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Rain-borne fungi in stemflow and throughfall of six tropical palm species

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The present survey documents rain-borne hyphomycetes in stemflow and throughfall of six palm species on the west coast of India during the monsoon season. A total of 61 species were recovered. Irrespective of the palms, throughfall was represented by a higher number of species than stemflow. Pearson correlation was significant and positive between richness of species and conidia with air humidity, air temperature, water temperature and water conductivity. Except for *Areca*, Shannon diversity was higher in throughfall compared to stemflow. Jaccard's percent similarity of species in stemflow was lowest between *Cocos* vs. *Roystonea* (16%) and highest between *Borassus* vs. *Caryota* (55.5%), while in throughfall it was lowest between *Areca* vs. *Livistona* (16.7%) and highest between *Caryota* vs. *Cocos* and *Livistona* vs. *Cocos* (50%).Two-way ANOVA revealed that the richness of species and that of conidia were significantly more dependent on palm species than stemflow or throughfall. The number of rain-borne fungi in palm species exceeded that in the nearby coastal stream with an overlap of about 40%.

Key words: Canopy, hyphomycetes, conidia, species richness, diversity, abiotic factors.

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Studie podává přehled hyfomycetů, zaznamenaných během monzunového období v dešťové vodě stékající po kmenech a prokapávající korunami šesti druhů palem rostoucích na západním pobřeží Indie. Celkem zde byl zjištěn 61 druh. Bez ohledu na druh palmy je ve vodě kapající z korun zastoupeno více druhů než v toku na kmeni. Hodnoty Pearsonova koeficientu ukázaly pozitivní korelaci množství druhů i počtu konidií se vzdušnou vlhkostí, teplotou vzduchu i stékající vody a konduktivitou vody. S výjimkou areky je u všech druhů palem vyšší Shannonův index diverzity pro korunový průtok ve srovnání s tokem po kmeni. V druhovém složení hub, hodnoceném Jaccardovým indexem podobnosti, je nejvyšší podobnost v toku po kmenech *Borassus* a *Caryota* (55.5 %) a nejnižší podobnost mezi *Cocos* a *Roystonea* (16 %), zatímco v korunovém průtoku jsou si nejvíce podobné *Caryota* s *Cocos* a *Livistona* s *Cocos* (50 %), kdežto nejméně *Areca* a *Livistona* (16.7 %). Dvoucestná analýza variance prokazuje, že druhová bohatost a množství konidií závisí více na druhu palmy než na tom, zda voda teče po kmeni nebo prokapává korunami. Celkový počet druhů hub šířených deštěm na palmách přesahuje počet zjištěný v nedalekém vodním toku, přičemž jen kolem 40 % druhů je shodných.

INTRODUCTION

Canopies of trees constitute complex ecosystems serving as an interface between atmosphere and terrestrial biomass conducive to the evolution of biota (Hammond et al. 1977, Nadkarni et al. 2001, Ozanne et al. 2003). The 'crown humus' accumulated in the canopy is the product of decomposed organic matter (e.g. leaf litter, twigs and inflorescences) which supports a variety of life forms. It possesses high quantities of exchangeable cations and total nitrogen compared to the humus that covers the forest floor (Finzi et al. 1998). Besides supporting a rich fauna (e.g. arthropods, gastropods and annelids), crown humus serves as a niche for different fungi including water-borne hyphomycetes (Ellwood & Foster 2004, Gönczöl & Révay 2006, Sridhar 2009). Carroll (1981) and Bandoni (1981) observed typical freshwater-borne hyphomycetes in stemflow as well as in throughfall of tree species.

There seems to be a difference in canopy structure as well as in composition of biota between dicot and monocot plant systems. Tropical regions are endowed with a variety of wild and cultivated palms having ornamental, aesthetic and economic importance (Johnson 1998, Kulkarni & Mulani 2004, Bhat 2011). Fungal diversity in tropical palms has been investigated in view of global fungal estimates and to document cryptic species (e.g. Fröhlich & Hyde 1999). Water-borne fungi have been reported regularly beyond their favourable lotic habitats (see Sridhar 2009). Canopies constitute one of the major terrestrial habitats outside preferred aquatic habitats and provide a variety of niches for colonisation by water-borne fungi (e.g. orchids, ferns, parasitic plants, live foliage, detritus, humus, tree holes, honey dew and floral honey) (Sridhar 2009). Rain-borne fungi have been reported from canopies of a variety of riparian and non-riparian tree species in different regions of the world (Gönczöl 1976, Révay & Gönczöl 2011: Hungary; Bandoni 1981: Canada; Ando & Tubaki 1984: Japan; Czeczuga & Orłowska 1998: Poland; Gönczöl & Révay 2006: Germany, Hungary, Romania and Sweden; Sridhar et al. 2006: India; Kaufman et al. 2008: USA). In Canada, gymnosperm needles were evaluated for endophytic aquatic hyphomycetes by Sokolski et al. (2006). Besides, honey dew (Croatia, Greece and Italy) and floral honey (South Africa) in canopies have also been evaluated for water-borne fungi (Magyar et al. 2005).

To our knowledge, information on the occurrence of rain-borne hyphomycetes in palm canopies is lacking. Hence, the objective of the present study is to document these fungi in six palm species of tropical southwestern India during the rainy season. Besides, selected statistical methods were employed to compare the richness and composition of the fungal communities between different palms.

