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Intact leaves as substrate for fungi: distribution of endophytes and phylloplane fungi in rattan palms

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Leaves of twelve species of *Calamus* from southern India were screened simultaneously for the presence of phylloplane and endophytic fungi. Sampling of 2400 leaf segments yielded 824 endophyte isolates belonging to 34 species. Thirty species of phylloplane fungi were recorded. Several fungal species were found to be shared as endophytes by different hosts. However, the overlap between endophyte assemblage and phylloplane fungi of each host was low, suggesting that these two distinct groups of fungi occupy different niches, thereby avoiding competition.

Key words: phylloplane fungi, endophytes, *Calamus*, India

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U listů dvanácti druhů ratanových palem rodu *Calamus* z jižní Indie byl sledován výskyt fyloplánních a endofytických hub. Z 2400 segmentů listů bylo získáno 824 izolátů endofytů patřících do 34 druhů. Bylo zaznamenáno celkem 13 duhů fyloplánních hub. Několik druhů hub se v podobě endofytů vyskytovalo zároveň u několika různých hostitelů. Podobnost druhového složení endofytů a fyloplánních hub byla u všech hostitelů malá, což naznačuje, že tyto dvě odlišné skupiny hub využívají rozdílné niky a tím se vyhýbají vzájemné kompetici.

INTRODUCTION

A leaf, even before abscission, is a suitable substrate for a wide variety of fungi. Apart from pathogenic fungi that infect a leaf and cause disease, a leaf supports two other groups of fungi – symptomless phylloplane fungi and symptomless endophytes. Phylloplane fungi are saprotrophs and are confined to the surfaces of living leaves, while the endophytes are biotrophic mutualists, benign commensals or latent pathogens and reside within the leaf tissues. The endophytes infect leaves of a wide variety of plants and remain without producing symptoms or any negative effects (Stone et al. 2000). There are several studies on fungal endophytes including their association with temperate trees (Carroll and Carroll 1978, Petrini 1986) and, more recently, with tropical plant hosts (Rodrigues and Samuels 1990, Rodrigues

1994, Fröhlich et al. 2000, Rajagopal and Suryanarayanan 2000, Kumaresan and Suryanarayanan 2001, Suryanarayanan and Vijaykrishna 2001, Devarajan et al. 2002, Suryanarayanan et al. 2002, 2003). There are, however, fewer studies on phylloplane fungi than on endophytes (Lee and Hyde 2002) and most of these are focused on pathogens of crops or economically important trees (Pugh and Williams 1968, Bainbridge and Dickinson 1972, Dickinson 1973, Vardavakis 1988, Carris 1992). Also, very few studies compare phylloplane and endophytic fungal communities of the leaf (Petrini 1991) and none exist with reference to tropical hosts. Simultaneous sampling of leaf is essential to understand the occurrence and distribution of these fungal groups in a host leaf. Therefore, we studied the phylloplane and endophytic fungi associated with leaves of 12 rattan palms of southern India.

Rattans (canes) belong to the genus *Calamus* in the family *Arecaceae* (*Palmae*). India has about 60 species of rattan (Renuka 1999) distributed in moist forests of the Western Ghats, sub-Himalayan hills and Andaman and Nicobar Islands (Ravikanth et al. 2002). Rattans are economically important palms and support over 300,000 people in rural India (Ravikanth et al. 2002). Natural populations of rattan are threatened due to habitat destruction and the increasing demand for rattan products (Biswas 1991).

Materials and Methods

Collection Site

Rattans were collected from the rattan germplasm collection at Kerala Forest Research Institute, Peechi, Kerala State, southern India (10° 32' N lat. and 76° 32' E lon.). This site is characterised by a tropical warm humid climate. The vegetation is of the moist deciduous type. The mean annual rainfall during the year of collection (Jan 2002 to Dec 2002) was 2849.4 mm. The monthly maximum temperature varied from 37.2 °C (April) to 25.1 °C (July). The collections were made during the southwest monsoon period (mid May to August).

