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REGULAR PAPER

Richness and diversity of conidial fungi associated with plant debris in three enclaves of Atlantic Forest in the Caatinga biome of Brazil

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Background and aims – A study of richness and diversity of conidial fungi associated with plant debris was conducted in three Atlantic Forest enclaves in the Caatinga biome: Serra da Jibóia-BA (SJ), Serra da Ibiapaba-CE (SI) and Brejo Paraibano-PB (BP).
Methods – The plant debris samples including leaves, twigs and barks were washed in running water, incubated in moist chambers and analysed for 40 days under a stereomicroscope. The fungal reproductive structures were transferred to slides containing PVL resin and identified with specialized literature.
Key results – The richness and diversity were similar in the three enclaves of interest. Cluster analysis using the Morisita similarity index indicated a group formed by fungal communities in SI and BP and another in SJ. Among these substrates, the leaves showed the greatest richness whereas the bark samples had the greatest diversity but any differences were significant. Multivariate analysis via NMDS revealed differences in the fungal community composition with respect to the substrate and area, but the similarity analysis (ANOSIM) indicated that the differences were significant only with respect to the substrate.
Conclusions – The survey data showed the great richness and diversity of conidial fungi in the studied areas. The richness and diversity values in these areas and substrates were similar, and the differences were not significant. Substrate was the most determinant factor for the distribution of fungi compared with area.

Key words – Biodiversity, ecology, fungal communities, leaf litter, rainforest, tropical fungi.

INTRODUCTION

The Brazilian semi-arid area corresponds to the Caatinga biome delimitation (Giulietti et al. 2006). For years, this ecosystem was considered only somewhat diverse, but many studies have demystified this idea and have demonstrated its diversity and endemism (Leal et al. 2003). In this region, there is a predominance of Caatinga vegetation and its various nuances as well as other vegetation types, providing heterogeneity and complexity to this semiarid ecosystem (Andrade-Lima 1981). Among the existing vegetation types, Atlantic Forest enclaves are also found in the Caatinga (Velloso et al. 2002, Giulietti et al. 2006).

The accumulated organic matter on the soil surface of these enclaves mainly consists of decaying plant material and functions as a reservoir of biodiversity. The fungi are significant drivers of nutrient cycling in the ecosystem across material decomposition via the production of enzymes, which allows degradation of these substrates (Maia 2003). These organisms exhibit great adaptive morphological variation to this type of environment and are favoured by appropriate conditions of temperature and humidity (Dix & Webster 1995). In this process, the conidial fungi stand out as having a powerful enzymatic apparatus capable of degrading several organic compounds (Dix & Webster 1995).

Several factors such as competition for resources, chemical composition of the substrates as well as climate and microclimate conditions influence the fungal community (Cooke & Whipps 1993, Fryar et al. 2005). Some studies suggest that some saprobic microfungi are restricted to certain plant species and in some cases, to specific tissue types (Paulus et al. 2006). However, other studies suggest that just few decomposing fungi are substrate-specific (Parungao et al. 2002).

The majority of studies of conidial fungi associated with plant debris in the Atlantic Forest enclaves from the Caatinga biome used the taxonomic approach (Barbosa et al. 2007, 2011, 2013, Fiuza et al. 2014, Marques et al. 2007a, 2007b, Silva et al. 2014a). Few studies have focused on the ecology of these organisms (Barbosa et al. 2009, Costa 2014, Magalhães et al. 2011, Marques et al. 2008, Silva et al. 2014b). This study evaluated the richness, diversity and distribution

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of conidial fungi associated with plant (leaves, twigs and barks) in three enclaves of Atlantic Forest in the Caatinga biome.

MATERIAL AND METHODS

Nine expeditions (three in each area) were conducted from 2011 to 2013 with a distance of at least 675 km from each other: Paraíba State, Brejo Paraibano (BP); Ceará State, Serra de Ibiapaba (SI); and Bahia State, Serra da Jibóia (SJ) (fig. 1). Six collection points were delimited in each area. At each point, an area of 10 × 10 m was delimited and subdivided into four squares of 5 × 5 m. In each square leaves, barks and twigs 10 cm in length and at an advanced stage of decomposition were collected for a total of 72 substrates per expedition. The samples were placed separately in Kraft paper bags and transported to the Mycology Laboratory of the State University of Feira de Santana. The samples were washed in running water and incubated in moist chambers at 25°C for 40 days (Castañeda Ruiz et al. 2016).

The material was analysed with a Leica EZ4 stereomicroscope for 40 days. Microscope slides containing the reproductive structures of fungi were made with resin PVL (polyvinyl alcohol + lactic acid + phenol), identified and deposited in the Herbarium of the State University of Feira de Santana (HUEFS).

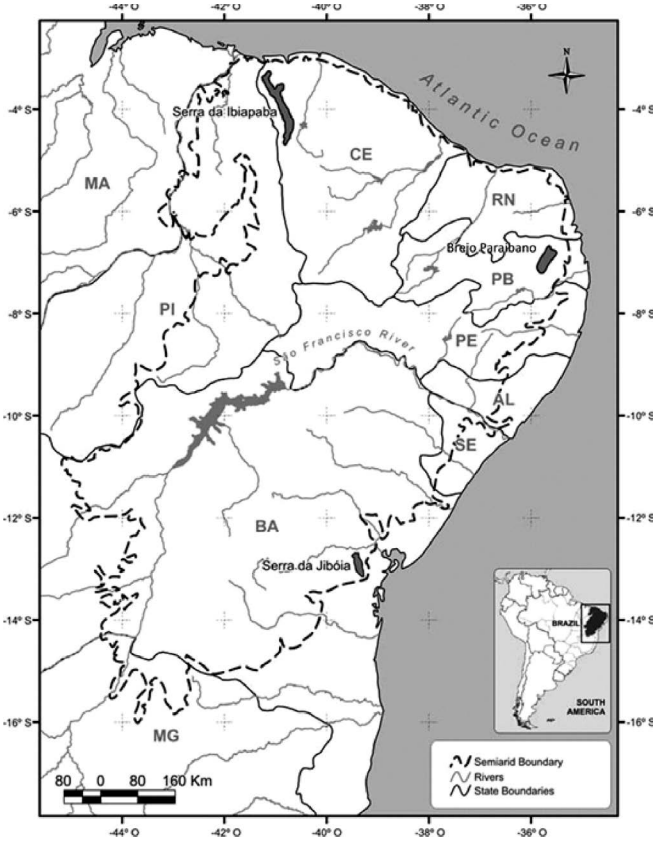

Figure 1 – Geographical location of Atlantic Forest enclaves investigated: Serra da Ibiapaba (Ceará State), Brejo paraibano (Paraíba State) and Serra da Jibóia (Bahia State); from Costa 2014.