Material and methods

P a l m s. Mangalore University Campus (12°49' N, 74°55' E; 100 m a.s.l.) having predominantly lateritic soils possesses up to 20 species of wild, cultivated and ornamental palms. Six palm species were selected for the study including the wild fishtail palm (*Caryota urens* L.), palmyra palm (*Borassus flabellifer* L.), cultivated utilitarian areca nut palm (*Areca catechu* L.) and coconut palm (*Cocos nucifera* L.), and cultivated ornamental fountain palm [*Livistona rotundifolia* (Lam.) Mart.] and royal palm [*Roystonea regia* (Kunth) O.F. Cook]. Four trees of each selected species were solitary without interference of other tree species and aged about 20–25 years, growing outside the riparian zone of the nearby Konaje stream.

S a m p l i n g. During the southwest monsoon period (August 21–26, 2014), before noon, 15 min. after a pulse of rain, each day about 100 ml water draining along the stem was collected from four palms in sterile beakers by holding the rim on the surface of the trunk and stored in sterile bottles. Similarly, about 100 ml water dripping down from the palm canopy was collected onto a spread sterile polythene sheet and transferred to sterile bottles. Air humidity and air temperature at each sampling time were determined adjacent to the trunk of each palm at about 2 m above the ground in the shade (Thermo Hygro Clock TM-1, Mextech Digital Thermohygrometer, Mumbai, accuracy ± 1%). Temperature of stemflow and throughfall were recorded using a thermometer (Solid Stem Stirring Thermometer 17-876, N.S. Dimple Thermometer, New Delhi, accuracy ± 0.2 °C). The pH and conductivity of stemflow and throughfall were determined using a water analyser (Digital Conductivity Meter 304, Systronics, Ahmedabad). During sampling dates, mean air humidity was high and ranged between 78.7 and 86.7%, while mean air temperature ranged between 26.1 and 27.1 °C (Tab. 1). Mean values of temperature of stemflow and throughfall ranged between 23 and 25.3 °C, pH between 6.8 and 7.2, and conductivity between 43.7 and 141.4 µS/cm.

A s s e s s m e n t o f f u n g i. Within 30 min. of sampling, aliquots of 25 ml stemflow and throughfall ($n = 4$) were separately filtered through Millipore filters (porosity 5 µm; diam. 25 mm) and stained with 0.1% aniline blue in lactophenol. Each filter was mounted on a glass slide and scanned under a light microscope (Nikon YS100, Nikon Corporation, Tokyo) for qualitative and quantitative assessment of conidia of rain-borne hyphomycetes. Conidia were identified based on monographs (Ingold 1975, Nawawi 1985, Marvanová 1997, Santos-Flores & Betancourt-López 1997, Zhao et al. 2007).

D a t a a n a l y s i s. As abiotic factors do usually not vary drastically, the relationship between number of species and conidia in stemflow and throughfall of all palm species vs. abiotic factors was assessed by means of the Pearson correlation analysis (P values, two tailed; confidence intervals of 95%) (SPSS 16.0:

Tab. 1. Humidity, air temperature and physicochemical features of stemflow and throughfall of six palm species (n = 4, mean ± SD).
Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Palm species	Air		Stemflow and throughfall (in parentheses)		
	Humidity (%)	Temperature (°C)	Temperature (°C)	pH	Conductivity (µS/cm)
ARCA	80.7 ± 1.5	26.1 ± 0.1	23.0 ± 0 (23.5 ± 0)	7.0 ± 0.1 (7.2 ± 0.2)	43.7 ± 10.7 (99.0 ± 14.2)
BOFL	78.7 ± 1.2	26.4 ± 0.1	23.5 ± 0 (23.4 ± 0.3)	7.2 ± 0.01 (7.1 ± 0.1)	129.7 ± 25.1 (80.3 ± 9.5)
CAUR	81.4 ± 1.5	26.1 ± 0.1	24.0 ± 0 (24.2 ± 0.3)	7.2 ± 0.02 (7.2 ± 0.1)	81.0 ± 2.0 (71.1 ± 2.1)
CONU	79.3 ± 1.2	26.8 ± 0.1	25.0 ± 0 (24.8 ± 0.3)	7.0 ± 0.1 (7.1 ± 0.1)	82.8 ± 3.8 (63.4 ± 3.9)
LIRO	86.7 ± 1.1	27.1 ± 0.2	25.3 ± 0.3 (25.1 ± 0.3)	7.1 ± 0.1 (7.2 ± 0.02)	118.3 ± 3.0 (141.4 ± 9.0)
RORE	80.3 ± 0.6	26.1 ± 0.2	23.5 ± 0 (23.5 ± 0)	6.9 ± 0.1 (6.8 ± 0.1)	59.6 ± 11.5 (71.1 ± 1.0)

www.spss.com). Shannon diversity (Magurran 1988) and Pielou's equitability (Pielou 1975) of fungi were calculated for each palm species. Jaccard's percent similarity of fungal species counts in stemflow and throughfall was calculated pair-wise between the palms (Kenkel & Booth 1992). Two-way ANOVA was employed to test the impact of palms on the richness of species and conidia in stemflow as well as throughfall by employing multiple comparisons using the Holm-Sidak method (SigmaPlot, version 11, Systat Inc., USA).

RESULTS

A total of 61 staurosporous, scolecosporous and helicosporous species of rain-borne fungi (Fig. 1) were recovered from the stemflow (Tab. 2) and throughfall (Tab. 3) of palms, representing 40 vs. 50 species and 1617 vs. 2178 conidia, respectively. The top five species in stemflow and throughfall included *Anguillospora crassa*, *Flagellospora penicillioides* and *Helicomyces* sp.

