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A True global hotspot of biodiversity:
discovery of *Geastrum crystallinum* sp. nov.
and *Geastrum complanatum* sp. nov.
(Basidiomycota, Geastraceae) for Brazilian Cerrado

Kairo Dourado BARBOSA,
Renan DE LIMA OLIVEIRA,
Alexandro DE ANDRADE DE LIMA,
Paulo MARINHO,
Iuri GOULART BASEIA &
Rhudson Henrique SANTOS FERREIRA DA CRUZ

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Center of Excellence in Fungal Research, Mae Fah Luang University 333 M. 1 T.Tasud Muang District, Chiang Rai 57100 (Thailand)

Sylvie RAPIOR

Laboratoire de Botanique, Phytochimie et Mycologie / UMR -CNRS 5175 CEFE, Faculté de Pharmacie, 15, avenue Charles-Flahault, Université Montpellier I, BP 14491, 34093 Montpellier Cedex 5 (France)

Franck RICHARD

Université de Montpellier II, CEFE/CNRS Campus du CNRS, 1919, route de Mende, 34293 Montpellier Cedex 5 (France)

Naritsada THONGKLANG

Center of Excellence in Fungal Research, Mae Fah Luang University, 333 M. 1 T.Tasud Muang District, Chiang Rai 57100 (Thailand)

Xiang-Hua WANG

CAS Key Laboratory for Plant Diversity and Biogeography of East Asia, Kunming Institute of Botany, Chinese Academy of Sciences, Lanhei Road 132, Kunming 650201, P. R. (China)

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A True global hotspot of biodiversity: discovery of *Geastrum crystallinum* sp. nov. and *Geastrum complanatum* sp. nov. (Basidiomycota, Geastraceae) for Brazilian Cerrado

Kairo Dourado BARBOSA
Renan DE LIMA OLIVEIRA

Centro de Biociências, Departamento de Botânica e Zoologia,
Programa de Pós-graduação em Sistemática e Evolução,
Universidade Federal do Rio Grande do Norte, Campus Universitário, Natal,
59072-970 Rio Grande do Norte (Brazil)
kairodourado8@gmail.com (corresponding author)
brazil_renan77@yahoo.com.br

Alexandro DE ANDRADE DE LIMA

Centro de Biociências, Programa de Pós-graduação em Biologia de Fungos,
Universidade Federal de Pernambuco,
50670-901 Campus Universitário, Recife, Pernambuco (Brazil)
alexandro.andrade@hotmail.com

Paulo MARINHO
Iuri GOULART BASEIA

Centro de Biociências, Departamento de Botânica e Zoologia,
Universidade Federal do Rio Grande do Norte, Campus Universitário, Natal,
59072-970 Rio Grande do Norte (Brazil)
paulo.marinho@ufrn.br
iuribaseia@gmail.com

Rhudson Henrique SANTOS FERREIRA DA CRUZ

Centro das Ciências Biológicas e da Saúde,
Universidade Federal do Oeste da Bahia, Campus Reitor Edgard Santos, Barreiras,
47810-047 Bahia (Brazil)
rhudsoncruz@yahoo.com.br

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ABSTRACT

In the present study, two new species of *Geastrum* Pers., with distinctive characteristics, are recorded for the first time for science in areas of the Brazilian Cerrado biome: *Geastrum complanatum* sp. nov. and *Geastrum crystallinum* sp. nov. Morphological characters and the placement of the species in the

KEY WORDS

Earthstar fungi,
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gasteroid fungi,
neotropical,
new species.

MOTS CLÉS
Champignons Earthstar,
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néotropical,
espèces nouvelles.

phylogenetic analyses indicate that *Geastrum complanatum* sp. nov. belongs to the Sect. *Geastrum*, Subsect. *Sulcostomata*, and *G. crystallinum* sp. nov. is inside the Sect. *Corollina*, Subsect. *Marginata*. Detailed morphological and phylogenetic descriptions of the new taxa are provided, along with a map of the collection site, photographs of macroscopic structures in the field, and images of microscopic structures under light and scanning electron microscopes.

RÉSUMÉ

Un haut lieu mondial de biodiversité : découverte de Geastrum crystallinum sp. nov. et Geastrum complanatum sp. nov. (Basidiomycota, Geastraceae) dans les zones du Cerrado au Brésil.

