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New records of Glomeromycota species from a tropical dry forest remnants in the Colombian Caribbean

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Abstract

Background

In tropical regions, studies on the diversity and symbiotic relationships of arbuscular mycorrhizal fungi (AMF) have primarily focused on crops and agroecosystems, with comparatively little attention given to natural ecosystems.

New information

This study reports the first records of *Funneliformis badius* (Oehl, D. Redecker & Sieverd.) C. Walker & A. Schüßler and *Diversispora epigea* (B.A. Daniels & Trappe) C. Walker & A. Schüßler in a Colombian tropical dry forest. Furthermore, it extends the known geographic distribution of *Acaulospora scrobiculata* Trappe to the Magdalena Department.

Keywords

spores, arbuscular-mycorrhizal-fungi, distribution, *Funneliformis, Diversispora,* Colombia, native hosts

Introduction

Arbuscular mycorrhizal fungi (AMF) belong to Phylum Glomeromycota. They are biotrophic symbionts that complete their life cycles and development by using the photosynthetic products they get through their association with plants, and that give in

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return essential nutrients they transport from the soil to the host. AMF are a common component of soil fungal communities (Smith and Read 2008), and their symbiosis with plant absorption organs is known as arbuscular mycorrhizas, which are widely distributed in diverse ecosystems, associated with 72% of the plants (Brundrett and Tedersoo 2018). AMF colonize plant root cells intracellularly through arbuscular structures. This association between AMF and the host plant allows nutrient exchange, such as phosphorus, and it provides hydric stress and pathogen infection tolerance (Smith and Read 2008, Jung et al. 2012). Also, AMF can significantly improve plant nutrient uptake and resistance to several abiotic stress factors (Ouledali et al. 2019). Hence, it can be used as a resource to improve crops (Montenegro et al. 2017) in agricultural biotas or natural ecosystems (van der Heijden et al. 1998, Begum et al. 2019).

Cofré et al. (2019) mentioned that in South America, Brazil, Argentina and Chile are the countries with the highest number of studies on AMF. In neotropical countries, these studies have been focused on AMF association with forests and grasslands in tropical ecosystems, while other biomes and ecoregions which are ecologically relevant have not been considered (Stürmer and Kemmelmeier 2021). In total, the AMF diversity of Colombia registered 19 genera and 77 species with 232 records, although the country reflects the same tendency, since most of its studies are focused on tropical agroecosystems such as cassava (Garzón 2016), oil palm (Rivera Méndez et al. 2014), corn (Serralde and Ramírez 2004, Rodríguez et al. 2015), avocado (Montenegro et al. 2017) and cocoa crops (Pérez-Moncada et al. 2019).

Additionally, Colombian Caribbean seasonally dry tropical forest (DTF) is mostly located in the departments of Magdalena, La Guajira, Cesar, Atlántico, Bolivar, Sucre and Córdoba, exhibiting a high level of transformation (González et al. 2018) from continuous threat through urbanization and land use change (Grau et al. 2008). The best-preserved areas of DTF are located along national protected parks (Carbonó-De la Hoz and García-Q 2010); other ones are covered with successional intermediate forest, with low to medium levels of intervention, most of them are surrounded by subsistence crops. The coastal city of Santa Marta is located in the Magdalena Department, the vegetation rises from very different habitat of xeric scrub and dry tropical forest.

In relation to the AMF diversity, in the Caribbean region, the genera *Glomus* Tul. & C. Tul.*, Paraglomus,* and *Gigaspora* have been reported in the Sucre Department (Espitia and Pérez 2016, Pérez and Peroza 2013), as well as *Acaulospora, Glomus,* and *Gigaspora* in the Magdalena Department (Luna-Fontalvo et al. 2016).

The aim of this work is to contribute to the knowledge concerning AMF diversity and to describe the spores from the native plant rhizospheric soil at the DTF from Santa Marta, in the Colombian Caribbean area.

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Materials and methods

The studied area is located at the *campus* of the University of Magdalena (Santa Marta, Colombia), characterized by seasonally dry tropical forest remnants with a high component of herbs located in an urban environment. The experimental area is made up of 3.5 ha at 11°13'8,08" N - 74°11'11,25" W, with a bimodal rain regime of two wet seasons (May-June and September-November) and two dry seasons (December-April and June-August). The annual average rain and temperature are 578 mm and 27°C respectively, while the mean relative humidity is 74% (Strewe et al. 2009). The sampling site soil had a loamy-sandy texture and it was physicochemically characterized by an alkaline pH (7.9), electric conductivity (10.4 dS m^{-1}), the presence of organic carbon (1.73%), phosphorus (0.38 ppm), and by deficient nitrogen levels (Aguirre et al. 2019).

