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Diversity of filamentous fungi isolated from the soil in the semiarid area, Pernambuco, Brazil

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ABSTRACT

The Caatinga (dryland) biome of Brazil is experiencing accentuated desertification due to deforestation and inappropriate uses of its natural resources. Studies examining the diversity of filamentous fungi in Caatinga soils are still scarce and the present work was designed to isolate and identify the soil fungi of this biome in the semiarid region of northeastern Brazil. Soil samples were taken at five random sites during the dry and rainy seasons from the soil surface and at depths of 20 cm. A total of 85 species of filamentous fungi were identified, including species of anamorphic fungi (71 species), Zygomycota (8) and Ascomycota (6). The most abundant genera were *Aspergillus* (28) and *Penicillium* (18). No significant differences were observed in the numbers of colony forming units in samples taken during either the rainy or dry seasons, or from surface or subsurface soils. Most of the fungi species isolated from caatinga soils were classified as rare. Our results indicate that anamorphic fungi dominate the soil mycobiota in the Brazilian semiarid region, with species of *Aspergillus* and *Penicillium* being most common.

1. Introduction

Fungi are among the most diverse groups of organisms on the planet, but they are usually associated with mega diverse groups and are not well known (Cannon, 1997). There are about 1.5 million fungi species spread throughout the world – although many have restricted distributions and are limited to a particular habitat type (Dix and Webster, 1995; Hawksworth, 2001).

Fungi are found in essentially every possible substrate and ecosystem, and may act as saprotrophs, parasites of plants, animals, and fungi, or be mutualistic symbionts of phototrophic organisms such as cyanobacteria, algae, and vascular plants. Saprotrophic fungi degrade many types of organic and some inorganic substrates (Metting, 1993; Sylvia et al., 1998), participating actively in the processes of biodegradation and nutrient cycling, thus helping to maintain ecosystem functioning (Allsopp and Seal, 1986; Eggins and Allsopp, 1975; Griffin, 1994; Hyde, 1997; Laurance and Bierregaard, 1997).

There is a growing interest in finding life in extreme environments and examining the impacts of global climate changes on ecosystem functioning. The ability of fungi to tolerate high or low temperatures in extreme environments indicates that there are species with adaptive mechanisms that can deal with considerable stress – and enzymes produced by both thermophiles and psychrophiles have been examined for biotechnological and pharmaceutical purposes (Kubicek et al., 2007).

The semiarid zone in northeastern Brazil occupies approximately 800,000 km^2 (approximately 11% of the land area of that country) (Drumond et al., 2004). The climate there is characterized by a high evapotranspiration potential (2000 mm/year), and an average precipitation of 700 mm that is concentrated into three to five months of the year, with annual average temperatures of 23–27 °C (Sampaio, 1995).

The predominant vegetation type in this region is known as “caatinga” – a word derived from the Tupi Amerindian dialect: “caa” meaning forest, and “tinga” meaning white. Caatinga is an exclusive Brazilian biome that comprises a mosaic of thorny shrub vegetation and seasonally dry forests that has been experiencing rapid processes of desertification due to deforestation and the inappropriate use of its natural resources (Drumond et al., 2004; Leal et al., 2005; Giulietti et al., 2006). Deforestation has resulted in decreasing plant biomass production, with resulting changes in soil interactions and biodiversity losses (Skujins and Allen, 1986).

Little is currently known about the diversity of filamentous soil fungi in the Caatinga biome, although Cavalcanti and Maia (1994) isolated cellulolytic soil fungi in the semiarid region of Pernambuco State; Costa et al. (2006) and Santiago and Souza-Motta (2006) reported Hyphomycetes and Mucorales in soils contaminated by mining activities in the semiarid region of Bahia State; while Souza et al. (2003) and Cavalcanti et al. (2006) studied