Dans la présente étude, deux nouvelles espèces de *Geastrum* Pers., présentant des caractéristiques distinctives, sont enregistrées pour la première fois pour la science dans des zones du biome Cerrado brésilien : *Geastrum complanatum* sp. nov. et *Geastrum crystallinum* sp. nov. Les caractères morphologiques et la position des espèces dans les analyses phylogénétiques indiquent que *Geastrum complanatum* sp. nov. appartient à la Sect. *Geastrum*, Subsect. *Sulcostomata*, et que *G. crystallinum* sp. nov. se trouve dans la Sect. *Corollina*, Subsect. *Marginata*. Des descriptions morphologiques et phylogénétiques détaillées des nouveaux taxons sont fournies, ainsi qu'une carte du site de collecte, des photographies de structures macroscopiques sur le terrain et des images de structures microscopiques au microscope optique et au microscope électronique à balayage.

INTRODUCTION

The Cerrado is one of the 36 priority regions for conservation and is regarded as a global hotspot by International Conservation. The region concentrates high levels of biodiversity (Myers *et al.* 2000; Strassburg *et al.* 2017; Gomes *et al.* 2018) and is the second largest biome in South America and Brazil, after the Amazon. The Cerrado covers almost 22% of Brazil's land area, with about 2 million km². The biome has great social importance for populations that survive and depend on its natural resources. However, in recent years the region has faced persistent threats to species extinction due to excessive human occupation, disorderly land use, and anthropogenic fires, in addition to monoculture plantations and wood extraction (Brannstrom *et al.* 2008; Ribeiro & Walter 2008; Mazzeto-Silva 2009; MMA 2018).

Even with a high level of endemism and having a rich fauna and flora, the known diversity of macrofungi is quite low, with entire regions presenting no data or having few records, as is the case of the Intermediate Geographical Region of Barreiras, in the western region of the state of Bahia (IBGE 2017). Data on gasteroid fungi for this area are practically non-existent in the literature, despite the presence of protected areas in the Cerrado of the Bahia State, such as the Environmental Protection Area (EPA) Janeiro River Basin, considered as "extremely high priority" for conservation, and the EPA São Desidério, considered as "very high priority" for conservation (Brazil 2016). In the last year, the first descriptions of macrofungi were recorded for the western Bahia, featuring the new species *Tulostoma irregulireticulatum* Dourado-Barbosa, R.L. Oliveira, A.A. Lima, Baseia & R. Cruz (Barbosa *et al.* 2024a), and six new records for the genus *Geastrum* Pers. (*G. fimbriatum* Fr., *G. hirsutum* Baseia & Calonge, *G. lageniforme* Vittad., *G. morgani* Lloyd, *G. aff. rusticum* Baseia, B.D.B. Silva & T.S. Cabral

and *G. triplex* Jungh.) in different phytophysionomies of the biome (Barbosa *et al.* 2024b). The substantial amount of new data is an evidence that demonstrates the research gap in this area and in the Brazilian Cerrado.

Regarding *Geastrum*, it is the most representative genus of the family Geastraceae Corda, with about 100-130 known species (Zamora *et al.* 2014; Wijayawardene *et al.* 2022). The genus is characterized as a gasteroid fungus and has a stellate development when fully mature, also presenting an apical opening in the endoperidium, called peristome, from which the reproductive spores come out when mature (Miller & Miller 1988; Sunhede 1989; Soto & Wright 2000).

In Brazil, *Geastrum* species are highly diverse, with 73 species catalogued in recent years (Accioly *et al.* 2019; Assis *et al.* 2019; Crous *et al.* 2019, 2020; Sousa *et al.* 2019; Cabral *et al.* 2022). Recently, two new species have been described for the Brazilian Caatinga and Atlantic Forest biomes: *G. albofibrosum* R.L. Oliveira, Dourado-Barbosa, R. Cruz, M.P. Martín & Baseia; and *G. tupiense* J.O. Sousa, Freitas-Neto & Baseia, respectively (Crous *et al.* 2023; Freitas-Neto *et al.* 2023), bringing the total number of species in Brazil to 75.

Geastrum specimens are important in nature for nutrient cycling and ecological balance, serving as food and habitat for some arthropods, and acting as saprophytic organisms (Calonge 1988; Pegler *et al.* 1995; Kuhar *et al.* 2016). They also have great biochemical potential for the pharmaceutical industry and the production of antibiotics, in addition to their antioxidant, anti-inflammatory and cytotoxic properties, which can be used, for example, in the control of asthma and eye infections (Dore-Guerra *et al.* 2007; Mustafa *et al.* 2017).

