Cryptogamie, Mycologie, 2013, 34 (3): 243-258
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Some freshwater fungi from the Brazilian semi-arid region, including two new species of hyphomycetes

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Résumé – Une étude préliminaire des champignons d'eau douce dans un ruisseau dans la zone semi-aride brésilienne a été effectuée. Des échantillons de débris végétaux submergés ont été collectés tous les trois mois entre 2007 et 2009 dans un petit ruisseau dans la « Serra da Jibóia », état de Bahia. Nous décrivons et illustrons deux nouvelles espèces de hyphomycètes, notamment *Dactylaria saccardoana* et *Quadracaea stauroconidia*, et nous rapportons 151 taxons comprenant à la fois des champignons meiosporiques et mitosporiques.

Ascomycètes / *Dactylaria* / débris végétaux / *Quadracaea* / Taxinomie

Abstract – A preliminary study on freshwater fungi in a stream in the Brazilian semi-arid region was performed. Samples of submerged plant debris were randomly collected every three months from 2007 to 2009 in a small stream surrounded by riparian vegetation in the "Serra da Jibóia" Bahia state. We described and illustrated two new species of hyphomycetes, *Dactylaria saccardoana* and *Quadracaea stauroconidia*, and reported one hundred and fifty-one taxa that consist of both meiosporic and mitosporic fungi.

Ascomycetes / *Dactylaria* / Plant debris / *Quadracaea* / Taxonomy

doi/10.7872/crym.v34.iss2.2013.243

INTRODUCTION

The Brazilian semi-arid region extends for 970.000 km^2 and includes both the North of Minas Gerais and eight states in the Northeast of Brazil (Giulietti & Queiroz, 2006). The latest mycological collection data show that 955 fungi have been recorded from the Brazilian semi-arid region (Gusmão *et al.*, 2006b). The most representative group studied includes the terrestrial mitosporic ascomycetes (407 spp.), followed by meiosporic ascomycetes (179 spp) (Gusmão *et al.*, 2006b). Since these fungi were collected only from terrestrial habitats (Bezerra & Maia, 2006, Gusmão *et al.,* 2006a), the knowledge of the biodiversity of freshwater fungi in the semi-arid region remains poorly understood.

The freshwater fungi represent a phylogenetically and ecologically diverse group composed of various ascomycetes (Shearer *et al.*, 2007). Recent studies have shown that 1337 fungi have been reported from freshwater habitats (Jones & Choeyklin, 2008; Jones *et al.*, 2009). In view of the lack of knowledge concerning freshwater fungi from the semi-arid region of Brazil, we initiated a taxonomic survey to determine the species richness of these fungi and previously described one new species (Barbosa *et al.*, 2008).

In this paper, we describe and illustrate two new mitosporic ascomycetes from freshwater habitats from the semi-arid of Brazil. In addition, we present a preliminary checklist of freshwater mitosporic and meiosporic ascomycetes collected during the study. Our study may provide baseline taxonomic data for the occurrence of freshwater fungal species in the Brazilian semi-arid region.

MATERIALS AND METHODS

Study area. – The "Serra da Jibóia" is one of nine hygrophilous forest patches in the Brazilian semi-arid region that extends along six cities in the eastern state of Bahia (12º51'S, 39º28'W). Its area is about 22.000 ha and the altitude ranges from 750 to 840 meters. In 2000, about 147 priority areas in Brazil were selected for conservation of biodiversity, and the "Serra da Jibóia" was designated as an extreme biological important area (Ministério do Meio Ambiente, 2000).

Sampling method. – A total of eight collection trips were made in Santa Terezinha City, Bahia State (12º51'S e 39º28'W). every three months from July 2007 to May 2009. Samples of submerged dead plant debris (twigs, leaves, barks and petioles) was randomly collected from a small stream along an altitudinal gradient and placed in plastic bags. In the laboratory, samples were placed in Petri dish moist chambers and stored in 170 L polystyrene boxes with 200 ml sterile water and 2 ml glycerol. The plant substrates were investigated and the fungal slides were prepared follow the method of Barbosa & Gusmão (2011). Dried herbarium samples, including slides of meiosporic ascomycetes, were sent to the Laboratory of Mycology in the University of Illinois at Urbana-Champaign for identification. Slides of material were made from dried herbarium samples using the double cover glass method of Volkmann-Kohlmeyer & Kohlmeyer (1996). All slides and air-dried materials of both mitosporic and meiosporic ascomycetes were deposited in Herbarium HUEFS. Illustrations were made as described by Barber & Keane (2007).

RESULTS

During the investigation of freshwater fungi on submerged plant debris, 151 taxa were identified and are listed herein (Table 1). Of these, 136 species were mitosporic fungi and 15 species belong to meiosporic ascomycetes. Among the mitosporic fungi, 134 species were hyphomycetes and only two species, *Dinemasporium lanatum* and *Satchmopsis brasiliensis*, were coelomycetes. With respect to ecological guild for mitosporic fungi, *Brachiosphaera tropicalis* and *Ingoldiella hamata* are Ingoldian fungi, while *Cancellidium applanatum, Candelabrum brocchiatum, Helicomyces roseus* and *Inesiosporium longispirale* belong to the aeroaquatic fungi. The 130 remaining species are miscellaneous mitosporic ascomycetes (Shearer *et al.*, 2007). Among meiosporic ascomycetes, 13 species belong to Sordariomycetes, one species, *Jahnula seychellensis* belongs to Dothideomycetes and one (*Orbilia*) to Orbiliomycetes. Woody debris was the highest colonized substrate with 74 species occurring on it, while 51 species were found on foliicolous debris. Twenty-six species were found on both woody and herbaceous debris.

