting that of *Vepris bilocularis*. The diversity of phellophytes in this forest was the highest (14.5) [Table 2]. A comparison of the distribution of phellophyte genera across the three forests revealed that some were confined to a forest type (Table 4a), and that more genera were shared between dry thorn and dry deciduous forest than dry deciduous and montane evergreen (Table 4b). A few genera were found in all the three forests and some of these had high isolation frequencies (Table 4b).

Although many species of fungi could be isolated from the bark of different trees, most of them had low isolation frequency while a few could be isolated with high frequency. For instance, out of the 42 species in dry thorn, only *Aspergillus* sp. 3, *Paecilomyces* sp. 1, *Phoma* sp. 1 and 2, *Phomopsis* sp. 1, *Torulomyces* sp. 1, Xylariaceous form 1 and sterile forms SDT 3, SDT 8 and SDT 12 were more frequently isolated (IF % >5); of the 55 species from dry deciduous forest, only *Acremonium* sp. 1, *Curvularia lunata*, *Fusarium* sp. 2 and 3, *Humicola grisea*, *L. theobromae*, *Nodulisporium* sp. 1, *N. gregarium*, *Paecilomyces* sp. 1, *Periconia* sp. 1, *Phialophora* sp. 1, *Phomopsis* sp. 1, *Saccobolus* sp. 1, *Torulomyces* sp. 1, Xylariaceous form 1 and sterile forms DD102, DD603 and DD605 had an isolation frequency of IF% >5; in the case of montane evergreen forest, of the 58 species, only *Colletotrichum* sp. 6 and 7, *Nodulisporium* sp. 1, *Phomopsis* sp. 1 and 2, *Trichoderma* sp. 1 and 2, Xylariaceous form 7 and sterile forms EGS 001, 003, and 006 were more frequently isolated (IF % >5).

A Correspondence Analysis separated phellophyte assemblages of the three forests into three distinct clusters (Fig 2). A Bray-Curtis analysis showed that the phellophyte assemblage of a single tree species, *Cordia wallichii* growing in dry thorn and dry deciduous forests overlapped by only 12.5% (Table 5). The phellophyte assemblage of six tree species belonging to Mimosoiceae and growing in dry thorn forest showed that the maximum similarity was 64% (Table 6).