Collection of samples

Twelve species of *Calamus* were selected for this study (Table 1). Twenty-five healthy leaflets from each host were collected and brought to the laboratory in sterilised polyethylene bags. The samples were processed within 24 hours after collection. Twenty-two leaflets were sampled for endophytes and the rest was used for isolating phylloplane fungi.

Table 1. Rattan species studied for phylloplane and endophytic fungi.

Host	Code
Calamus hookerianus Becc.	CH
Calamus thwaitesii Becc. et Hook. f.	CTH
Calamus rotang L.	CR
Calamus metzianus Schlecht.	CM
Calamus travancoricus Bedd. ex Becc. et Hook. f.	CTR
Calamus nagabettai Fernandez et Dey	CN
Calamus vattayila Renuka	CV
Calamus pseudotenuis Becc. ex Becc. et Hook. f.	CP
Calamus tenuis Roxb.	CTN
Calamus tetradactylus Hance.	CTE
Calamus dransfieldii Renuka	CD
Calamus andamanicus Kurz.	CAN

Isolation of endophytes

From each leaflet, ten segments (including midvein and lamina) of approximately 0.5 cm^2 were randomly excised using a pair of sterile scissors. The 220 segments thus obtained were surface sterilised by consecutive immersion for 60 seconds in 75 % ethanol, 180 seconds in NaOCl (4 % available chlorine) and 30 seconds in 75 % ethanol (Fisher et al. 1993). From this, 200 segments were randomly selected and plated on potato dextrose agar medium amended with an antibiotic (150 $mg.l^{-1}$) in Petri dishes (9 cm diam.). The efficacy of surface sterilisation was confirmed by the method of Schulz et al. (1998).

Isolation of phylloplane fungi

All 12 species of *Calamus* were also examined simultaneously for the presence of phylloplane fungi using the leaf washing method (Gunasekera et al. 1997). This method is not quantitative since fungi that adhere firmly to the leaf surface may not be isolated (Lee and Hyde 2002). Ten segments of approximately 0.5 cm^2 in size were randomly excised (including lamina and midvein) and were shaken for 20 minutes in 20 ml of autoclaved sterile water containing 0.05 % Tween 20. A dilution series was prepared from the washings. The aliquots were then plated on PDA medium and observed for the growth of fungi. A 1:10 dilution was found to be the most suitable and this was used for all the hosts studied.

The Petri dishes were incubated at 26 °C for 21 days in a light chamber for endophytes and 7 days for phylloplane fungi. The light regime was a 12 h light:

12 h dark cycle. Endophytic fungi were isolated and colonies were transferred to PDA slants and identified. The sterile isolates were given code numbers based on cultural characteristics (Suryanarayanan et al. 1998).

Analysis of results

Colonisation frequency of endophytes was calculated following the method of Hata and Futai (1995). Colonisation frequency (CF) = $N_{col}/N_t \times 100$, where N_{col} is the number of segments colonised by a particular fungus and N_t is the number of segments observed. For comparing the various groups of fungi (phylloplane vs. endophyte, endophyte vs. endophyte), Jaccard's similarity coefficient was used. Jaccard's similarity index = $(c/\ (a+b-c)) \times 100$, where a is the number of fungal species present in host 1; b is the number of fungal species present in host 2 and c is the number of common fungi. Relative percentage of occurrence (RPO) of a group of fungi was calculated using the formula, RPO = (colonisation frequency of one group of fungi/ colonisation frequency of all groups of fungi) × 100.

RESULTS AND DISCUSSION

Sampling of 2400 leaf segments from 12 different *Calamus* species yielded 824 isolates of endophytes belonging to 34 species (Table 2). *Calamus vattayila* and *C. andamanicus* showed the highest densities of colonisation by endophytes. In all other cases, the CF % was rather low (Table 2). Previous studies on *Licuala* sp. (Rodrigues and Samuels 1990), *Euterpe oleracea* (Rodrigues 1994), *Sabal bermudana* and *Livistona chinensis* (Southcott and Johnson 1997), and *Trachycarpus fortunei* (Taylor et al. 1999) have also shown that palms are less densely colonised by endophytes. Generally, tropical dicotyledonous trees show higher densities of endophyte colonisation (typically above 80 %) (Lodge et al. 1996; Suryanarayanan et al. 2002, 2003) and hence further studies are needed to explain the low frequency of endophyte colonisation in members of *Arecaceae*.