TAXONOMY

Dactylaria saccardoana F.R. Barbosa & Gusmão, sp. nov. **Figs 1-6**

MycoBank: MB 801604

Setae 4-7-septate, unbranched, rect, smooth, brown at the base becoming paler towards the rounded, sterile apex, 97-127 × 3-4.5 µm. Conidiophores mononematous, macronematous, aggregated or solitary, unbranched, 2-3-septate, erect, rect or flexuous, smooth-walled, brown at the base, paler above, 25-76 × 2.3-3 µm. Conidiogenous cells polyblastic, terminal, integrated, sympodial with inconspicuous, narrow denticles, subhyaline, 15-34 × 3-4 µm. Conidia solitary, dry, 0-1-septate, smooth, triangle-shaped, truncate at the apex, tapering towards the rounded base, subhyaline to hyaline, 9-12 µm high, 1.5-3 µm wide at the apex, 0.8-1.5 µm wide at the base.

Holotype: BRAZIL. BAHIA: Santa Terezinha, Serra da Jibóia, water temperature 23 C, pH 7.4. On submerged leaves, 13 Apr 2009, *F.R. Barbosa* and *L.F.P. Gusmão* (HUEFS 155280).

Etymology: in honor of P. A. Saccardo (1845-1921), who described the genus.

Teleomorph: Unknown.

Commentary: *Dactylaria* Sacc. was erected to accommodate *D. purpurella* (Sacc.) Sacc., collected from decaying Oak wood from Italy and described as *Acrothecium purpurellum* Sacc. (Saccardo, 1877; 1880). Since then, *Dactylaria* has been revised, but its taxonomy remains complex. In a revision of the genus, de Hoog (1985) recognized 41 species and subdivided them into four sections: *Dactylaria*, *Mirandina* (G. Arnaud ex Matsush.) de Hoog, *Diplorhinotrichum* (Höhn.) de Hoog and *Pleurophragmium* (Constantin) de Hoog. Later, Goh & Hyde (1997) provided a key to 37 species of *Dactylaria,* which were described after the taxonomic treatment of de Hoog (1985). Additionally, fourteen described species were later treated in a synopsis by Paulus *et al.* (2003). Species of this genus occurr worldwide and have been recorded previously as saprobes from fresh water (Hyde & Goh, 1998a) and terrestrial habitats (Gené *et al.*, 2000). In addition, its

