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Brazilian tropical dry forest (Caatinga) in the spotlight: an overview of species of *Aspergillus*, *Penicillium* and *Talaromyces* (Eurotiales) and the description of *P. vascosobrinhous* sp. nov.

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ABSTRACT

A literature-based checklist of species of *Aspergillus*, *Penicillium*, and *Talaromyces* recorded in the Brazilian tropical dry forest (Caatinga), the largest tropical dry forest region in South America, is provided. A total of 130 species (60 *Aspergillus*, 57 *Penicillium*, and 13 *Talaromyces*) are reported. Soil was the most common substrate, with 122 species records. Various reported species are well known in biotechnological processes. This checklist reflects the limited knowledge of fungal species in tropical dry environments. These data provide a good starting point for biogeographical studies on species of *Aspergillus*, *Penicillium*, and *Talaromyces* in dry environments worldwide. In addition, the new species *Penicillium vascosobrinhous* is introduced, an endophytic fungus isolated from cactus of the Caatinga forest in Brazil.

Keywords: ascomycetes, Aspergillaceae, biodiversity, conservation, Trichocomaceae

Introduction

Brazil harbors the largest biodiversity in the world, including biomes regarded as hotspots for the biological diversity assessment and conservation (Françoso *et al.* 2015; Frehse *et al.* 2016; Molotoks *et al.* 2018). Some vegetational types/biomes, and the extent of uniqueness in the ecological complexity it harbors, are exclusive to Brazil, such as the Atlantic Forest and the two Brazilian tropical dry forests named "Cerrado" and "Caatinga". The Brazilian semiarid is one of the most important dry landscapes in the world, with about 24 million people, equivalent about 12 % of the Brazilian population (Alvalá *et al.* 2019). The Caatinga forest is the largest tropical dry forest in South America, and it has a substantial diversity of plants (about 123 families are reported), mammals, fish, insects, amphibians, and recently its fungal diversity has been studied from several substrates and hosts (Leal *et al.* 2003; Maia *et al.* 2015; Silva *et al.* 2017). The climate in the Caatinga forest is semiarid with irregular rains and elevated temperatures. On a global scale, Caatinga is part of the seasonally dry tropical forests, a global biome that was not recognized by the scientific community as distinct until a few years ago (Santos *et al.* 2011).

Fungi can occupy almost every habitat on Earth, and like many other taxonomic groups, most of their diversity is found in the tropics (Aime & Brearley 2012). However, many substrates still need to be examined in order to improve the knowledge on the fungal biodiversity and functional

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diversity, especially those that cannot be cultivated or that are little known (Blackwell 2011). According to Maia *et al.* (2015), the Brazilian fungal diversity is represented by 5,719 species, distributed over 1,246 genera and 102 orders. The Caatinga forest had 999 fungal species recorded, demonstrating an underexplored diversity when considering the fungal richness of endophytes, soil and plant decaying fungi (*e.g.* Fiuza *et al.* 2017; Leão-Ferreira *et al.* 2017; Gusmão *et al.* 2017; Barbosa *et al.* 2016; Bezerra *et al.* 2013; Cruz *et al.* 2013a). The Caatinga forest is Brazil's only large ecological region that is not shared with any other country. For a long time, the biodiversity of Caatinga was underestimated, which resulted in decreased research funding when compared to other Brazilian ecoregions (Santos *et al.* 2011).

Aspergillus, *Penicillium* and *Talaromyces* (Eurotiales, Eurotiomycetes) are phenotypically diverse filamentous ascomycetes, encompassing species important to the environment and to several sectors of economy, such as biotechnology and medicine, causing significant social impacts (Tsang *et al.* 2018). Species of these genera are ubiquitous and can be found in several substrates, such as soil, vegetation, dung, as well as indoor and extreme environments (*e.g.* Visagie *et al.* 2014a; Yilmaz *et al.* 2014; Chen *et al.* 2016; Barbosa *et al.* 2016; 2018; Diao *et al.* 2018). Some of the most remarkable attempts in order to present a natural classification for these groups were presented by Houbraken & Samson (2011), Samson *et al.* (2011), Visagie *et al.* (2014a) and Yilmaz *et al.* (2014). The number of species described in these genera increased rapidly in the last decade (*e.g.* Gonçalves *et al.* 2011; Guinea *et al.* 2015; Hubka *et al.* 2015; Visagie *et al.* 2015; Chen *et al.* 2016; Houbraken *et al.* 2016; Yilmaz *et al.* 2016; Wang *et al.* 2017; Barbosa *et al.* 2018; Frisvad *et al.* 2019). However, many environments remain understudied and can house a large number of species to be discovered, especially in tropical regions (Hawksworth & Lücking 2017).

Fungi are rarely considered in conservation actions, and the conservation of microfungi is even less addressed, even though there is clear evidence that many of these species may be endangered as well (for further information see www.cybertruffle.org.uk/darwin-microfungi.). A major development in the fungal conservation world happened with the launch of the Global Fungal Red Data List Initiative (see http://iucn.ekoo.se/en/iucn/welcome). Biodiversity checklists are main steps in providing relevant biodiversity information for planning applications. Although the inventory of fungi and fungus-like organisms lag behind those of animals and plants, the list is crucial for conservation, considering major threats, such as habitats' fragmentation, degradation (pollution), exotic/invasive species and climate change (Heilmann-Clausen *et al.* 2015; Boddy 2015). It is particularly important to ensure the production of a check list of species adapted to dry environments, such Caatinga, aiming to allow comparison between regions, enabling identification and prioritization of threatened species and their habitats, as well as providing data for ecological/biogeographical predictive modeling of exotic species, both at the landscape level and hence, enable this knowledge to be effectively considered in overall global conservation strategies.

Considering the relevance of checklists as important tools in taxonomy, systematics and conservation, especially in poorly known biomes, this study aimed to summarize the records of *Aspergillus*, *Penicillium* and *Talaromyces* species/names in the Caatinga tropical dry forest, by presenting an up to date list of valid species names, their substrate and distribution. This paper contributes to close the knowledge gaps of the fungal diversity of Caatinga. In addition, a new species of *Penicillium* is described here based on phenotypic and molecular data.

Materials and methods

Study area

For this list, recorded data were compared with the cities included in the Caatinga biome of Northeast region of Brazil. This region includes the territory of nine Brazilian states (Fig. 1): Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe, including the area of the "drought polygon" (Ab'Saber 1974; Carvalho 1988).

Data collection

An extensive literature review was made. It includes data gathered on published papers and books up to December 2019 issued in English and Portuguese. We located papers using the internet search engines Thomson Reuters' ISI Web of Science and Google Scholar, as well as by scanning bibliographies and reading books. With exception of the online version of the List of Species of the Brazilian Flora (Flora do Brasil 2020 em construção 2019 - http://floradobrasil.jbrj.gov.br/), information from websites and Masters/PhD dissertations were not considered. Unidentified taxa were not included (*e.g. Aspergillus* sp.). This study was improved by invited experts who studied the *Aspergillus*, *Penicillium* and *Talaromyces* diversity on different substrates and habitats (*e.g.* soil, endophytic, coprophilous). The used species names are based on the most recent taxonomic insights. These names were mainly retrieved from the Index Fungorum and MycoBank database, and the lists of accepted species in Samson *et al.* (2014), Visagie *et al.* (2014a), Yilmaz *et al.* (2014), and Frisvad *et al.* (2019).

Species description

The new species described here was collected as described by Bezerra *et al.* (2013). Morphological and molecular

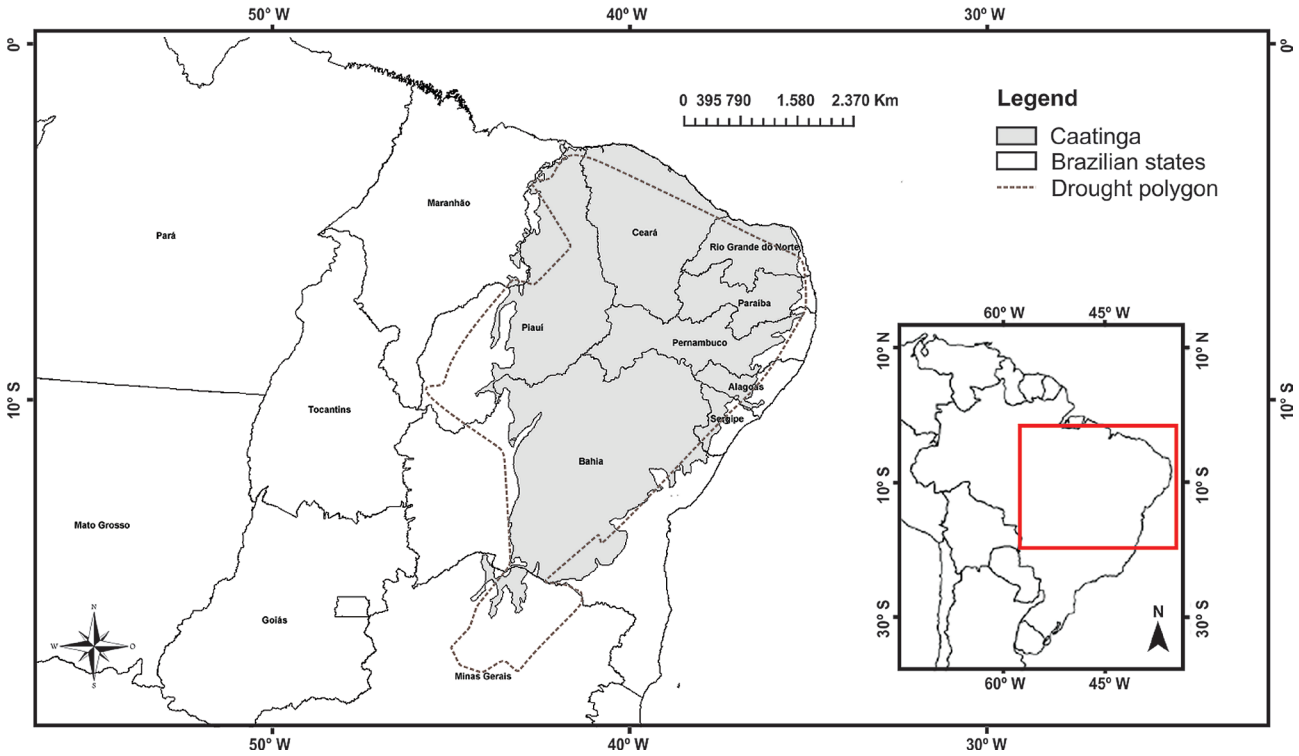

Figure 1. Geographical location of the Caatinga domain including the area of the "drought polygon".