Twenty five soil samples of 0.5 kg were gathered from five randomly distributed sampling sites. The soil samples were associated with herbaceous plant roots from *Amaranthus tortuosus* Hornem. (Amaranthaceae), *Sporobolus tenuissimus* (Mart. Ex Schrank) Kuntze, and *Chloris barbata* Sw. (Poaceae), the most abundant and frequent non-woody vegetation. Five samples were taken from each site, deposited in plastic Ziploc bags, labelled, and processed at the Laboratory of Water Quality from the University of Magdalena. The extraction and characterisation of AMF spores were carried out following Sieverding (1983) and Brundrett (2008). Spores were identified according to their morphological characteristics (colour, diameter, subtending hyphae presence, and number of walls), and resorting to Blaszkowski's taxonomic keys (2012) as well as to the data bases INVAM (2019) and AMF-Phylogeny (2024). The optic microscope Zeiss Primo Star was used for observation, while the programme ToupView v.3.7 was used to measure the diameter and width of the subtending hyphae. The material collected is deposited in the Center of Biological Collections (CBUMAG) at the University of Magdalena.

Data deposition

The data underpinning the analysis reported in this paper are deposited at GBIF, the Global Biodiversity Information Facility and are available at Dataset/Occurrence. https://doi.org/10.15472/p16ua9 (Luna-Fontalvo et al. 2022).

Taxon treatments

Funneliformis badius (Oehl, D. Redecker & Sieverd.) C. Walker & A. Schüßler

Material

a. scientificName: ***Funneliformis badius***; scientificNameAuthorship: (Oehl, D.Redecker & Sieverd.) C.Walker & A.Schüßler; continent: América del Sur; country: Colombia;

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countryCode: CO; stateProvince: Magdalena; county: Santa Marta; locality: Universidad del Magdalena - Campus Principal; verbatimElevation: 21; minimumElevationInMeters: 21; verbatimCoordinates: 11°13'08"N, 74°11'7.50"W; verbatimLatitude: 11°13'08"N; verbatimLongitude: 74°11'7.50"W; verbatimCoordinateSystem: Grados, minutos, segundos; verbatimSRS: WGS84; decimalLatitude: 11.21889; decimalLongitude: -74.18528; geodeticDatum: WGS84; year: 2019; month: 01; day: 14; verbatimEventDate: 2019-14-I; habitat: Bosque seco tropical; catalogNumber: CBUMAG:FUN:36; recordNumber: JLF | GS | LA | ML 02; recordedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; identifiedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; type: Stillmage; basisOfRecord: MachineObservation; occurrenceID: 585595B9-B46F-556A-9A38-20739213AE2E

Description

Spore characteristics: From reddish-hazel to dark reddish-hazel, globose shape, (45-) 55 (-65) µm in diameter. Triple-layered wall: outer wall layer (OWL, Fig. 1B), mucilaginous, hyaline, evanescens, slightly deteriorated or absent in mature spores; second wall layer (SWL, Fig. 1B), dark hazel, (3,5-) 4 (-5) µm thick; inner wall layer (IWL, Fig. 1B), semiflexible, light hazel, (0,5-) 1,7 (-2) µm thick. The subtending hypha (SH, Fig. 1B), light hazel, lighter than the spore, (5-) 7,4 (-7,5) µm wide at the spore base. The spores are clustered in aggregates with 2 to 4 spores, (120-) 160 (-250) µm in diameter.

Observations: Low number of aggregates, mostly broken, which is reflected on the scarce spores per aggregate, probably due to spore loss.

Distribution

Funneliformis badius has been reported in a wide range of environments, including dry areas, grasslands, savannahs, tropical and humid forests, and shrublands in countries such as Brazil, Argentina, and Chile, as well as in other tropical and subtropical regions (Cofré et al. 2019, Stürmer and Kemmelmeier 2021). Additionally, this species has been recorded in several European countries, including Germany, France, Switzerland, and Italy (Oehl et al. 2005), and in Poland under the synonym *Glomus badium* (Blaszkowski 2012), which was later reclassified as *Funneliformis badius* (Schüßler and Walker 2010). According to Oehl et al. (2005), the fungus has been found in association with *Dactylis glomerata* L. and other grasses in soils with pH values ranging from 6 to 8. Furthermore, Blaszkowski (2012) reported its presence in both cultivated and uncultivated sites in Poland, including coastal dunes, noting that it sporulated more abundantly when associated with wild plant species. The detection of *Funneliformis badius* in Colombia represents a new record of arbuscular mycorrhizal fungi (AMF) for the country.