Taxa were registered as either present (1) or absent (0) for each substrate (leaves, twigs and barks) and areas (BP, SI and SJ). The abundance was calculated by the number of records of the species in each substrate (Brower et al. 1998). The richness of the fungal species was compared between substrates with a confidence interval of 95% as calculated from the bootstrap method (Grünwald et al. 2003). Shannon (H') indices were calculated to estimate the diversity in the areas and according to substrates. A comparison of diversity indices was performed with 95% confidence intervals via the bootstrap method.

The taxa found were divided into constancy categories per substrate using the index $C = P / N \times 100$, where P = number of collections containing species on a substrate and N = total number of collections. That index value was used to discriminate between constant taxon ($C > 50\%$), accessory taxon ($25\% < C \leq 50\%$) and accidental taxon ($C \leq 25\%$) (Dajoz 1983).

Data ordering used the NMDS method (Multidimensional Scaling Non Metric) from the dissimilarity matrix Morisita (Kruskal 1964). The permutation test ANOSIM (analysis of similarity one way) was used to assess differences/similarities between the sample groups considering 5% significance (Clarke 1993).

Similarities in species composition between collection points and areas were verified by UPGMA method (unweighted pair group method with arithmetic mean) using the Morisita index (Magurran 1988). The analyses were conducted in the PAST 3:01 (Hammer et al. 2013) and R ver. 3.01 program (R Core Team 2014).

RESULTS

A total of 213 taxa were recorded and distributed in 99 genera, and 158 of these taxa were identified at a specific level (table 1). The SJ area was the most diverse (114 species) with the largest number of occurrences (324), whereas the richness in BP was 105 taxa with 286 occurrences and SI showed 104 taxa with 273 occurrences. These differences in richness values were not significant based on the confidence intervals generated by Bootstrap method at 95% confidence level. Concerning diversity, SI and SJ showed the same value (H' = 4.23), whereas BP had the lowest recorded diversity among the studied areas (H' = 4.14). The diversity values showed no significant differences based on the confidence intervals obtained (table 2).

Among the substrates under study, the leaves had the highest number of occurrences and highest richness values (395 and 111, respectively) followed by barks (260 and 100, respectively) and twigs (230 and 90, respectively). However, the differences in the richness among the substrates were not significant according to confidence intervals. The barks had the highest diversity (H' = 4.14) followed by leaves (H' = 4.07) and twigs (H' = 3.74). The differences in the diversity between substrates were not significant based on confidence intervals (table 3).

The NMDS ordering showed separation between the fungal communities in relation to substrates and areas. In the first axis, the left group was formed by fungi associated with

Table 1 – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
Acremonium sp.	0	1	0	0	0	1	0	0	0
Acrogenospora sp.	0	0	0	0	0	0	0	0	1
A. sphaerocephala (Berk. & Broome) M.B.Ellis	0	0	0	0	0	0	0	1	2
Alternaria sp.	0	0	0	0	0	0	1	0	0
Anungitea continua Matsush.	1	0	0	0	0	0	0	0	0
A. heterospora P.M.Kirk	0	0	0	1	0	0	0	0	0
A. parvispora R.F.Castañeda & W.B.Kendr.	1	0	0	0	0	0	0	0	0
A. uniseptata Matsush.	0	0	0	1	0	0	0	0	0
Arthrobotrys oligospora Fresen.	0	0	0	1	0	1	0	0	0
Aspergillus sp. 1	1	0	0	0	0	0	0	0	0
Aspergillus sp. 2	0	0	0	0	1	0	0	0	0
Atractilina biseptata R.F.Castañeda	0	0	0	0	0	0	1	0	0
Atrosetaphiale flagelliformis Matsush.	2	0	0	0	0	0	0	0	0
Bactrodesmium longisporum M.B.Ellis	0	0	1	0	0	2	0	2	2
Basipetospora sp. 1	0	0	0	0	1	0	0	0	0
Belemnospora navicularis R.F.Castañeda & Heredia	0	0	0	0	0	1	0	0	0
Beltrania rhombica Penz.	12	0	0	3	0	0	6	0	0
Beltraniella portoricensis (F.Stevens) Piroz. & S.D.Patil	6	0	0	11	0	0	9	0	0
Beltraniopsis ramosa R.F.Castañeda	2	0	0	3	0	0	4	0	0
Bipolaris sorokiniana (Sacc.) Shoemaker	0	0	0	0	1	0	0	0	0
Blastophorum sp.	2	0	0	0	0	0	0	0	0
Brachysporiella gayana Bat.	0	3	7	1	3	2	0	6	3
Cacumisporium pleuroconidiophorum (Davydkina & Melnik) R.F.Castañeda, Heredia & Iturr.	0	1	0	0	1	1	0	0	0
Catenularia cubensis Hol.-Jech.	0	0	0	0	0	0	0	0	1
Chaetochalara aspera Piroz. & Hodges	2	0	0	0	0	0	0	0	0
Chaetopsina sp. 1	0	0	0	1	0	0	0	0	0
Chaetopsina sp. 2	0	0	0	0	0	0	1	0	0
C. fulva Rambelli	3	2	0	0	0	0	0	0	0
Chaetosphaeria chloroconia W.Gams & Hol.-Jech.	0	0	0	0	1	0	0	0	0
Chaetosphaeria vermicularioides (Sacc. & Roum.) W.Gams & Hol.-Jech.	0	0	2	0	0	0	0	0	2
Chalara sp. 1	1	0	0	0	0	0	0	0	0
Chalara sp. 2	0	0	0	0	0	1	0	0	0
Chalara sp. 3	0	0	1	0	0	0	0	0	1
C. alabamensis Morgan-Jones & E.G.Ingram	1	0	0	2	0	0	2	3	2
C. cladii M.B.Ellis	0	0	1	0	0	0	0	0	0
C. unicolor S.Hughes & Nag Raj	0	0	0	0	1	1	0	0	0
Chloridium sp. 1	0	0	0	0	0	0	1	0	0
C. lignicola (F.Mangenot) W.Gams & Hol.-Jech.	0	2	0	0	2	3	0	2	2
C. transvaalense Morgan-Jones, R.C.Sinclair & Eicker	4	7	2	0	5	2	0	3	1
C. virescens (Pers.) W.Gams & Hol.-Jech.	4	10	12	0	0	1	0	1	4
Circinotrichum maculiforme Nees	0	0	0	1	0	0	0	0	0