analyses were performed following Houbraken *et al.* (2011). The phylogenetic relationship of the new species within section *Citrina* was studied using single gene and a combined dataset of ITS, β-tubulin, calmodulin, and *RPB2* sequences. Sequence datasets were generated by combining the newly generated sequences with reference (preferably ex-type) sequences from Houbraken *et al.* (2011), Visagie *et al.* (2014a), and Phookamsak *et al.* (2019), all deposited at the National Center for Biotechnology Information (NCBI) (Tab. S1 in supplementary material). The sequences were aligned using MAFFT v.7 (Katoh & Standley 2013) and manually optimized using MEGA v. 6.06 (Tamura *et al.* 2013). Individual alignments were concatenated by using Mesquite v. 3.61 (Maddison & Maddison 2019). The most suitable substitution model (Tab. S2 in supplementary material) was determined using jModelTest v. 2.1.7 (Posada 2008). Phylogenetic trees were constructed using Maximum Likelihood analyses (ML) using RAxML-HPC v. 8.2.8 (Stamatakis 2014) BlackBox with 1,000 rapid bootstrap inferences via the CIPRES science gateway (http://www.phylo.org/) (Miller *et al.* 2012), while Bayesian inference (BI) analysis was performed in MrBayes 3.2.2 (Ronquist *et al.* 2012). In the Bayesian analyses, every 1,000 generations was sampled and the first 25 % of the samples were discarded. Trees were visualized in FigTree v. 1.4.3 (Rambaut 2016) and edited in Adobe Illustrator v. 5.1. Bayesian inference (BI) posterior probabilities (pp) values and bootstrap (bs) values are labelled at the nodes. Sequences generated in this study are deposited in NCBI. The name of the new species is deposited at the MycoBank.

Results

According to the literature survey carried out, 35 papers published between 1964 and 2019 reported members of *Eurotiales*, and were included in this checklist. In total, 130 species (60 *Aspergillus*, 57 *Penicillium*, and 13 *Talaromyces*) have been recorded in the Caatinga forest. In *Aspergillus*, 14 sections are reported, with *Flavi*, *Fumigati*, *Nidulantes*, *Nigri* and *Terrei* as the most common. In *Penicillium*, species names from 16 sections are listed, mainly in sections *Aspergilloides*, *Citrina*, *Exilicaulis* and *Fasciculata*. A new species, *P. vascosobrinhous*, isolated as an endophyte from *Melocactus zehntneri*, one of the more common cactus from Brazil, is introduced in the *Penicillium* section *Citrina*. Regarding the genus *Talaromyces*, four sections have been recorded in the Caatinga, with *Islandici* and *Talaromyces* being the most common.

Regarding the distribution of records by Brazilian states, Pernambuco has the highest number of records. The most common substrates associated with the records are soil (122 records) and plant organs (as endophytes) (25 records). A total of 22 species occur in both substrates, and 100 species were registered only in soil. Based on this list, 88 species were exclusively recorded from soil, two species were reported only as endophytes, and two from termite nests. Grapes, seeds and "as phytopathogenic" fungus have also reports (one each).

Considering the Caatinga's expansion, some species have been registered only in the following states so far: Alagoas-

AL: *A. caespitosus*, *A. granulosus*, *A. restrictus*, *A. stellatus*; Bahia-BA: *A. asperescens*, *A. penicillioides*, *A. nutans*, *A. welwitschiae*; Ceará-CE: *A. oryzae*; Maranhão-MA: *A. clavatus*, *A. montevidensis*, *A. pseudoglaucus*, *A. unguis*, *P. capsulatum*, *P. egyptiacum*, *P. namyslowskii*, *P. novae-zeelandiae*, *T. varians*; Paraíba-PB: *A. glaucus*, *A. lucknowensis*, *P. atramentosum*, *P. aurantioviolaceum*, *P. purpurescens*, *P. raciborskii*, *T. duclauxii*, *T. flavus* and for Pernambuco-PE: *A. allahabadii*, *A. arcoverdensis*, *A. aureolus*, *A. avenaceus*, *A. brasiliensis*, *A. brevipes*, *A. caatingaensis*, *A. caelatus*, *A. insuetus*, *A. japonicus*, *A. lentulus*, *A. pernambucoensis*, *A. pulvinus*, *A. puniceus*, *A. recurvatus*, *A. serratalhadensis*, *A. westerdijkiae*, *P. bilaiae*, *P. brefeldianum*, *P. citreonigrum*, *P. crustosum*, *P. digitatum*, *P. glandicola*, *P. lapidosum*, *P. levitum*, *P. melinii*, *P. miczynskii*, *P. vulpinum*, *T. pernambucoensis*.

New species

Penicillium vascosobrinhous R.N. Barbosa & J.D.P. Bezerra, sp. nov.

Fig. 2 MycoBank MB833816

Etymology: In honour of Professor João Vasconcelos Sobrinho, a leading Brazilian ecologist and environmentalist.

Type: Brazil: Pernambuco: Itaíba, as endophyte from *Melocactus zehntneri* (Cactaceae), September 2013, J.D.P. Bezerra. Holotype URM 94140 (slide preparation) is deposited in the URM fungarium (Recife, Brazil); ex-type strain URM 8193.

ITS barcode: LR744067. Alternative markers: *BenA* = LR744069; *CaM* = LR744063; *RPB2* = LR744065.

Colony diam, 7 days (mm): CYA 20–22; CYA 15 °C 4–5; CYA 30 °C 25–27; CYA 37 °C 5–9; MEA 20–25; DG18 15–20; CYAS 18–20; OA 16–20; CREA 7–9; YES 15–27.

Colony characters: CYA, 25 ºC, 7 days: colonies plane to moderately deep at centre, radially sulcate; margins irregular, low, narrow; mycelium inconspicuously white to greyish; colony texture velvety; sporulation moderate; conidial colour *en masse* greyish; exudate present as clear droplets; soluble pigment absent; reverse brownish. MEA, 25 ºC, 7 days: colonies plane, radially sulcate; margins entire, low, narrow; mycelium white; colony texture velvety to floccose at centre; sporulation poorly to moderate; conidial colour *en masse* greyish turquoise; exudate present as clear droplets; soluble pigment absent; reverse brownish. DG18, 25 ºC, 7 days: colonies plane; margins low, entire; mycelium white; colony texture floccose; sporulation sparsely after prolonged incubation; conidial colour *en masse* indeterminate; exudate absent; soluble pigment absent; reverse cream to clear brown close centre. OA, 25 ºC, 7 days: colonies plane, entire; margins regular; mycelium white; colony texture velvety; sporulation moderate to sparse; conidial colour *en masse* greyish green; exudate absent; soluble pigment absent; reverse pale to white. YES, 25 ºC, 7 days: colonies moderately deep, randomly sulcate, raised; margins regular, low, narrow; mycelium inconspicuously white to greenish; colony texture velvety; sporulation poor to moderate; conidial colour *en masse* greyish; exudate and soluble pigment absent; reverse brownish. CREA, 25 ºC, 7 days: growth poor, acid production absent.

Micromorphology: Conidiophores monoverticillate. Stipes smooth walled, 10.5–50 × 2–2.5 µm, apex slightly swollen. Phialides 3–4 per stipe, ampulliform, tapering to very fine necks, 4–5.0 (–5.5) × 2.0–2.5 µm; conidia globose to subglobose, smooth, 2.0–2.5 (–3.0) µm. Ascomata and sclerotia not observed.

Additional material examined: URM 8194 (ITS: LR744068, *BenA*: LR744062, *CaM*: LR744064, *RPB2*: LR744066).

Check list of ***Aspergillus***, ***Penicillium*** and ***Talaromyces*** from the Caatinga Dry Forest

Aspergillus P. Micheli ex Haller, Hist. stirp. Helv. 3: 113. 1768.

Section ***Aspergillus*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB548676].

A. chevalieri (L. Mangin) Thom & Church, The Aspergilli: 111. 1926. [MB292839].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); As endophyte from cladodes of *Cereus jamacaru* (Pernambuco-PE, Pires *et al.* 2015).

A. glaucus (L.) Link, Mag. Ges. Naturf. Freunde Berlin 3: 16. 1809. [MB161735].

Record: Seeds (Paraíba-PB, Nascimento *et al.* 2018).

A. montevidensis Talice & Mackinnon, Compt. Rend. Soc. Biol. Fr. 108: 1007. 1931. [MB309231].

Record: (as *A. amstelodami*) Soil (Maranhão-MA, Batista *et al.* 1964).

Note: *Aspergillus amstelodami* is considered a synonym of *A. montevidensis* (Pitt 1985 and also see taxonomy clarification in Hubka *et al.* 2013).

A. pseudoglaucus Blochwitz, Ann. Mycol. 27: 207. 1929. [MB275429].

Record: (as *A. repens*) Soil (Maranhão-MA, Batista *et al.* 1964).

Note: According to Hubka *et al.* (2013), *Aspergillus repens* (de Bary) Fischer is a later homonym of *Aspergillus repens* (Corda) Sacc. 1882 pertaining to a different species, and *A. pseudoglaucus* is considered the correct name for *Eurotium repens*.

A. ruber (Jos. König *et al.*) Thom & Church, Aspergillus: 112. 1926. [MB276893].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Pernambuco-PE, Barbosa *et al.* 2016).

Section ***Candidi*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832512].