In stemflow, *Cocos* showed the highest species richness (22) and *Livistona* showed the highest number of conidia (544), while *Roystonea* was represented by the lowest number of species (8) as well as conidia (27) (Fig. 2). In throughfall, species (34) as well as conidial numbers (761) were the highest in *Livistona*, while *Areca* had the lowest number of species (8) and *Roystonea* the lowest number of conidia (77). However, Pearson correlation analysis of species richness against the abiotic factors showed a significant positive correlation with air tem-

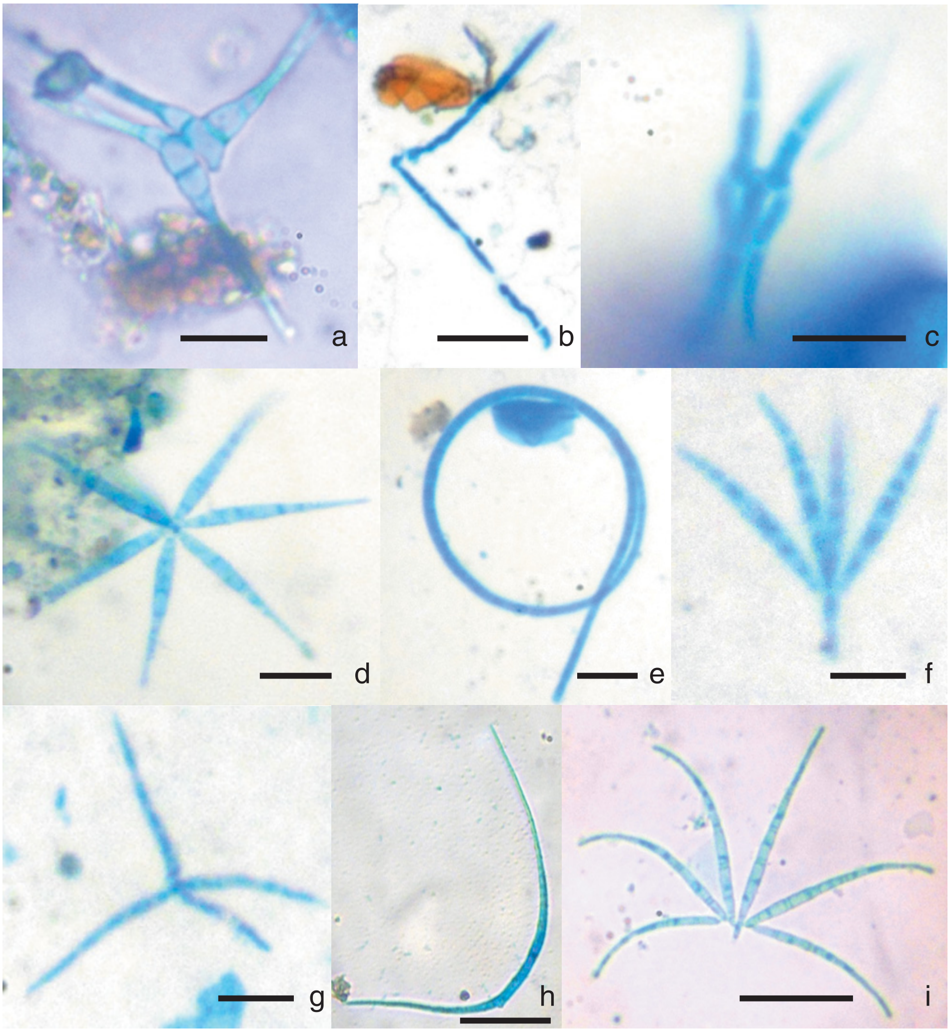

Fig. 1. Rain-borne hyphomycete conidia found in stemflow and throughfall of palms: **a** – *Campylospora chaetocladia*, **b** – *Condylospora spumigena*, **c** – *Dwayaangam cornuta*, **d** – *Flabellospora verticillata*, **e** – *Helicomyces roseus*, **f** – *Isthmotricladia gombakiensis*, **g** – *Lemonniera aquatica*, **h** – *Lunulospora curvula*, **i** – *Magdalaenaea* sp. Scale bar = 20 µm. Photo Sudeep D. Ghate.

perature (P < 0.001), air humidity (P = 0.028), temperature of stemflow/throughfall (P < 0.001) and conductivity (P = 0.017). Conidial richness against abiotic factors followed the same trend as in species richness (P values: air temperature, 0.005; air humidity, 0.023; temperature of stemflow/throughfall, 0.001; conductivity, 0.041) (Tab. 4).