Table 1. Freshwater fungi from Brazilian semi-arid area on different substrates

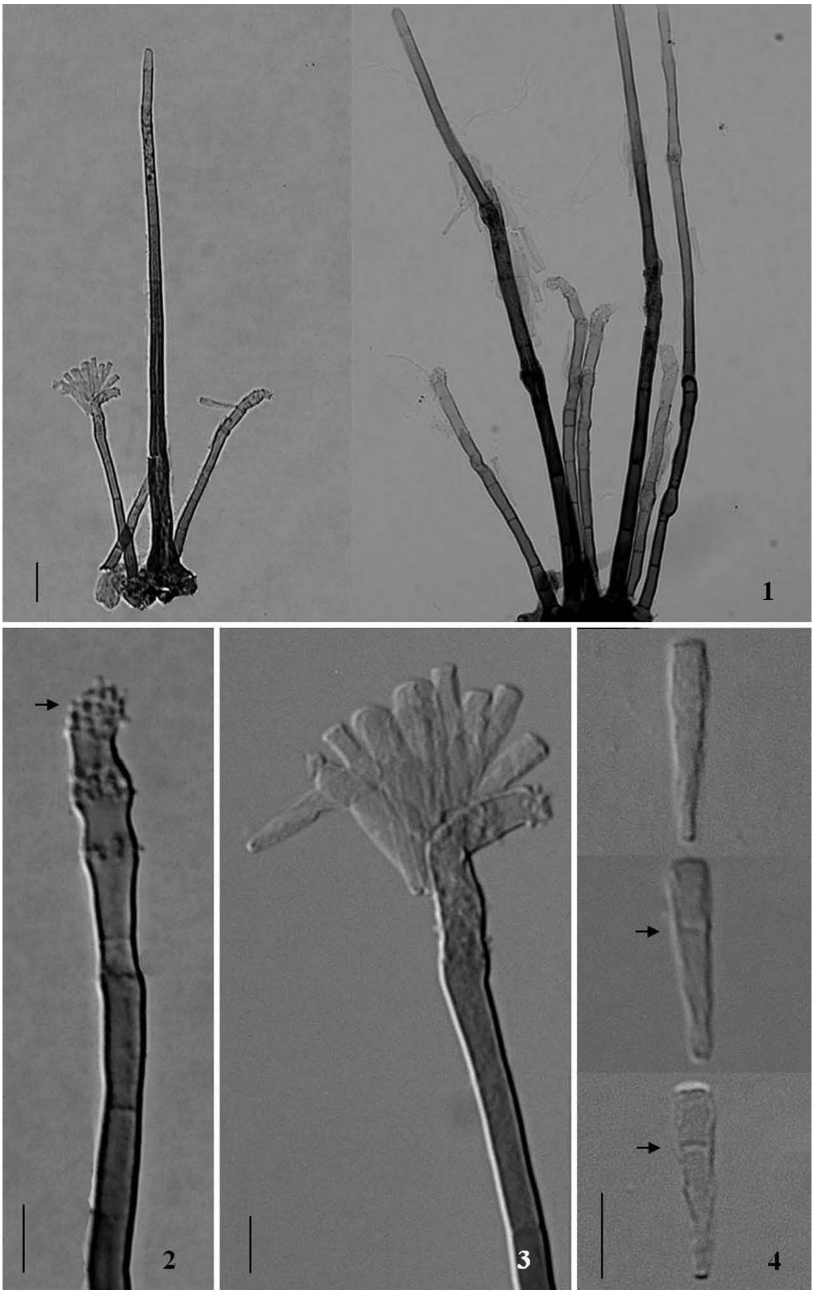
Fungus name	*Twig*	*Bark*	*Leaf*	*Petiole*
Meiosporic ascomycetes				
Aniptodera chesapeakensis Shearer & M.A. Mill.	+			
Annulatascus apiculatus F.R. Barbosa & Gusmão	+			
Annulatascus velatisporus K.D. Hyde	+			+
Anthostomella aquatica K.D. Hyde & Goh	+	+		+
Calosphaeria sp.	+			
Chaetomium homopilatum Omvik	+			
C. longicolleum Krzemien. & Badura			+	
Chaetosphaeria lignomollis F.A. Fernández & Huhndorf	+			
Jahnulla seychellensis K.D. Hyde & S.W. Wong	+			
Nectria sp.				+
Linocarpon sp.	+			
Ophioceras venezuelensis Shearer *et al*.	+			
Orbilia sp.				+
Tamsiniella labiosa S.W. Wong *et al*.	+			
Torrentispora crassiparietis Fryar & K.D. Hyde		+		
Coelomycetes				
Dinemasporium lanatum Nag Raj & R.F. Castañeda			+	+
Satchmopsis brasiliensis B. Sutton & Hodges			+	
Hyphomycetes				
Acrogenospora sphaerocephala (Berk. & Broome) M.B. Ellis	+	+	+	
Actinocladium rhodosporum Ehrenb.	+			
A. verruculosum W.P. Wu	+			
Arthrobotrys oligospora Fresen.			+	
Bactrodesmium longisporum M.B. Ellis	+	+		
Beltrania rhombica Penz.			+	+
Beltraniella portoricensis (F. Stevens) Piroz. & S.D. Patil			+	
Berkleasmium corticola (P. Karst.) R.T. Moore		+		
Brachiosphaera tropicalis Nawawi		+		
Brachydesmiella anthostomelloidea Goh & K.D. Hyde				+
B. caudata V. Rao & de Hoog				+
Brachysporiella gayana Bat.	+	+		
B. pulchra (Subram.) S. Hughes	+			
Cacumisporium pleuroconidiophorum (Davydkina & Melnik) R.F. Castañeda *et al*.	+	+		
C. sigmoideum Mercado & R.F. Castañeda	+			
Camposporidium cristatum Nawawi & Kuthub.			+	+
Canalisporium caribense (Hol.-Jech. & Mercado) Nawawi & Kuthub.		+		
C. exiguum Goh & K.D. Hyde			+	
Cancellidium applanatum Tubaki	+			
*Candelabrum brocchiatum*Tubaki	+	+		
Chaetopsina fulva Rambelli			+	+
C. splendida B. Sutton & Hodges				+
Chalara alabamensis Morgan-Jones & E.G. Ingram				+
Chloridium obclaviforme J. Mena & Mercado		+		
C. virescens (Pers.) W. Gams & Hol.-Jech.	+			
Circinotrichum papakurae S. Hughes & Piroz.			+	
Craspedodidymum sp.	+			
C. cubense J. Mena & Mercado		+		
Cryptophiale kakombensis Piroz.			+	
C. udagawae Piroz. & Ichinoe	+		+	
Cryptophialoidea fasciculata Kuthub. & Nawawi	+			+
C. secunda (Kuthub. & B. Sutton) Kuthub. & Nawawi	+			

Table 1. Freshwater fungi from Brazilian semi-arid area on different substrates *(continued)*