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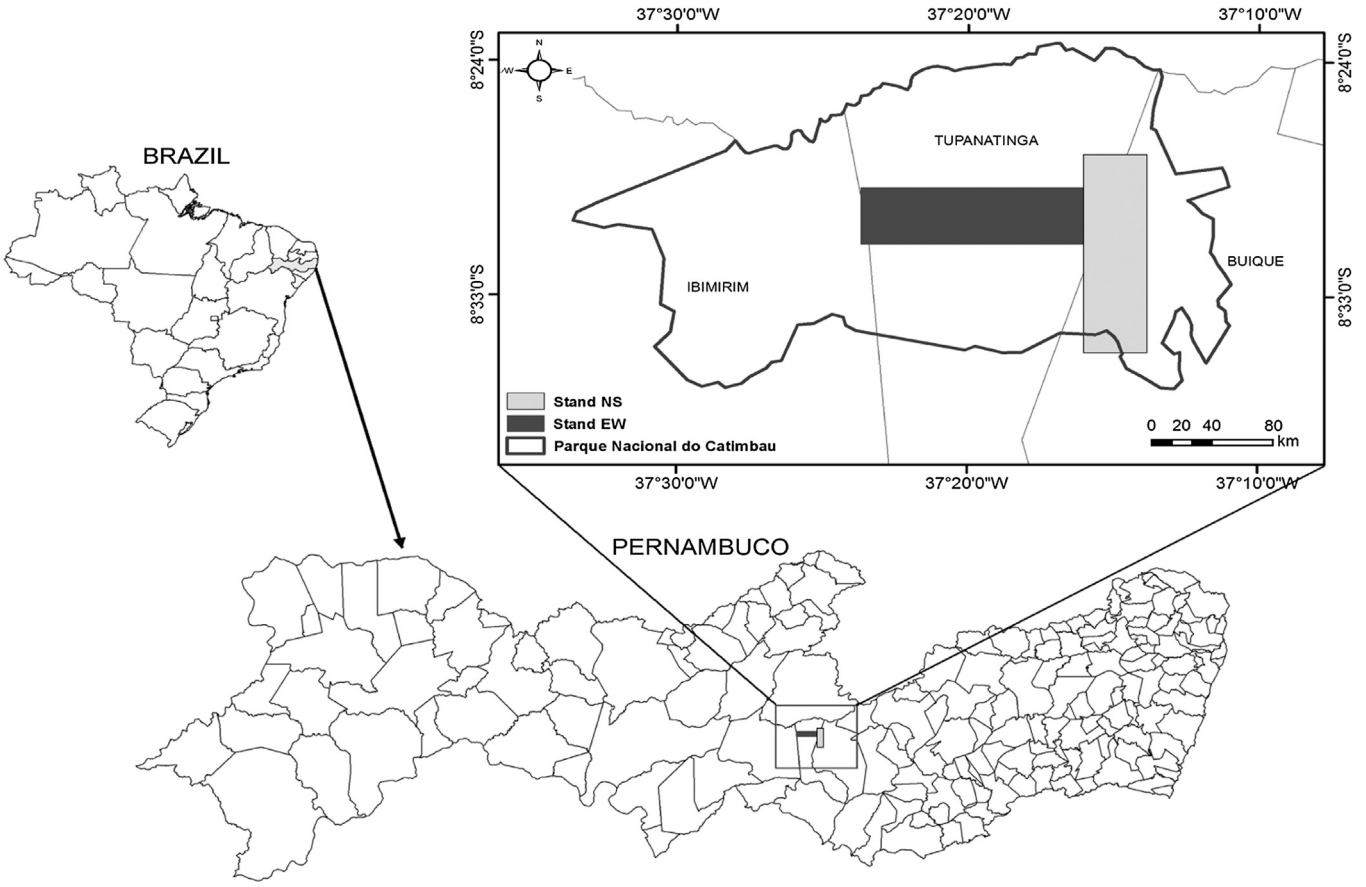

Fig. 1. Location of the study area.

arbuscular mycorrhizal fungi and Hyphomycetes, respectively, in the Xingó region.

The study of soil fungi in semiarid regions is still incipient in spite of the pioneering work of Abdel-Hafez (1982), El-Dohlob and Al-Helfi (1982), Abdullah et al. (1986), and Abdullah and Al-Bader (1990) in Saudi Arabia and Iraq, and Grishkan and Nevo (2010) in the Negev Desert (Israel).

In the view of the scarcity of works examining the filamentous soil mycota of the Caatinga biome, the present work isolated and identified filamentous fungi soil in the municipality of Buíque in the semiarid region of Pernambuco State, Brazil.

2. Materials and methods

2.1. Study area

The study area, known as the "Chapada de São José", was located 4 km from municipality of Buíque, in the Vale do Catimbau National Park (Fig. 1) (Rodal et al., 1998). The regional climate is hot and dry, with temperatures often reaching 45 °C during the day (classified as Bsh according to the Köppen system), with a mean annual temperature of 25.5 °C. Precipitation rates are shown in Fig. 2. The soils there are mostly sandy (Jacomine et al., 1973) and the vegetation is a mixture of deciduous thorny plants and evergreen shrubs, with a more species-rich semideciduous thorny vegetation being found on higher altitude and more level "Chapada" areas; with high numbers of endemic species (Neta et al., 2004).

The regional flora is represented by the families Anacardicaceae, Annonaceae, Bignoniaceae, Caesalpiniaceae, Celatraceae, Chysobalanaceae, Clusiaceae, Erythroxylaceae, Fabaceae, Lamiaceae, Lauraceae, Lythraceae, Malpighiaceae, Mimosaceae, Myrtaceae, Nyctagenaceae, Ochnaceae, Olacaceae, Rubiaceae, Rutaceae, Sapotaceae, Simaroubaceae, Sterculiaceae, Turneraceae, and Verbenaceae (Rodal et al., 1998).

2.2. Soil collections

Soil samples were collected at five randomly chosen sites (Site I: 08° 34′ 00″ S × 37° 15′ 07″ W; Site II: 08° 31′ 55″ S × 37° 15′ 08″ W; Site III: 08° 32′ 53″ S × 37° 14′ 30″ W; Site IV: 08° 32′ 49″ S × 37° 15′ 08″ W; Site V: 08° 29′ 54″ S × 37° 14′ 48″ W) in the Catimbau Valley, from the soil surface as well as at 20 cm depths, during the dry (September and October/05) and rainy seasons (May and June/

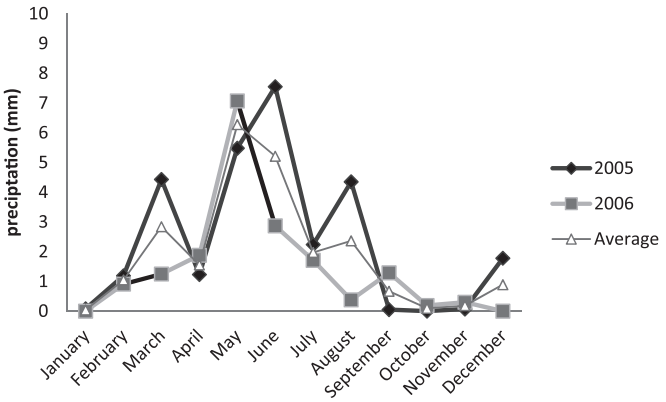

Fig. 2. Precipitation data for the study area.