The genus *Geastrum* can be found in humid environments such as tropical and temperate forests, or even in environments with variable climates, including arid regions such as the deserts of North America and semi-arid regions such as

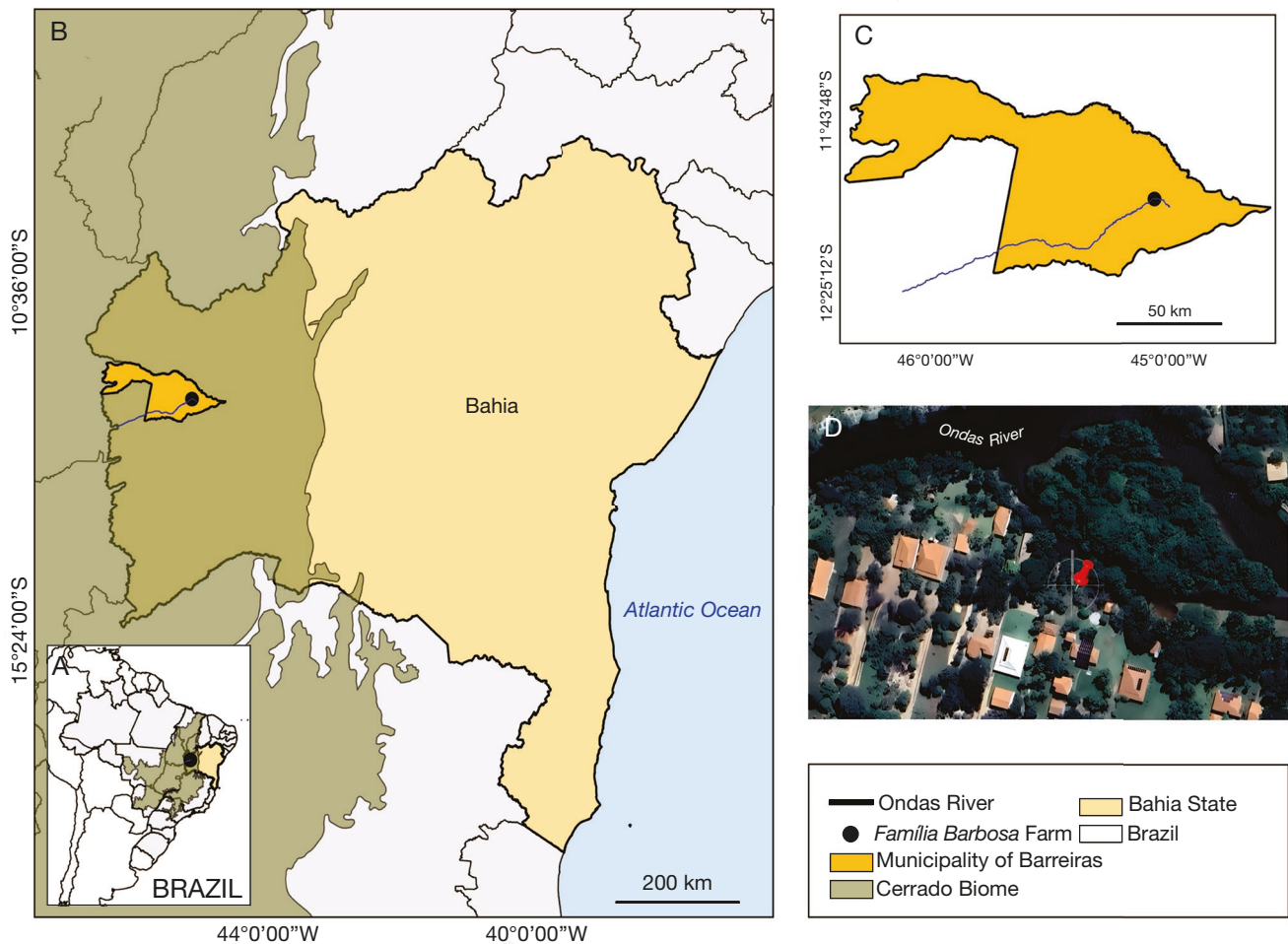


FIG. 1. — Collection location: **A**, Brazil; **B**, map of the state of Bahia and the municipality of Barreiras inserted in the Cerrado Biome; **C**, a zoom in the municipality of Barreiras, showing the Ondas river and the collection site, *Família Barbosa Farm*; **D**, collection area *Família Barbosa Farm*.

the Caatinga and Cerrado of Brazil (Sunhede 1989; Baseia *et al.* 2003; Bates 2004; Moreno *et al.* 2010; Silva *et al.* 2011; Barbosa *et al.* 2024b). They are considered cosmopolitan, since they are distributed in all continents of the planet, except Antarctica (Douanla-Meli *et al.* 2005; Kasuya *et al.* 2011).

In this context, the present study aims to increase the knowledge of gasteroid fungi for the Cerrado areas in the extreme west of the state of Bahia-Brazil, describing two new species of *Gastrum* based on morphological and phylogenetic data, in order to contribute to a better understanding of the conservation and importance of these organisms in the Brazilian Cerrado and in the world.