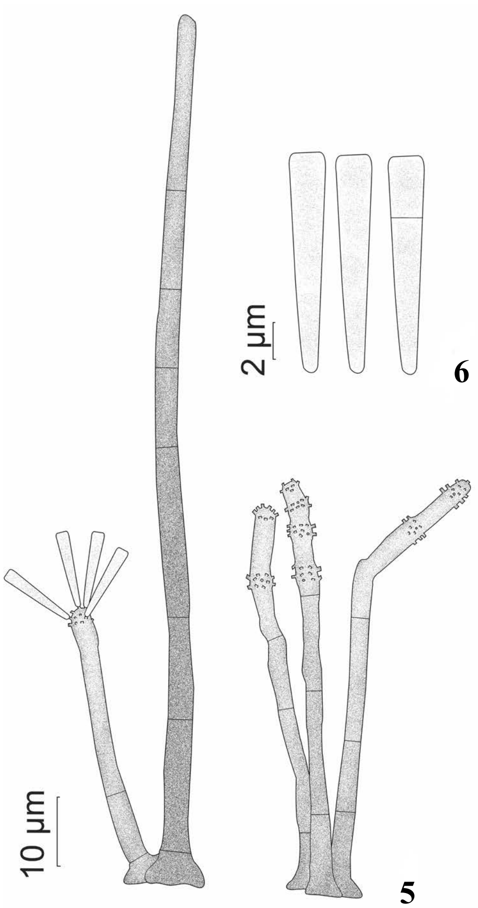
Fungus name	*Twig*	*Bark*	*Leaf*	*Petiole*
Dactylaria botulispora R.F. Castañeda & W.B. Kendr.	+			
D. candidula (Höhn.) G.C. Bhatt & W.B. Kendr.	+			
D. fusiformis Shearer & J.L. Crane			+	+
D. hyalotunicata K.M. Tsui *et al*.	+	+		
***D. saccardoana* F.R. Barbosa & Gusmão**			+	
Dactylella ellipsospora (Preuss) Grove	+			
Dendryphiopsis atra (Corda) S. Hughes	+			
Dictyochaeta anam. *Chaetosphaeria pulchriseta* S. Hughes *et al*.	+	+		
D. britannica (M.B. Ellis) Whitton *et al*.				+
D. fertilis (S. Hughes & W.B. Kendr.) Hol.-Jech.	+	+	+	+
D. heteroderae (Morgan-Jones) Carris & Glawe	+			
D. microcylindrospora Whitton *et al*.	+		+	+
D. pluriguttulata Kuthub. & Nawawi	+			
D. simplex (S. Hughes & W.B. Kendr.) Hol.-Jech.	+	+	+	+
Dictyochaetopsis gonytrichoides (Shearer & J.L. Crane) Whitton *et al*.	+		+	
D. polysetosa R.F. Castañeda *et al*.			+	+
Dictyosporium digitatum J.L. Chen *et al*.			+	+
D. elegans Corda	+		+	+
Dischloridium inaequiseptatum (Matsush.) Hol.-Jech.		+		
Ellisembia adscendens (Berk.) Subram.	+	+		
E. bambusicola (M.B. Ellis) J. Mena & G. Delgado	+			
Endophragmiella boothii (M.B. Ellis) S. Hughes		+		
E. fasciata (R.F. Castañeda) R.F. Castañeda			+	
E. rostrata P.M. Kirk	+			
Exserticlava sp.	+			
E. triseptata (Matsush.) S. Hughes	+	+		
E. vasiformis (Matsush.) S. Hughes		+		
Gonytrichum chlamydosporium G.L. Barron & G.C. Bhatt	+	+	+	
Gyrothrix circinata (Berk. & M.A. Curtis) S. Hughes	+			+
G. cornuta V. Rao & de Hoog			+	
G. magica Lunghini & Onofri			+	
G. microsperma (Höhn.) Piroz.	+		+	+
G. podosperma (Corda) Rabenh.			+	
G. verticiclada (Goid.) S. Hughes & Piroz.			+	
Helicomyces roseus Link		+	+	
Heliocephala elegans (R.F. Castañeda) R.F. Castañeda & Unter.			+	
Hermatomyces sphaericus (Sacc.) S. Hughes	+			
Idriella cagnizarii R.F. Castañeda & W.B. Kendr.			+	
I. ramosa Matsush.			+	+
Inesiosporium longispirale (R.F. Castañeda) R.F. Castañeda & W. Gams		+	+	
Ingoldiella hamata D.E. Shaw		+		+
Ityorhoptrum verruculosum (M.B. Ellis) P.M. Kirk		+		
Junewangia martinii (J.L. Crane & Dumont) W.A. Baker & Morgan-Jones		+		
Kionochaeta ramifera (Matsush.) P.M. Kirk & B. Sutton			+	
Lauriomyces sakaeratensis Somrith. *et al*.			+	+
Linkosia ponapensis (Matsush.) R.F. Castañeda *et al*.			+	
Melanocephala australiensis (G.W. Beaton & M.B. Ellis) S. Hughes	+	+		
Menisporopsis novae-zelandiae S. Hughes & W.B. Kendr.	+		+	+
M. pirozynskii Varghese & V.G. Rao			+	
M. theobromae S. Hughes	+		+	+
Mirandina corticola G. Arnaud	+			
Monodictys putredinis (Wallr.) S. Hughes	+			

Table 1. Freshwater fungi from Brazilian semi-arid area on different substrates *(continued)*

Fungus name	*Twig*	*Bark*	*Leaf*	*Petiole*
Mycoenterolobium platysporum Goos		+		
Nakataea fusispora (Matsush.) Matsush.	+			
Parasympodiella laxa (Subram. & Vittal) Ponnappa			+	
Periconia minutissima Corda	+			
Phaeoisaria clematidis (Fuckel) S. Hughes	+			
Pithomyces elaeidicola M.B. Ellis		+		
P. niger Mercado & J. Mena		+		
Pleurophragmium malaysianum Matsush.	+			
Pseudobotrytis terrestris (Timonin) Subram.	+			
Pseudotracylla dentata B. Sutton & Hodges	+		+	+
Pyricularia rabaulensis Matsush.			+	
***Quadracaea stauroconidia* F.R. Barbosa & Gusmão**	+		+	
Rhexoacrodictys erecta (Ellis & Everh.) W.A. Baker & Morgan-Jones	+	+		+
Scutisporus brunneus K. Ando & Tubaki				+
Selenodriella fertilis (Piroz. & Hodges) R.F. Castañeda & W.B. Kendr.			+	
S. perramosa W.B. Kendr. & R.F. Castañeda	+			
Speiropsis scopiformis Kuthub. & Nawawi			+	
Sporendocladia bactrospora (W.B. Kendr.) M.J. Wingf.	+			
Sporidesmiella ciliaspora W.P. Wu		+		
S. hyalosperma (Corda) P.M. Kirk	+			
S. parva (M.B. Ellis) P.M. Kirk	+			
S. vignalensis W.B. Kendr. & R.F. Castañeda			+	
Sporidesmium tropicale M.B. Ellis	+			
Sporoschisma juvenile Boud.	+			
S. saccardoi E.W. Mason & S. Hughes	+			
Stachybotrina sp.nov F.R. Barbosa *et al.*			+	
Stachybotrys sphaerospora Morgan-Jones & R.C. Sinclair				+
Subulispora longirostrata Nawawi & Kuthub.				+
S. procurvata Tubaki	+		+	
Tetraploa aristata Berk. & Broome			+	
Thozetella cristata Piroz. & Hodges	+		+	+
T. cubensis R.F. Castañeda & G.R.W. Arnold	+		+	+
T. gigantea B.C. Paulus *et al.*	+		+	
T. pinicola S.Y.Q. Yeung *et al.*			+	
T. submersa F.R. Barbosa & Gusmão	+			
Torula herbarum (Pers.) Link	+			
Umbellidion radulans B. Sutton & Hodges			+	
Vermiculariopsiella cubensis (R.F. Castañeda) Nawawi *et al.*			+	+
V. immersa (Desm.) Bender			+	
Virgariella atra S. Hughes	+	+		
V. globigera (Sacc. & Ellis) S. Hughes		+		
Virgatospora echinofibrosa Finley				+
Wiesneriomyces laurinus (Tassi) P.M. Kirk			+	
Xylomyces chlamydosporus Goos *et al.*		+		
X. elegans Goh *et al.*		+		
X. foliicola W.B. Kendr. & R.F. Castañeda		+	+	+
Zanclospora novae-zelandiae S. Hughes & W.B. Kendr.		+		
Zygosporium echinosporum Bunting & E.W. Mason			+	+
Z. masonii S. Hughes	+			
Z. minus S. Hughes	+			