Tab. 2. Percent contribution of rain-borne fungal species in stemflow of six palm species. Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Fungal species	Palm species						Total
	ARCA	BOFL	CAUR	CONU	LIRO	RORE	
Isthmotricladia gombakiensis Nawawi	5.1	3.8	–	1.6	28.5	–	10.0
Anguillospora crassa Ingold	3.4	6.1	24.2	13.4	6.2	–	6.3
Helicomyces sp.	–	9.5	3.7	19.3	0.7	–	5.7
Flagellospora penicillioides Ingold	7.6	1.9	25.7	5.1	7.6	–	5.6
Alatospora acuminata Ingold	–	–	–	–	7.7	–	5.1
Trinacrium incurvum Matsush.	–	–	–	8.7	–	–	4.8
Unidentified sp. 1 (sigmoid conidia)	18.5	–	–	–	–	–	4.8
Flabellospora crassa Alas.	11.2	14.2	5.6	4.3	14.8	13.6	4.4
Flagellospora curvula Ingold	19.6	7.9	14.5	10.2	2.0	13.6	4.1
Helicomyces torquatus L.C. Lane & Shearer	–	11.0	6.0	–	2.0	–	4.0
Helicosporium virescens (Pers.) Sivan.	–	–	–	7.1	–	–	3.9
Helicoma sp.	–	–	–	7.1	–	–	3.9
Lemonniera terrestris Tubaki	–	–	–	–	5.5	–	3.6
Flabellospora verticillata Alas.	–	8.5	1.5	–	4.9	–	2.9
Helicomyces roseus Link	–	13.2	3.0	2.4	0.7	–	2.9
Anguillospora longissima (Sacc. & P. Syd.) Ingold	5.1	11.7	3.4	3.5	2.7	6.8	2.6
Helicoma vaccinii Carris	–	–	–	4.7	–	–	2.6
Lemonniera aquatica de Wild.	7.6	10.4	0.7	–	5.3	13.6	2.6
Dactylella submersa (Ingold) Sv. Nilsson	–	–	3.7	–	–	–	2.2
Flabellospora multiradiata Nawawi	–	–	–	3.2	–	–	1.7
Trifurcospora irregularis (Matsush.) K. Ando & Tubaki	–	–	–	–	2.6	20.4	1.5
Alatospora pulchella Marvanová	5.1	–	–	–	–	–	1.3
Trinacrium subtile Riess	5.1	–	–	0.8	2.7	–	1.3
Trinacrium robustum Tzean & J.L. Chen	3.4	–	3.0	–	2.0	11.3	1.1
Curucispora sp.	–	–	0.7	–	1.8	–	1.0
Cylindrocarpon sp.	3.4	–	–	–	–	–	0.9
Dwayaangam cornuta Descals	–	–	1.5	–	–	–	0.9
Helicosporium murinum Goos	–	–	–	1.6	–	–	0.9
Helicomyces colligatus R.T. Moore	–	1.9	–	–	–	–	0.9
Hydrometrospora symmetrica J. Gönczöl & Révay	3.4	–	–	–	–	–	0.9
Trisulcosporium sp.	–	–	–	–	–	13.6	0.9
Dendrospora torulosa Descals & J. Webster	–	–	–	1.2	–	–	0.7
Helicoma viridis (Corda) S. Hughes	–	–	–	1.2	–	–	0.7
Helicosporium sp.	–	–	0.7	1.6	–	–	0.7
Triscelophorus acuminatus Nawawi	–	–	–	0.8	1.3	–	0.7
Ypsilina graminea (Ingold, P.J. McDougall & Dann) Descals, J. Webster & Marvanová	–	–	2.2	0.8	–	6.8	0.7
Dendrospora juncicola S.H. Iqbal	1.7	–	–	–	–	–	0.4

Fungal species	Palm species						Total
	ARCA	BOFL	CAUR	CONU	LIRO	RORE	
Dendrospora nana Descals & J. Webster	–	–	–	0.8	–	–	0.4
Helicosporium guianense Linder	–	–	–	0.8	0.7	–	0.4
Triscelophorus monosporus Ingold	–	–	–	–	0.7	–	0.4

Tab. 3. Percent contribution of rain-borne fungal species in throughfall of six palm species. Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Fungal species	Palm species						Total
	ARCA	BOFL	CAUR	CONU	LIRO	RORE	
Anguillospora crassa Ingold	16.3	11.8	11.3	4.2	12.8	–	6.2
Flagellospora curvula Ingold	39.6	11.8	22.1	1.3	5.9	8.9	5.7
Trifurcospora irregularis (Matsush.) K. Ando & Tubaki	–	2.4	–	13.0	6.2	–	5.5
Helicomyces sp.	–	–	–	13.0	2.2	–	4.9
Flagellospora penicillioides Ingold	–	–	6.9	3.0	6.3	–	4.6
Isthmotricladia gombakiensis Nawawi	–	–	2.0	5.9	5.1	–	4.2
Flabellospora crassa Alas.	5.9	4.7	8.8	9.8	5.2	19.1	4.0
Helicosporium virescens (Pers.) Sivan.	–	–	–	4.8	–	–	3.9
Alatospora acuminata Ingold	–	–	1.0	8.0	4.3	3.6	3.7
Lemonniera aquatica de Wild.	7.4	–	8.2	5.4	4.8	20.2	3.6
Lunulospora curvula Ingold	–	–	–	–	4.0	–	3.6
Lemonniera sp.	–	–	–	–	4.0	–	3.6
Alatospora pulchella Marvanová	–	–	2.0	4.3	–	–	2.9
Anguillospora longissima (Sacc. & P. Syd.) Ingold	9.9	7.9	4.9	1.3	7.0	–	2.8
Lemonniera terrestris Tubaki	–	4.7	2.9	5.2	4.8	7.1	2.7
Helicomyces roseus Link	–	–	4.3	4.2	0.8	8.9	2.5
Dactylella submersa (Ingold) Sv. Nilsson	–	9.5	4.4	–	–	–	2.3
Trinacrium robustum Tzean & J.L. Chen	–	–	1.0	0.4	4.0	–	2.1
Lemonniera pseudofloscula Dyco	–	–	1.6	–	3.0	–	1.8
Lambdasporium sp.	–	–	–	–	2.0	–	1.8
Phalangispora constricta Nawawi & J. Webster	–	–	2.2	–	1.6	–	1.8
Tridentaria sp.	–	–	–	4.8	0.8	–	1.8
Unidentified sp. 2 (sigmoid conidia)	–	11.8	–	–	–	–	1.8
Lemonniera filiformis R.H. Petersen	–	–	2.2	–	–	–	1.6
Flabellospora verticillata Alas.	–	–	1.7	0.4	2.8	7.1	1.4
Helicomyces torquatus L.C. Lane & Shearer	–	–	1.5	2.2	–	–	1.4
Triscelophorus acuminatus Nawawi	–	13.0	1.5	–	1.8	3.6	1.4
Trinacrium incurvum Matsush.	–	–	1.5	3.0	0.8	–	1.2
Isthmotricladia laeensis Matsush.	–	–	1.0	2.2	0.8	–	1.1
Phalangispora bharathensis T.S.K. Prasad & Bhat	–	–	1.5	–	–	–	1.1
Triscelophorus konajensis K.R. Sridhar & Kaver.	–	–	–	–	1.2	–	1.1