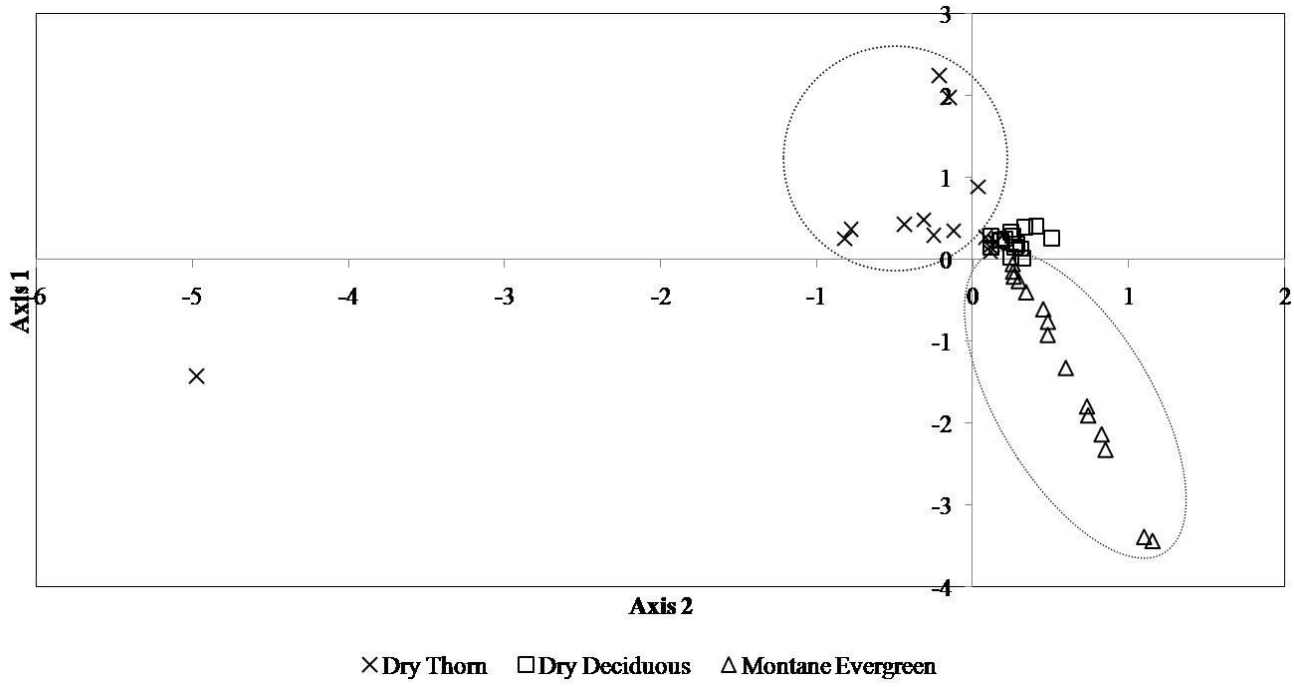

Fig. 2 – Correspondence analysis for the phellophyte assemblages of the three forests.

Table 1 Tree hosts of tropical Dry thorn, Dry deciduous and Montane evergreen forests of the Nilgiri Biosphere Reserve screened for their phellophyte assemblages.

Dry thorn forest		
Host	**Code**	**Family**
Albizzia amara	AA	Mimosoiceae
Acacia sundra	AC	Mimosoiceae
Acacia ferruginea	AF	Mimosoiceae
Acacia leucophloea	AL	Mimosoiceae
Acacia suma	AS	Mimosoiceae
Canthium parviflorum	CP	Rubiaceae
Chloroxylon swietenia	CS	Rutaceae
Cordia wallichii	CW	Boraginaceae
Gmelina asiatica	GA	Verbenaceae
Holoptelea integrifolia	HI	Ulmaceae
Phyllanthus emblica	PE	Euphorbiaceae
Pongamia pinnata	PP	Fabaceae
Randia dumetorum	RD	Rubiaceae
Semecarpus anacardium	SA	Anacardiaceae
Samanea saman	SS	Mimosoiceae
Dry deciduous forest		
Host	**Code**	**Family**
Anogeissus latifolia	ALA	Combretaceae
Careya arborea	CA	Barringtoniaceae
Cordia obliqua	CO	Boraginaceae
Cordia wallichii	CW	Boraginaceae
Gmelina arborea	GAR	Verbenaceae
Grewia tilifolia	GT	Tiliaceae
Helicteres isora	HIS	Sterculiaceae
Kydia calycina	KC	Malvaceae
Lagerstroemia microcarpa	LM	Lythraceae
Ougenia oojeinensis	OO	Fabaceae
Premna tomentosa	PT	Verbenaceae
Syzygium cumini	SCU	Myrtaceae
Tectona grandis	TG	Verbenaceae
Terminalia crenulata	TC	Combretaceae
Vitex altissima	VA	Verbenaceae
Montane evergreen Forest		
Host	**Code**	**Family**
Cinnamomum wightii	CWI	Lauraceae
Elaeocarpus serratus	ES	Elaeocarpaceae
Glochidion zeylanicum	GZ	Euphorbiaceae
Ilex denticulata	ID	Aquifoliaceae
Ilex wightiana	IW	Aquifoliaceae
Lasianthus venulosus	LV	Rubiaceae

Ligustrum roxburghii	LR	Oleaceae
Litsea floribunda	LF	Lauraceae
Litsea stocksii	LS	Lauraceae
Memecylon malabaricum	MM	Melastomaceae
Psychotria bisulcata	PB	Rubiaceae
Symplocos cochinchinensis	SC	Symplocaceae
Syzygium densiflorum	SD	Myrtaceae
Turpinia nepalensis	TN	Staphyleaceae
Vepris bilocularis	VB	Rutaceae

Table 2 Number of species, isolates, and diversity of phellophytes from the three different forests.

	Dry thorn forest	**Dry deciduous forest**	**Montane evergreen forest**
Total No. of species	42	55	58
Total No. of isolates	1639	1744	785
Density of Colonization %	73	77	35
Dominant species	*Phomopsis* sp. 1 (366*)	*Fusarium* sp. 3 (216*)	Sterile form EGS1 (90*)
Co-dominant species	*Phoma* sp. 1 (225*)	*Paecilomyces* sp. 1 (205*)	Sterile form EGS3 (73*)
Fisher's alpha	7.9	10.8	14.5
Mean annual rainfall	800 mm	1200 mm	1450 mm