Coelomycete fungi dominated the endophyte assemblages in ten host species studied (Fig. 1). Coelomycetes are ubiquitous and dominant endophytes in many tropical dicotyledonous trees (Suryanarayanan et al. 1998, 2002). In other palms, the most frequently isolated endophytes were *Idriella* sp., *Glomerella cingulata* (Stonem.) Spauld et Schrenk. and *Letendraeopsis palmarum* K. F. Rodrigues et Samuels (Rodrigues and Samuels 1990, Rodrigues 1994, Taylor et al. 1999). Xylariaceous fungi are common endophytes of tropical plants including palms (Rodrigues 1994, Lodge et al. 1996). In the present study also, a xylariaceous form (form 3) occurred in 8 of the 12 rattan species screened. This fungus was the dominant endophyte in *Calamus thwaitesii* and *Calamus rotang* (Table 2).

Table 2. Colonisation frequency of endophytic fungi isolated from leaves of rattan plants. See Table 1 for host codes.

Fungus	CH	CTH	CR	CM	CTR	CN	CV	CP	CTN	CTE	CD	CAN
Ascomycetes												
Xylariaceous form 1		4.0										
Xylariaceous form 2		6.0										
Xylariaceous form 3	8.0	10.5	16.5	1.0	7.5		1.0	1.5		1.0		
Xylariaceous form 4			2.5									
Xylariaceous form 5			0.5									0.5
Xylariaceous form 6			0.5									
Coelomycetes												
Colletotrichum sp. 1									1.5	0.5		
Colletotrichum sp. 2		1.5										
Phoma sp. 1				0.5							1.0	
Phomopsis sp. 1	4.5	7.5	4.5		0.5		15.5	0.5		1.0		1.0
Phyllosticta sp. 1	27.5	6.0	11.5	24.5	33.5	6.5	60.0	4.5	18.5	26.0	4.5	65.5
Hyphomycetes												
Aspergillus flavus Link : Fr.											1.5	
Aspergillus niger van Tieghem						0.5						
Aureobasidium pullulans (de Bary) Arnaud	0.5											
Cladosporium sp. 1			0.5								0.5	
Cladosporium sp. 2		0.5	0.5									
Corynespora sp. 1	0.5											
Fusarium sp. 1		1.0										
Fusarium sp. 2					0.5							
Nigrospora sp. 1		1.0										
Zygomycetes												
Mortierella sp. 1		0.5										
Rhopalomyces sp. 1								1.0				
Yeast form												
Yeast sp. 1	0.5											
Sterile forms												
Sterile form 1			0.5				0.5					
Sterile form 2							0.5			0.5	1.5	0.5
Sterile form 3											1.5	
Sterile form 4		1.0										
Sterile form 5	0.5											
Sterile form 6				1.5								
Sterile form 7		1.0										
Sterile form 8								1.0				
Sterile form 9						0.5						
Sterile form 10	0.5			0.5								
Sterile form 11		1.0										
Total CF %	**42.5**	**41.5**	**37.5**	**28**	**42**	**7.5**	**77.5**	**8.5**	**20**	**29**	**10.5**	**67.5**
Total no. of isolates	**85**	**83**	**75**	**56**	**84**	**15**	**155**	**17**	**40**	**58**	**21**	**135**
Total no. of species	**8**	**13**	**9**	**5**	**4**	**3**	**5**	**5**	**2**	**5**	**6**	**4**