Fungal species	Palm species						Total
	ARCA	BOFL	CAUR	CONU	LIRO	RORE	
Ypsilina graminea (Ingold, P.J. McDougall & Dann) Descals, J. Webster & Marvanová	–	–	–	–	1.1	–	1.0
Curucispora sp.	–	–	1.5	–	0.8	–	0.9
Helicoma griseum Bonord.	–	5.9	–	–	–	–	0.9
Helicosporium sp.	–	–	–	0.9	1.2	–	0.9
Trinacrium subtile Riess	8.9	2.4	1.0	2.2	1.0	5.4	0.9
Heliscella stellata (Ingold & V.J. Cox) Marvanová	5.9	4.7	1.5	–	–	–	0.8
Dwayaangam cornuta Descals	5.9	–	–	–	–	–	0.7
Helicoma viridis (Corda) S. Hughes	–	–	–	0.9	–	–	0.7
Magdalaenaea sp.	–	–	–	–	0.8	–	0.7
Anguillospora sp.	–	–	–	–	–	7.1	0.7
Tricladium sp.	–	–	–	–	0.8	–	0.7
Triscelophorus monosporus Ingold	–	7.1	–	–	0.6	5.4	0.6
Helicoma sp.	–	–	1.0	–	0.4	–	0.5
Campylospora chaetocladia Ranzoni	–	–	0.5	–	–	–	0.4
Condylospora spumigena Nawawi	–	–	–	–	–	3.5	0.4
Dendrospora sp.	–	–	–	–	0.4	–	0.4
Helicoma vaccinii Carris	–	2.4	–	–	–	–	0.4
Ingoldiella fibulata Nawawi	–	–	–	–	0.4	–	0.4
Retiarius sp.	–	–	0.5	–	–	–	0.4

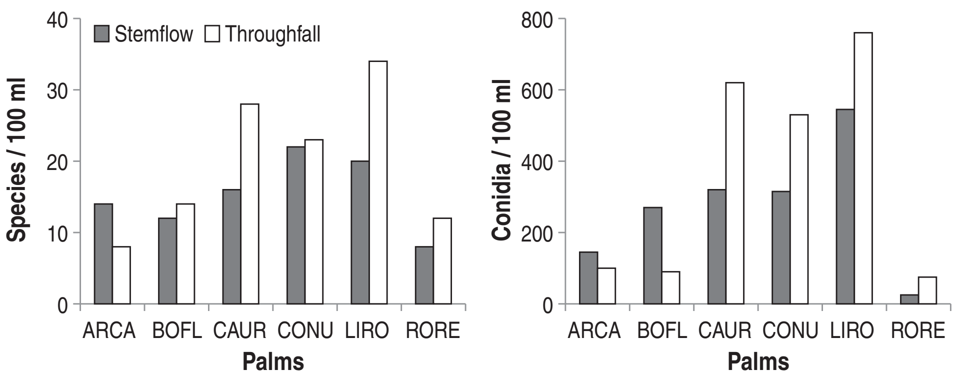

Fig. 2. Richness of species and richness of conidia of rain-borne hyphomycetes in stemflow and throughfall of six palm species.
Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Tab. 4. Pearson correlation coefficients between species and conidial richness of rain-borne fungi in six palms against abiotic factors (P values in parenthesis).

Richness	Air		Stemflow and throughfall		
	Humidity	Temperature	Temperature	pH	Conductivity
Species	0.365 (0.028)	0.588 (<0.001)	0.705 (<0.001)	0.263 (0.121)	0.393 (0.017)
Conidia	0.376 (0.023)	0.453 (0.005)	0.590 (0.001)	0.305 (0.070)	0.342 (0.041)