Table 1
Chemical and granulometric characteristics of the soil in the Vale do Catimbau, Buíque (PE).

Collect site	pH (H_2O-1:2, 5)	P (mg/dm^3)	Na^+ ($cmol_c/dm^3$)	K^+ ($cmol_c/dm^3$)	$Ca^{+2} + Mg^{+2}$ ($cmol_c/dm^3$)	Ca^{+2} ($cmol_c/dm^3$)	Al^{+3} ($cmol_c/dm^3$)	Granulometric
I	5.5	0	0.41	0.03	2.55	1.40	0.10	Sandy
II	4.4	0	0.40	0.12	5.00	3.40	0.15	Sandy
III	5.9	0	0.33	0.11	7.15	4.00	0.15	Sandy
IV	5.2	11	0.35	0.09	4.00	3.20	0.25	Sandy
V	5.2	11	0.39	0.12	5.00	3.40	0.15	Sandy

06). The soil samples were collected in a bucket and subsequently packed in plastic bags for later manipulation.

Rainfall during the periods of the soil collections totaled 2 and 0 mm in September and October/2005, and 219 and 86 mm in May and June/2006.

2.3. Soil analyses

Chemical and granulometric analyses of the soils were performed at the Physics and Soil Fertility Laboratories of the Universidade Federal Rural de Pernambuco, and determined the soil pH, and the levels of phosphorus (P), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and aluminum (Al) (Table 1).

2.4. Statistical analyses

The fungi species frequencies were calculated for each sampling site using the formula: $Di = (Ni/N) \times 100$, where Di = the frequency of species i; Ni = number of number of colony forming units (CFU) of species i; N = total number of colony forming units (CFU). According to this formula, the species frequencies can be classified as: <0.5% = rare, ≥0.5 <1.5% = occasional, ≥1.5 <3.0% = common, ≥3.0% = abundant (Schnittler and Stephenson, 2000).

The Kruskal–Wallis test was used to determine if there were significant differences in the numbers of colony forming units (CFU) with respect to the time of collection (rainy or dry season) and soil depth (surface or 20 cm deep) considering a 5% level of significance, using Bioestat 5.0 software (Ayres et al., 2007).

The Shannon–Wiener Diversity Index ($\log_2$: $H' = \Sigma (pi) \times (\log_2 pi)$, where pi = number of CFU of each species/total CFU) was used to calculate the diversity of filamentous fungi in the study area (Krebs, 1999).

Multiple regression analysis was used to analyze correlation between the soil properties and fungi community using Statistica 6.0 (Statsoft, 2001).

2.5. Fungal isolation, purification, and identification

The method described by Clark (1965, modified) was used to isolate the fungi according to the following procedure: 25 g of each soil sample was diluted in 225 ml of sterile distilled water (SDW) (1:10 w/v). Ten mL of this suspension was then added to 990 ml of SDW (1:1000 v/v) and 1 ml of this final volume was spread on the surface of Sabouraud agar medium plus chloramphenicol (100 mg/l) in Petri plates, in triplicate. The Petri dishes were maintained at room temperature (28 °C ± 1 °C) for 96 h. The colonies were then counted to determine the numbers of colony forming units (CFU), and inoculums of the colonies formed were transferred to test tubes containing Sabouraud agar medium plus chloramphenicol (50 mg/l) and their growth was for 72 h. The fungi samples were subsequently transferred to selective culture media (Czapeck Agar, Potato Dextrose Agar, and Malt Agar) and identified by their macroscopic (color, appearance, and colony diameters) and microscopic (microstructural) characteristics, according to Raper and Thom (1949), Rifai (1969), Booth (1971), Ellis (1971, 1976), Samson (1974), Raper and Fennell (1977), Domsch et al. (2007), Cannon and Hawksworth (1984), Schipper and Stalpers (1984), and Pitt (1988), among others.

3. Results

A total of 85 species of fungi were identified during both the rainy and dry seasons, at and under the soil surface, in Catimbau Valley. The anamorphic fungi were best represented, with 71 species: *Penicillium* (28 species), *Aspergillus* (18), *Fusarium* (5), *Cladosporium* and *Trichoderma* (3), *Pithomyces*, *Humicola* and *Myrothecium* (2), *Curvularia*, *Drechslera*, *Monodictys*, *Paecilomyces*, *Scopulariopsis*, *Scytalidium*, *Staphylotrichum* and *Stillbella* (1 each) (Table 2). The Zygomycota comprised 8 species (Table 3), followed by Ascomycota with 6 (Table 4).

Table 2
Colony forming units of Anamorphic species isolated from the soil in the Vale do Catimbau, Buíque-Pernambuco.