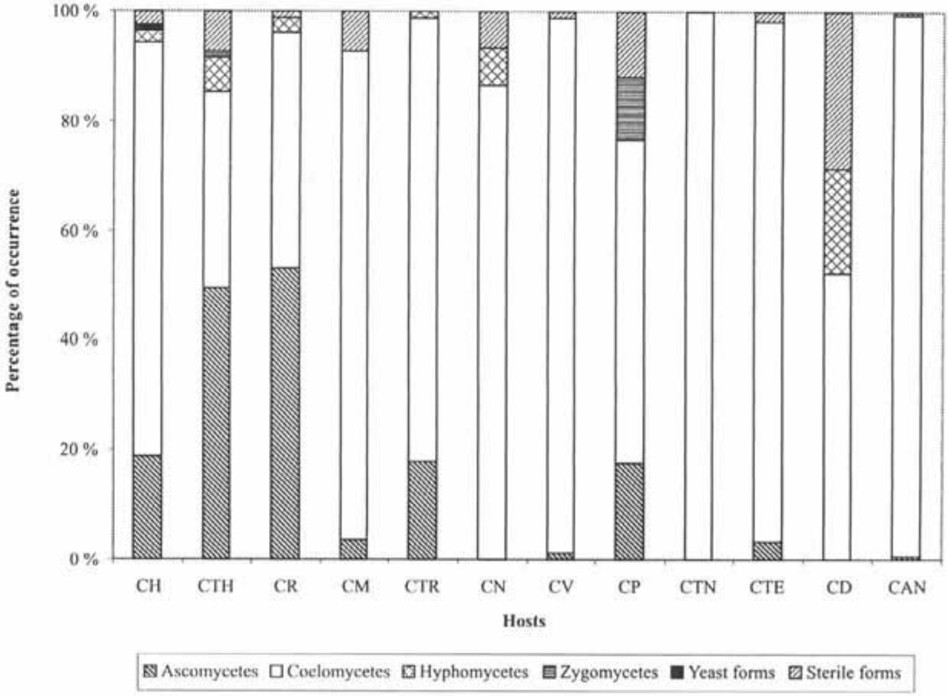

Fig. 1 Relative occurrence of different groups endophytic fungi in rattan palms. See Table 1 for host codes.

Thirty species of phylloplane fungi were recovered in this study (Table 3). These included common phylloplane fungi such as species of *Cladosporium*, *Aureobasidium*, *Aspergillus*, *Pestalotiopsis* and *Colletotrichum* (Cabral 1985, Lee and Hyde 2002).

The overlap between the endophyte assemblages of the different hosts was calculated (Table 4). Out of the sixty six combinations, sixty one had an overlap of more than 10 %. The maximum overlap was between *Calamus vattayila* and *Calamus tetradactylus* (67 %). However, the overlap between the phylloplane and endophytic fungi of each host was low (Table 5). There was absolutely no overlap between these two groups of fungi in seven of the rattan hosts. The maximum overlap was only 17 % (Table 5). Thus, although the leaves of the 12 different species of rattans harboured phylloplane fungi and endophytic fungi, these two groups were distinct. Only a few fungi, such as *Aureobasidium* and *Cladosporium* occurred both as endophytes and phylloplane fungi. Even these fungi may not be 'true' endophytes (Petrini 1991), because phylloplane fungi, in addition to residing on the surface of the leaf, are known to penetrate occasionally the wax layer or

Table 3. Phylloplane fungi isolated from the host species. See Table 1 for host codes.

FUNGUS	CH	CTH	CR	CM	CTR	CN	CV	CP	CTN	CTE	CD	CAN
Ascomycetes												
Talaromyces sp. 1										+		
Coelomycetes												
Pestalotiopsis sp. 1	+	+		+	+		+				+	+
Phomopsis sp. 1							+		+			
Hyphomycetes												
Aspergillus flavus Link : Fr.												+
Aspergillus niger van Tieghem		+	+	+		+		+	+	+		+
Aspergillus ochraceus Wilhelm	+											
Aspergillus sp. 1						+						
Aureobasidium pullulans (de Bary) Arnaud	+			+	+	+						
Cladosporium sp. 1	+	+	+	+	+	+		+				
Cladosporium sp. 2	+	+	+	+	+						+	
Curvularia lunata (Wakker) Boedijn	+		+	+	+							
Drechslera sp. 1	+											
Drechslera hawaiiensis (Bugnicourt) Subram. et Jain ex M. B. Ellis					+							
Fusarium sp. 1									+			
Fusarium sp. 2										+		+
Fusarium sp. 3								+				
Monodictys levis (Wiltshire) Hughes	+											
Nigrospora sp. 1	+											
Trichoderma sp. 1												+
Penicillium sp. 1	+	+			+							
Penicillium sp. 2			+									
Penicillium sp. 3												+
Zygomycetes												
Mucor racemosus Fresen.	+			+								
Yeast forms												
Yeast sp. 2	+	+	+	+	+		+					
Yeast sp. 3	+	+	+									
Yeast sp. 4		+										
Sterile forms												
Sterile form 12					+							
Sterile form 13					+							
Sterile form 14					+							
Sterile form 15			+									
Total no. of species	13	8	8	8	11	4	3	3	3	3	2	6