MATERIAL AND METHODS

COLLECTION LOCATION

The specimens were collected at the *Família Barbosa Farm*, near the Ondas River, in the municipality of Barreiras, Bahia, Brazil (Fig. 1), in sandy soil during the rainy season of the region, which varies from November to March, between the geographic coordinates 12°7'11.25"S, 45°4'26.43"W (latitude

and longitude). The Ondas River Basin has altitudes ranging from 439.45 m to 714.06 m and a drainage area of almost 5.560 km², located in western Bahia, in a Cerrado region (Castro *et al.* 2015). The vegetation phytophysiology is characterized as a Cerrado *stricto sensu* that presents typical herbaceous-subshrub vegetation with often inclined, distorted or branched formations, and woody plants with the presence of a thick cork, and rigid and leathery leaves, typical of xeromorphic species (Eiten 1994; Ribeiro & Walter 2008).

SPECIES COLLECTION, HERBORIZATION AND ANALYSIS INFORMATION

In total, nine basidiomata were collected: two of the new species *Gastrum complanatum* Dourado-Barbosa, R. L. Oliveira, A. A. Lima, P. Marinho, Baseia & R. Cruz, sp. nov., and seven of the new species *Gastrum crystallinum* Dourado-Barbosa, R. L. Oliveira, A. A. Lima, P. Marinho, Baseia & R. Cruz, sp. nov. The fieldwork followed the modified protocol by Lodge *et al.* (2004) and Baseia *et al.* (2014), where pre-existing trails or trails opened during the expedition were randomly observed for substrates suitable for the growth of the genus *Gastrum*, such as old trunks,

TABLE 1. — Taxa included in molecular analyses, with geographical data of the species, herbarium voucher and GenBank accession number for each of the DNA region markers used (ITS and LSU). The new sequences generated in this study are shown in bold.

Taxon	Country and state/province	Herbarium voucher	ITS	LSU	References
<i>Geastrum complanatum</i> sp. nov.	Brazil, Bahia	BRBA–Fungos 0027	OR479886	OR479888	This study
<i>Geastrum crystallinum</i> sp. nov.	Brazil, Bahia	BRBA–Fungos 0137	OR479887	OR479889	This study
<i>Geastrum biplicatum</i> Berk. & M.A. Curtis	Japan, Mie	TNS Sakamoto 182	JN845113	JN845231	Zamora <i>et al.</i> 2015
<i>Geastrum caatingense</i> J.O. Sousa, M.P. Martín & Baseia	Brazil, Paraíba	UFRN Fungos 2843	NR166237	NG068261	Sousa <i>et al.</i> 2019
<i>Geastrum campestre</i> Morgan	Spain, Madrid	MICH 28566	KF988358	KF988480	Zamora <i>et al.</i> 2015
<i>Geastrum corollinum</i> (Batsch) Hollós	Spain, Madrid	MA-Fungi 5746	KF988359	KF988481	Zamora <i>et al.</i> 2015
<i>Geastrum elegans</i> Vittad.	Spain, Madrid	Herb. Zamora 189	KF988366	KF988488	Zamora <i>et al.</i> 2014
<i>Geastrum flexuosum</i> (L.S.Dominguez & Castellano) Jeppson & E.Larss.	Sweden	UPS F–119844	KF988371	KF988493	Zamora <i>et al.</i> 2015
<i>Geastrum floriforme</i> Vittad.	Spain, Madrid	MA-Fungi 69173	KF988372	KF988494	Zamora <i>et al.</i> 2014
<i>Geastrum glaucescens</i> Speg.	Argentina, La Rioja	MA-Fungi 83762	KF988378	KF988500	Zamora <i>et al.</i> 2015
<i>Geastrum lageniforme</i> Vittad.	Spain	Herb. Zamora 207	KF988388	KF988513	Sousa <i>et al.</i> 2015
<i>Geastrum meridionale</i> J.C.Zamora	Spain, Valladolid	AVM 2708	KP687508	KP687469	Zamora <i>et al.</i> 2015
<i>Geastrum morganii</i> Lloyd	Canada	Herb. Lebeuf HRL0177	KF988406	KF988534	Zamora <i>et al.</i> 2015
<i>Geastrum papinutii</i> J.C.Zamora	Argentina, Santiago del Estero	MA-Fungi 83764	KF988380	KF988502	Zamora <i>et al.</i> 2015
<i>Geastrum parvistriatum</i> J.C.Zamora & Calonge	Spain, Madrid	MA-Fungi 69583	JN943160	JN939560	Zamora <i>et al.</i> 2015
<i>Geastrum pectinatum</i> Pers.	Spain, Lugo	MA-Fungi 28156	KP687516	KP687478	Zamora <i>et al.</i> 2015
<i>Geastrum pleosporum</i> Douanla-Meli	Spain, Madrid	MA-Fungi 56971	KF988416	KF988544	Zamora <i>et al.</i> 2015
<i>Geastrum plicatum</i> Berk.	Argentina, Buenos Aires	MA-Fungi 83774	KF988415	KF988543	Zamora <i>et al.</i> 2015
<i>Geastrum saccatum</i> Fr.	Spain, Madrid	MA-Fungi 83778	KF988433	KF988563	Zamora <i>et al.</i> 2015
<i>Geastrum schmidelii</i> Vittadini	Spain, Madrid	Herb. Zamora 199	KJ588618	KJ588624	Zamora <i>et al.</i> 2014
<i>Geastrum schweinitzii</i> (Berkeley & M.A. Curtis) Zeller	Spain, Madrid	MA-Fungi 83780	KF988439	KF988569	Zamora <i>et al.</i> 2014
<i>Geastrum smardae</i> V.J. Stanek	Spain, Madrid	Herb. Zamora 527	KF988441	KF988574	Zamora <i>et al.</i> 2015
<i>Geastrum striatum</i> de Candolle	Sweden, Uppland	MA-Fungi 86672	KF988443	KF988577	Zamora <i>et al.</i> 2015
<i>Geastrum tenuipes</i> Berk.	Australia, Australian Capital Territory	CANB 738350	KP687526	KP687488	Zamora <i>et al.</i> 2015
<i>Geastrum triplex</i> Jungh.	Spain, Madrid	MA-Fungi 83784	KF988445	KF988579	Zamora <i>et al.</i> 2015
<i>Geastrum velutinum</i> Morgan	Argentina	MA-Fungi 83785	KF988446	KF988581	Zamora <i>et al.</i> 2015
<i>Geastrum violaceum</i> Rick	Argentina	BAFC 51671	KF988450	KF988585	Zamora <i>et al.</i> 2015
<i>Myriostoma calongei</i> Baseia, J.O. Sousa & M.P. Martín	Brazil, Rio Grande do Norte	UFRN-Fungos 2019	NR155399	NG060345	Zamora <i>et al.</i> 2015