* No. of isolates within parenthesis

Discussion

A general observation was that a few phellophyte species had a high isolation frequency while many species had a low isolation frequency. This result is similar to those obtained for some temperate trees including *Alnus* species (Fisher & Petrini 1990) and *Fagus sylvatica* (Danti et al. 2002). The exterior of the outer bark of trees consists of dead cells with highly suberized cell walls which is impermeable to water and is mainly protective in function (Beck 2010). The bark provides mechanical support for the tree and resistance against fire (Paine et al. 2010), and being rich in antimicrobial compounds including terpenes and polyphenols (Flores & Hubbes 1980, Pearce 1996); it also protects the tree from pests and pathogens (Paine et al. 2010). Hence, the association of phellophytes with healthy bark suggests that they are adapted to survive in this microhabitat that is generally inimical to fungi due its hydrophobic nature and antimicrobial chemical content (Alfredsen et al. 2008). It is not clear if phellophytes are active in the bark or if the bark is a reservoir of the spores and other dormant structures of such fungi. Nevertheless, the high frequency of isolation of certain species of fungi such as those of *Phoma* and *Phomopsis* from dry thorn, *Fusarium* and *Paecilomyces* from dry deciduous and sterile forms EGS1 and EGS3 from montane evergreen forest in the present study and the observation of Suryanarayanan et al (2009b) in these forests that the phellophyte assemblages are distinct from the foliar endophyte or leaf litter fungal assemblages of a given tree species go to suggest that phellophytes are not passive residents of barks but may be well adapted to live in bark tissues.

The dry thorn and dry deciduous forest are semi-arid habitats and experience episodic dry season fires with the average fire-return interval being as short as five years (Kodandapani et al. 2004). Trees growing in such fire-prone forests develop thick barks as defence against fire (Hoffman et al. 2003). Consequently, trees of dry thorn and dry deciduous forests must have thick barks offering more tissue for exploitation by phellophytes. This could be one of the reasons for the higher recovery of phellophyte isolates from these forests compared to the montane evergreen forest (Table 2). It is also probable that fire, along with prolonged drought periods that are

Table 3 Number of isolates, species and diversity index for phellophytes isolated from different tree species in the three forests (Refer host code Table 1).

Dry thorn forest	**AA**	**AC**	**AF**	**AL**	**AS**	**CP**	**CS**	**CW**	**GA**	**HI**	**PE**	**PP**	**RD**	**SA**	**SS**
No. of species	7	12	12	7	12	10	13	9	12	10	10	5	10	12	8
No. of isolates	93	141	109	107	70	131	94	129	78	104	90	106	121	101	165
Fisher's α	1.7	3.1	3.4	1.7	4.2	2.5	4.1	2.2	4	2.7	2.89	1.1	2.6	3.5	1.7
Dry deciduous forest	**ALA**	**CA**	**CO**	**CW**	**GA**	**GT**	**HIS**	**KC**	**LM**	**OO**	**PT**	**SCU**	**TC**	**TG**	**VA**
No. of species	13	13	11	9	15	11	10	13	10	12	13	10	7	11	10
No. of isolates	127	72	100	122	149	110	147	128	38	140	104	98	122	164	122
Fisher 's α	3.6	4.6	3.1	2.2	4.2	3	2.4	3.6	4.4	3.1	3.9	2.8	1.6	2.7	2.6
Montane evergreen forest	**CWI**	**ES**	**GZ**	**ID**	**IW**	**LF**	**LR**	**LS**	**LV**	**MM**	**PB**	**SC**	**SD**	**TN**	**VB**
No. of species	16	11	11	8	12	9	15	16	16	10	10	13	8	7	10
No. of isolates	54	63	33	40	58	73	50	43	46	43	16	64	44	86	72
Fisher's α	7.7	3.9	5.8	3	4.6	2.7	7.2	9.2	8.7	4.1	11.4	4.9	2.7	1.8	3.1

Table 4a Fungal genera unique to each forest and their mean isolation frequency (IF)**.**

Dry thorn (IF%)	**Dry deciduous (IF%)**	**Montane evergreen (IF%)**
Helicoma (0.04)	*Achaetomium* (0.04)	*Cryptosporiopsis* (0.04)
	Acremonium (0.36)	*Fusicoccum* (0.04)
	Alternaria (0.27)	*Geotrichum* (0.04)
	Corynespora (0.04)	*Myrioconium* (0.04)
	Mucor (0.13)	*Pithomyces* (0.09)
	Saccobolus (0.36)	*Taeniolella* (0.31)
		Tritirachium (0.09)

Table 4b Fungal genera in any two or all the three forests and their isolation frequency (IF).