Species	Rainy		Dry		Total of CFU	%
	S	De	S	De		
Anamorphic fungi						
Aspergillus aculeatus Iizuka	0	0	6	0	6	0.56
A. brevipes G. Sm.	1	0	0	0	1	0.09
A. carbonarius (Bainier) Thom	0	0	1	0	1	0.09
A. duricaulis Raper & Fennell	0	2	15	6	23	2.15
A. flavus Link	0	3	0	4	7	0.65
A. fumigatus Fresen.	31	55	77	4	167	15.59
A. japonicus Saito	3	1	4	1	9	0.84
A. niger Tiegh.	0	1	9	0	10	0.93
A. niveus Blochwitz	0	0	0	1	1	0.09
A. ochraceus G. Wilh.	3	0	0	2	5	0.47
A. ostianus Wehmer	0	0	1	0	1	0.09
A. parasiticus Speare	0	0	1	0	1	0.09
A. puniceus Kwon-Chung & Fennell	0	0	0	1	1	0.09
A. versicolor (Vuill.) Tirab.	0	0	0	38	38	3.55
A. viride-nutans Ducker & Thrower	0	0	1	1	2	0.19
A. tamarii Kita	3	0	0	20	23	2.15
A. terreus Thom	2	42	3	9	56	5.23
A. ustus (Bain. & Sart.) Thom & Church	2	2	0	0	4	0.37
Cladosporium cladosporioides (Fresen.) G.A. de Vries	1	0	1	0	2	0.19
C. sphaerospermum Penz.	0	0	1	0	1	0.09
C. tenuissimum Cooke	1		3		4	0.37
Curvularia pallescens Boedijn	1	0	1	0	2	0.19
Drechslera australiensis M.B. Ellis	0	0	1	0	1	0.09
Fusarium equiseti (Corda) Sacc.	0	5	1	0	6	0.56
F. lateritium Nees	11	5	1	5	22	2.05
F. oxysporum Schltdl.	0	1	0	0	1	0.09
F. solani (Mart.) Sacc.	12	8	14	1	35	3.27
F. stilboides Wollenw.	0	0	0	2	2	0.19
Humicola fuscoatra Traaen	0	0	2	1	3	0.28
H. rugosa De Bert.	0	0	1	0	1	0.09
Monodictys castaneae (Wallr.) S. Hughes	0	0	2	0	2	0.19
Myrothecium indicum Pavgi, R.A. Singh & Dular	0	0	1	2	3	0.28

(*continued on next page*)

Table 2 (*continued*)

Species	Rainy		Dry		Total of CFU	%
	S	De	S	De		
M. roridum Tode	0	0	1	2	1	0.09
Paecilomyces lilacinus (Thom) Samson	2	6	0	0	8	0.75
Penicillium aurantiogriseum Dierckx	1	0	0	1	2	0.19
P. brevicompactum Dierckx	0	4	7	0	11	1.03
P. canescens Sopp	1	0	0	0	1	0.09
P. citreonigrum Dierckx	0	15	1	0	16	1.49
P. commune Thom	1	31	24	0	56	5.23
P. corylophilum Dierckx	1	0	7	0	8	0.75
P. crustosum Thom	0	0	0	1	1	0.09
P. decumbens Thom	78	81	8	0	167	15.59
P. fellutanum Biourge	0	1	0	0	1	0.09
P. glabrum (Wehmer) Westling	0	0	0	1	1	0.09
P. griseofulvum Dierckx	0	1	0	0	1	0.09
P. implicatum Biourge	1	2	0	1	4	0.37
P. janthinelum Biourge	18	5	1	1	25	2.33
P. lividum Westling	16	0	0	3	19	1.77
P. melinii Thom	0	1	0	0	4	0.37
P. mineoluteum Dierckx	0	4	1	0	5	0.47
P. pinophilum Thom	0	0	1	22	23	2.15
P. restrictum J.C. Gilman & E.V. Abbott	67	1	3	5	76	7.10
P. roseopurpureum Dierckx	0	0	0	1	1	0.09
P. simplicissimum (Oudem.) Thom	3	3	8	0	14	1.31
P. solitum Westling	1	0	0	0	1	0.09
P. thomii Maire	0	4	0	0	4	0.37
P. turbatum Westling	0	0	0	3	3	0.28
P. variabile Sopp	1	0	0	0	1	0.09
P. verruculosum Peyronel	33	27	4	6	70	6.54
P. vinaceum J.C. Gilman & E.V. Abbott	0	0	2	15	17	1.59
P. viridicatum Westling	0	0	0	24	24	2.24
P. waksmanii K.M. Zalessky	0	41	0	0	41	3.83
Pestalotiopsis palustris Nag Raj	0	0	0	1	1	0.09
Pestalozziella artocarpi Nag Raj	0	0	5	0	5	0.47
Pithomyces chartarum (Berk. & M.A. Curtis) M.B. Ellis	0	0	3	1	4	0.37
P. sacchari (Speg.) M.B. Ellis	0	0	0	1	1	0.09
Scopulariopsis chartarum (G. Sm.) F.J. Morton & G. Sm.	1	0	0	0	1	0.09
Scytalidium lignicola Pesante	0	1	0	0	2	0.19
Staphylotrichum cocosporum J.A. Mey. & Nicot	0	1	0	0	1	0.09
Stillbella clavispora Seifert	0	1	0	0	1	0.09
Trichoderma aureoviride Rifai	0	0	1	0	1	0.09
T. koningii Oudem.	5	1	0	0	6	0.56
T. pseudokoningii Rifai	1	0	0	0	1	0.09
Total	302	356	224	187	1071	100

R: rainy period, D: dry period, S: soil surface, De: soil depth, % distribution of specie.