leaf litter, herbivore manure, and soil. Before removing the basidiomata, the specimens are photographed and removed with the aid of a pocketknife. The basidiomata were packed in compartmentalized plastic cases and the samples were tagged with collection information such as date, collector, geographic position, and locality. The color of the basidiomata followed the color chart and names by Kornerup & Wanscher (1978). The samples were dehydrated at 40°C for a period of 24 hours.

Macroscopic and microscopic structures of *Geastrum* were described using specific literature for the genus (Miller & Miller 1988; Sunhede 1989; Zamora *et al.* 2014; Sousa 2015). The macroscopy was performed using a Leica EZ4 stereomicroscope and a Nikon SMZ1500 with a camera lucida, and a Nikon DS-Ri1 camera for image capture. The light microscopy (LM) analyses were performed using a Nikon Eclipse Ni with a Nikon DS-Ri1 camera attached, using the NIS-Elements Ar v.4.51.00 software to obtain the measurements. The microscope slides for the analysis and measurements of

the exoperidium layers, and for the measurements of the gleba structures were mounted in 5% KOH.

The measurements of the random selected spores and microscopic structures were realized with a n = 30, following the procedures described by Sousa (2015) and Bates (2004); \bar{x} = mean ± standard deviation of the basidiospore, for diameter and height (including ornamentation); and Q_m = mean height/width quotient. The collected specimens were divided into two collections, one deposited as Holotype in the BRBA-Fungos (BRBA Herbarium) of the Federal University of Western Bahia (UFOB), city of Barreiras, State of Bahia; and as Isotype in the UFRN-Fungos Fungarium of the Federal University of Rio Grande do Norte (UFRN), city of Natal, State of Rio Grande do Norte; both located in Brazil.

The Scanning Electron Microscopy (SEM) analysis to visualize the ornamentation of the spores, the shape of the crystals, and the capillitium surface was performed on a Tescan Vega3 Scanning Electron Microscope, following the procedures described by Silva *et al.* (2011).