Genera shared by Dry thorn and Dry deciduous (IF%)	**Genera shared by Dry deciduous and Montane evergreen (IF%)**	**Genera shared by Dry thorn and Montane evergreen (IF%)**	**Genera in Dry thorn, Dry deciduous and Montane evergreen (IF%)**
Chaetomium (0.09)	*Arthrinium* (0.27)	*Botrytis* (0.31)	*Aspergillus* (0.76)
Curvularia (0.56)	*Aureobasidium* (0.18)	*Sordaria* (0.09)	*Colletotrichum* (1.24)
Drechslera (0.09)	*Cladosporium* (0.22)	Yeast (0.33)	*Fusarium* (4.77)
Nigrospora (0.44)	*Humicola* (0.58)		*Lasiodiplodia* (1.66)
Sporormiella (0.18)	*Phialophora* (0.73)		*Paecilomyces* (3.63)
Talaromyces (0.27)			*Penicillium* (0.77)
			Periconia (2.09)
			Pestalotiopsis (0.24)
			Phoma (3.53)
			Phomopsis (9.47)
			Trichoderma (1.48)
			Xylaria (6.93)

characteristic of these forests select fungal species which are tolerant to these abiotic stresses thus reducing the diversity of phellophytes in these locations (Table 4a). Suryanarayanan et al (2011b) observed unusual thermotolerance in spores of some genera such as *Curvularia*, *Drechslera*, *Pestalotiopsis* and *Phoma* from the dry thorn and dry deciduous forests. Spores of these fungi survive several hours of exposure to dry heat of more than l00°C. It is pertinent that these fungi (excepting *Pestalotiopsis*) were more frequently isolated as phellophytes from dry thorn and dry deciduous forests (Tables 2 and 4b). A few earlier studies on individual tree species have suggested that the degree of colonization of twigs and branches by symptomless fungi depends on, among others, factors such as host plant diversity and fungal inoculum density (Kowalski & Kehr 1996) and pollutants (Barengo et al. 2000). The present study with more tree species and from different forest types enables us to conclude that the environment rather than the tree host species is a major determinant of diversity and distribution of the phellophytes. The phellophyte assemblages of the three forests formed separate clusters in an ordination analysis showing that these are distinct for each type of forest studied. Furthermore, while the phellophyte assemblage of a given tree species from two different forests overlapped only by 12.5%, the assemblage of six different tree species growing in a single forest overlapped by more than 60% suggesting a stronger role for environment in determining the fungal assemblages of the tree barks. It is pertinent to mention here that foliar endophyte assemblages in these and other forests are also determined more by the environment than by the host tree species (Suryanarayanan et al. 2002, Zimmerman & Vitousek 2012, Garćia et al. 2013).

The higher diversity of the phellophytes in montane evergreen when compared to that in dry thorn or dry deciduous could be a reflection of the higher precipitation in this forest (Table 2) since moisture favours fungal spore dispersal and infection (Helander et al. 1993, Bahnweg et al. 2005) and phellophyte colonization is known to be influenced by drought stress (Schoeneweiss 1983, Sutton & Davison 1983). It is also possible that the higher tree species diversity in this forest when compared to that of dry thorn and dry deciduous (H.S. Dattaraja, H.S. Suresh & R. Sukumar, unpublished data - see Suryanarayanan et al. 2011a) supports a higher phellophyte diversity as has been observed for endophytic fungi (Arnold et al. 2000).

Tree bark as a niche for microfungi has to be investigated in detail considering the recent report that the species richness and diversity of endophytes in bark and branches are more than those in harboured by the leaf (Wu et al. 2013). A species level identification of the fungi was not attempted in the present study due to the enormity of the sample size. Considering the fact that some genera such as *Phomopsis* and *Phoma* which are reported as phellophytes here are also common endophytes in these forests (Suryanarayanan et al. 2011a), such an exercise would reveal if the same fungal species is adapted to survive as foliar endophyte, phellophyte and pioneer leaf litter degrader in the forest ecosystem. Apart from this, the use of different isolation media and molecular techniques may reveal even new fungal species among phellophytes (Vujanovic & St-Arnaud 2003, Magyar et al. 2011).

Table 5 A Bray-Curtis similarity measure (percentile proportion) for the phellophytes of the bark of *C. wallichi* growing in Dry thorn and Dry deciduous forest.