Table 1 (continued) – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
C. olivaceum (Speg.) Piroz.	0	0	0	6	0	0	3	0	0
Cladosporium sp. 1	1	0	2	0	0	2	0	0	0
Cladosporium sp. 2	0	0	0	0	0	0	0	0	2
Cladosporium sp. 3	0	0	0	0	0	0	1	0	0
Cladosporium sp. 4	0	2	1	0	0	0	0	0	0
Clonostachys compactiuscula (Sacc.) D.Hawksw. & W.Gams	4	0	0	0	0	0	0	0	0
Codinaea sp. 1	2	0	0	0	0	0	0	0	0
C. brittanica M.B.Ellis	4	0	0	5	0	0	3	0	0
C. fertilis S.Hughes & W.B.Kendr.	1	2	0	0	0	0	0	0	0
C. matsushimae Hewings & J.L.Crane	0	0	0	0	0	0	0	1	0
C. novae-guineensis Matsush.	0	0	0	0	0	0	0	1	0
C. simplex S.Hughes & W.B.Kendr.	3	0	2	6	0	1	7	2	6
Cordana sp. 1	0	0	0	0	0	0	0	1	0
Cordana sp. 2	0	0	0	0	1	4	0	0	0
C. musae (Zimm.) Höhn.	0	0	0	0	2	2	0	0	1
Corynespora sp. 1	0	0	0	0	0	1	0	0	0
Corynespora sp. 2	0	0	0	0	0	0	0	0	1
Corynespora sp. 3	0	0	0	0	1	0	0	0	0
Corynespora sp. 4	0	0	0	0	0	0	0	4	0
C. cassiicola (Berk. & M.A.Curtis) C.T.Wei	0	0	0	0	1	0	0	0	0
C. calicioidea (Berk. & Broome) M.B.Ellis	0	0	0	0	1	0	0	0	0
Corynesporopsis sp.1	0	0	0	0	0	1	0	0	0
Craspedodidymum nigroseptatum Yanna, W.H.Ho, Goh & K.D.Hyde	0	0	0	0	0	0	0	0	5
Cryptophiale guadalcanalensis Matsush.	3	0	0	0	0	0	0	0	0
C. kakombensis Piroz.	15	0	0	2	0	1	3	2	1
C. minor M.L.Farr	0	0	0	0	0	1	0	0	0
C. udagawae Piroz. & Ichinoe	2	0	0	0	0	0	0	1	0
Cryptophialoidea fasciculata Kuthub. & Nawawi	0	1	1	0	0	0	0	0	0
Curvularia lunata (Wakker) Boedijn	0	1	0	0	0	0	0	0	0
Cylindrocladium scoparium Morgan	0	0	0	1	0	0	0	0	0
Dactylaria affinis (O.Rostr.) G.C.Bhatt & W.B.Kendr.	0	1	1	0	0	0	0	0	0
D. candidula (Höhn.) G.C.Bhatt & W.B.Kendr.	0	0	0	0	0	1	0	6	2
D. curviclavata Matsush.	0	0	0	0	1	0	0	0	0
D. palmae Pinnoi, E.B.G.Jones, McKenzie & K.D.Hyde	0	0	0	0	0	0	0	0	1
Dactylella stenocrepis Drechsler	0	0	0	1	1	1	0	0	0
D. yunnanensis K.Q.Zhang, Xing Z.Liu & L.Cao	2	0	0	0	0	0	0	1	0
Dendryphiopsis atra (Corda) S.Hughes	0	0	0	0	1	1	0	1	0
D. biseptata Morgan-Jones, R.C.Sinclair & Eicker	0	1	0	0	2	2	0	0	2
Dictyochaeta sp. 1	1	0	0	0	0	1	0	0	1
Dictyochaeta sp. 2	0	0	0	0	0	0	1	0	0
Dictyochaeta sp. 3	0	0	0	0	0	0	1	0	0
Dictyochaeta sp. 4	1	0	0	0	0	1	0	0	1