Table 3
Colony forming units of Zygomycota species isolated from the soil in the Vale do Catimbau, Buíque-Pernambuco.

Species	Rainy		Dry		Total of CFU	%
	S	De	S	De		
Zygomycota						
Absidia cylindrospora Hagem	4	0	2	0	6	10.34
Cunninghamella blakeslleeana Lendn.	3	0	0	0	3	5.17
C. vesiculosa P.C. Misra	0	1	0	0	1	1.72
Gongronella butleri (Ledner) Peyronel & Dal Vesco	0	13	0	26	39	67.24
Mucor fuscus Bainier	0	0	0	3	3	5.17
Rhizopus microsporus var. *microsporus* Tiegh.	3	0	0	0	3	5.17
R. oryzae Went & Prins. Geerl.	0	0	1	0	1	1.72
Syncephalastrum racemosum Cohn ex J. Schröt	1	0	0	1	2	3.45
Total	11	14	3	30	58	100

R: rainy period, D: dry period, S: soil surface, De: soil depth, % distribution of specie.

Table 4
Colony forming units of Ascomycota species isolated from the soil in the Vale do Catimbau, Buíque-Pernambuco.

Species	Rainy		Dry		Total of CFU	%
	S	De	S	De		
Ascomycota						
Chaetomium aureum Chivers	1	0	0	0	1	4.17
C. globosum Kunze	0	1	3	0	4	16.67
Emericela variecolor Berk. & Broome	0	0	0	1	1	4.17
Eupenicillium brefeldianum B.O. Dodge) Stolk & D.B. Scott	1	3	0	0	4	16.67
Neocosmospora vasinfecta var. *africana* E. F. Sm.	7	3	1	1	12	50.00
Thielavia terricola (J.C. Gilman & E.V. Abbott) C.W. Emmons	0	0	0	2	2	8.33
Total	9	7	4	4	24	100

R: rainy period, D: dry period, S: soil surface, De: soil depth, % distribution of specie.

In terms of the total number of colony forming units (1150×10^3 CFU/g), *Penicillium decumbens* Thom, *Penicillium restrictum* JC Gilman & EV Abbott, and *Penicillium commune* Thom had 167×10^3, 76×10^3, and 56×10^3 CFU/g respectively. Greater numbers of CFU were observed in the subsurface soil (598×10^3 CFU) and during the rainy season (699×10^3 CFU/g).

Of the fungi isolated from the five soil sampling sites, *Aspergillus fumigatus* Fresenius (14.52%), *Aspergillus versicolor* (Vuill.) Tirab. (3.30%), *Aspergillus terreus* Thom (4.86%), *Fusarium solani* (Mart.) Appel & Wollenw (3.04%), *Penicillium commune* Thom (4.87%), *P. decumbens* Thom, (14.52%), *P. restrictum* (6.61%). C. Gilman & EV Abbott, *Penicillium verruculosum* Peyronel (6.09%), and *Penicillium waksmanii* Zaleski (3.57%) were classified as abundant.

No significant differences were observed in the numbers of colony forming units found during the rainy or dry seasons or between the soil surface and below surface depths ($H = 1.5254$; gl = 3, $p = 0.6764$). No correlation between soil proprieties and fungi community was observed. The Diversity Index of fungi species in relation to the total number of colony forming units (CFU) was 4.84 bits per individual.

4. Discussion and conclusions

Most of the species identified in this study are cited as have been isolated from soils (Domsch et al., 2007; Ellis, 1971, 1976; Sammson and Frisvad, 2004; Raper and Fennell, 1977). According to Cardoso et al. (1992), microorganisms have active roles in soil dynamics in terms of soil formation, fertility, structure, and health conditions, through processes of reduction and oxidation, and by producing and releasing enzymes and metabolic products that can provoke important changes in soil properties, such as pH and its structural and chemical composition and temperature. Nutrients important to soil organisms (such as nitrogen, potassium, magnesium, sulfur and calcium) can become scarce through leaching, with those losses being regulated by rainfall rates, vegetation cover type, and soil texture. Lauber et al. (2008) noted that soil fungal community compositions are closely associated with soil nutrient status, and specific changes in edaphic properties can alter microbial community compositions across a given landscape. Titus et al. (2002) noted that nutrient accumulations at the soil surface in arid regions are influenced by factors such as erosion, the soil (micro) biota, and atmospheric and biogeochemical processes.

Soil is considered a world of asexual microfungi (anamorphic fungi). A major proportion of soil micromycetes is active only in low-stress habitats, and predominate wherever readily assimilable carbon sources are available. By contrast, sexual ascomycetes are believed to be mainly stress-selected, occupying environments

with various stress levels that exclude many asexual fungi (Dix and Webster, 1995; Grishkan et al., 2003).

According to Raymundo and Tauk-Tornisielo (1997), when there are only small numbers of plants growing in the soil abiotic factors such as temperature and water content can negatively interfere with soil fungi diversity, as was corroborated by Peuke and Rennenberg (2004).