Table 4. Similarity coefficients (%) between the endophyte assemblages of different rattan palm species. See Table 1 for host codes.

Host	CH	CTH	CR	CM	CTR	CN	CV	CP	CTN	CTE	CD	CAN
CH	100	17	21	30	33	10	30	30	11	30	8	20
CTH		100	22	13	21	7	20	20	7	20	5	13
CR			100	17	30	9	40	27	10	27	15	30
CM				100	29	14	25	25	17	25	22	13
CTR					100	17	50	50	20	50	11	33
CN						100	14	14	25	14	13	17
CV							100	43	17	67	22	50
CP								100	17	43	10	29
CTN									100	40	14	20
CTE										100	22	50
CD											100	25
CAN												100

Table 5. Similarity coefficients (%) between phylloplane fungi and endophyte assemblage of a rattan host. See Table 1 for host codes.

Host	Similarity coefficient
CH	5
CTH	5
CR	13
CM	0
CTR	0
CN	17
CV	14
CP	0
CTN	0
CTE	0
CD	0
CAN	0

cuticle on the surface of the leaf. When they do so, they escape the effects of surface sterilisation and grow on agar plates (Verhoeff 1974); such fungi would fall within the ambit of endophytes by definition.

It is thought that phylloplane and endophytic fungi are involved in different physiological and ecological phenomena unique to the phyllosphere ecosystem

(Petrini 1991). Phylloplane fungi and endophytic fungi are exposed to different environments. Phylloplane fungi are exposed to rapid environmental changes and have a remarkable ability to withstand periodic wetting and drying (Park 1982), while the endophytes have to defend themselves against the defense reactions of the host (Petrini 1991). Our results indicate that these two distinct groups of fungi (phylloplane and endophytic) may avoid competition by occupying different niches offered by a leaf. Such a compartmentalisation could be advantageous to both groups although a brief period of encounter between the two groups on the leaf surface (when the endophyte propagules fall on the leaf surface and enter the host) is unavoidable.

Computation of the similarity index showed that 5–67 % of the endophyte assemblage was shared by all the hosts indicating that certain fungi such as *Phyllosticta*, xylariaceous forms and sterile form 2 occurred as endophytes in many species of rattan. *Phyllosticta* and xylariaceous forms occur as endophytes in many plant species (Rodrigues 1994, Suryanarayanan et al. 2002). Recently, Suryanarayanan et al. (2002) – while studying the distribution of endophytes in different tropical forests – reported that some endophytes were ubiquitous and could be recovered from host species belonging to different families. Such a lack of host specificity among endophytes could depress fungal diversity in a plant community. Thus, it is clear that certain fungal genera could infect unrelated host species and hence there is no direct relationship between the taxonomy of the hosts and that of their endophytes.

The fact that certain genera of fungi occur invariably as endophytes in leaf tissues of taxonomically unrelated (Suryanarayanan et al. 2002, 2003) and geographically isolated (Suryanarayanan and Kumaresan 2000) host plants strongly suggests that these fungi have evolved strategies to lead an endophytic mode of life. Such fungi could well constitute an ecological group dominating the niche created by the internal tissues of plant hosts. Community ecology studies on tropical endophytes are very few (Arnold et al. 2000, 2001; Suryanarayanan et al. 2002, 2003) and there is much room for further studies on the ecology of fungal endophytes and phylloplane fungi especially since we have very limited knowledge of the spread and stabilisation of tropical endophytes as well as the interaction between these two groups of fungi.

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