Table 1 (continued) – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
Dictyochaeta sp. 5	1	0	0	0	0	0	0	0	0
D. heteroderae (Morgan-Jones) Carris & Glawe	0	0	0	0	0	0	0	0	2
D. pluriguttulata Kuthub. & Nawawi	0	0	0	0	3	3	0	0	0
D. pulchriseta S.Hughes, W.B.Kendr. & Shoemaker	0	0	0	0	1	1	0	0	0
D. subfucospora Kuthub. & Nawawi	0	0	0	0	0	0	0	0	1
Dictyosporium elegans Corda	0	0	0	0	1	0	0	0	1
Dinemasporium sp. 1	0	0	0	1	1	0	0	0	0
Diplococcium pulneyense Subram & Sekar	0	0	0	0	0	1	0	0	0
D. stoveri (M.B.Ellis) R.C.Sinclair, Eicker & Bhat	0	0	0	0	0	1	0	0	1
Dischloridium sp. 1	0	0	1	0	0	0	0	0	0
D. laeense (Matsush.) B.Sutton	0	0	2	0	0	0	0	0	0
Ellisembia sp. 1	0	0	0	0	1	0	0	1	0
Ellisembia sp. 2	0	0	0	0	0	0	0	0	1
Ellisembia sp. 3	0	0	0	0	1	0	0	0	0
Ellisembia sp. 4	0	0	0	0	1	1	0	0	0
Ellisembia sp. 5	0	0	0	0	1	1	0	0	0
Ellisembia sp. 6	0	1	0	0	0	0	0	0	0
E. adscendens (Berk.) Subram.	0	4	8	0	25	13	0	12	7
E. brachypus (Ellis & Everh.) Subram.	0	0	0	0	0	0	0	1	0
E. leonensis (M.B.Ellis) McKenzie	0	1	0	0	0	0	0	0	0
E. minigelatinosa (Matsush.) W.P.Wu	0	0	0	0	0	0	0	0	0
Endophragmiella biseptata (Peck) S.Hughes	0	0	1	0	0	0	0	0	0
E. boothii (M.B.Ellis) S.Hughes	0	2	0	0	0	0	0	0	0
Exserticlava triseptata (Matsush.) S.Hughes	0	0	1	1	0	1	0	1	2
E. vasiformis (Matsush.) S.Hughes	0	3	1	0	0	0	0	0	1
Gangliostilbe costaricensis Mercado, Gené & Guarro	0	0	2	0	0	0	2	0	0
Gonytrichum macrocladum (Sacc.) S.Hughes	1	0	0	0	0	0	0	0	0
Gyrothrix sp.	0	0	0	2	0	0	1	0	0
G. circinata (Berk. & M.A.Curtis) S.Hughes	3	0	0	0	0	0	0	0	0
G. magica Lunghini & Onofri	0	0	0	2	0	0	0	0	1
G. microsperma (Höhn.) Piroz.	2	0	0	6	1	0	0	0	0
G. podosperma (Corda) Rabenh.	2	0	0	7	0	0	0	0	0
G. verticiclada (Goid.) S.Hughes & Piroz.	1	0	0	1	0	0	0	0	0
Hansfordia pulvinata (Berk. & M.A.Curtis) S.Hughes	4	0	0	2	0	0	2	0	0
Helicoma ambiens Morgan	0	0	0	0	0	0	0	1	1
H. dennisii M.B.Ellis	0	0	0	0	0	0	0	1	1
Helicosporium sp.	0	0	0	0	0	0	1	0	1
H. aureum (Corda) Linder	1	0	0	0	0	1	0	0	0
H. gracile (Morgan) Linder	0	1	0	1	0	0	0	1	2
H. hongkongense K.M.Tsui, Goh, K.D.Hyde & Hodgkiss	1	0	0	0	1	0	0	0	0
H. guianense Linder	0	0	0	0	2	1	0	1	0
H. murinum Goos	0	0	0	0	2	1	0	1	0
H. panachaeum R.T.Moore	1	0	0	0	0	0	1	0	0

Table 1 (continued) – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
Helminthosporium sp.	0	0	1	0	0	1	0	0	1
Inesiosporium longispirale (R.F.Castañeda) R.F.Castañeda & W.Gams	1	1	1	0	0	0	0	0	0
Intercalarispora nigra J.L.Crane & Schokn.	0	0	1	0	0	0	0	0	0
Junewangia globulosa (Tóth) W.A.Baker & Morgan-Jones	0	0	0	0	0	2	0	0	0
Junewangia martini (J.L.Crane & Dumont) W.A.Baker & Morgan-Jones	0	0	0	0	0	3	0	0	0
Kionochaeta malaysiana P.M.Kirk	1	0	0	0	0	0	0	0	0
Kionochaeta ramifera (Matsush.) P.M.Kirk & B.Sutton	2	0	0	0	0	0	0	0	0
Kionochaeta spissa P.M.Kirk & B.Sutton	1	0	0	0	0	0	0	0	0
Lauriomyces heliocephalus (V.Rao & de Hoog) R.F.Castañeda & W.B.Kendr.	1	0	0	0	0	0	1	1	0
Melanocephala australiensis (G.W.Beaton & M.B.Ellis) S.Hughes	0	0	0	0	0	3	0	0	0
M. triseptata (Shearer, J.L.Crane & M.A.Mill.) S.Hughes	0	0	0	0	1	0	0	0	0
Memnoniella echinata (Rivolta) Galloway	3	0	0	0	0	0	2	0	0
M. levispora Subram.	0	0	0	0	0	0	1	0	0
Menisporopsis nova-zelandiae S.Hughes & W.B.Kendr.	11	0	1	1	0	0	0	0	0
M. profusa Piroz. & Hodges	1	0	0	0	0	0	0	0	0
M. theobromae S.Hughes	1	0	0	4	0	0	1	0	0
Minimidochium sp.	0	0	0	0	1	0	0	0	0
Monodictys melanocephaloides Goh & K.D.Hyde	0	0	0	0	1	1	0	0	0
M. nitens (Schwein.) S.Hughes	0	0	0	0	0	1	0	0	0
M. striata (Petch) V.Rao & de Hoog	0	0	0	0	0	2	0	0	0
Monotosporella rhizoidea V.Rao & de Hoog	0	0	1	0	0	1	0	0	0
M. setosa (Berk. & M.A.Curtis) S.Hughes	0	0	1	0	0	0	0	1	2
Oidiodendron sp.	0	1	0	0	0	0	0	0	0
Paliphora intermedia Alcorn	1	0	0	0	0	0	1	0	0
Paraceratocladium polysetosum R.F.Castañeda	1	2	0	0	0	0	0	0	0
P. silvestre R.F.Castañeda	2	2	0	0	0	0	0	0	0
Penicillium sp.	0	0	0	0	0	1	0	0	0
Penzigomyces australiensis (M.B.Ellis) Subram.	0	1	0	0	0	0	0	0	0
Periconia sp.	0	0	0	0	0	0	1	0	0
Periconia cookei E.W.Mason & M.B.Ellis	1	0	0	0	0	0	0	0	0
Phaeodactylium venkatesanum Agnihothr.	1	0	0	1	0	1	0	0	0
Phaeosaria sp.	1	0	0	0	0	0	0	0	0
Phaeoisaria clematidis (Fuckel) S.Hughes	1	0	1	0	3	1	0	0	0
P. glauca (Ellis & Everh.) de Hoog & Papendorf	0	0	0	0	1	0	0	0	0
P. infrafertilis B.Sutton & Hodges	2	0	0	0	0	0	0	0	0
P. triseptata Hol.-Jech.	0	2	1	0	0	0	0	1	0
Phaeostalagmus tenuissimus (Corda) W.Gams & Hol.-Jech.	0	0	0	0	0	0	1	0	0
Phialocephala sp.	1	0	0	0	0	0	0	0	0
Phialocephala humicola S.C.Jong & E.E.Davis	0	0	0	0	0	0	1	0	1
Phialogeniculata guadalcanalensis Matsush.	0	0	0	0	0	0	0	0	6