	Dry thorn	Dry deciduous
Dry thorn	*	12.5
Dry deciduous	*	*

Table 6 A Bray-Curtis similarity measure (percentile proportion) for phellophytes from six tree species of Mimosoiceae from Dry thorn forest (Refer Table 1 for host code).

	AA	AC	AF	AL	AS	SS
AA	*	4.27	12.9	2	11	3.88
AC	*	*	6.4	3.23	7.58	3.27
AF	*	*	*	2.78	29.1	3.65
AL	*	*	*	*	13.6	64
AS	*	*	*	*	*	15.3
SS	*	*	*	*	*	*

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References

Alfredsen G, Solheim H, Slimestad R. 2008 – Antifungal effect of bark extracts from some European tree species. European Journal of Forest Research 127, 387–393.

Arnold AE, Maynard Z, Gilbert GS, Coley PD, Kursar TA. 2000 – Are tropical fungal endophytes hyperdiverse? Ecology Letters 3, 267–274.

Bahnweg G, Heller W, Stich S, Knappe C, Betz G, Heerdt C, Kehr RD, Ernst D, Langebartels C, Nunn AJ, Rothenburger J, Schbert R, Wallis P, Mueller-Starck G, Werner H, Matyssek R, Sandermann H Jr. 2005 – Beech leaf colonization by the endophyte *Apiognomonia errabunda* dramatically depends on light exposure and climatic conditions. Plant Biology 7, 659–669.

Barengo N, Sieber TN, Holdenrieder O. 2000 – Diversity of endophytic mycobiota in leaves and twigs of pubescent birch (*Betula pubescens*). Sydowia 52, 305–320.

Beck CB. 2010 – An introduction to plant structure and development, II (ed.) Cambridge University Press.

Cotter HVT, Blanchard RO. 1982 – The fungal flora of *Fagus grandifolia.* Mycologia 74, 836–843.

Danti R, Thomas N, Sieber TN, Sanguineti G. 2002 – Endophytic mycobiota in bark of European beech (*Fagus sylvatica*) in the Apennines. Mycological Research 106, 1343–1348.

Fisher PJ, Petrini O, Sutton BC. 1993 – A comparative study of fungal endophytes in leaves, xylem and bark of *Eucalyptus nitens* in Australia and England. Sydowia 45, 338–345.

Fisher PJ, Petrini O. 1990 – A comparative study of fungal endophytes in xylem and bark of *Alnus* species in England and Switzerland. Mycological Research 94, 313–319.

Flores G, Hubbes M. 1980 – The nature and role of phytoalexin produced by aspen (*Populus tremuloides* Michx). European Journal of Forest Pathology 10, 95–103.

García E, Alonso A, Platas G, Sacristán S. 2013 – The endophytic mycobiota of *Arabidopsis thaliana*. Fungal Diversity DOI 10.1007/s13225–012-0219-0

Helander ML, Neuvonen S, Sieber T, Petrini O. 1993 – Simulated acid rain affects birch leaf endophyte populations. Microbial Ecology 26, 227–234.

Hoffmann WA, Orthen B, Nascimento PKVD. 2003 – Comparative fire ecology of tropical savanna and forest trees. Functional Ecology 17, 720–726.

Kamiyama M, Hirayama K, Tanaka K, Mel'nik VA. 2009 – Transfer of *Asterosporium orientale* to the genus *Prosthemium* (Pleosporales, Ascomycota): a common coelomycetous fungus with stellate conidia occurring on twigs of *Betula* spp. Mycoscience 50, 438–441.

Kliejunas JT, Kuntz JE. l974 – Microorganisms associated with *Eutypella parasitica* in *Acer saccharum* and *A. rubrum.* Canadian Journal of Forest Research 4, 207–212.

Kodandapani N, Cochrane MA, Sukumar R. 2004 – Conservation threat of increasing fire frequencies in the Western Ghats, India. Conservation Biology 18, 1553–1561.

Kowalski T, Kehr RD. 1992 – Endophytic fungal colonization of branch bases in several forest tree species. Sydowia 43, 137–168.

Kowalski T, Kehr RD. 1996 – Fungal endophytes of living branch bases in several European tree species. In: Endophytic fungi in grasses and woody plants (eds. SC Redlin, LM Carris) St. Paul, Minnesota.

Ludwig JA, Reynolds JF. 1988 – Statistical ecology: A primer on methods and computing. John Wiley and Sons, New York, USA.