Figs 1-4. *Dactylaria saccardoana.* **1.** Overview: setae, conidiophores and conidia. **2.** Details of the conidiogenous cells. Arrow indicates denticles. **3.** Conidia attached to the conidiogenous cells. **4.** Conidia. Arrow indicates septum. Scale bars= 1,3 = 10 µm, 2 = 5 µm, 4 = 5 µm.



Figs 5-6. *Dactylaria saccardoana.* **5.** Setae, conidiophores and conidia. **6.** Conidia.

species can play a role as predators of nematodes, and pathogens of plants, as well as fungal agents of animal disease (Goh & Hyde, 1997).

Dactylaria is characterized as having whitish, brownish and dark brown colonies; conidiophores cylindrical or somewhat tapering, erect, thick-walled or undifferentiated, (sub) hyaline or brown, continuous or septate, with cylindrical or tapering denticles in the apical region; conidia hyaline or pale brown, thin-walled, septate (de Hoog, 1985). Our collection from Brazil differs from all previously described species in the genus in having sterile setae between the conidiophores. In this case, we emend the concept of *Dactylaria* to include presence or absence of setae.

Four species of *Dactylaria* have triangle-shaped conidia: *D. isoscelispora* W.B. Kendr. & R.F. Castañeda, *D. manifesta* R.F. Castañeda & W.B. Kendr., *D. obtriangularia* Matsush., and *D. ponapensis* Matsush. Both *D. obtriangularia* and *D. ponapensis* have conidia with a rounded apex (de Hoog, 1985; Matsushima, 1975, 1985), which is distinct from the truncate apex seen in *D. saccardoana. Dactylaria isoscelispora* and *D. manifesta* are the closest species to *D. saccardoana.* However, *D. isoscelispora* has much larger conidiophores (70-300 × 8-13 µm) and conidia (18-23 × 3 × 1 µm) (Castañeda & Kendrick, 1990) and *D. manifesta* has larger, 2-5-septate conidia (14-20 × 3-3.5 × 1-1.5 µm) and conidiophores (55-200 × 5-9 µm) (Castañeda & Kendrick, 1991).

Key to species of *Dactylaria* with triangle-shaped conidia

1. Setae present . . . . *D. saccardoana*
1. Setae absent 2

2. Conidia with rounded apex. 3
2. Conidia with truncate apex. 4

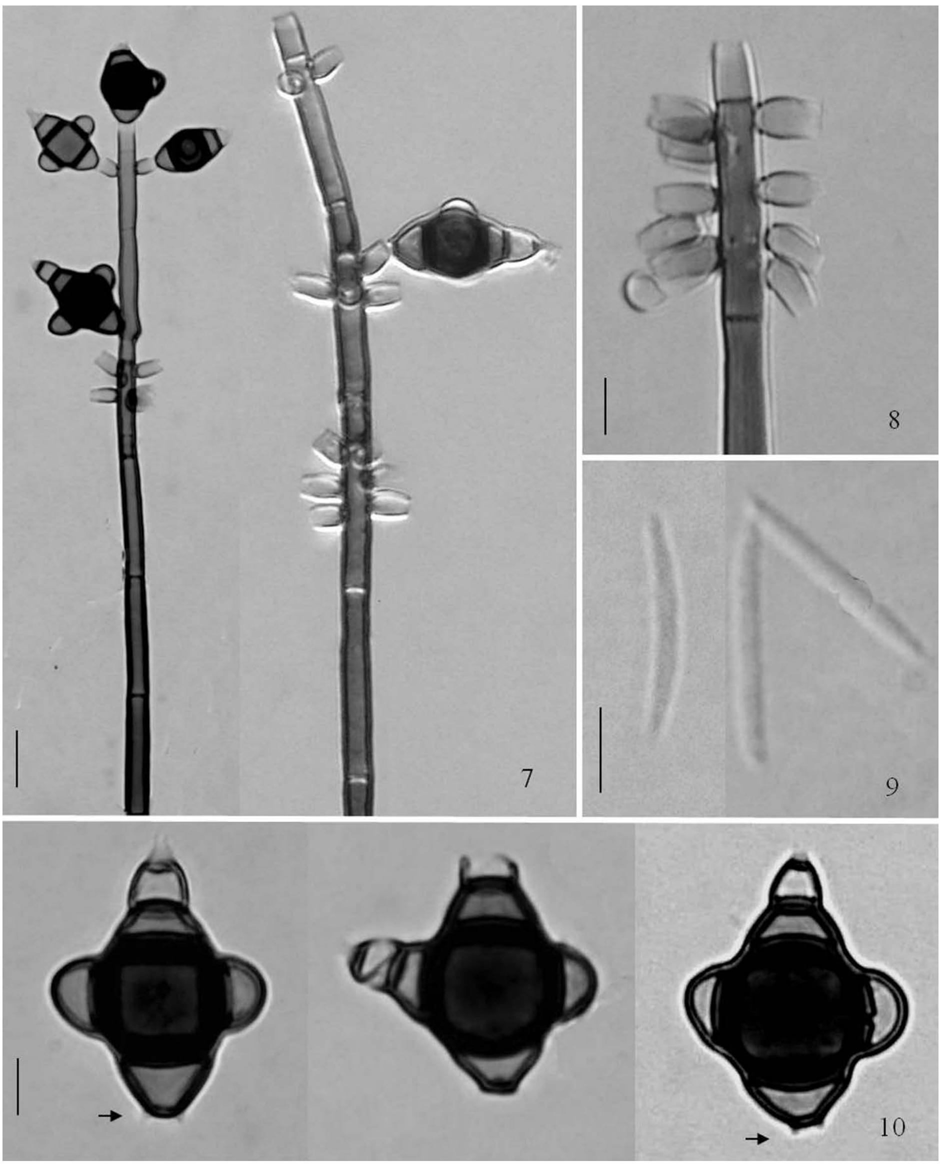
3. Conidia 2-septate, slightly constricted at the septum, 13.5-22.5 × 2-3 µm . . . . *D. ponapensis*
3. Conidia 0-2-septate, not constricted at the septum, 18-37 × 2.2-2.8 µm . . . . *D. obtriangularia*