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Diversispora epigaea (B.A. Daniels & Trappe) C. Walker & A. Schüßler 2010

Material

a. scientificName: *Diversispora epigaea*; scientificNameAuthorship: (B.A.Daniels & Trappe) C.Walker & A.Schüssler; continent: América del Sur; country: Colombia; countryCode: CO; stateProvince: Magdalena; county: Santa Marta; locality: Universidad del Magdalena - Campus Principal; verbatimElevation: 21; minimumElevationInMeters: 21; verbatimCoordinates: 11°13'15"N, 74°11'7.50"W; verbatimLatitude: 11°13'15"N; verbatimLongitude: 74°11'7.50"W; verbatimCoordinateSystem: Grados, minutos, segundos; verbatimSRS: WGS84; decimalLatitude: 11.22083; decimalLongitude: -74.18528; geodeticDatum: WGS84; year: 2019; month: 01; day: 14; verbatimEventDate: 2019-14-I; habitat: Bosque seco tropical; catalogNumber: CBUMAG:FUN:37; recordNumber: JLF | GS | LA | ML 02; recordedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; identifiedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; type: Stillmage; basisOfRecord: MachineObservation; occurrenceID: 94E089F7-53DF-5430-8096-0B9D00549252

Description

Spore characteristics: pale yellow, subglobose shape, (90-) 117 (-120) µm in diameter. Double-layered spore wall: outer wall layer (OWL, Fig. 1C), (0,6-) 0,8 (-1,5) µm thick, no Melzer reaction; inner wall layer (IWL, Fig. 1C), laminate, light yellow, (4,5-) 6,2 (-6,5) µm thick, Melzer positive reaction. The subtending hypha (SH, Fig. 1 C), with septa, hyaline, (5-) 6,2 (-6,5) µm wide at the spore base.

Observations: only single spores in soil, aggregates were not found.

Distribution

Diversispora epigea represents a new record for Colombia. This species grows in saline soils of the tropical dry forest and has generally been found associated with native herbaceous species, as well as in agroecosystems in India and Brazil (Channabasava and Lakshman 2015, Marinho et al. 2018). In their review on the diversity of Glomeromycota in the Neotropics, Stürmer and Kemmelmeier (2021) reported 15 species belonging to the family Diversisporaceae, of which six belong to the genus Diversispora: D. aurantia (Błaszk., Blanke, Renker & Buscot) C. Walker & A. Schüßler, D. eburnea (L.J. Kenn., J.C. Stutz & J.B. Morton) C. Walker & A. Schüßler, D. pustulata (Koske, Fries, C. Walker & Dalpé) Oehl, G.A. Silva & Sieverd, D. spurca (C.M. Pfeiff., C. Walker & Bloss) C. Walker & A. Schüßler, D. trimurales (Koske & Halvorson) C. Walker & A. Schüßler, and D. versiformis (P. Karst.) Oehl, G.A. Silva & Sieverd. The present study is the first record of D. epigea in Colombian territory.

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Acaulospora scrobiculata Trappe 1977

Material

a. scientificName: Acaulospora scrobiculata; scientificNameAuthorship: Trappe; continent: América del Sur; country: Colombia; countryCode: CO; stateProvince: Magdalena; county: Santa Marta; locality: Universidad del Magdalena - Campus Principal; verbatimElevation: 21; minimumElevationInMeters: 21; verbatimCoordinates: 11°13'23"N, 74°11'2.75"W; verbatimLatitude: 11°13'23"N; verbatimLongitude: 74°11'2.75"W; verbatimCoordinateSystem: Grados, minutos, segundos; verbatimSRS: WGS84; decimalLatitude: 11.22305; decimalLongitude: -74.18389; geodeticDatum: WGS84; year: 2019; month: 01; day: 10; verbatimEventDate: 2019-10-I; habitat: Bosque seco tropical; catalogNumber: CBUMAG:FUN:38; recordNumber: JLF | GS | LA | ML 01; recordedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; identifiedBy: Jorge Luna-Fontalvo | Gabriel Santos | Luis Atencia | Monica A. Lugo; type: Stillmage; basisOfRecord: MachineObservation; occurrenceID: DA9CADE8-8726-5631-92E2-0E1D046E5904

Description

Spore characteristics: Subhyaline when young, whitish-yellow, sublogobse shape, (105-) 116 (-125) µm in diameter. Triple-layered spore walls: outer wall layer (OWL, Fig. 1D), mucilaginous, hyaline, short lived, evanescent easily deteriorated, (0,9-) 1,2 (-1,4) µm thick; second wall layer (SWL, Fig. 1D), laminate, yellow, (3-) 4 (-5,2) µm thick, with irregular pits, positive Melzer reaction; inner wall layer (IWL, Fig. 1D), hyaline, (0,3-) 0,5 (-0,6) µm thick.