Although research efforts have been scarce in areas of Brazilian Caatinga, the results of the present study were similar to those reported from other arid regions. In a study of the soil fungi in Saudi Arabia, Abdel-Hafez (1982) reported 80 species of filamentous fungi, with species of the genera *Aspergillus* and *Penicillium* demonstrating the greatest diversity – and these results corroborated those of the present study in terms of those taxa. The studies of Abdullah and Al-Bader (1990) on the thermophilic and thermotolerant mycota of the soils in Iraq likewise noted a predominance of *Aspergillus* species. Mouchacca (2005) presented a list of fungi found in arid regions in the Middle East between 1940 and 2000 and noted the prevalence of anamorphic fungi and Ascomycota (70%), with high numbers of species of *Penicillium* (17) and *Aspergillus* (7) – likewise corroborating the results of the present research; Grishkan and Nevo (2010) reported 186 species of filamentous fungi from the Negev Desert (Israel), with anamorphic fungi being the most abundant (128 species). Loro et al. (2012) studied the incidence and diversity of fungal endophytes in semiarid in Venezuela compared with others arids regions.

There have been relatively few studies of the soil fungi of the semiarid region of Brazil. Cavalcanti and Maia (1994) studied cellulolytic soil fungi in the semiarid region of Pernambuco State and observed high diversity of the anamorphic fungi, including *Aspergillus niger*, *A. versicolor*, *Aspergillus ustus*, *Curvularia palescens*, *Humicola fuscoatra*, *Penicillium pinophilum*, *P. verruculosum*, *P. waksmanii*, and *Pithomyces chartarum*, many of which were also encountered in the present study. Cavalcanti et al. (2006) reported 96 species from the Xingó region in the semiarid Brazilian northeast (of which 49 were also found in the present study), with a predominance of species of the genera *Aspergillus* and *Penicillium*. Costa et al. (2006) reported the occurrence of Hyphomycetes in soils affected by mining activities in the semiarid region of Bahia State (BA) with a predominance of *Aspergillus* and *Penicillium*; the high numbers of colony forming units of *Penicillium* found corroborate the present results. Santiago and Souza-Motta (2006) reported finding species of Mucorales in the same region, as well as *Absidia cylindrospora*, *Cunninghamella elegans*, *Rhizopus microsporus*, *Rhizopus oryzae,* and *Sincephalastrum racemosum* in the soil from Catimbau Valley, Buíque, Pernambuco State, Brazil.

Aspergillus and *Penicillium* were the most abundant genera in the present study, and it is known that many species of both genera can survive in dry environments (Dix and Webster, 1995).

In their study of conidial fungi in Australian tropical forests by direct observations of leaves and the filtration of 4.11–4.73 μ particles, Paulus et al. (2006) found that the Shannon–Wiener diversity indices of fungi on six species of plants collected varied from 2.96 to 3.76. Jones et al. (2006) reported diversity indexes ranging from 3.44 to 3.31 in Atlantic Forest sites in Pernambuco State (Brazil). According to Washington (1984), this index will not, in practice, exceed 5.0 for biological communities.

The fungi isolated in the present study were predominantly cosmopolitan anamorphic fungi frequently encountered in the Atlantic Forest (Schoenlein-Crusius and Milanez, 1998), Tropical Savanna (Raymundo and Tauk-Tornisielo, 1997), and Caatinga (Maia and Gibertoni, 2002) ecosystems of Brazil. The presence of these fungi must certainly reflect the dynamics and complexity of the abiotic factors affecting these soils, and certain species would be expected to be specific to certain soil conditions (Kang and Mills, 2006; Lodge, 1997). Additionally, not all of the fungi present in a soil sample may grow on the culture media offered, while others could be favored (Bing-Ru et al., 2006; Kirk et al., 2004).

The results of this study *indicate* that anamorphic soil fungi predominate in the study site in the semiarid region of Brazil, with many species of *Aspergillus* and *Penicillium* – although additional studies will be needed to determine the full extent of the soil fungal diversity to be found there.