Table 1 (continued) – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
Pleurophragmium sp.	1	0	0	0	0	0	0	0	0
Pleurothecium recurvatum (Morgan) Höhn.	0	0	0	0	0	0	0	0	2
Quadracaea mediterranea Lunghini, Pinzari & Zucconi	0	0	0	0	0	0	0	0	1
Ramichloridium sp.	0	2	1	0	0	0	0	0	0
Rinochladiella sp.	0	0	0	0	1	0	0	1	0
Sarcopodium circinatum Ehrenb.	0	0	0	0	0	0	0	0	1
Spadicoides sp. 1	0	0	0	0	0	0	0	0	1
Spadicoides sp. 2	0	0	0	0	0	2	0	0	0
S. bambusicola D.Q.Zhou, Goh & K.D.Hyde	0	0	0	0	0	0	0	0	1
Speiropsis scopiformis Kuthub. & Nawawi	2	0	1	0	0	0	1	0	0
Sporendocladia bactrospora (W.B.Kendr.) M.J.Wingf.	1	0	0	0	0	0	0	0	0
Sporidesmiella aspera Kuthub. & Nawawi	1	0	0	0	1	0	1	0	0
S. garciniae Matsush.	0	0	0	0	1	1	1	0	0
S. parva (M.B.Ellis) P.M.Kirk	0	0	0	1	0	0	0	0	0
Sporidesmium sp. 1	0	0	0	0	1	0	0	1	0
Sporidesmium sp. 2	0	0	0	0	0	0	0	1	3
S. eupatoriicola M.B.Ellis	0	1	0	0	0	0	0	0	0
S. pedunculatum (Peck) M.B.Ellis	0	1	0	0	1	0	0	1	0
S. queenslandicum Matsush.	0	0	0	0	0	0	0	0	2
S. tropicale M.B.Ellis	0	2	0	0	11	1	0	3	1
Stachybotrys sp.	0	1	0	0	0	0	0	0	0
S. chartarum (Ehrenb.) S.Hughes	0	0	5	0	0	1	0	1	0
S. globosa P.C.Misra & S.K.Srivast.	3	2	3	3	0	1	2	0	0
S. longispora Matsush.	2	0	0	1	0	0	1	0	0
S. nephrospora Hansf.	1	0	0	0	0	0	1	0	0
S. parvispora S.Hughes	2	0	0	1	0	0	2	0	0
Subulispora sp.	3	0	0	0	0	0	0	0	0
S. rectilineata Tubaki	1	0	0	0	0	0	0	0	0
Thozetella aculeata P.Silva & Grandi	1	0	0	0	0	0	0	0	0
T. cristata Piroz. & Hodges	7	0	2	11	0	1	6	0	1
T. cubensis R.F.Castañeda & G.R.W.Arnold	1	0	0	1	0	0	0	0	0
T. falcata B.C.Paulus, Gadek & K.D.Hyde	0	0	0	2	0	0	0	0	0
Uberispora sp. 1	0	0	0	0	0	0	0	0	1
Uberispora simplex (Ichinoe) Piroz. & Hodges	0	0	0	0	0	0	1	0	0
Umbellidion radulans B.Sutton & Hodges	1	0	0	0	0	0	1	0	0
Venustosynnema ciliata (R.F.Castañeda, G.R.W.Arnold & A.G.Guerra) R.F.Castañeda & W.B.Kendr.	2	0	0	1	0	0	1	0	0
Vermiculariopsiella cornuta (V.Rao & de Hoog) Nawawi, Kuthub. & B.Sutton	0	0	0	1	0	0	0	0	0
V. cubensis (R.F.Castañeda) Nawawi, Kuthub. & B.Sutton	0	0	0	0	0	0	0	1	1
Verticillium sp.	1	0	0	0	0	0	0	0	0
Virgariella atra S.Hughes	0	1	1	0	1	2	0	0	1
Volutella sp.	16	1	0	2	0	0	0	0	0

Table 1 (continued) – Conidial fungi associated with leaves (L), twigs (T) and barks (B) present in the Serra da Jibóia, Brejo Paraibano and Serra da Ibiapaba.

Species	Serra da Jibóia			Brejo Paraibano			Serra da Ibiapaba		
	L	T	B	L	T	B	L	T	B
Volutella minima Höhn	1	0	0	2	0	0	3	0	0
Wiesneriomyces laurinus (Tassi) P.M.Kirk	5	0	0	0	2	0	1	0	0
Zanclospora bonfinensis D.A.C.Almeida, Gusmão & M.F.O.Marques	1	0	0	0	0	0	0	0	0
Z. brevispora var. *brevispora* S.Hughes & W.B.Kendr.	0	0	0	0	0	0	0	0	1
Z. novae-zelandiae S.Hughes & W.B.Kendr.	0	1	0	0	2	2	0	1	1
Zygosporium echinosporum Bunting & E.W.Mason	3	0	0	1	0	0	0	0	0
Z. masonii S.Hughes	1	0	0	0	0	0	1	0	0
Occurrence	187	67	70	102	96	88	83	71	93
Richness	75	34	33	40	45	54	42	37	52

Table 2 – Occurrence, richness, and Shannon diversity of the communities in the areas: Serra da Jibóia (SJ), Brejo Paraibano (BP) and Serra da Ibiapaba (SI) in the six collection points.
Numbers in parentheses refer to the confidence interval 95% confidence obtained by the bootstrap method.