A. candidus Link, Mag. Ges. Naturf. Freunde Berlin 3: 16. 1809. [MB204868].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cruz *et al.* 2013a; Cruz *et al.* 2017); Seeds (Paraíba-PB, Nascimento *et al.* 2018).

Section ***Cervini*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832497].

A. nutans McLennan & Ducker, Aust. J. Bot. 2: 355. 1954. [MB292850].

Record: Soil (Bahia-BA, Costa *et al.* 2006).

Section ***Circumdati*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832508].

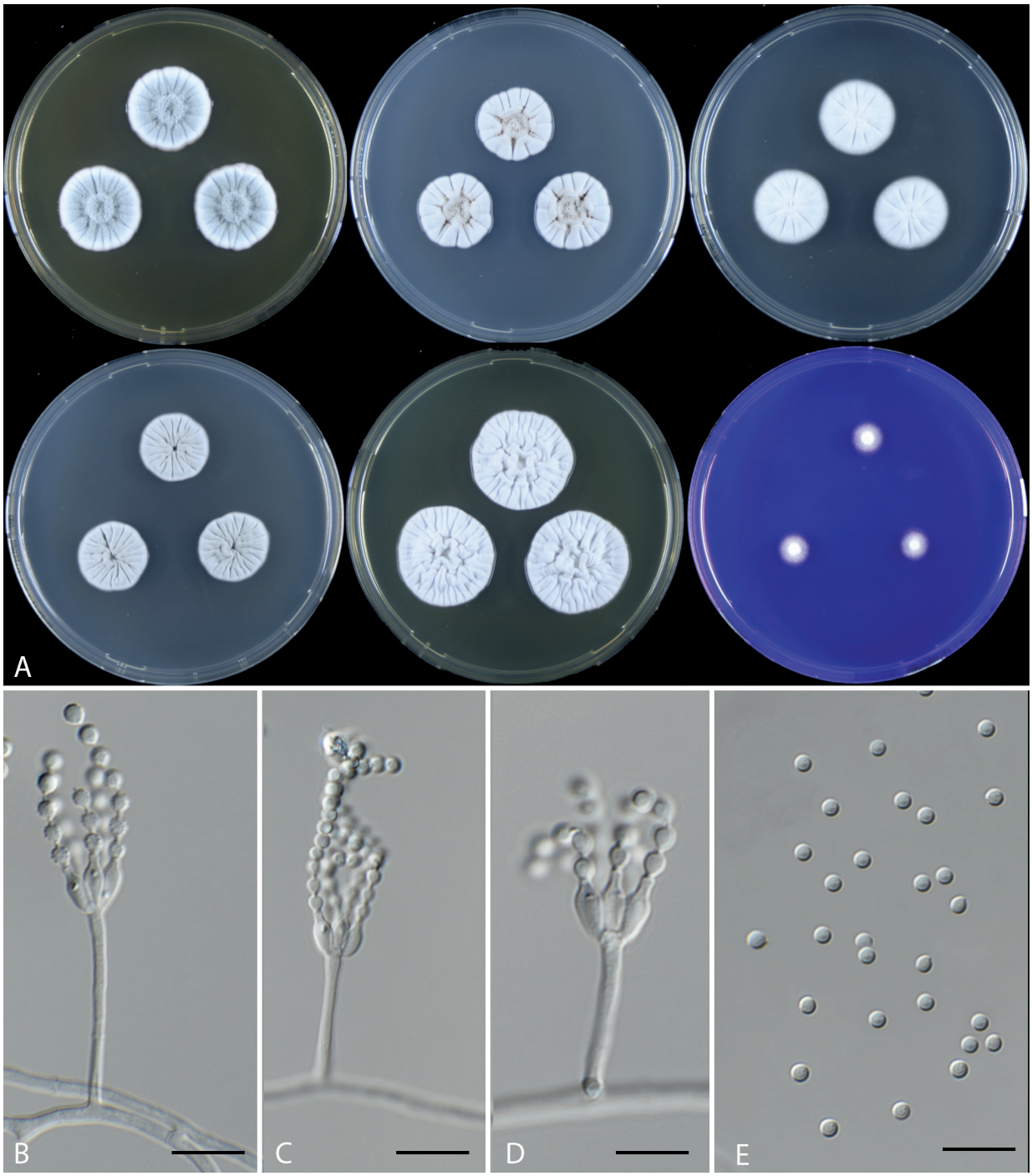

Figure 2. Morphological features of the new species *Penicillium vascosobrinhous*. **A**- Colonies from left to right (top row) MEA, CYA and DG18; (bottom row) CYAS, YES and CREA. **B, C, D**- Conidiophores. **E**- Conidia. Scale bars 10 µm.

A. fresenii Subram., Hyphomycetes (New Delhi): 552. 1971. [MB309222].

Records: (as *A. sulphureus* [nom. illeg.]) Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Cruz *et al.* 2013a; 2017).

Note: Previously incorrectly named *A. sulphureus* (Fresen.) Wehmer (see taxonomy clarification in Visagie *et al.* 2014b).

A. ochraceopetaliformis Bat. & Maia, Anais Soc. Biol. Pernambuco 15: 213. 1957. [MB292851].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

A. ochraceus K. Wilh., Beitr. Kenntn. Aspergillus: 66. 1877. [MB190223].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *Cereus jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013); Seeds (Paraíba-PB, Nascimento *et al.* 2018).

A. ostianus Wehmer, Bot. Centralbl. 80: 461. 1899. [MB179393].

Record: Soil (Pernambuco-PE, Oliveira *et al.* 2013).

A. sclerotiorum G. A. Huber, Phytopathology 23: 306. 1933. [MB277707].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; Cruz *et al.* 2017).

A. westerdijkiae Frisvad & Samson, Stud. Mycol. 50: 30. 2004. [MB500000].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

Section ***Clavati*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832500].

A. clavatus Desm., Ann. Sci. Nat., Bot., ser. 2, 2: 71. 1834. [MB211530].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

Section ***Cremei*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832513].

A. pulvinus Kwon-Chung & Fennell, Gen. Aspergillus: 45. 1965. [MB326651].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. stromatoides Raper & Fennell, Gen. Aspergillus: 421. 1965. [MB326660].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; Cruz *et al.* 2017).

A. wentii Wehmer, Centralbl. Bakteriol., 2. Abth., 2: 149. 1896. [MB172623].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

Section ***Flavi*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832510].

A. avenaceus G. Sm., Trans. Brit. Mycol. Soc. 26: 24. 1943. [MB284296].

Record: Soil (Pernambuco-PE, Cruz *et al.* 2013a, 2017).

A. caelatus B.W. Horn, Mycotaxon 61: 186. 1997. [MB436955].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. flavus Link, Mag. Ges. Naturf. Freunde Berlin 3: 16. 1809. [MB209842].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016; Fonseca *et al.* 2017); Water samples of watersheds (Paraíba-PB, Lima *et al.* 2014); Termite nests (*Nasutitermes corniger*) (Paraíba-PB, Mello *et al.* 2016); Seeds (Paraíba-PB, Nascimento *et al.* 2018); Goat and horse dung (Pernambuco-PE, Melo *et al.* 2017); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017). Also reported as *A. oryzae* as endophyte from leafs of *Combretum leprosum* (Ceará-CE, Santos *et al.* 2012).

Note: *A. oryzae* is the domesticated form of *A. flavus* (Frisvad *et al.* 2019).

A. parasiticus Speare, Bull. Div. Pathol. Physiol., Hawaiian Sugar Planters Assoc. Exp. Sta. 12: 38. 1912. [MB191085].

Records: Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Reis *et al.* 2015); Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016); Goat dung (Pernambuco-PE, Melo *et al.* 2017). Also reported as *A. sojae* in Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017).

Note: *A. sojae* is the domesticated form of *A. parasiticus* (Frisvad *et al.* 2019).

A. tamarii Kita, Centralbl. Bakteriol. 2. Abth. 37: 433. 1913. [MB191425].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016; Fonseca *et al.* 2017); Caves (Minas Gerais-MG, Bahia-BA and Piauí-PI, Melo *et al.* 2013); Termite nests (*Constrictotermes*

cyphergaster) (Paraíba-PB, Barbosa-Silva *et al.* 2016). Also reported as *A. flavofurcatus* in soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017).

Note: According to Frisvad *et al.* (2019) representative strains of *A. flavofurcatus*, including Brazilian strains, cluster together with the type of *A. tamarii* (NRRL 20818) in all phylogenetic analysis performed by these authors.

Section ***Flavipedes*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832506].

A. flavipes (Bainier & Sartory) Thom & Church, Aspergilli: 155. 1926. [MB265045].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006).

Section ***Fumigati*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832496].

A. arcoverdensis Y. Horie, Matsuz., Yaguchi & Takaki, Mycoscience 56: 130, 2015. [MB804028].

Record: Soil (Pernambuco-PE, Matsuzawa *et al.* 2015).

A. aureolus Fennell & Raper, Mycologia 47: 71. 1955. [MB292836].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. brevipes G. Sm., Trans. Brit. Mycol. Soc. 35: 241. 1952. [MB292837].

Record: Soil (Pernambuco-PE, Oliveira *et al.* 2013).

A. caatingaensis Y. Horie *et al.* Mycoscience 55: 84. 2014. [MB801323].

Record: Soil (Pernambuco-PE, Matsuzawa *et al.* 2014).

A. duricaulis Raper & Fennell, Gen. Aspergillus: 249. 1965. [MB326627].

Records: Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013).

A. fumigatus Fresen., Beitr. Mykol.: 81. 1863. [MB211776].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013, Barbosa *et al.* 2016); As endophyte from cladodes of *Opuntia ficus-indica* and *Pilosocereus gounellei* (Pernambuco-PE, Freire *et al.* 2015 and Pires *et al.* 2015); Termite nests (*Nasutitermes corniger*) (Paraíba-PB, Mello *et al.* 2016); As endophyte from plant barks of *Anacardium occidentale* (Paraíba-PB, Cavalcanti *et al.* 2017); Cattle dung (Pernambuco-PE, Melo *et al.* 2017).