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References

Abdel-Hafez, S.I.I., 1982. Survey of the mycoflora of desert soils in Saudi Arabia. Mycopathologia 80, 3–8.
Abdullah, S.K., Al-Bader, S.M., 1990. On the thermophilic and thermotolerant mycoflora of Iraqi soils. Sydowia 42, 1–7.
Abdullah, S.K., Al-Khesraji, T.O., Al-Edany, T.Y., 1986. Soil mycoflora of the Southern desert of Iraq. Sydowia 39, 8–16.
Allsopp, D., Seal, K.J., 1986. Introduction to Biodeterioration. Edward Arnold, London.
Ayres, M., Ayres Junior, M., Ayres, D.L., Santos, A.A.S., 2007. BioEstat 5.0.: aplicações estatísticas nas áreas das Ciências Biomédicas. Pará, Sociedade Civil Mamirauá Aplicações.
Bing-Ru, L., Guo-Mei, J., Jian, C., Gang, W., 2006. A review of methods for studying microbial diversity in soils. Pedosphere 16, 18–24.
Booth, C., 1971. The Genus Fusarium. Commonwealth Institute, Kew, Surrey.
Cannon, P.F., 1997. Strategies for rapid assessment of fungal diversity. Biodiversity and Conservation 6, 669–680.
Cannon, P.F., Hawksworth, D.L., 1984. A revision of the genus *Neocosmospora* (Hypocreales). Transactions of the British Mycological Society 82, 673–688.
Cardoso, E.J.B.N., Tsai, S.M., Neves, M.C.P., 1992. Microbiologia do solo. Sociedade Brasileira de Ciência do Solo, Campinas.
Cavalcanti, M.A.Q., Maia, L.C., 1994. Cellulolytic fungi isolated from allluvial soil in semi-arid area of the northeast of Brazil. Revista de Microbiologia 25, 251–254.
Cavalcanti, M.A.Q., Oliveira, L.G., Fernandes, M.J.S., Lima, D.M.M., 2006. Fungos filamentosos isolados do solo em municípios na Região Xingó, Brasil. Acta Botânica Brasílica 53, 831–837.
Clark, F.E., 1965. Agar-plate method for total microbial count. In: Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark, F.E., Dinaver, R.C. (Eds.), Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. Madson Inc, New York, pp. 1460–1466.
Costa, I.P.M.W., Cavalcanti, M.A.Q., Fernandes, M.J.S., Lima, D.M.M., 2006. Hyphomycetes from soil of an area affected by copper mining activities in the state of Bahia, Brazil. Brazilian Journal of Microbiology 37, 290–295.
Dix, N.I., Webster, J., 1995. Fungal Ecology. University, Cambridge.
Domsch, K.H., Gams, W., Anderson, T.H., 2007. Compendium of Soil Fungi. Editora IHW-Verlag, San Francisco.
Drumond, M.A., Kill, L.H.P., Lima, P.C.F., Oliveira, M.C., Oliveira, V.R., Albuquerque, S.G., Nascimento, C.E.S., Cavalcante, J., 2004. Estratégias para o uso sustentável da biodiversidade da Caatinga. In: Silva, J.M.C., Tabarelli, M., Fonseca, M.T., Lins, L.V. (Eds.), Biodiversidade da Caatinga: áreas e ações prioritárias para a conservação. Ministério do Meio ambiente, Brasília, pp. 329–340.
Eggins, H.O., Allsopp, D., 1975. Biodeterioration and biodegradation by fungi. In: Smith, J.E., Berry, D.R. (Eds.), The Filamentous Fungi. Edward Arnold, London, pp. 301–319.
El-Dohlob, S.M., Al-Helfi, M.A., 1982. Soil fungi of the South Iraq. Bas. Natural History Museum Bulletin 5, 23–37.
Ellis, M.B., 1971. Dematiaceous Hyphomycetes. Commonwealth Mycology Institute, England.
Ellis, M.B., 1976. More Dematiaceous Hyphomycetes. Commonwealth Mycology Institute, England.
Giulietti, A.M., Harley, R.M., Queiroz, L.P., Rapini, A., 2006. To set the scene. In: Giulietti, A.M., Queiroz, L.P., Rapini, A. (Eds.), Towards Greater Knowledge of the Brazilian Semi-arid Biodiversity. Ministério da Ciência e Tecnologia, Brasília, pp. 15–19.
Griffin, D.H., 1994. Fungal Physiology, second ed. Wiley-Liss, Inc., New York.
Grishkan, I., Nevo, E., 2010. Spatiotemporal distribution of soil microfungi in the Makhtesh Ramon area, central Negev desert, Israel. Fungal Ecology 3, 326–337.