4. Conidia subovoid, 2-5-septate, 14-20 × 3-3.5 µm . . . . *D. manifesta*
4. Conidia isosceles triangle-like, 1-septate, 18-23 × 3 µm . . . . *D. isoscelispora*

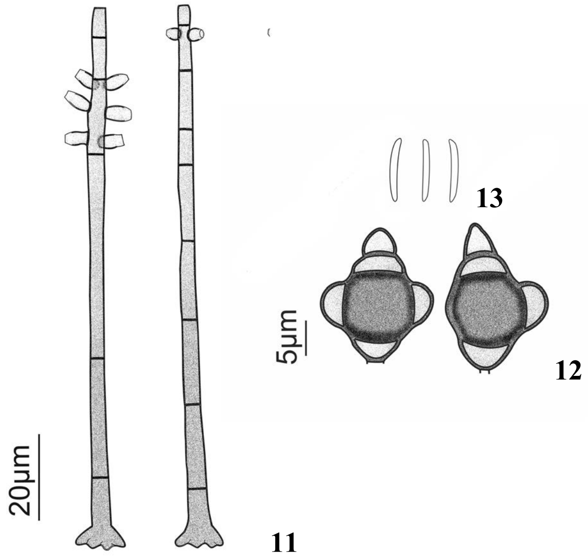
Quadracaea stauroconidia F.R. Barbosa & Gusmão, sp. nov. **Figs 7-13**

MycoBank: MB 801605

Conidiophores mononematous, macronematous, unbranched, septate, erect, straight, smooth, brown at the base, becoming paler toward the apex, 84-225 × 3-9 µm. Conidiogenous cells polyblastic, terminal or intercalary, integrated,



Figs 7-10. *Quadracaea stauroconidia.* **7.** Conidiophore with conidium attached in separating cell. **8.** Details of the separating cells. **9.** Falcate conidia. **10.** Stauroform conidia. Arrow indicates basal frill. Scale bars: 7 = 10 µm, 8-10 = 5 µm.



Figs 11-13. *Quadracaea stauroconidia.* **11.** Conidiophores. **12.** Stauroform conidia. **13.** Falcate conidia.

sometimes with percurrent proliferations, cylindrical, light brown, 12-16.5 × 3-3.8 µm. Separation cells single or in clusters up to 5, thin-walled, smooth, ampulliform, pale brown, 3-6 × 3 µm. Conidia solitary, dry, septate, constricted at the septa, separating rhexolytically, smooth, thin-walled, stauroform; central cell angular, dark brown, 8.5-13 × 7.5-11 µm; apical cells conical, pale brown, first cell 4-5 × 6 µm and second cell phialidic, 4-5 × 3-4.5 µm; two (rarely one) lateral cells conical rounded at the top, pale brown 4-5 × 4-6 µm, sometimes with a middle septum that form a phialidic cell; basal cell conical, truncate at base with a short frill, pale brown, 4-5 × 5-6 µm; phialidic cells produce apical, 0-septate, smooth, falcate, hyaline, 7.5-9 × 0.7-0.9 µm conidia.

Holotype: BRAZIL. BAHIA: Santa Terezinha, Serra da Jibóia, water temperature 20.8 C, pH 4.6. On submerged leaves, 16 Aug 2007, *F.R. Barbosa* and *L.F.P. Gusmão* (HUEFS 155282).

Additional material examined: BRAZIL. BAHIA: Santa Terezinha, Serra da Jibóia, water temperature 21.3 C, pH 6, on submerged leaves, 03 Feb 2009, *F.R. Barbosa* and *L.F.P. Gusmão* (HUEFS 155283); water temperature 21.8 C, pH 4, on submerged twigs, 01 Jul 2009, *F.R. Barbosa* and *L.F.P. Gusmão* (HUEFS 155281).

Etymology: From latin "stauroconidia", referring to the star-shaped conidia.

Teleomorph: Unknown.