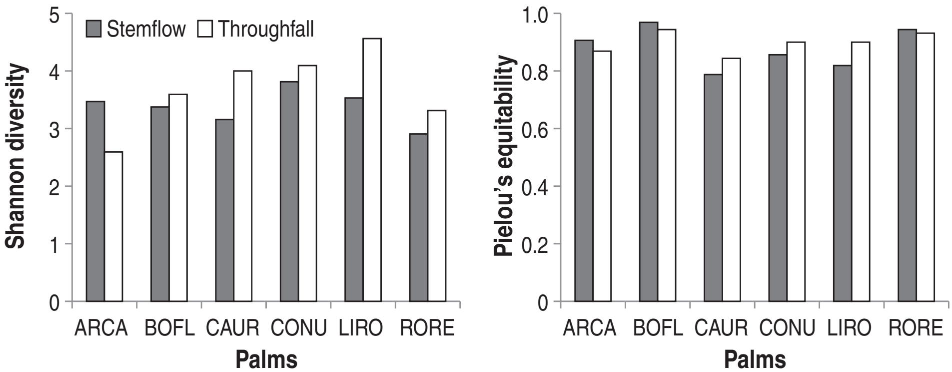

Fig. 3. Shannon diversity and Pielou's equitability of rain-borne hyphomycetes in stemflow and throughfall of six palm species.
Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Except for *Areca*, Shannon diversity was higher in throughfall than in stemflow (Fig. 3). Throughfall of *Livistona* showed the highest Shannon diversity followed by *Cocos* and was the lowest in *Areca*. In stemflow, diversity was the highest in *Cocos* and the lowest in *Roystonea*. Pielou's equitability was the highest in stemflow as well as throughfall of *Borassus*, while it was the lowest in *Caryota*. Jaccard's percent similarity of species counts in stemflow among the palms ranged between 16% (*Cocos* vs. *Roystonea*) and 55.5% (*Borassus* vs. *Caryota*), while for throughfall it ranged between 16.7% (Areca vs. *Livistona*) and 50% (*Caryota* vs. *Cocos* and *Livistona* vs. *Cocos*) (Tab. 5).

A two-way ANOVA revealed that species richness was significantly affected by palm species ($P < 0.001$) but not by stemflow and throughfall ($P = 0.07$) (Tab. 6). Based on multiple comparisons with the Holm-Sidak method, we found a significant difference in the overall species richness (stemflow + throughfall) between *Livistona* and *Roystonea* ($P = 0.003$), *Livistona* and *Areca* ($P = 0.004$), and

Tab. 5. Jaccard's similarity (%) of rain-borne fungi in stemflow and throughfall of six palm species. Abbreviations: ARCA – *Areca catechu*; BOFL – *Borassus flabellifer*; CAUR – *Caryota urens*; CONU – *Cocos nucifera*; LIRO – *Livistona rotundifolia*; RORE – *Roystonea regia*.

Stemflow	BOFL	CAUR	CONU	LIRO	RORE
ARCA	36.85	30.4	29.0	36.0	29.4
BOFL		55.5	30.7	52.3	25.0
CAUR			31.0	52.0	33.3
CONU				52.3	16.0
LIRO					27.2

Throughfall	BOFL	CAUR	CONU	LIRO	RORE
ARCA	35.3	25.0	24.0	16.7	28.5
BOFL		27.2	22.5	23.6	30.0
CAUR			50.0	48.7	30.0
CONU				50.0	30.7
LIRO					27.8

Livistona and *Borassus* ($P = 0.004$). There was a significant difference in species richness between stemflow and throughfall of *Caryota* ($P = 0.036$). There was also a significant difference in species richness between stemflow of *Livistona* and *Roystonea* ($P = 0.003$), throughfall of *Livistona* and *Areca* ($P < 0.001$), *Livistona* and *Roystonea* ($P < 0.001$), and *Livistona* and *Borassus* ($P < 0.001$). The conidial richness was significantly dependent on palm species ($P = 0.006$) and also a significant difference was seen between the overall conidial richness (stemflow + throughfall) between *Livistona* and *Roystonea* ($P < 0.001$), and *Livistona* and *Areca* ($P = 0.002$).

Tab. 6. Two-way ANOVA of the impact of palm species and samples (stemflow and throughfall) on richness of species and conidia of rain-borne fungi in six palms.
Abbreviations: df – degrees of freedom; F – ratio of two mean square values; P – level of significance.

Treatment	Species richness			Conidial richness		
	df	F	P	df	F	P
Palm	5	8.838	<0.001	5	4.327	0.006
Sample	1	3.605	0.070	1	1.169	0.290
Palm × Sample	5	1.360	0.274	5	0.702	0.627

Discussion

The oldest reports on the occurrence of aquatic hyphomycetes are from terrestrial habitats (see Bärlocher 1992). Many studies have supported Carroll's (Carroll 1981) hypothesis that canopies serve as a guild for a variety of fungi (see Sridhar 2009). Being a macroecological niche, the canopy is one of the major reservoirs of water-borne fungi, replenishing their propagules in streams and other habitats. The total area of canopy of a specific forest region could be comparable to the catchment area of a stream (watercourse and boundary). It is not surprising that rain-borne fungi in the canopy function similarly to those in streams, especially during the rainy season, and survive on the substrates (leaf litter, wood, bark, humus and live tissues) during unfavourable conditions. Our study showed a positive correlation of species as well as conidial richness of rain-borne fungi in palms with abiotic factors (strong correlation: air temperature and flow water temperature; relatively weak correlation: air humidity and conductivity). Palm species has a stronger impact on species/conidial richness than only temperature, as is seen from the Pearson coefficients.

Canopies are known to provide microhabitats for fungal colonisation and stratification (Hedger 1985). The zonation of fungi in canopies may depend on the canopy structure of a specific tree species (e.g. branching, total surface area, crevices/holes and leaf/stem/bark features), availability of detritus, and allellopathic impacts. Unlike dicot tree species, palm canopies may support a higher accumulation of autochthonous and allochthonous litter and sediment. However, tree species associating epiphytes such as ferns, orchids and parasitic plants have the additional advantage of accumulating higher quantities of litter and humus than those lacking such association. For instance, *Borassus* and *Cocos* accommodate orchids (e.g. *Vanda*) and ferns (e.g. *Drynaria*). Besides, palms vary in their ability to shed or retain senescent/dead leaves, which may influence the occurrence of rain-borne fungi in stemflow and throughfall. Based on the extent of leaf shedding (or retention of drooping senescent/dead leaves), it is possible to roughly grade the palms studied from most to least shedding: *Cocos* < *Areca* < *Borassus* < *Caryota* < *Roystonea* < *Livistona*. However, the species and conidial richness in our study did not match exactly with the above sequence, although it is likely that the stemflow of palms partly consists of washings of erect (young) and senescent/dead (drooping) leaves at least in some palms, so that the stemflow also contains fungal spores found in throughfall.