A. lentulus Balajee & K.A. Marr, Eukaryot. Cell 4: 631. 2005. [MB356679].

Record: Soil, misspelled as *"lentilus"* (Pernambuco-PE, Barbosa *et al.* 2016).

A. pernambucoensis Y. Horie *et al.* Mycoscience 55: 86. 2014. [MB801324].

Record: Soil (Pernambuco-PE, Matsuzawa *et al.* 2014).

A. viridinutans Ducker & Thrower, Aust. J. Bot. 2: 355. 1954. [MB292864].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Soil (Bahia-BA, Costa *et al.* 2006).

Section ***Nidulantes*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832502].

A. asperescens Stolk, Antonie van Leeuwenhoek 20: 303. 1954. [MB292835].

Record: Soil (Bahia-BA, Costa *et al.* 2006).

A. caespitosus Raper & Thom, Mycologia 36: 563. 1944. [MB284298].

Record: Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

A. nidulans (Eidam) G. Winter, Rabenh. Krypt.-Fl., ed. 2, 1: 62. 1884. [MB182069].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. recurvatus Raper & Fennell, Gen. Aspergillus: 529. 1965. [MB326653].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. stellatus Curzi, C.R. Accad. Lincei 19: 428. 1934. [MB254841].

Record: Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

A. sydowii (Bainier & Sartory) Thom & Church, Aspergilli: 147. 1926. [MB279636].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Barbosa *et al.* 2016; Cruz *et al.* 2017). Misspelled as "*sidowii*" from soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

A. unguis (Emile-Weill & L. Gaudin) Thom & Raper, Mycologia 31: 667. 1939. [MB255264].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

A. versicolor (Vuill.) Tirab., Ann. Bot. (Roma) 7: 9. 1908. [MB172159].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016).

Section ***Nigri*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832511].

A. aculeatus Iizuka, J. Agric. Chem. Soc. Japan 27: 806. 1953. [MB292831].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017).

A. brasiliensis Varga, Frisvad & Samson, Int. J. Syst. Evol. Microbiol. 57(8): 57. 2007. [MB510581].

Record: Soil (Petrolina-PE, Coutinho *et al.* 2014).

A. carbonarius (Bainier) Thom, J. Agric. Res. 7: 12. 1916. [MB100545].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017).

A. japonicus Saito, Bot. Mag. (Tokyo) 20: 61. 1906. [MB160656].

Records: Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Bahia-BA, Simões & Tauk-Tornisielo 2005b); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); As endophyte from cladodes of *O. ficus-indica* and *C. jamacaru* (Pernambuco-PE, Bezerra *et al.* 2012; Paraíba-PB, Bezerra *et al.* 2013); Caves (Minas Gerais-MG, Bahia-BA and Piauí-PI, Melo *et al.* 2013); Soil (Pernambuco-PE, Oliveira *et al.* 2013); Horse dung (Pernambuco-PE, Melo *et al.* 2017). Also reported as *A. violaceofuscus* in Soil (Pernambuco-PE, Barbosa *et al.* 2016).

Note: *A. violaceofuscus* is considered as a doubtful species, and is considered a synonym of *A. japonicus* (Hubka & Kolarick 2012).

A. niger Tiegh., Ann. Sci. Nat., Bot., ser. 5, 8: 240. 1867, nom. cons. (Kozakiewicz *et al.* 1992). [MB284309].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Bahia-BA, Simões & Tauk-Tornisielo 2005a, Costa *et al.* 2006); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Stingless bees (Mossoró-RN, Ferraz *et al.* 2008); As endophyte from cladodes of *C. jamacaru* and barks of *Anadenanthera colubrina* (Paraíba-PB, Bezerra *et al.* 2013; Cavalcanti *et al.* 2017); Caves (Minas Gerais-MG, Bahia-BA- and Piauí-PI, Melo *et al.* 2013); Soil (Pernambuco-PE, Oliveira *et al.* 2013; Barbosa *et al.* 2016; Cruz *et al.* 2013a; 2017; Fonseca *et al.* 2017); Water samples of watersheds (Paraíba-PB, Lima *et al.* 2014); Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016); Termite nests (*Nasutitermes corniger*) (Paraíba-PB, Mello *et al.* 2016); Seeds (Paraíba-PB, Nascimento *et al.* 2018); Horse dung (Pernambuco-PE, Melo *et al.* 2017); Oral cavity of *Nothobachia ablephara* (Pernambuco-PE, Svedese *et al.* 2017); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017). Also reported as *A. phoenicis* in soil (Pernambuco-PE, Cruz *et al.* 2013a) and as *A. foetidus* in caves (Minas Gerais-MG, Bahia-BA and Piauí-PI, Melo *et al.* 2013).

Note: *Aspergillus foetidus* and *A. lacticoffeatus* is considered a synonym of *A. niger* (Varga *et al.* 2011).

A. serratalhadensis L.F. Oliveira, R.N. Barbosa, G.M.R. Albuq., Souza-Motta & Viana Marques, Persoonia 40: 263. 2018. [MB824978].

Record: Soil (Pernambuco-PE, Crous *et al.* 2018).

A. welwitschiae (Bres.) Henn. apud Wehmer, Centrbl. Bakteriol. ParasitK. 2 18: 294. 1907. [MB490584].

Records: Sisal bole rot disease (Bahia-BA, Duarte *et al.* 2018). Also reported as *A. awamori* in Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a, Cruz *et al.* 2017).

Note: *A. awamori* is a synonym of *A. welwitschiae* (Perrone *et al.* 2011).

Section ***Restricti*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832494].

A. penicillioides Speg., Revista Fac. Agron. Univ. Nac. La Plata 2: 246. 1896. [MB309234].

Record: Soil (Bahia-BA, Costa *et al.* 2006).

A. restrictus G. Sm., J. Textile Inst. 22: 115. 1931. [MB276290].

Record: Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

Section ***Terrei*** Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832505].

A. allahabadii B.S. Mehrotra & Agnihotri, Mycologia 54: 400. 1963. [MB326609].

Records: Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Barbosa *et al.* 2016).

A. aureoterreus Samson *et al.* Stud. Mycol. 69: 45. 2011. [MB560392].

Records: (as *A. terreus var. aureus*) in Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; Barbosa *et al.* 2016).

Note: *A. terreus* var. *aureus* has been previously recognized as a variety of *A. terreus* based on morphological characteristics, and the phenotype of this species is strikingly distinct from that of *A. terreus* (Balajee 2009; Samson *et al.* 2011).

A. carneus Blochwitz, Ann. Mycol. 31: 81. 1933. [MB259903].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017).

A. niveus Blochwitz, Ann. Mycol. 27: 205. 1929. [MB272402].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Cruz *et al.* 2013a; Oliveira *et al.* 2013; Barbosa *et al.* 2016); As endophyte from cladodes of *C. jamacaru* (Pernambuco-PE, Pires *et al.* 2015); Goat dung (Pernambuco-PE, Melo *et al.* 2017).

A. terreus Thom, Am. J. Bot. 5: 85. 1918. [MB191719].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Stingless bees (Mossoró-RN, Ferraz *et al.* 2008); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Cattle, goat and horse dung (Pernambuco-PE, Melo *et al.* 2017).

Section *Usti* Gams *et al.* Advances in *Penicillium* and *Aspergillus* systematics. 1985. [MB832504].

A. deflectus Fennell & Raper, Mycologia 47: 83. 1955. [MB292841].

Records: Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Bahia-BA, Costa *et al.* 2006).

A. granulosus Raper & Thom, Mycologia 36: 565. 1944. [MB284302].

Record: Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

A. insuetus (Bainier) Thom & Church, Manual of the Aspergilli: 153. 1929. [MB267997].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

A. lucknowensis J. N. Rai *et al.* Can. J. Bot. 46: 1483. 1968. [MB326643].

Record: Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016).

A. puniceus Kwon-Chung & Fennell, Gen. Aspergillus: 547. 1965. [MB326652].

Record: Soil (Pernambuco-PE, Oliveira *et al.* 2013).

A. ustus (Bainier) Thom & Church, Aspergilli: 152. 1926. [MB281216].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Bahia-BA, Costa *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013); As endophyte from cladodes of *C. jamacaru* (Pernambuco-PE, Pires *et al.* 2015).

Penicillium Link: Fries, Systema Mycologicum 3: 406. 1832.

Section ***Aspergilloides*** Dierckx, Annls. Soc. Scient. Brux. 25: 85. 1901. [MB832951].

P. aurantioviolaceum Biourge, Cellule 33: 282. 1923. [MB257885].

Record: Soil (Paraíba-PB, Batista *et al.* 1970).

P. frequentans Westling, Ark. Bot. 11: 133. 1911. [MB152118].

Records: Soil (Pernambuco-PE, Ramos & Upadhyay 1966); Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

P. glabrum (Wehmer) Westling, Ark. Bot. 11: 131. 1911. [MB120545].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017; Oliveira *et al.* 2013); Grapes (Pernambuco -PE and Bahia - BA, Freire *et al.* 2017).

P. lividum Westling, Ark. Bot. 11: 134. 1911. [MB178817].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013).

P. montanense M. Chr. & Backus, Mycologia 54: 574. 1962. [MB335752].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *O. ficus-indica* (Pernambuco-PE, Pires *et al.* 2015); Soil (Pernambuco-PE, Cruz *et al.* 2017).

P. purpurescens (Sopp) Biourge [as "*purpurascens*"] Biourge, La Cellule 33:5. 1923. [MB335761].

Record: Soil. Reported as *P. purpurrescens* (Paraíba-PB, Batista *et al.* 1970).

Note: The original Sopp epithet "*purpurrescens*" presents a correctable orthographic error (there is no Latin word "purpurreus"). The *Penicillium* combination was first published by Biourge, who corrected the –rr– error, but replaced the original –escens ending with "–ascens" (another correctable error) [these two endings are both acceptable Latin and convey the same meaning, but they are not interchangeable]. The basionym author and date are cited,

and the basionym genus is indicated by the abbreviation "(Citr.)". So, the correct citation is *Penicillium purpurescens* (Sopp) Biourge [as "purpurascens"], and the Raper & Thom "combination" is an isonym (with no nomenclatural standing). (Pers. comm. K. Bensch).