Areas/Points	Occurrences	Total	Richness	Total	Shannon index	Global Shannon index
SJ1	70	324	42 (39–53)	114 (109–130)	3.60 (3.41–3.86)	4.23 (4.20–4.47)
SJ2	57		41 (34–46)		3.61 (3.3–3.74)	
SJ3	66		42 (37–50)		3.54 (3.39–3.82)	
SJ4	46		34 (28–39)		3.41 (3.15–3.61)	
SJ5	47		30 (29–40)		3.24 (3.17–3.41)	
SJ6	51		31 (29–43)		3.24 (3.21–3.68)	
BP1	46	286	36 (27–38)	105 (102–123)	3.43 (3.15–3.59)	4.14 (4.13– 4.44)
BP2	54		34 (32–44)		3.31 (3.25–3.70)	
BP3	48		31 (30–40)		3.28 (3.17–3.63)	
BP4	47		29 (28–40)		3.15 (3.14–3.61)	
BP5	42		27 (26–36)		3.10 (3.05–3.54)	
BP6	48		26 (25–39)		3.17 (3.10–3.61)	
SI1	49	247	32 (30–41)	104 (94–114)	3.24 (3.20–3.66)	4.23 (4.10–4.39)
SI2	41		27 (26–36)		3.15 (3,08–3.53)	
SI3	41		27 (26–36)		3.11 (3.06–3.53)	
SI4	35		29 (22–32)		3.30 (2.93–3.42)	
SI5	42		32 (27–36)		3.37 (3.10–3.54)	
SI6	42		25 (24–35)		3.1 (3.08–3.54)	

Table 3 – Occurrence, richness, Shannon index and constancy of species in the substrates: leaf, twig and bark.
Numbers in parentheses refer to the confidence interval 95% confidence obtained by the bootstrap method.

Substrate	Occurrences	Richness	Shannon index	Constancy		
				Constant	Accessory	Accidental
Leaf	395	111 (105–125)	4.08 (3.8–4.28)	7 (6%)	13 (12%)	91 (82%)
Twig	230	90 (88–110)	3.80 (3.74–4.07)	3 (3%)	6 (7%)	81 (90%)
Bark	260	100 (96–117)	4.14 (4.11–4.41)	5 (5%)	17 (17%)	78 (78%)

Table 4 – **Morisita-Horn similarity index between the fungal communities associated with plant debris in the three enclaves of Atlantic Forest.**

Substrate	Leaf	Bark	Twig
Leaf	–	0.19	0.093
Bark		–	0.77
Twig			–

Table 5 – **Morisita-Horn similarity index between the fungal communities in the three enclaves of Atlantic Forest.**

Areas	Serra da Jiboia	Brejo Paraibano	Serra da Ibiapaba
Serra da Jiboia	–	0.46	0.54
Brejo Paraibano		–	0.72
Serra da Ibiapaba			–

the leaves. In the right group, fungi were associated with barks and twigs (fig. 2). On the second axis, the lower end was formed by a group of fungi recorded in Serra da Jibóia and in the upper by fungi from Brejo Paraibano and Serra da Ibiapaba (fig. 2). The ANOSIM test demonstrates significant differences between the pre-formed groups by the NMDS on axis 1 (R = 0.86, P = 0.007), but not in axis 2 (R = 0.12, P = 0.25).

The similarity analysis between the fungal community associated with plants debris demonstrated more similarity among the fungi associated with twigs and barks (0.77) with lower value between leaves and twigs (0.093) (table 4).

The species distributions by constancy classes revealed the prevalence of accidental taxa in the three substrates (table 3). The leaves hosted 91 taxa (82%), the twigs 81 (90%) and the barks 78 (78%). Thirteen taxa (12%) were classified as incidental in the leaves, six in the twigs (7%) and 17 in the barks (17%). Seven species were constant in the leaves: *Beltrania rhombica* (67% of collections), *Beltraniella portoricensis* (78%), *Beltraniopsis ramosa* (56%), *Codianea brittanica* (67%), *Codianea simplex* (89%), *Cryptophiale kakombensis* (66%) and *Thozetella cristata* (67%). In the twigs, three species were constant: *Chloridium transvalense* (78%), *Ellisembia adscendens* (89%) and *Sporidesmium tropicale* var. *tropicale* (67%). Five taxa were constant in the bark: *Brachsporiella gayana* (67%), *Chloridium virescens* var. *virescens* (67%), *Codianea simplex* (67%), *Ellisembia adscendens* (89%) and *Virgariella atra* (56%).

Of the studied substrates, the leaves had the highest number of unique taxa (71) corresponding to 33% of the registered taxa. The bark had 44 unique taxa (21%), and the twigs had 28 (13%). Only 16 taxa (7%) were common to all sub-