Filtering stemflow, throughfall and water accumulated in tree holes is an easy method to assess the occurrence of rain-borne fungi in canopies. Other methods like incubation of trapped litter or part of the host (in still water and bubble chamber) and baiting canopy humus/sediment onto sterile leaf disks provide further insights into functional attributes of rain-borne fungi in canopies. The present observation on the occurrence of rain-borne fungi in tropical palms is interesting, since a wide variety of known and unknown staurosporous, scolecosporous and helicosporous species were obtained. Although the palm species studied are located in the same geographic region, species richness in stemflow and throughfall differed widely (Jaccard's similarity, 16–55.5%). Richness of species as well as conidia showed a more or less increasing trend from *Roystonea* through *Areca*, *Borassus*, *Caryota*, and *Cocos* to *Livistona*. When pooling data from all palms, throughfall contained a higher number of species as well as conidia than stemflow. Two-way ANOVA revealed a strong dependence of fungal species richness and conidial counts on palm species rather than stemflow and throughfall, which was also supported by Jaccard's similarity, which showed a wide variation between palm species.

Our study revealed presence of a mosaic of conidia from true aquatic hyphomycetes, pseudo-aquatic hyphomycetes and aero-aquatic helicosporous conidial fungi in palm canopies. Occurrence of a wide variety of rain-borne fungi in canopies reveals that many of them have adopted an endophytic lifestyle. Occurrence of conidia in stemflow and throughfall alone, however, does not provide definitive evidence of fungal functions in canopies. Our study revealed that 5% of conidia trapped on filters had germinated, providing evidence that they are alive and that the fungi presumably have a role in canopies (e.g. decomposition). The number of rain-borne fungi in stemflow and throughfall in 14 non-riparian dicot tree species studied in the same region (Sridhar & Karamchand 2009) were almost equivalent to that of the six palm species in the present study (63 vs. 61 species). However, the species richness in non-riparian dicots as well as palms was higher than species richness in the nearest Konaje stream (63 vs. 25 species) with an overlap of up to 40% (Sridhar & Kaveriappa 1984, Sridhar & Karamchand 2009, Sridhar & Sudheep 2010, Sridhar et al. 2013; Sridhar unpubl. obs.). Occurrence of several unidentified conidial forms supports the assumption that canopies provide niches for hitherto undescribed species.

Several potential questions need to be addressed based on the present and earlier studies on rain-borne fungi in tree canopies. Do palms accommodate more rain-borne fungi than other tree species? Does the composition of rain-borne fungi in riparian palms differ from non-riparian palms? Are rain-borne fungi in palm canopies zone-dependent? Should we look for sexual states of rain-borne hyphomycetes in canopies? What are the roles of rain-borne fungi in nutrient cycles in canopies? Appropriate molecular approaches may certainly answer some of these questions more precisely. We are currently applying molecular tools to investigate such questions in our laboratory.

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REFERENCES

ANDO K., TUBAKI K. (1984): Some undescribed hyphomycetes in the rain drops from intact leaf surface. – Trans. Mycol. Soc. Japan 25: 21–37.

BANDONI R.J. (1981): Aquatic hyphomycetes from terrestrial litter. – In: Wicklow D.T., Carroll G.C., eds., The fungal community – its organization and role in the ecosystem, p. 693–708. Marcel Dekker, New York.

BÄRLOCHER F. (1992): Research on aquatic hyphomycetes: historical background and overview. – In: Bärlocher F., ed., The ecology of aquatic hyphomycetes, p. 1–15. Springer-Verlag, Berlin.

BHAT K.G. (2011): Palms of Karnataka. – 100 p., published by the author (Madhuca, Srinivasa Nagara, Chitpady, Udupi), Karnataka, India.

CARROLL G.C. (1981): Mycological inputs to ecosystem analysis. – In: Wicklow D.T., Carroll G.C., eds., The fungal community – its organization and role in ecosystem, p. 25–35. Marcel Dekker, New York.

CZECZUGA B., ORŁOWSKA M. (1998): Hyphomycetes in rain water draining from intact trees. – Roczniki Akademii Medycznej w Białymstoku 43: 66–84.

ELLWOOD M.D.F., FOSTER W.A. (2004): Doubling the estimate of invertebrate biomass in a rainforest canopy. – Nature 429: 549–551.

FINZI A.C., CANHAM C.D., BREEMEN V. (1998): Canopy tree-soil interactions within temperate forests: Species effects on pH and cations. – Ecological Applications 8: 447–454.

FRÖHLICH J., HYDE K.D. (1999): Biodiversity of palm fungi in the tropics: are global fungal diversity estimates realistic? – Biodiversity and Conservation 8: 977–1004.

GÖNCZÖL J. (1976): Ecological observations on the aquatic hyphomycetes of Hungary II. – Acta Bot. Acad. Sci. Hung. 22: 51–60.

GÖNCZÖL J., RÉVAY Á. (2006): Species diversity of rainborne hyphomycete conidia from living trees. – Fungal Diversity 22: 37–54.