P. spinulosum Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 76. 1910. [MB215401].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Barbosa *et al.* 2016).

P. thomii Maire, Bull. Soc. Hist. Nat. Afrique N. 8: 189. 1917. [MB202819].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013).

Section ***Brevicompacta*** Thom, The Penicillia: 289. 1930. [MB834006].

P. brevicompactum Dierckx, Ann. Soc. Sci. Bruxelles 25: 88. 1901. [MB149773].

Records: Soil, misspelled as "*brevi-compactum*" (Paraíba-PB, Batista *et al.* 1970). Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017). Also reported as *Penicillium stoloniferum* in soil (Pernambuco-PE, Ramos & Upadhyay 1966).

Note: *P. stoloniferum* was described by Thom (1910) from a decaying mushroom in Connecticut. Later, Thom (1930) reduced this species to synonymy with *P. brevicompactum*. Pitt (1980) suggested that isolates of *P. stoloniferum* and *P. brevicompactum* showed a continuum of variation, and confirmed the synonymy.

Section ***Canescentia*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB 563135].

P. canescens Sopp, Skr. Vidensk.-Selsk. Christiana Math.-Nat. Kl. 11: 181. 1912. [MB153765].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013).

P. janczewskii Zaleski, Bull. Int. Acad. Polon. Sci., Cl. Sci. Math., Sér. B, Sci. Nat., 1927: 488. 1927. [MB120703].

Record: Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Barbosa *et al.* 2016).

P. nigricans Bainier ex Thom, Penicillia: 351. 1930. [MB119303].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Ramos & Upadhyay 1966).

Note: The taxonomy of *Penicillium* section *Cancescentia* is not yet resolved, but recent data (Visagie *et al.* 2016) indicated that *P. nigricans* is an accepted species in this section.

P. novae-zeelandiae J.F.H. Beyma, Antonie van Leeuwenhoek 6: 275. 1940. [MB522253].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

Section ***Charlesia*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB563125].

P. fellutanum Biourge, Cellule 33: 262. 1923. [MB264748].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Oliveira *et al.* 2013).

Section ***Chrysogena*** Frisvad & Samson, Stud. Mycol. 49: 17. 2004. [MB700796].

P. chrysogenum Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 58. 1910. [MB165757].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Cruz *et al.* 2013b). Goat and horse dung (Pernambuco-PE, Melo *et al.* 2017). Also reported as *P. notatum* in soil (Maranhão-MA, Batista *et al.* 1964).

Note: *Penicillium notatum* Westling is considered a synonym of *P. chrysogenum* (Samson *et al.* 1977).

P. egyptiacum J.F.H. Beyma, Zentralbl. Bakteriol. Parasitenk., Abt. 2 88: 137. 1933. [MB263790].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

Note: Misspelled as "*egyptiarum*" in Batista *et al.* 1964.

Section ***Citrina*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB563132].

P. citrinum Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 61. 1910. [MB165293].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Cruz *et al.* 2013b; 2017; Barbosa *et al.* 2016); As endophyte from cladodes of *O. fícus-indica* and *P. gounellei* (Pernambuco-PE, Freire *et al.* 2015; Pires *et al.* 2015); Cattle dung (Pernambuco-PE, Melo *et al.* 2017); Grapes (Pernambuco -PE and Bahia - BA, Freire *et al.* 2017). Also reported as *P. implicatum* in Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Grapes (Pernambuco -PE and Bahia - BA, Freire *et al.* 2017).

Note: *Penicillium implicatum* Biourge is considered a synonym *P. citrinum* (Houbraken *et al.* 2010).

P. miczynskii K.M. Zalessky, Bull. Int. Acad. Polon. Sci., Ser. B., Sci. Nat. 1927: 482. 1927. [MB271171].

Records: Soil (Pernambuco-PE, Barbosa *et al.* 2016; Cruz *et al.* 2017).

P. roseopurpureum Dierckx, Ann. Soc. Sci. Bruxelles 25: 86. 1901. [MB213447].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013).

P. steckii K.M. Zalessky, Bull. Int. Acad. Polon. Sci., Ser. B., Sci. Nat. 1927: 469. 1927. [MB278769].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

P. vascosobrinhous R.N. Barbosa & J.D.P. Bezerra. This study. [MB833816].

Record: Endophyte (Pernambuco-PE, Barbosa *et al.* – this study)

P. waksmanii K.M. Zalessky, Bull. Int. Acad. Polon. Sci., Ser. B., Sci. Nat.: 468. 1927. [MB121677].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); misspelled as "*P. walksmanii*" from Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Oliveira *et al.* 2013; Cruz *et al.* 2013b; 2017; Barbosa *et al.* 2016); Horse dung (Pernambuco-PE, Melo *et al.* 2017).

Section ***Exilicaulis*** Pitt, The Genus *Penicillium*: 205. 1980. [MB832954].

P. citreonigrum Dierckx, Ann. Soc. Sci. Bruxelles 25: 86. 1901. [MB165197].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

P. corylophilum Dierckx, Ann. Soc. Sci. Bruxelles 25: 86. 1901. [MB178294].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Cattle and horse dung (Pernambuco-PE, Melo *et al.* 2017). Reported as *Penicillium humuli* in soil (Pernambuco-PE, Ramos & Upadhyay 1966).

Note: *P. humuli* is a synonym of *P. corylophilum* (Visagie *et al.* 2016).

P. decumbens Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 71. 1910. [MB156582].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017).

P. lapidosum Raper & Fennell, Mycologia 40: 524. 1948. [MB289094].

Record: Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017).

P. melinii Thom, Penicillia: 273. 1930. [MB270876].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013).

P. namyslowskii K.M. Zalessky, Bull. Int. Aead. Polonc. Sci., Cl. Sci. Math., Ser. B, Sci. Nat. 1927: 479. 1927. [MB272006].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

P. raciborskii K.M. Zalessky, Bull. Int. Acad. Polon. Sci., Ser. B., Sci. Nat. 1927: 454. 1927. [MB276002].

Record: Soil (Paraíba-PB, Batista *et al.* 1970).

P. restrictum J.C. Gilman & E.V. Abbott, Iowa St. Coll. J. Sci. 1: 297. 1927. [MB276289].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *C. jamacaru* and *P. gounellei* (Paraíba-PB and Pernambuco-PE, Bezerra *et al.* 2013; Pires *et al.* 2015); Soil (Pernambuco-PE, Oliveira *et al.* 2013; Cruz *et al.* 2013b; 2017; Barbosa *et al.* 2016).

P. vinaceum J.C. Gilman & E.V. Abbott, Iowa St. Coll. J. Sci. 1: 299. 1927. [MB281754].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013; Barbosa *et al.* 2016).

Section ***Fasciculata*** Thom, The Penicillia: 374. 1930. [MB834008].

P. aurantiogriseum Dierckx, Ann. Soc. Sci. Bruxelles 25: 88. 1901. [MB247956].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Forage cactus (Itaíba-PE, Bezerra *et al.* 2012); As endophyte from cladodes of *O. ficus-indica* and *C. jamacaru* (Pernambuco-PE, Bezerra *et al.* 2012; Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

P. cyclopium Westling, Ark. Bot. 11: 90. 1911. [MB156739].

Record: Reported as *P. puberulum* in soil (Pernambuco-PE, Cavalcanti & Maia 1994).

Note: Frisvad & Samson (2004) treated *P. puberulum* as a synonym of *P. cyclopium*; however, they were uncertain about this result. Unpublished molecular data confirms this finding, which can have impact on the use of the name *P. cyclopium*. *Penicillium puberulum* predates *P. cyclopium*. We applied the current taxonomic insights and use *P. cyclopium*.

P. commune Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 56. 1910. [MB164241].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte

from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Oliveira *et al.* 2013; Cruz *et al.* 2013b; Barbosa *et al.* 2016); Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016).

P. crustosum Thom, The Penicillia: 399. 1930. [MB262401].

Record: Soil (Pernambuco-PE, Oliveira *et al.* 2013).

P. solitum Westling, Ark. Bot. 11: 65. 1911. [MB206172].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013); Grapes (Pernambuco-PE and Bahia - BA, Freire *et al.* 2017).

P. viridicatum Westling, Ark. Bot. 11: 88. 1911. [MB163349].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013).

Section ***Lanata-Divaricata*** Thom, The Penicillia: 328. 1930. [MB834002].

P. brefeldianum B.O. Dodge, Mycologia 25: 92. 1933. [MB258851].

Records: Soil (Pernambuco-PE, Ramos & Upadhyay, 1966). Also reported as *P. dodgei* in Soil (Alagoas-AL, Cavalcanti *et al.* 2006).

Note: Dodge (1933) based on CBS 235.81 described *P. brefeldianum* as a holomorphic species. Pitt (1980) did not accept teleomorph species in *Penicillium* and a neotype (CBS 233.81) was selected of *P. brefeldianum* distributed by Dodge no longer produced cleistothecia. Subsequently, Dodge's strain (CBS 235.81) was used for the description of the anamorph of *Eupenicillium brefeldianum* (as *Penicillium dodgei*), therefore Dodge's *P. brefeldianum* was re-instated (Houbraken & Samson 2011).

P. janthinellum Biourge, Cellule 33: 258. 1923. [MB119134].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Oliveira *et al.* 2013; Barbosa *et al.* 2016); As endophyte from cladodes of *P. gounellei* and *O. ficus-indica* (Pernambuco-PE, Pires *et al.* 2015; Freire *et al.* 2015).

P. javanicum J.F.H. Beyma, Verh. Kon. Ned. Akad. Wetensch., Afd. Natuurk. 26: 17. 1929. [MB268394].

Records: Soil (Pernambuco-PE, Ramos & Upadhyay 1966). Reported as *P. indonesiae* in soil (Alagoas-AL, Cavalcanti *et al.* 2006).