Commentary: *Quadracaea* was typified by Lunghini, Pinzari & Zucconi as *Q. mediterranea* (the type species) collected from leaves of *Quercus ilex* L. from central Italy (Lunghini *et al.*, 1996). Recently, Zhang *et al.* (2012) described a new species, *Q. roureae* Y.D. Zhang & X.G. Zhang found on dead branches of *Rourea minor* (Gaertn.) Alston from China. The genus is characterized by percurrent proliferations, polyblastic conidiogenous cells producing ampulliform separating cells, rhexolytic conidial secession and occurrence of a synanamorph (Lunghini *et al.*, 1996). *Uberispora* Piroz. & Hodges and *Physalidiopsis* R.F. Castañeda & W.B. Kendr. are the genera closest to *Quadracaea* in having conidia seceding rhexolytically and the presence of a synanamorph (Ichinoe, 1972; Pirozynski & Hodges, 1973; Castañeda-Ruiz & Kendrick, 1990; Bhat & Kendrick, 1993; Castañeda-Ruiz *et al.*, 1996). In *Uberispora tropicalis,* Bhat & W.B. Kendr. (Bhat & Kendrick, 1993), the authors report the presence of schizolytic conidial secession. However, they illustrated and described the conidia as "often carrying the upper portion of the conidiogenous cell as basal frill", a feature which characterizes rhexolytic conidial secession as in *Quadracaea.* In *Uberispora* species, it differs from *Quadracaea* in not producing separating cells and by a different arrangement of satellite cells around the central cell of the conidium (Pirozynski & Hodges, 1973; Bhat & Kendrick, 1993; Castañeda-Ruiz *et al.*, 1996). *Physalidiopsis* differs from *Quadracaea* in having short branches developing on conidiophores (Castañeda-Ruiz & Kendrick, 1990). The presence of stauroconidia in *Physalidiopsis* was a character used by Lunghini *et al.* (1996) to differentiate the genus from *Quadracaea. D*ue to the presence of stauroconidia in our species, we emend the concept of *Quadracaea* to include the presence of stauroform conidia.

Quadracaea stauroconidia can be differentiated from the two current species in the genus. In *Q. mediterranea,* the conidium is suboval to obpyriform with two central cells, darker than the apical and basal cells, without lateral cells (Lunghini *et al.*, 1996). In *Q. roureae,* the conidiophore is much smaller and the conidium is obpyriform with 0-1 lateral cell (Zhang *et al.*, 2012).

Key to species of *Quadracaea*

1. Conidiophores branched, conidia without lateral cells. . . . . *Q. mediterranea*
1. Conidiophores unbranched, conidia with 0-2 lateral cells 2

2. Conidiophores up to 81 µm long, 3-4,5 µm wide, conidia obpyriform with 0-1 lateral cell. . . . . *Q. roureae*
2. Conidiophores 84-225 µm long, 3-9 µm wide, conidia stauriforms with rarely 1 or mainly 2 lateral cells. . . . . *Q. stauroconidia*

DISCUSSION

Fungi found in freshwater ecosystems play an important role in the degradation of dead organic plant material due to their ability to break down lignocellulose (Wong MKM *et al.*, 1998). Among the higher filamentous fungi, the groups often found in fresh water are meiosporic and mitosporic ascomycetes, while basidiomycetes are rare to generally absent (Shearer *et al.*, 2007). Recent data suggested that about 592 species of meiosporic ascomycetes and 539 species of mitosporic ascomycetes (13 species of coelomycetes and 526 species of hyphomycetes) have been recorded from freshwater habitats worldwide (Shearer & Raja, 2011).

As shown in Table 1, a total of 151 species of fungi were found in this study (15 meiosporic ascomycetes and 136 mitosporic fungi). Higher prevalence of the mitosporic fungi on submerged leaves has been previously observed (Suberkropp & Klug, 1974) on the surface of leaves collected from fresh water using a scanning electron microscope.

In previous studies, freshwater mitosporic fungi were found to be dominant, as compared to ascomycetes, by Raja *et al.* (2009), Abdel-Aziz (2008), Tsui *et al.* (2001a) and Schoenlein-Crusius & Milanez (1998) who reported the freshwater fungi from the Florida Peninsula, Egypt, Hong Kong and Brazil, respectively. A contradictory result was observed by Vijaykrishna & Hyde (2006) who analyzed the biodiversity of lignicolous freshwater fungi in five tropical streams in Australia. These authors recorded 101 species of meiosporic ascomycetes and 61 species of mitosporic fungi. Vijaykrishna & Hyde (2006) concluded that the reason for the larger ratio of the teleomorphic state was unknown. In our study, mitosporic fungi were found on different substrate types (twig, bark, leaf and petiole), while meiosporic ascomycetes were predominantly restricted to wood (Table 1). This could be one of the reasons why mitosporic fungi were higher in number compared to the meiosporic ascomycetes. Alternatively, mitosporic fungi produce large numbers of conidia by mitosis, which could colonize different types of organic substrates available in freshwater, which may also enhance their detection.

Among the 136 mitosporic fungi in this study, only two species were coelomycetes (Table 1). Our results support previous studies where the ratio of hyphomycetes to coelomycetes was larger, both from terrestrial (Gusmão *et al.*, 2001; Wong & Hyde, 2001) and freshwater habitats (Tsui *et al.*, 2000; Sivichai *et al.*, 2002). Reports of coelomycetes in fresh water have been scarce. Thus far, only thirteen species have been reported worldwide (Shearer & Raja, 2011). According to Shearer *et al.* (2007), the low occurrence of coelomycetes in freshwater habitat reflects the lack of specialized human resources. Descals & Moralejo (2001) believe that coelomycetes are abundant but ignored in the aquatic environment, since these fungi are not easily identified. In a recent study of freshwater fungi occurring on *Phragmites australis* (Cav.) Trin. ex Steud. in Egypt, Abdel-Aziz (2008) observed a different result: a higher number of coelomycetes than hyphomycetes, and an increase in coelomycetes diversity with increasing salinity. Similar results were also reported in a study of fungal diversity on *P. australis* in a brackish tidal marsh in the Netherlands. Van Ryckegem & Verbeken (2005a) found 31 coelomycetes and 9 hyphomycetes species on leaves. Moreover, Van Ryckegem & Verbeken (2005b) found 16 coelomycetes and 4 hyphomycetes species on stems. These results suggest that coelomycetes species richness may be higher in brackish water habitats. Explanations for this phenomenon needs further study.