MOLECULAR AND PHYLOGENETIC ANALYSIS

DNA extractions, amplifications and purifications were performed at the Laboratory of Plant Molecular Genetics and Biointeractions of the Department of Cell Biology and Genetics at UFRN. The extraction step followed the protocol of the DNeasy Plant Mini Kit® (Qiagen), with adaptations to the “lysis buffer incubation” step, performed overnight at 55°C to obtain a better extraction result (Martín & Winka 2000). For amplification, sequences were obtained from two distinct regions: the Internal Transcribed Spacer of the ribosomal DNA (ITS rDNA, including the ITS1, 5.8s and ITS2 regions), using the primers ITS1-F/ITS4 (White *et al.* 1990), and the Large Subunit of the ribosomal DNA (LSU rDNA), using the primers LR0R/LR5 (Vilgalys & Hester 1990). PCR amplifications was performed according to the protocol of the 5x FIREPol® Master Mix (Solis BioDyne Data Sheet), with basic reactions with 0.2-0.6 µl of each primer at 10 µM concentration, 4 µl of the 5x FIREpol Master Mix, 1-10 µl of DNA, and sterile ultrapure water, making a final volume of 20 µl, and using the indicated program for each specific primer in the thermocycler.

PCR products were observed on an 1% agarose gel using the loading conditions: 5 µl of the amplification product, 2 µl of running buffer, 2 µl of GelRed™ (Biotium) and 3 µl of the 100-bp ladder. The electrophoresis run for 40 minutes at 100V and 300mA as settings, and gels were visualized under ultraviolet light followed by photographic documentation. Single bands purification was performed using ExoSAP-IT™ PCR Product Cleanup Reagent, according to the manufacturer's protocol, and sent to be sequenced at Macrogen®, South Korea.

The sequences were submitted to a similarity search in the Nucleotide BLAST® database (Basic Local Alignment Search Tool)-<https://blast.ncbi.nlm.nih.gov/>. For the analysis of the phylogenetic relationships, the ITS and LSU rDNA sequences obtained in this study were aligned with *Geastrum* sequences available in the works of Zamora *et al.* (2015), and Sousa *et al.* (2019), as well as other *Geastrum* sequences obtained in the GenBank database (www.ncbi.nlm.nih.gov/genbank/). All samples used in the dataset are presented in Table 1, showing the name of the taxon, country of origin, herbarium voucher, and GenBank code for each molecular marker (Table 1).

The sequences were initially aligned using the ClustalW algorithm, and then manually aligned in MEGA v 11.0.1 (Tamura *et al.* 2021). The phylogenetic analyses were performed at the CIPRES Science Gateway V.3.3 (www.phylo.org). Maximum Parsimony (MP), Maximum Likelihood (ML) and Bayesian analyses were performed using the tools PAUP 4.0a169 (Swofford 2003), RAxML-HPC v.8 (Stamatakis 2014) and MrBayes v.3.2.2 (Ronquist *et al.* 2012), respectively. The best nucleotide substitution model for each partition (ITS 1, 5.8s, ITS 2 and LSU) was selected through the jModelTest2 (Darriba *et al.* 2012) using the AIC (Akaike Information Criterion) and AICc (Corrected Akaike Information Criterion). MP analysis of the concatenated dataset was performed with 10 000 bootstrap replicates in a full heuristic search. The stepwise addition was set to random with 10 replicates, and the TBR swapping algorithm

was used. The tree scores were measured, and a consensus tree was computed using the majority rule (50%). The ML analysis of the concatenated dataset was performed with a partitioned analysis (ITS1, 5.8s, ITS2 and LSU), using the nucleic acid option GTRCAT for the partitions, with bootstraps set to 1000. For the Bayesian analyses, the MCMC run was performed in 20 million generations, with the tree sampled at every 1000 generations, using the models TPM2uf+G for the ITS1, K80 for the 5.8s, TPM2uf+G for the ITS2, and TrN+I+G for LSU. Values above 0.01 in the Average Standard Deviation of Split Frequencies (AvgStdDev) were used to discard a portion of the trees during the burn-in phase. The resulting trees were examined in FigTree v.1.4.2 (<http://tree.bio.ed.ac.uk/software/figtree>), exported as PDF, and edited in Corel Draw® Graphics Suite 2021 software.

RESULTS

The combined ITS-LSU tree is composed of samples from eight main sections of *Geastrum*, as shown in Fig. 2: Sect. *Trichaster*, Sect. *Elegantia*, Sect. *Campestris*, Sect. *Schimidelia*, Sect. *Papillata*, Sect. *Myceliostroma* (with the Subsects. *Velutina* and *Epigeae*), Sect. *Corollina* (with the Subsects. *Marginata*, *Plicostomata* and *Lageniformia*), and Sect. *Geastrum* (with the Subsect. *Sulcostomata*). *G. complanatum* sp. nov. is included in the Sect. *Geastrum*-Subsect. *Sulcostomata*, and *G. crystallinum* sp. nov. is placed in the Sect. *Corollina*-Subsect. *Marginata*. Details and discussion of the position of the species within the section, sister groups, and morphological similarities and differences of each new species are presented in the comments part of the description.

Family GEASTRACEAE Corda
 Gender *Geastrum* Pers.