Note: See taxonomy clarification about *P. indonesiae* in Houbraken & Samson (2011).

P. levitum Raper & Fennell, Mycologia 40: 511. 1949. [MB289096].

Record: Soil (Pernambuco-PE, Ramos & Upadhyay 1966).

P. oxalicum Currie & Thom, J. Biol. Chem. 22: 289. 1915. [MB121033].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017); Cattle and horse dung (Pernambuco-PE, Melo *et al.* 2017).

P. simplicissimum (Oudem.) Thom, Penicillia: 335. 1930. [MB278201].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

Section ***Paradoxa*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB563134].

P. atramentosum Thom, U.S.D.A. Bur. Animal Industr. Bull. 118: 65. 1910. [MB237291].

Record: Termite nests (*Constrictotermes cyphergaster*) (Paraíba-PB, Barbosa-Silva *et al.* 2016).

Section ***Penicillium*** Link, Mag. Ges. Naturf. Freunde Berlin 3: 16. 1809. [MB549140].

P. digitatum (Pers.: Fr.) Sacc., Fung. Ital.: tab. 894. 1881. [MB169502].

Record: Soil (Pernambuco-PE, Cruz *et al.* 2013b).

Section ***Ramigena*** Thom, The Penicillia: 225. 1930. [MB834004].

P. capsulatum Raper & Fennell, Mycologia 40: 528. 1948. [MB289079].

Record: Soil (Maranhão-MA, Batista *et al.* 1964).

P. cyaneum (Bainier & Sartory) Biourge, Cellule 33: 102. 1923. [MB251712].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

Section ***Ramosa*** (as "Ramosum") Stolk & Samson, Adv. Pen. Asp. Syst.: 179. 1985. [MB832722].

P. lanosum Westling, Ark. Bot. 11: 97. 1911. [MB178497].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, (Ramos & Upadhyay 1966; Cruz *et al.* 2013b; 2017).

P. raistrickii G. Sm., Trans. Brit. Mycol. Soc. 18: 90. 1933. [MB276069].

Records: Soil (Paraíba-PB, Batista *et al.* 1970); Cattle and horse dung (Pernambuco-PE, Melo *et al.* 2017); Misspelled as *P. vaistrickii* in Soil (Maranhão-MA, Batista *et al.* 1964).

Section ***Robsamsonia*** Houbraken & Frisvad, Persoonia 36: 309. 2016. [MB815870].

P. glandicola (Oudem.) Seifert & Samson, Adv. Penicillium Aspergillus Syst.: 147. 1985. [MB114761].

Record: As endophyte from cladodes of *O. ficus-indica* (Pernambuco-PE, Bezerra *et al.* 2012).

P. griseofulvum Dierckx, Ann. Soc. Sci. Bruxelles 25: 88. 1901. [MB120566].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013; Barbosa *et al.* 2016). Also reported as *Penicillium urticae* in soil (Pernambuco-PE, Ramos & Upadhyay 1966).

Note: *Penicillium urticae* is currently known as *P. griseofulvum*.

P. vulpinum (Cooke & Massee) Seifert & Samson, Adv. Penicillium Aspergillus Syst.: 144. 1985. [MB114763].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017).

Section ***Sclerotiora*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB563124].

P. adametzii Zalessky, Bull. Int. Acad. Polon. Sci., Cl. Sci. Math., Sér. B, Sci. Nat., 1927: 507. 1927. [MB119777].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2013b); Soil (Pernambuco-PE, Barbosa *et al.* 2016; Cruz *et al.* 2017).

P. bilaiae Chalab., Bot. Mater. Otd. Sporov. Rast. 6: 165. 1950. [MB302379].

Record: Soil (Pernambuco-PE, Barbosa *et al.* 2016).

P. herquei Bainier & Sartory, Bull. Soc. Mycol. France 28: 121. 1912. [MB536431].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

P. sclerotiorum J.F.H. Beyma, Zentralbl. Bakteriol. Parasitenk., Abt. 2 96: 418. 1937. [MB277708].

Records: Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Barbosa *et al.* 2016); Grapes (Pernambuco-PE and Bahia-BA, Freire *et al.* 2017).

Section ***Turbata*** Houbraken & Samson, Studies in Mycology 70. 2011. [MB563133].

P. turbatum Westling, Ark. Bot. 11: 128. 1911. [MB202895].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Oliveira *et al.* 2013).

Talaromyces C.R. Benj., Mycologia 47: 681. 1955.

Section ***Helici*** Samson, N. Yilmaz & Frisvad, Studies in Mycology 78: 2014. [MB809558].

T. varians (G. Sm.) Samson, N. Yilmaz & Frisvad, Studies in Mycology 70: 177. 2011. [MB560677].

Record: As *P. varians* in Soil (Maranhão-MA, Batista *et al.* 1964).

Note: *P. varians* does not belong to *Penicillium* s. str. and was recombined as *T. varians* (Samson *et al.* 2011).

Section ***Islandici*** (Pitt) Yilmaz, Frisvad &Samson, Studies in Mycology 78: 2014. [MB809565].

T. islandicus (Sopp) Samson *et al.*, Studies in Mycology 71: 176. 2011. [MB560654].

Records: As *P. islandicum* in Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Paraíba-PB, Batista *et al.* 1970).

Note: *P. islandicum* does not belong to *Penicillium* s. str. and was recombined as *T. islandicum* (Samson *et al.* 2011)

T. rugulosus (Thom) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 177. 2011. [MB560672].

Records: As *P. tardum* in Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970); reported as *P. rugulosum* in soil (Alagoas-AL, Cavalcanti *et al.* 2006).

Note: *P. chrysitis*, *P. tardum* and *T. echinosporus* are synonyms of *T. rugulosus* (Yilmaz *et al.* 2014).

T. wortmannii (Klöcker) C.R. Benj. Mycologia 47: 683. 1955. [MB344294].

Records: Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Oliveira *et al.* 2013). As *P. variabile* in Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Paraíba-PB, Batista *et al.* 1970).

Note: Four-gene phylogeny, morphology and extrolite data revealed that *T. variabilis*, *P. concavorugulosum* and *T. sublevisporus* are synonyms of *T. wortmanni* (Yilmaz *et al.* 2014).

Section ***Talaromyces*** Stolk & Samson, Studies in Mycology 2: 56. 1972. [MB549314].

T. duclauxii (Delacr.) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 175. 2011. [MB560650].

Record: As *P. duclauxi* in soil (Paraíba-PB, Batista *et al.* 1970).

Note: *P. duclauxii* does not belong to *Penicillium* s. str. and was recombined as *T. duclauxii* (Samson *et al.* 2011).

T. flavus (Klöcker) Stolk & Samson, Studies in Mycology 2: 10. 1972. [MB324416].

Record: As *P. vermiculatum* in Soil (Paraíba-PB, Batista *et al.* 1970).

Note: *P. vermiculatum* was described by Dangeard (1907) and transferred to *Talaromyces* by Benjamin (1955). According to Yilmaz *et al.* 2014 "Orr *et al.* (1963) considered *Gymnoascus flavus* and *T. vermiculatus* as synonyms and this was followed by Stolk & Samson (1972) and Pitt (1980). Ghosh *et al.* (1961) re-evaluated the type strains of *Arachniotus indicus* and *A. indicus* var. *major* and both isolates proved to represent *Talaromyces vermiculatus* and therefore they synonymised it with *T. flavus*."

T. funiculosus (Thom) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 176. 2011. [MB560653].

Records: As *P. funiculosum* in Soil (Maranhão-MA, Batista *et al.* 1964); Soil (Pernambuco-PE, Ramos & Upadhyay 1966; Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *Cereus jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Caves (Minas Gerais-MG, Bahia-BA and Piauí-PI, Melo *et al.* 2013); As endophyte from cladodes of *O. ficus-indica* and *P. gounellei* (Pernambuco-PE, Freire *et al.* 2015); Soil (Pernambuco-PE, Cruz *et al.* 2013a; 2017).

T. verruculosus (Peyronel) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 177.2011. [MB560678].

Records: As *P. verruculosum* in Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

Note: *P. verruculosum* does not belong to *Penicillium* s. str. and was combined in *Talaromyces* as *T. verruculosus* (Samson *et al.* 2011).

T. pinophilus (Hedgc.) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 176. 2011. [MB560662].

Records: As *P. pinophilum* in Soil (Pernambuco-PE, Cavalcanti & Maia 1994); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b; 2017; Oliveira *et al.* 2013).

Note: Note: *P. pinophilum* does not belong to *Penicillium* s. str. and was combined in *Talaromyces* as *T. pinophilus* (Samson *et al.* 2011).

T. purpurogenus (Stoll) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 176. 2011. [MB560667].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2017). Reported as *P. purpurogenum* in Soil (Paraíba-PB, Batista *et al.* 1970); Soil (Alagoas-AL, Cavalcanti *et al.* 2006); Soil (Pernambuco-PE, Cruz *et al.* 2013b); As endophyte from cladodes of *C. jamacaru* (Pernambuco-PE, Pires *et al.* 2015); Horse dung (Pernambuco-PE, Melo *et al.* 2017).

Note: *P. purpurogenum* does not belong to *Penicillium* s. str. and was combined in *Talaromyces* as *T. purpurogenus* (Samson *et al.* 2011).

T. ruber (Stoll) N. Yilmaz, Houbraken, Frisvad & Samson, Persoonia 29: 48. 2012. [MB801360].

Records: As *P. rubrum* in Soil (Pernambuco-PE, Ramos & Upadhyay, 1966); Soil (Paraíba-PB, Batista *et al.* 1970).

Note: *P. rubrum* does not belong to *Penicillium* s. str. and was combined in *Talaromyces* as *T. ruber* (Yilmaz *et al.* 2012).

Section ***Trachyspermi*** Yaguchi & Udagawa. Mycoscience 37. 1996. [MB701485].