Two species found in this study, namely, *Ingoldiella hamata* and *Brachiosphaera tropicalis* are Ingoldian fungi (Table 1). *Ingoldiella hamata* has a wide tropical distribution, since it has been collected from fresh water in Australia (Shaw, 1972), Malaysia (Nawawi, 1973), India (Sridhar & Kaveriappa, 1989), Singapore (Tubaki *et al.*, 1993) and Brazil (Schoenlein-Crusius, 2002). More recently, it was recorded on submerged woody debris in Florida, USA (Raja *et al.*, 2009). *Brachiosphaera tropicalis* is also a common species in tropical regions and was collected from fresh water in Malaysia (Descals *et al.*, 1976), Thailand (Tubaki *et al.*, 1983), Puerto Rico (Santos-Flores & Betancourt-Lopez, 1994), Taiwan (Chang, 1994), China (Ho *et al.*, 2002) and Venezuela (Smits *et al.*, 2007). It was also recorded on submerged wood in South Africa by Hyde *et al.* (1998) and on submerged herbaceous debris in United States (Florida) by Raja *et al.* (2009).

Four aeroaquatic species were collected herein, namely, *Cancellidium applanatum, Candelabrum brocchiatum, Helicomyces roseus* and *Inesiosporium longispirale*. Except for *I. longispirale*, which was found in Cuba (Castañeda & Gams, 1997), *Canc. applanatum, Cand. brocchiatum* and *H. roseus* have tropical and temperate distributions (Raja *et al.*, 2007; Hyde & Goh, 1998a,b; Tubaki, 1975; Sivichai *et al.*, 2002; Delgado-Rodrigues *et al.*, 2002).

The remaining 130 mitosporic species recorded in this study are miscellaneous mitosporic ascomycetes (Shearer *et al.*, 2007) (Table 1). These fungi do not have conidia distinctly modified for an aquatic existence and can be found both in aquatic and terrestrial habitats (Goh & Hyde, 1996). The collection and incubation methodology employed here most likely contributed to the emergence of a large number of miscellaneous mitosporic ascomycetes instead of Ingoldian and aeroaquatic fungi.

Among the meiosporic ascomycetes, *Calosphaeria* sp., *Chaetomium homopilatum*, *C. longicoleum*, *Chaetosphaeria lignomolis*, *Linocarpon* sp. and *Orbilia* sp. often occur in terrestrial habitats (Ames, 1961; Kale, 1965; Liu *et al.*, 2006; Hyde, 1997; Fernández & Huhndorf, 2005) and *Aniptodera chesapeakensis, Annulatascus velatisporus, Anthostomella aquatica, Jahnula seychellensis*, *Ophioceras venezuelense*, *Tamsiniella labiosa,* and *Torrentispora crassiparietis* are reported from freshwater habitats (Shearer, 1989; Hyde & Goh, 1998a,b; Wong SW *et al.*, 1998; Hyde & Wong, 1999; Tsui *et al.*, 2001b; Kohlmeyer & Volkmann-Kohlmeyer, 2002; Fryar & Hyde, 2004). *Annulatascus apiculatus* was found only once on a submerged twig in Brazil (Barbosa *et al.*, 2008). Thus far, *Annulatascus velatisporus*, *A. apiculatus*, *J. seychellensis*, *Ophioceras venezuelense* and *Tamsiniella labiosa* have been reported only from fresh water (Hyde & Goh, 1998b; Wong SW *et al.*, 1998; Hyde & Wong, 1999; Tsui *et al.*, 2001b; Barbosa *et al.*, 2008).

Most of the freshwater meiosporic ascomycetes reported here are included in Sordariomycetes (sensu Lumbsch & Huhndorf, 2010). Some taxa in this class may be adapted to life in fresh water (Vijaykrishna *et al.*, 2006). Adaptations can include: deliquescent asci, ascospores with mucilaginous sheath, ornamented wall and appendages etc. (Wong MKM *et al.*, 1998; Jones, 2006).

With respect to the substrate, most freshwater species found in this study (74 species) occurred exclusively on submerged woody debris (twig and/or bark). Fifty-one species were foliicolous species (leaf and/or petiole) and 26 species were generalists found on all types of substrate (Table 1). These results agree with previous studies reported in the literature (Shearer & Raja, 2011). In a study of freshwater ascomycetes, Abdel-Raheem & Shearer (2002) and Simonis *et al.* (2008) found no difference in enzyme production among lignicolous, herbaceous and generalist species, indicating that enzymatic capacity is not a limiting factor for the colonization of substrates. Shearer (1992) concluded that wood remains available for longer durations due the low rate of decomposition and large size. The longer turnover time would allow a larger number of fungi to colonize wood other than foliicolous substrates, which decompose faster.

Acknowledgments. The authors FR Barbosa and LFP Gusmão deeply thank to CNPq for the financial support to conduct the identification of ascomycetes in the University of Illinois at Urbana-Champaign (process number 201670/2009-7) and to the Department of Plant Biology of that University to support this work. The authors also thank to "Programa de Pós-graduação em Botânica – PPGBot/UEFS" and to Davi Augusto for doing the line drawing.

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