Grishkan, I., Korol, A.B., Nevo, E., Wasser, S.P., 2003. Ecological stress and sex evolution in soil microfungi. Proceedings the Royal of Society of Biological Sciences 270, 13–18.
Hawksworth, D.L., 2001. The magnitude of fungal diversity: the 1.5 million species estimate revised. Mycological Research 105, 1422–1432.
Hyde, K.D., 1997. Biodiversity of Tropical Microfungi. Hong Kong University Press, Hong Kong.
Jacomine, P.T., Cavalcanti, A.C., Burgos, N., Pessoa, S.C.P., Silveira, C.O., 1973. Levantamento exploratório-reconhecimento de solos do estado de Pernambuco. SUDENE/Divisão de Pesquisa Pedológica, Recife.
Jones, M.M., Tuomisto, H., Clark, D.B., Olivas, P., 2006. Effects of mesoscale environmental heterogeneity and dispersal limitation of floristic variation in rain forest ferns. Journal of Ecology 94, 181–195.
Kang, S., Mills, A.L., 2006. The effect of sample size in studies of soil microbial community structure. Journal of Microbiological Methods 66, 242–250.
Kirk, J.L., Bedaute, L.A., Hart, M., Moutoglis, P., Klironomos, L.H., Trevors, J.T., 2004. Reviews Methods of studying soil microbial diversity. Journal of Microbiological Methods 58, 169–188.
Krebs, C.J., 1999. Ecological Methodology, second ed. Adson Wesley Longman, New York.
Kubicek, C.P., Druzhinina, I.S., Esser, K., 2007. Fungi in extreme environments. In: Esser, K. (Ed.), Mycota: a Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research vol. 4. Springer, Berlin, pp. 85–103.
Lauber, C.L., Strickland, M.S., Bradford, M.A., Fierer, N., 2008. The influence of soil properties on the structure of bacterial and fungal communities across land-use types. Soil Biology & Biochemistry 40, 2407–2415.
Laurance, W.F., Bierregaard, R.O., 1997. Tropical Forest Remnants Ecology, Management, and Conservation of Fragmented Communities. University of Chicago, Chicago.
Leal, I.R., Silva, J.M.C., Tabarelli, M., Lacher Jr., T.E., 2005. Mudando a o curso da conservação da biodiversidade na Caatinga do Nordeste do Brasil. Megadiversidade 1, 139–146.
Lodge, D.J., 1997. Factors related to diversity of decomposer fungi in tropical forests. Biodiversity and Conservation 6, 681–688.
Loro, M., Valero-Jiménez, C.A., Nozawa, S., Márquez, L.M., 2012. Diversity and composition of fungal endophytes in semiarid Northwest Venezuela. Journal of Arid Environments 85, 46–55.
Maia, L.C., Gibertoni, T.B., 2002. Fungos registrados no semi-árido nordestino. In: Sampaio, E.V.S.B., Giulietti, A.M., Virginio, J., Gamarras-Rojas, C.F.I. (Eds.), Vegetação e flora da Caatinga APNE/CNIP, Recife, pp. 163–176.
Metting, B.F., 1993. Soil Microbial Ecology. Marcel Dekker, New York.
Mouchacca, J., 2005. Mycobiota of the arid Middle East: check-list of novel fungal taxa introduced from 1940 to 2000 and major recent biodiversity titles. Journal of Arid Environment 60, 359–387.
Neta, A.L.D.B., Paula, A.R.L., Barbosa, D.C., Nogueira, E., Sampaio, E.V.S.B., Silva, G.C., Machado, I.C., Virgínio, J.F., Maia, L.C., Griz, L.M.S., Queiroz, L.P., Lima, J.L.S., Silva, M.A., Figueiredo, M.A., Rodal, M.J.N., Barrradas, M.M., Barbosa, M.R.V., Harley, R.M., Chaves, S.M., 2004. Vegetações áreas e ações prioritárias para a conservação da Caatinga. In: Silva, J.M.C., Tabarelli, M., Fonseca, M.T., Lins, L.V. (Eds.), Biodiversidade da caatinga: áreas e ações prioritárias para conservação. Ministério do Meio Ambiente, Universidade Federal de Pernambuco, pp. 115–131.
Paulus, B.C., Kanowski, P.A., Gadek, P.A., Hyde, K.D., 2006. Diversity and distribution of saprobic microfungi in leaf litter of an Australian tropical rainforest. Mycological Research 110, 1441–1454.
Peuke, A.D., Rennenberg, H., 2004. Carbon, nitrogen, phosphorus, and sulphur concentration and partitioning in beech ecotypes (*Fagus sylvatica* L.): phosphorus most affected by drought. Trees 18, 639–648.
Pitt, J.I.A., 1988. A Laboratory Guide to Commons Penicillium Species. Commonwealth, England.
Raper, K.B., Fennell, D.I., 1977. The Genus Aspergillus. Robert e Krieger, Florida.
Raper, K.B., Thom, C., 1949. A Manual of the Penicillia. The Williams & Wilkins Company, Baltimore.
Raymundo Jr., O., Tauk-Tornisielo, S.M., 1997. Occurrence of Hyphomycetes and Actinomycetes in red-yellow latosol from a cerrado region in Brazil. Revista de Microbiologia 28, 197–203.
Rifai, M.A., 1969. A revision of the genus *Trichoderma*. Mycological Papers 116, 1–56.
Rodal, M.J.N., Andrade, K.V.A., Sales, M.F., Gomes, A.P.S., 1998. Fitossociologia do componente lenhoso de um refúgio vegetacional do município de Buíque, Pernambuco. Revista Brasileira de Botânica 58, 517–526.
Samson, R.A., 1974. *Paecilomyces* and some allied Hyphomycetes. Studies in Mycology 6, 1–119.
Sammson, R.A., Frisvad, J.C., 2004. *Penicillium* subgenus *Penicillium* new taxonomic schemes, mycotoxins and other extrolites. Studies in Mycology 49, 1–240.
Sampaio, E.V.S.B., 1995. Overview of the Brazilian caatinga. Páginas. In: Bullock, S.H., Mooney, H.A., Medina, E. (Eds.), Seasonally Dry Tropical Forests. Cambridge, New York, pp. 35–63.
Santiago, A.L.C.M.A., Souza-Motta, C.M., 2006. Mucorales isolados de mineração de cobre e produção de amilase e inulinase. Acta Botânica Brasílica 20, 641–647.
Schipper, M.A.A., Stalpers, J.A., 1984. A revision of the genus Rhizopus. Studies in Mycology 25, 1–34.
Schnittler, M., Stephenson, S.L., 2000. Myxomycetes biodiversity in four different forest types in Costa Rica. Mycologia 92, 626–637.
Schoenlein-Crusius, I.H., Milanez, A.I., 1998. Fungos zoospóricos (Mastigomycotina) da mata atlântica da Reserva Biológica do Alto da Serra de Paranapiacaba, município de Santo André, SP. Revista Brasileira de Botânica 21, 177–181.
Skujins, J., Allen, M.F., 1986. Use of mycorrhizae for land rehabilitation. Mircen Journal 2, 161–176.
Souza, R.G., Maia, L.C., Sales, M.F., Trufem, S.F.B., 2003. Diversidade e potencial de infectividade de fungos micorrízicos arbusculares em área de caatinga, na Região Xingó, Estado de Alagoas, Brasil. Revista Brasileira de Botânica 26, 49–60.
Statsoft, 2001. Statistica for Windows. Statsoft, Inc, Tulsa. (CD-ROM).
Sylvia, D.M., Fuhrmann, J.J., Hartel, P.G., Zuberer, D.A., 1998. Principles and Applications of Soil Microbiology. Prentice Hall, New Jersey.
Titus, J.H., Nowak, R.S., Smith, S.D., 2002. Soil resource heterogeneity in the Mojave Desert. Journal of Arid Environments 52, 269–292.
Washington, H.G., 1984. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystems. Water Research 18, 653–694.