T. minioluteus (Dierckx) Samson, N. Yilmaz, Frisvad & Seifert, Studies in Mycology 70: 176. 2011. [MB560657].

Records: Soil (Pernambuco-PE, Cruz *et al.* 2017). Also reported as *P. minioluteum* in soil (Alagoas-AL, Cavalcanti *et al.* 2006); As endophyte from cladodes of *C. jamacaru* (Paraíba-PB, Bezerra *et al.* 2013); Soil (Pernambuco-PE, Cruz *et al.* 2013b; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

Note: *P. minioluteum* does not belong to *Penicillium* s. str. and was combined in *Talaromyces* as *T. minioluteus* (Samson *et al.* 2011).

T. pernambucoensis R. Cruz, C. Santos, Houbraken, R.N. Barbosa, Souza-Motta, Persoonia. 42: 467. 2019. [MB830189].

Record: Soil (Pernambuco-PE, Crous *et al.* 2019).

Discussion

The *Eurotiales* is a relatively large order with members frequently impinging upon human activities. The most well-known species of this order belong to the genera *Aspergillus*, *Penicillium* and *Talaromyces*. Those genera comprise a diverse group of species, which have significant impacts on biotechnology, food production, indoor environments, and human health (Pitt & Hocking 2009, Houbraken & Samson 2011). Species can survive in diverse habitats, ranging from soil, vegetation, air, indoor environments, and various food products (Visagie *et al.* 2014a; Diao *et al.* 2018; Barbosa *et al.* 2018; Frisvad *et al.* 2019).

In our compilation of studies, soil is the most frequently reported as a source of *Aspergillus*, *Penicillium* and *Talaromyces* isolations from the Caatinga forest. Fungi living in dry soils are specially adapted to high temperature, low moisture and less availability of organic carbon, giving those fungal communities have unique properties. Species of *Aspergillus*, *Penicillium* and *Talaromyces* are highly diverse allowing them to survive at different temperatures, low water activity and variations of pH and O_2 concentration in soil (Pitt & Hocking 2009; Cruz *et al.* 2013a; b; Oliveira *et al.* 2013; Barbosa *et al.* 2016).

Some species, such as *A. arcoverdensis*, *A. caatingaensis*, *A. pernambucoensis*, *A. serratalhadensis* and *T. pernambucoensis*, has only been reported from Caatinga soils, and there are no records found elsewhere in the world until the date of

our study. It is possible that these species will be discovered in other parts of the planet. Allen & Lendemer (2015) assume that climatically similar regions will share similar fungal communities leading to unending uncertainty about the distribution of species, resulting in the idea that fungi cannot have narrowly endemic ranges or follow biogeographic patterns such as those documented for other organism groups. However, it is important to mention the fungal diversity can be directly and indirectly affected by soil and plant properties, providing evidence for strong links between soil fungal diversity and plant and soil properties (Yang *et al.* 2017). The Caatinga forest harbors rare and/or endemic species highlighting the importance of its conservation. The highest number of fungal records is registered for the Brazilian state named Pernambuco. Since 1954, the fungal diversity in Pernambuco state has been studied by several mycologists because of the existence of the former Institute of Mycology of the University of Recife (Currently the Departamento de Micologia at the Universidade Federal de Pernambuco) which was founded by Augusto Chaves Batista and many fungal surveys in the area has been focused on soil (Bezerra *et al.* 2017).

Aspergillus species belonging to sections *Fumigati*, *Nidulantes* and *Nigri* are most frequently reported in our list. Species of those sections are saprophytic and have been isolated from soils around the world (Klich & Pitt 1988; Varga *et al.* 1994; Samson *et al.* 2007). *Aspergillus fumigatus* is the most reported species in section *Fumigati*. This is a ubiquitous fungus, well adapted to colonize diverse environments through its metabolic diversity, broad stress and thermal tolerances, and easily dispersed conidia. This species is also an important opportunistic human pathogen. *Aspergillus niger* is the most common species from section *Nigri*, widely distributed and is often found in dry regions, and its distribution is related to the climate, vegetation and soil. Klich (2002a), when studying the biogeography of *Aspergillus* in samples of soil and leaf litter, noted that species of this genus occurs more frequently in desert environments. In our study, species belonging to section *Nidulantes* are also common in soil samples. The number of reports (richness) of section *Nigri* is high when compared with section *Nidulantes*; however, the number of species (diversity) reported from soil is similar. It is important to mention the taxonomy of many sections of *Aspergillus*, such the section *Nigri*, is most confusing and complex due to the subtle differences between the many species, thus the polyphasic taxonomy is strongly recommended.

Members of *Penicillium* section *Citrina* are abundant in Caatinga. Species of this section have a worldwide distribution, are very common in soil (Monteiro 2012), but are also found in foods, indoor air and many other substrates. The distribution of species appears to be climate-related, for example *P. citrinum* is more common in (sub) tropical soils, but present in low numbers in temperate regions (*e.g.* The Netherlands). Species of this section are good producers of secondary metabolites that may confer benefit by providing a competitive advantage when colonizing a new substrate (Houbraken *et al.* 2011). The new species described here as *Penicillium vascosobrinhous* belongs to this section. The data from the single-gene analyses showed that the new species is placed as a distinct lineage between the clade of *P. roseopurpureum* CBS 266.29 and *P. sanguifluum* CBS 127032 (Fig. 3) and the combined sequence analyses of the four loci (Fig. 4) with the clade of *P. anatolicum* CBS 47966, *P. argentinense* CBS 130371 and *P. euglaucum* CBS 323.71. The new species differs from those in several morphological features. For example, the reverse colour of *P. roseopurpureum* and *P. sanguifluum* on CYA is in shades of red with red-brown diffusible pigments, while the reverse colour in *P. vascosobrinhous* is brownish and soluble pigment production is absent. The conidiophores of *P. vascosobrinhous* are monoverticillate and no sclerotia or cleistothecia are produced. In contrast, *P. anatolicum* predominantly produces biverticillate conidiophores and cleistothecia on most agar media, the conidiophores in *P. argentinense* are monoverticillate or biverticillate, and cleistothecia are produced on CYA and oatmeal agar, and in *P. euglaucum* the conidiophores are simple when young becoming biverticillate in age. This last species is characterised by the production of warm-grey coloured cleistothecia, strong yellow soluble pigment production and good growth at 30 °C.

The taxonomic history of anamorphic species attributed to *Penicillium* subgenus *Biverticillium* was reviewed by Samson *et al.* (2011). They concluded that the subgenus *Biverticillium* is distinct from other subgenera in *Penicillium* and transferred all accepted species of subgenus *Biverticillium* to *Talaromyces*. Applying the current taxonomic classification, nine species marked in the literature for Caatinga and originally classified in *Penicillium*, currently belong to *Talaromyces*. For *Talaromyces*, the species classified in section *Talaromyces* are most commonly occurring in our study. Initially, this section was introduced for species producing yellow, white, creamish, pinkish or reddish ascomata and yellow ascospores, but currently contains both asexual and sexual morphs. This group is the largest section of the genus and the members show a great diversity in morphological characters (Yilmaz *et al.* 2014). Species belonging to this section are frequently isolated from soil, indoor environments and food products. In this study, the most common species were *T. funiculosus* and *T. purpurogenus*. These species are known as producers of biotechnologically interesting enzymes (Rando *et al.* 1997; Sukhacheva *et al.* 2004). *Talaromyces purpurogenus* produces rubratoxin, which is a well-known hepa-carcinogenic toxin (Kihara *et al.* 2001; Frisvad *et al.* 2013).

In our checklist, the melanic fungi such *A. niger* and *A. fumigatus* were prevalent. For example, in *Aspergillus* section *Fumigati*, *A. fumigatus* can produce two types of melanin (dihydroxynaphthalene melanin and pyomelanin). These