Magyar D, Shoemaker RA, Bobvos J, Crous PW, Groenewald JZ. 2011 – *Pyrigemmula*, a novel hyphomycete genus on grapevine and tree bark. Mycological Progress 10, 307–314.

Paine C, Stahl C, Courtois EA, Patino S, Sarmiento C, Baraloto C. 2010 – Functional explanations for variation in bark thickness in tropical rain forest trees. Functional Ecology 24, 1202–1210.

Pearce RB. 1996 – Tansley Review No. 87. Antimicrobial defences in the wood of living trees. New Phytologist 132, 203–233.

Schoeneweiss D. 1983 – Drought predisposition to *Cytospora* canker in blue spruce. Plant Disease 67, 308–314.

Suresh HS, Bhat HR, Dattaraja HS, Sukumar R. 1999 – Flora of Mudumalai wildlife sanctuary, Nilgiris, Tamil Nadu. Technical Report No. 64. Center for Ecological Sciences, Indian Institute of Science, Bangalore, India.

Suresh HS, Sukumar R. l999 – Phytogeographical affinities of flora of Nilgiri Biosphere Reserve. Rheedea 9, 1–21.

Suryanarayanan TS, Murali TS, Thirunavukkarasu N, Govinda Rajulu MB, Venkatesan G, Sukumar R. 2011a – Endophytic fungal communities in woody perennials of three tropical forest types of the Western Ghats, southern India. Biodiversity and Conservation 20, 913–928.

Suryanarayanan TS, Govinda Rajulu MB, Thirumalai E, Reddy MS, Money NP. 2011b – Agni's fungi: heat-resistant spores from the Western Ghats, southern India. Fungal Biology 115, 833–838.

Suryanarayanan TS, Kumaresan V, Johnson JA. 1998 – Foliar fungal endophytes from two species of the mangrove *Rhizophora.* Canadian Journal of Microbiology 44, 1003–1006.

Suryanarayanan TS, Murali TS, Venkatesan G. 2002 – Occurrence and distribution of fungal endophytes in tropical forests across a rainfall gradient. Canadian Journal of Botany 80, 818–826.

Suryanarayanan TS, Rajagopal K. 2000 – Fungal endophytes (phellophytes) of some tropical forest trees. The Indian Forester 126, 165–170.

Suryanarayanan TS, Thirunavukkarasu N, Govindarajulu MB, Sasse F, Jansen R, Murali TS. 2009a – Fungal endophytes and bioprospecting. Fungal Biology Reviews 23, 9–19.

Suryanarayanan TS, Thirumalai E, Prakash CP, Govinda Rajulu MB, Thirunavukkarasu N. 2009b – Fungi from two forests of southern India: a comparative study of endophytes, phellophytes, and leaf litter fungi. Canadian Journal Microbiology 55, 419–426.

Suryanarayanan TS, Thirunavukkarasu N, Govindarajulu MB, Gopalan V. 2012. – Fungal endophytes: an untapped source of biocatalysts. Fungal Diversity 54, 19–30.

Sutton BC, Davison EM. 1983 – Three stromatic Coelomycetes from Western Australia. Transactions of the British Mycological Society 81, 291–301.

Taylor LR. 1978 – Bates, Williams, Hutchinson-a variety of diversities. In: Diversity of insect faunas. Symposia of the Royal Entomological Society of London No. 9. *(*eds. LA Mound, N Warloff). Blackwell Scientific, Oxford, England.

Verma VC, Gond SK, Kumar A, Mishra A, Kharwar RN, Gange AC. 2009 – Endophytic Actinomycetes from *Azadirachta indica* A. Juss.: Isolation, Diversity and Antimicrobial Activity. Microbial Ecology 57, 749–756.

Vujanovic V, St-Arnaud M. 2003 – A new species of *Pseudorobillarda*, an endophyte from *Thuja occidentalis* in Canada, and a key to the species. Mycologia 95, 955–958.
Webber J. 1981. A natural biological-control of Dutch elm disease. Nature 292, 449–451.
Wu L, Han T, Li W, Jia M, Xue L, Rahman K, Qin L. 2013 – Geographic and tissue influences on endophytic fungal communities of *Taxus chinensis* var. *mairei* in China. Current Microbiology 66, 40–48.
Zimmerman N, Vitousek P. 2012 – Fungal endophyte communities reflect environmental structuring across a Hawaiian landscape. Proceedings of the National Academy of Sciences 109, 13022–13027.