Geastrum complanatum Dourado-Barbosa, R. L. Oliveira,
 A. A. Lima, P. Marinho, Baseia & R. Cruz, sp. nov.
 (Fig. 3)

DIAGNOSIS. — *Geastrum complanatum* sp. nov. is characterized by presenting fornicate basidiomata, discrete apophysis, flattened pedicel, and a “farinaceous” crystalline matter on the endoperidial surface, with pupa-shaped (pupiform) crystals under SEM.

ETYMOLOGY. — Based on the flattened shape of the pedicel.

MATERIAL EXAMINED. — **Brazil** • Bahia, Barreiras, *Familia Barbosa* Farm, Cerrado *stricto sensu*; found on termite mound in a gregarious growth; 12°7'11.25"S, 45°4'26.43"W; 13.IV. 2020; K.D. Barbosa, KD0038; Holotype: BRBA-Fungos 0027; Isotype: UFRN-Fungos 3677.

HABIT. — Gregarious, growing on termite mound

MYCOBANK. — MB#849825.

GENBANK ACCESSION NUMBER. — OR479886 (ITS), OR479888 (LSU).

TABLE 2. — Morphological comparison of *Geastrum* Pers. complanatum and closely related species based on descriptions by Zamora *et al.* (2015). In **bold**, characteristics of the new species.

<i>Geastrum biplicatum</i> Berk. & M.A. Curtis	<i>Geastrum glaucescens</i> Speg.	<i>Geastrum meridionale</i> J.C.Zamora	<i>Geastrum papinuttii</i> J.C.Zamora	<i>Geastrum parvistriatum</i> J.C.Zamora & Calonge	<i>Geastrum plicatum</i> Berk.	<i>Geastrum pectinatum</i> Pers.	<i>Geastrum striatum</i> de Candolle	<i>Geastrum tenuipes</i> Berk.	<i>Geastrum complanatum</i> sp. nov.
Exoperidium									
34 mm diam., with 7 non-hygroscopic rays	18-45 mm diam., with 6-8 non-hygroscopic rays	45-125 mm diam., with 5-12 non-hygroscopic rays	12-24 mm diam., with 6-11 non-hygroscopic rays	(13-)19-47 diam., with 5-12 non-hygroscopic rays	38-62 mm diam., with 6-9 non-hygroscopic rays	20-135 mm diam., with (4-) 6-10 (-11) non-hygroscopic rays	21-85 mm diam., with (4-) 6-10 (-12) non-hygroscopic rays	25-82 mm diam., with 6-11 raiois non-hygroscopic rays	17-28 mm diam., with 7-11 non-hygroscopic rays
Endoperidium									
11 mm diam., dark brown, crystalline matter surface of COD bipyramidal crystals with 15.0 µm diam.	5-16 mm diam., dark brown to black, crystalline matter surface of COD bipyramidal crystals with 6.0-15.0 µm diam.	12-33 mm diam., cream to brownish grey, rarely dark brown, crystalline matter surface of COD bipyramidal crystals with 6.0-13.0 µm diam.	3.5-6.5 mm diam., mainly dark brown to black, crystalline matter surface of COD bipyramidal crystals with 6.0-12.0 µm diam.	5-16 mm diam., mainly dark brown to blackish, crystalline matter surface of COD bipyramidal crystals with 5.5-12.5 µm diam.	10-18 mm diam., light to dark brown, crystalline matter surface of COD bipyramidal crystals with 7.0-20.0 (-32.0) µm diam.	(4,5-) 10-25 (-36) mm diam., dark brown, crystalline matter surface of COD bipyramidal crystals with 5.0-15.0 µm diam.	5.5-26 mm diam., brown to black, crystalline matter surface of COD bipyramidal crystals with 5.0-15.0 µm diam.	8-17 mm diam., grayish to dark brownish gray, crystalline matter surface of COD bipyramidal crystals with (20-) 25-55 µm diam.	5-13 mm diam., grayish brown, crystalline matter surface of COD pupal-like crystals with (4.1-) 5.5-18.0 µm diam.
Peristome									
Sulcate, slightly delimited, with 19 folds	Sulcate, distinctly or not distinctly delimited, with 11-25 folds	Sulcate, distinctly or not distinctly delimited, with (17-) 22-52 (-60) folds.	Sulcate, distinctly or not distinctly delimited, with 12-20 folds	Sulcate, distinctly or not distinctly delimited, with 7-23 folds	Sulcate, distinctly or not distinctly delimited, with 16-30 folds	Sulcate, distinctly or not distinctly delimited, with 11-35 folds	Sulcate, sometimes well delimited, with 19-36 folds	Sulcate, mainly well delimited, with 14-27 folds	Slightly sulcate, sometimes well delimited, with 16-21 folds
Pedicel									
Brownish, 2.0 mm in height	Brown to dark brown, 0.5-2.5 mm in height	Cream to dark brownish gray, (2.5-) 3.0-9.0 (-9.5) mm in height	Brown to grayish brown, 0.5-1.3 mm in height	Brown to dark brown, rarely pale in color, 0.5-2.5 (-3.0) mm in height	Light or dark coloured, often very slender, 3.5-6.0 mm in height	Mostly light coloured, slender to more or less stout, (1.5-) 3.5-13 (-15 mm in height	White to brownish, (1.0-) 2.0-9.0 mm in height	Light or dark coloured, very slender, 3.0-7.0 mm in height	Yellowish white, 2.0-3.0 mm in height
Apophysis									
Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Well developed, solid, in ring shape with acute border	Not observed	Discrete, sulcate, color lighter than the endoperidium
Capillitium									
Hyphae thick up to 10.5 µm diam.	Hyphae thick, 6.0-9.0 µm diam.	Hyphae thick, (5.5-) 6.0-9.0 (-9.5) µm diam.	Hyphae thick, 4.5-6.0 µm diam.	Hyphae thick, (5.0-) 5.5-8.0 (-8.5) µm diam.	Hyphae thick, 6.0-8.0 µm diam.	Hyphae thick, (8.0-)9.0-13.0 (-15.0) µm diam.	Not observed	Hyphae thick, 6.0-9.0 µm diam.	Hyphae thick, 3.0-6.0 µm diam.