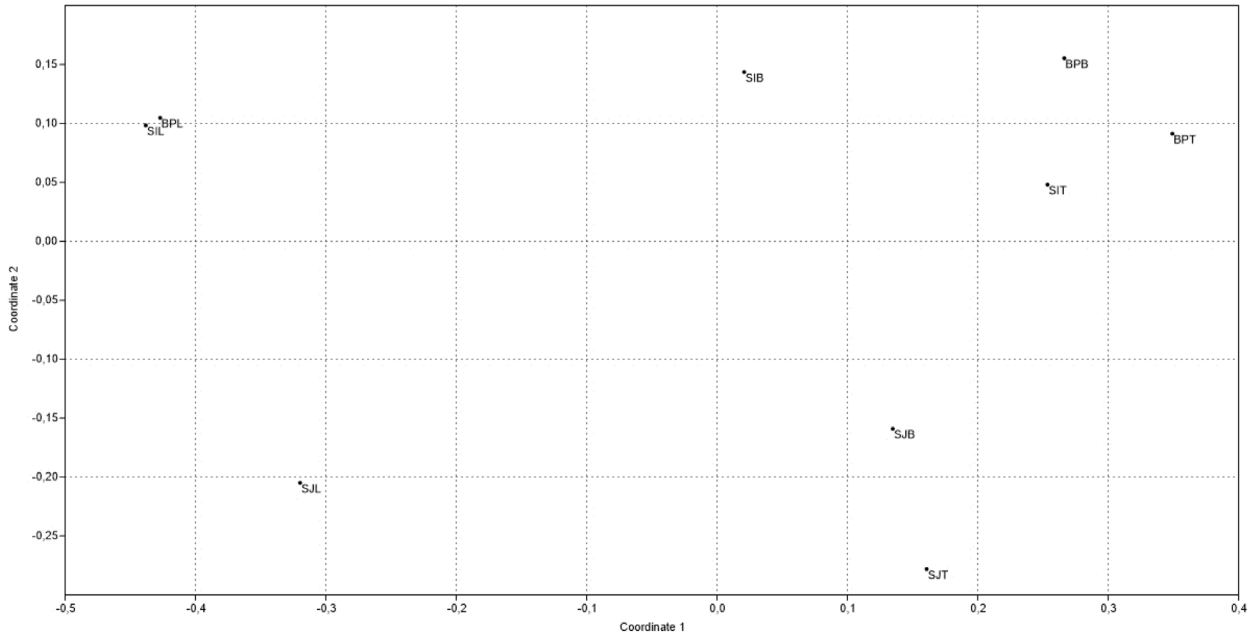

Figure 2 – Ordination in two dimensions of fungal communities by Multidimensional Scaling Not Metric (NMDS) in Serra Ibiapaba (SI), Brejo Paraibano (BP) and Serra da Jibóia (SJ) associated with leaves (L), twigs (T) and barks (B). Stress = 0.07.

strates; 31 (15%) were exclusive to twigs and barks, 15 (7%) to leaves and twigs, and nine (4%) to leaves and barks.

Regarding areas, 51 taxa occurred exclusively in the Serra da Jibóia (24% of the registered taxa), 43 taxa (20%) in Brejo Paraibano, whereas Serra da Ibiapaba had 42 taxa (20%). Thirty-three taxa (15%) were recorded in the three areas, and fifteen taxa (7%) were unique to SJ and BP as well as SJ and SI. Fourteen taxa (7%) were exclusive to SI and BP.

The similarity analysis was highest between SI and BP (0.72), and SJ and BP had the lowest similarity (0.46) (table 5). Cluster analysis indicated a group formed by SJ points. There was no differentiation between the SI and BP points (fig. 3).

DISCUSSION

Most studies of fungal diversity have been performed in temperate regions, however knowledge and interest for microfungi in tropical regions has grown in recent years (Kodsueb et. al 2008). Lee et al. (2004) evaluated the diversity of saprobic microfungi associated with leaves, stems, inflorescences of Proteaceae and Restionaceae in South Africa, and Paulus et al. (2006) studied the diversity and distribution of microfungi associated with four species of an Australian rainforest. Wang et al. (2008) studied the diversity of fungi on decomposing leaves of different *Ficus* species in Thailand.

Some studies were carried out on the richness of conidial fungi associated with plant debris in enclaves of the Atlantic forest in the semi-arid region and recorded several species in common to the present study. Marques et al. (2008) studied the conidial fungi associated with leaves, petioles, twigs and barks, in five expeditions in the Serra da Jibóia, and recorded 106 taxa, among them 44 were common with the present study. Barbosa et al. (2009) studied the conidial fungi community associated with leaves of *Clusia melchiorii* Gleason and *C. nemorosa* G.Mey in Serra da Jibóia. They carried out five expeditions and found 79 taxa (32 in common). Magalhães et al. (2011) made four collecting expeditions in three protected areas in southern Bahia and recorded 52 species of conidial fungi (16 in common). Silva et al. (2014b) studied the conidial fungi associated with plant debris submerged in lotic environments in five areas of the Caatinga biome, one collection in each area, and recorded 90 species (37 in common). Costa (2014) studied the litter of *Vismia guianensis* (Aubl.) Pers. in the same enclaves of Atlantic forest as in this study, carried out six expeditions and recorded 142 taxa (37 in common). *Beltrania rhombica* and *Atrosetaphiale flagelliformis* were recorded in all these studies. The higher number of taxa recorded here (213) may be due to the greater collecting effort.

Among the decaying plant debris, the leaves are the most significant part of the litter (Meguro et al. 1979). A high richness of fungi was seen on the leaves in other studies conducted in the semi-arid region. Marques et al. (2008) recorded 50 taxa in the leaves: 28 in the petioles and 47 in the barks and twigs. Silva et al. (2014b) registered 63 taxa in the leaves: 20 in the twigs, 18 in the barks, and 11 in the petioles. On the other hand, Ananda & Sridhar (2004) studied the diversity of filamentous fungi in an Indian mangrove and recorded a higher species richness in decaying wood (65 taxa) than in the leaves (49 taxa). Marques et al. (2008) suggested that the differences in these results as a function of forest area may be due to the particularities of each environment and substrates.