Distribution

It is a new record for Colombia and it grows in saline soils associated with the rhizospheric soil. In addition, Bolaños et al. 2000 reported it for the Colombian Departamento del Valle (Municipio de Albán, El Cairo) in the rhizospheric soil where the native crop “uchuva” *Physalis peruviana* L. (Solanaceae) grows. Moreover, in South American the species was reported for countries such as Argentina, Chile, and Brazil, where it is associated with different forest ecosystems, grasslands, and savannahs, among others, and it was considered a generalist species (Cofré et al. 2019). The species is one of the most frequent based on the 212 records for the Neotropics (Stürmer and Kemmelmeier 2021), also found in the six continents (Stürmer et al. 2018).

Analysis

For the first time, the species *Funneliformis badius* (Oehl, D. Redecker & Sieverd.) C. Walker & A. Schüßler (Glomeraceae), together with *Diversispora epigaea* (B.A. Daniels and Trappe) C. Walker & A. Schüßler (Diversisporaceae) were reported for Colombia. In addition, the distribution of *Acaulospora scrobiculata* Trappe (Acaulosporaceae) was

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extended to the Magdalena Department, in Colombia. These species were found in the rhizospheric soil associated with herbs from *Amaranthus tortuosus* Hornem. (Amaranthaceae), *Sporobolus tenuissimus* (Mart. ex Schrank) Kuntze, and *Chloris barbata* Sw. (Poaceae). Additionally, data on their diagnostic features and distribution are provided.

Discussion

In this paper, we highlight the occurrence *Funneliformis badius* (Oehl, D. Redecker & Sieverd.) C. Walker & A. Schüßler, *Diversispora epigaea* (B.A. Daniels & Trappe) C. Walker & A. Schüßler for the first time as components of rhizospheric soil at the tropical dry forest in Colombia; additionally, we registered *Acaulospora scrobiculata* Trappe for the Magdalena Department. Our results highlight the importance of exploring new areas to enhance our knowledge of the Phylum Glomeromycota in seasonally dry tropical forest in Colombia.

This work presents two new AMF records for the Colombian dry tropical forest: *Funneliformis badius* and *Diversispora epigea*, as well as it extends the distribution of *Acaulospora scrobiculata* to the Magdalena Department. Neotropical forests are increasingly becoming deteriorated by anthropic activities, which turn them into agricultural grasslands. The dry tropical forest is one of the most threatened ones, since it currently occupies less than 10% of its original extension. Meanwhile, the impact of this change on AMF diversity remains unknown. AMF-plant interaction is relevant since it enables plants to optimize their use of water, nutrients and minerals; therefore, AMF loss or decrease has negative effects on plant communities. As a matter of fact, AMF association had a restorative effect on the species chosen for this project, which include the native hosts *Sporobolus tenuissimus* (Mart. ex Schrank) Kuntze, *Chloris barbata* Sw. (Poaceae), and *Amaranthus tortuosus* Hornem. (Amaranthaceae). These hosts grow quickly and abundantly after deforestation or fires; hence, they can protect the soil from erosion. This work is also a contribution to the Colombian fungal diversity and to the education of young researchers in the field.

Finally, it is necessary to generate species inventories from Colombia and others unexplored regions from the Neotropics which are scarcely surveyed for AMF diversity. These fungi play important roles that provide useful information for conservation of the ecosystems.

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This is the scientific contribution No. 26 from the Centro de Colecciones Biológicas de la Universidad del Magdalena (CBUMAG).

Author contributions

The project has been conducted by all authors. GSC, LAM, and JLF collected and processed the rhizospheric soil samples; MAL, GSC, LAM, and JLF and MAL photographed and identified AMF species; KRR and MAN identified plant species; JLF, MAN, and MAL wrote this work.

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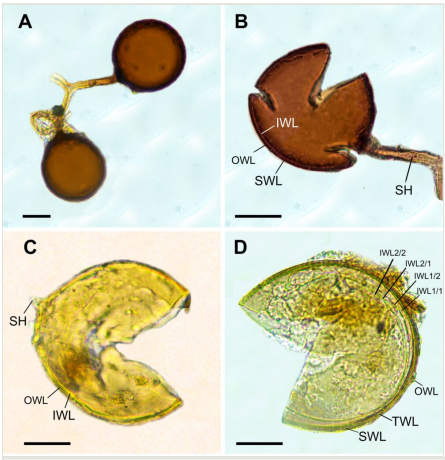

Figure 1.

AMF species found in an area of the dry tropical forest, in the Colombian Caribbean. **A, B** *Funneliformis badius*, **C** *Diversispora epigaea*, **D** *Acaulospora scrobiculata*. Scale bars: 25 µm.