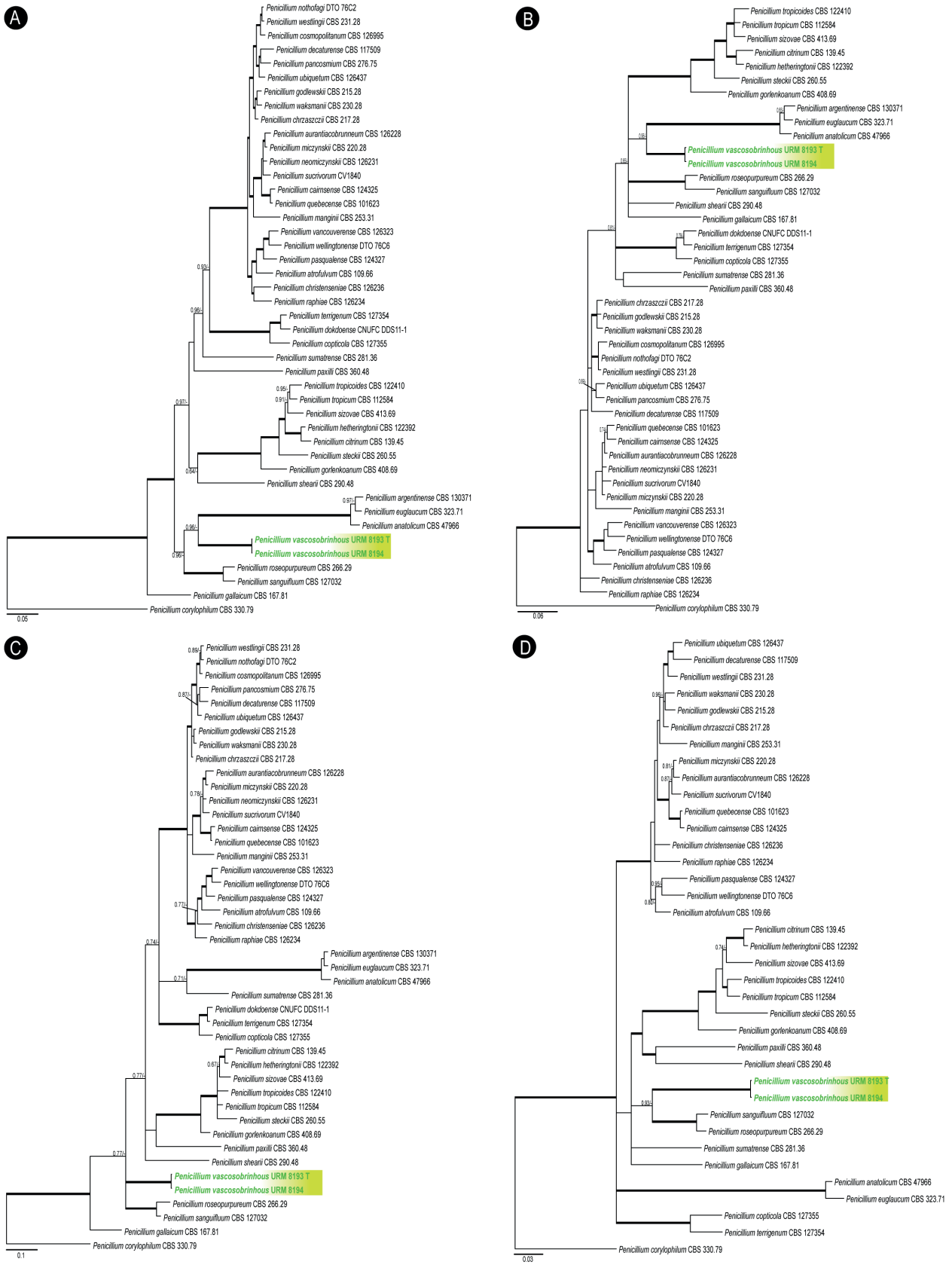

Figure 3. Single gene phylogenies of *Penicillium* section *Citrina* strains and the new species *P. vascosobrinhous*. **A**- ITS phylogeny; **B**- *BenA* phylogeny, **C**- *CaM* phylogeny, **D**- *RPB2* phylogeny. The new species is highlighted. Values below 0.95 pp and 70 % are not shown and indicated with a hyphen. Branches with posterior probability values of 1.00 and >95 % are thickened.

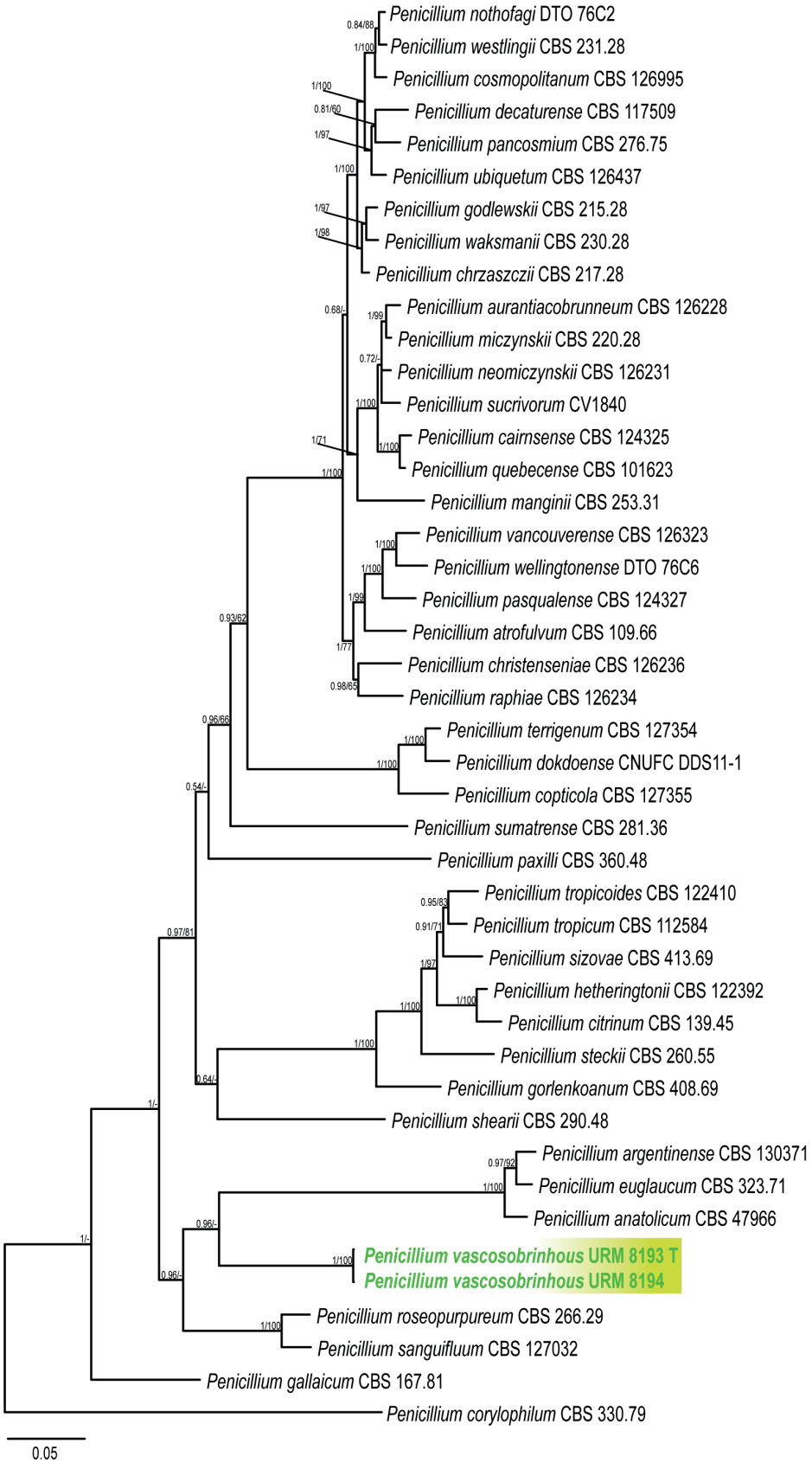

Figure 4. Phylogenetic position of *Penicillium* section *Citrina* strains and the new species *P. vascosobrinhous* based on a combined dataset containing ITS, *BenA*, *CaM* and *RPB2* sequences. The new species is highlighted. Values below 0.95 pp and 70 % are not shown and indicated with a hyphen.

pigments are considered important resistance mechanisms to stress, as well as virulence factors (Perez-Cuesta *et al.* 2019). Fungal melanins are brown to black pigments formed by oxidative polymerization of phenolic compounds (Jacobson 2000). The melanins are not essential for normal growth; however, these pigments confer on the fungus the ability to several stress-tolerant, such as solar radiation, high temperature, water deficiency (Butler & Day 1998), common features in the Caatinga.

Aspergillus, *Penicillium* and *Talaromyces* species are known as important producers of several bioactive secondary metabolites that provide ecological fitness roles (Frisvad 2008; Drott *et al.* 2017; Rohlfs & Churchill 2011). The loss or overproduction of specific compounds can alter fungal development, survival or inter-kingdom and intra-kingdom encounters, for example, the secondary metabolite aflatoxin produced by *A. flavus* has toxic properties towards insects, providing a fitness advantage to *A. flavus* when the fungus encounters insects (Rohlfs 2014; Drott *et al.* 2017; Keller 2019).

In this study we did not include unidentified taxa (*e.g. Aspergillus* sp., *Penicillium* sp. and *Talaromyces* sp.) because they cannot be placed in a correct section or species in which genus, and in some cases, they can represent the same species. In this paper, our proposal was to present a list of valid names for fungal species reported in the Caatinga forest, thus we choose not to consider these records. However, we understand that unidentified records at the species level may represent an unexplored diversity in the Caatinga which needs to be studied in future studies (if strains are available).

Aspergillus, *Penicillium*, and *Talaromyces* were traditionally classified according to their morphological features. The identification of the majority of species ranked in our list was mostly based on Raper & Fennell (1965), Pitt (1973; 1980), Domsch *et al.* (1980), Klich & Pitt (1988), Klich (2002b) and Pitt & Hocking (2009). The modern concept to the identification of species belonging to those genera are based on polyphasic approach including morphology, multigene phylogenies, physiology and extrolite data (*e.g.* Hong *et al.* 2005; Frisvad *et al.* 2007; Chen *et al.* 2016; 2017; Barbosa *et al.* 2018). We recommend following the standardised methods described in *e.g.* Samson *et al.* (2010), Houbraken *et al.* (2011), Visagie *et al.* (2014a), Yilmaz *et al.* (2014), and Frisvad *et al.* (2019). In addition, it is extremely important to preserve strains (at minimum a representative) in a public reference fungal culture collection, such as the Micoteca URM in Brazil (https://www.ufpe.br/micoteca), and whenever possible in an international collection such as the CBS collection housed in the Westerdijk Fungal Biodiversity Institute in The Netherlands (http://www.wi.knaw.nl/Collections) and/or the Micoteca da Universidade do Minho (MUM) in Portugal (http://www.micoteca.deb.uminho.pt/en/). These guidelines should be used not just for describe new species, but for all studies of species prospection.

In tropical countries like Brazil, it is still necessary to increase and to incentive the development of research including collection and preservation of specimens in fungal herbaria and culture collections. The collection, isolation, identification and conservation of fungi is relevant to agriculture, pharmacology, food and biotechnology industries, and this research can be used as basis for political decisions. In the last years, Brazilian government had put forward some initiatives in order to better preserve the Caatinga biodiversity. However, these strategies suffer with lack of taxonomic data, and species lists for each area are an important tool to establish protected areas.

Conclusions

This checklist shows that the Caatinga forest has been scarcely studied so far. The characterization of fungi in unique ecosystems, apart from being a fundamental step to the taxonomic survey of a group, can lead to the development of studies on biotechnology, ecological roles and conservation status of this ecosystem. This also reflects the importance to increase the number of mycologists, in particular specialists in taxonomy, to perform research on dry environments. Otherwise, fungal diversity of extreme environments such as the Caatinga forest will largely remain unexplored. Our data is a framework to a study of biogeography of *Aspergillus*, *Penicillium*, and *Talaromyces* species in dry environments worldwide.

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