HAMMOND P.M., STORK N.E., BRENDELL M.J. (1977): Tree crown beetles in context: a comparison of canopy and other ecotone assemblages in a lowland tropical forest in Sulawesi. – In: Stork N.E., Adis J., Didham R., eds., Canopy arthropods, p. 184–223. Chapman and Hall, London.

HEDGER J. (1985): Tropical agarics, resource relations and fruiting periodicity. – In: Moore D., Casselton L.A., Wood D.A., Frankland J.C., eds., Developmental Biology of Higher Plants, p. 41–86. Cambridge University Press, Cambridge.

INGOLD C.T. (1975): An illustrated guide to aquatic and water-borne Hyphomycetes (Fungi Imperfecti) with notes on their biology. – Freshwater Biological Association Scientific Publication No. 30, 96 p., Ambleside, Cumbria.

JOHNSON D.V. (1998): Tropical Palms. – Food and Agriculture Organization of the United Nations, Rome; www.fao.org/3/a-x0451e.pdf. [accessed 1 March 2015]

KAUFMAN M.G., CHEN S., WALKER E.D. (2008): Leaf-associated bacterial and fungal taxa shifts in response to larvae of the tree hole mosquito, *Ochlerotatus triseriatus*. – Microbial Ecology 55: 673–684.

KENKEL N.C., BOOTH T. (1992): Multivariate analysis in fungal ecology. In: Wicklow D.T., Carroll G.C., eds., The fungal community: its organization and role in the ecosystem, 2nd ed., p. 209–227. Marcel Dekker, New York.

KULKARNI A.R., MULANI R.M. (2004): Indigenous palms of India. – Current Science 86: 1598–1603.

LUDWIG J.A., REYNOLDS J.F. (1988): Statistical ecology: A primer on methods and computing. – 337 p., Wiley, New York.

MAGURRAN A.E. (1988): Ecological diversity and its measurement. – 260 p., Chapman and Hall, New Jersey.

MAGYAR D., GÖNCZÖL J., RÉVAY Á., GRILLENZONI F., SEIJO-COELLO M.D.C. (2005): Stauro- and scolecoconidia in floral and honeydew honeys. – Fungal Diversity 20: 103–120.

MARVANOVÁ L. (1997): Freshwater hyphomycetes: a survey with remarks on tropical taxa. – In: Janardhanan K.K., Rajendran C., Natarajan K., Hawksworth D.L., eds., Tropical mycology, p. 169–226. Science Publishers, New York.

NADKARNI N.M., MEWIN M.C., NIEDERT J. (2001): Forest canopies, plant diversity. – In: Levin S.A., ed., Encyclopedia of Biodiversity, Volume 3, p. 27–40. Academic Press, New York.

NAWAWI A. (1985): Aquatic hyphomycetes and other water-borne fungi from Malaysia. – Malay. Nat. J. 39: 75–134.

OZANNE C.M.P., ANHUF D., BOULTER S.L., KELLER M., KITCHING R.L., KORNER C., MEINZER F.C., MITCHELL A.W., NAKASHIZUKA T., SILVA DIAS P.L., STORK N.E., WRIGHT S.J., YOSHIMURA M. (2003): Biodiversity meets the atmosphere: A global view of forest canopies. – Science 301: 183–186.

PIELOU F.D. (1975): Ecological diversity. – 165 p., Wiley InterScience, New York.

RÉVAY Á., GÖNCZÖL J. (2011): Canopy fungi ("terrestrial aquatic hyphomycetes") from twigs of living evergreen and deciduous trees in Hungary. – Nova Hedwigia 92: 303–316.

SANTOS-FLORES C.J., BETANCOURT-LÓPEZ C. (1997): Aquatic and water-borne hyphomycetes (Deuteromycotina) in streams of Puerto Rico (including records from other Neotropical locations). – Carib. J. Sci. (special publication No. 2): 1–116.

SOKOLSKI S., PICHÉ Y., CHAUVET E., BÉRUBÉ J.A. (2006): A fungal endophyte of black spruce (*Picea mariana*) needles is also an aquatic hyphomycete. – Molecular Ecology 15: 1955–1962.

SRIDHAR K.R. (2009): Fungi in the tree canopy – an appraisal. – In: Rai M., Bridge P., eds., Applied Mycology, p. 73–91. CAB International, Wallingford.

SRIDHAR K.R., KARAMCHAND K.S. (2009): Diversity of water-borne fungi in throughfall and stemflow of tree canopies in India. – Sydowia 61: 327–344.

SRIDHAR K.R., KARAMCHAND K.S., BHAT R. (2006): Arboreal water-borne hyphomycetes with oakleaf basket fern *Drynaria quercifolia*. – Sydowia 58: 309–320.

SRIDHAR K.R., KARAMCHAND K.S., SEENA S. (2013): Fungal assemblage and leaf litter decomposition in coastal stream and riparian tree holes of the south-west India. – Mycology 4: 118–124.

SRIDHAR K.R., KAVERIAPPA K.M. (1984): Seasonal occurrence fungi in Konaje stream (Mangalore), India. – Hydrobiologia 119: 101–105.

SRIDHAR K.R., SUDHEEP N.M. (2010): Diurnal fluctuation of spores of freshwater hyphomycetes in two tropical streams. – Mycosphere 1: 89–101.

ZHAO G.Z., LIU X.Z., WU W.P. (2007): Helicosporous hyphomycetes from China. – Fungal Diversity 26: 313–524.