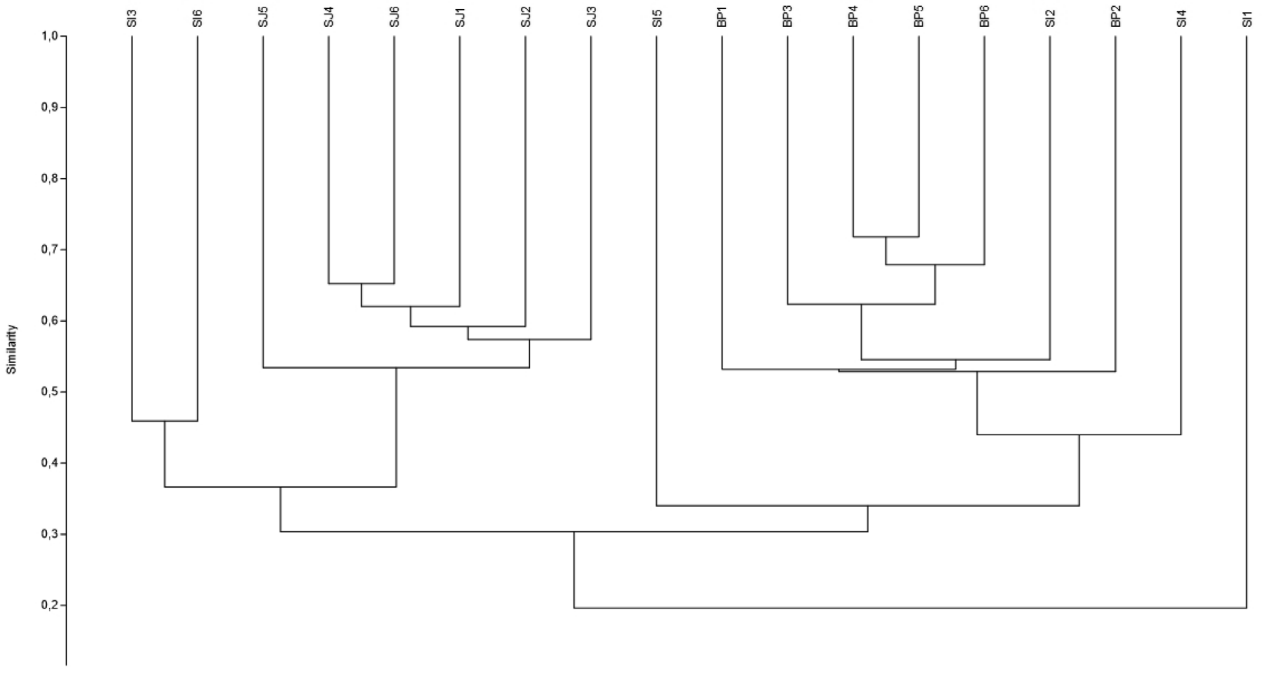

Figure 3 – Cluster analysis of fungal communities in the six collection points in the Serra da Jibóia (SJ), Brejo Paraibano (BP) and Sierra Ibiapaba (SI) associated with plant debris. UPGMA-Morisita. Cophenetic correlation coefficient = 0.88.

Other studies comparing the fungal diversity associated with the same three plant substrates (leaf, bark and twig) have shown different results. Sunayana & Prakash (2012) studied the endophytic fungi of *Boswellia serrata* Roxb in India and recorded the greatest diversity in the twigs (H' = 2.16) followed by bark (H' = 1.60) and leaves (H' = 1.38). Sunayana et al. (2014) analysed the diversity of endophytic fungi of *Vitex negundo* L. and recorded the greatest diversity in the twigs (H' = 2.48) followed by barks (H' = 2.36) and leaves (H' = 2.28). This lower diversity in the leaves associated with endophytic fungi may be due to the fact that fresh leaves produce secondary metabolites that can inhibit the occurrence of fungi, which are not present in decomposing leaves (Rocha et al. 2004).

Multivariate analysis NMDS and ANOSIM revealed that the substrate was a more significant factor in ordering the fungal community than the area. The similarity analysis showed a high similarity between bark and twigs and a low similarity of these substrates with leaves. The similarity values can be explained by the composition of the substrates. Twigs and barks have larger amounts of lignocellulose and low nitrogen content compared to leaves (Wong et al. 1998). The fungi produce a complex set of hydrolytic and oxidative enzymes for the degradation of these substances, but only few fungi have the enzymatic capacity to decompose all these compounds (Gosh & Gosh 1992, Bucher et al. 2004). The data suggest that a fungal community is associated with the leaves because many fungi were associated exclusively with this substrate and that is another community associated with barks and twigs (fig. 3, table 4).

Few taxa (7%) were common to the three substrates. Similar result was also found by Silva et al. (2014b) and Marques et al. (2008). Polishook et al. (1996) and Parungao et al. (2002) showed that some fungi may prefer a given substrate, and Hyde & Alias (2000) reported that different parts of the plant can harbour different fungi. This indicates that some of them may grow preferentially in certain tissue types.

The fact that most species were classified as accidental in the three substrates may be explained by the fact that some conidial fungi occur in the substrates under specific conditions. These factors include temperature, pH, aeration, senescence time, chemical composition and structure of substrates. Alone or together, these factors can influence the fungal growth on a substrate (Dix & Webster 1995). Other studies of Atlantic Forest enclaves in the Caatinga biome demonstrated similar results (Marques et al. 2008, Barbosa et al. 2009, Magalhães et al. 2011).

Lodge & Cantrell (1995) suggested that variables such as location and environmental disturbances may affect the distribution of conidial fungi in the leaf litter. According to Hyde et al. (2007), many studies on saprobes and endophytic fungi associated with palms have indicated that specific local factors and geographical distances can be more important than the substrate in the fungal communities' formation. This was not observed in this study because few taxa are unique to a particular area and many taxa were shared between areas.

The similarity and cluster analysis between areas showed that BP and SI are more similar. Costa (2014) studied the saprobe fungal community associated with the leaves from *Vismia guianensis* (Aubl.) Pers. in the same areas of this study and reported a similar result. The greatest similarity observed between areas was probably related to the geographical location. Similarities between the compositions of vegetation are seen in the endemism centre located north of San Francisco River (SJ composes the Atlantic Forest south of San Francisco) (Rêgo & Hoeflich 2001).

The survey data shows the great richness and diversity of conidial fungi in the studied areas. Studies of this nature can provide policy for conservation of these and other areas in the Brazilian semi-arid region.

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