TABLE 2. — Continuation.

<i>Geastrum biplicatum</i> Berk. & M.A. Curtis	<i>Geastrum glaucescens</i> Speg.	<i>Geastrum meridionale</i> J.C.Zamora	<i>Geastrum papinuttii</i> J.C.Zamora	<i>Geastrum parvistriatum</i> J.C.Zamora & Calonge	<i>Geastrum plicatum</i> Berk.	<i>Geastrum pectinatum</i> Pers.	<i>Geastrum striatum</i> de Candolle	<i>Geastrum tenuipes</i> Berk.	<i>Geastrum complanatum</i> sp. nov.
Basidiospores									
Globose, ornamentation baculate-pilate, (4.5–) 5.0–6.0 µm diam.	Globose, ornamentation verrucose to irregularly pilate 5.0–7.0 (–7.5) µm diam.	Globose, ornamentation baculate-pilate (5.5–) 6.0–7.5 (–8.5) µm diam.	Globose, ornamentation verrucose to irregularly pilate 4.0–5.5 µm diam.	Globose, ornamentation verrucose to irregularly pilate (4.5–) 5.0–7.0 (–7.5) µm diam.	Globose, ornamentation baculate-pilate, (4,5–) 5.0–6.5 µm diam.	Globose, ornamentation baculate-pilate, 5.5–7.5 (–8.0) µm diam.	Globose, ornamentation verrucose to irregularly pilate 5.0–6.0 µm diam.	Globose, ornamentation baculate-pilate, 5.5–7.5 (–8.5) µm diam.	Globose, ornamentation baculate-pilate, 4.8–8.5 µm diam.

DESCRIPTION

Unexpanded basidiomata absent. Expanded basidiomata fornicate, 14–30 mm high (including peristome), 17–28 mm wide. Exoperidium opening into 7–11 triangular rays, revolute, non-hygroscopic, fornicate. Mycelial layer cottonous, heavily encrusted, greyish white (1B1). Fibrous layer, papyraceous to coriaceous, persistent, pale yellow to greyish yellow (4A3, 4B3). Pseudoparenchymatous layer persistent, slightly rimose, collar absent, light brown (6D4). Endoperidium globose, 5–13 mm high (including peristome) × 10–13 wide mm, with “farinaceous” crystalline matter, and pupa-shaped (pupiform) crystals under SEM (4.1–18.0 µm diam.), greyish brown (6D3). Apophysis discrete, grooved, lighter than the endoperidium. Stalk/pedicle 2.0–3.0 mm high × 3.0–6.0 mm wide, yellowish white (1A2), flattened. Peristome delicately/roughly sulcate, slightly darker than the endoperidium, 16–21 folds, 0.3–0.4 mm high. Gleba dark brown (6F4). Mycelial layer composed of hyphae, 1–2.5 µm in diameter, thick walled (0.4–1 µm), encrusted, slightly sinuous, unbranched, lumen evident, hyaline. Fibrous layer composed of coiled hyaline hyphae, 4.1–8.9 µm in diameter, thick-walled (1.9–4.1 µm), slightly encrusted, unbranched, lumen evident, slightly sinuous. Pseudoparenchymatous layers composed of globose to subglobose cells, hyaline, 19.3–54 × 11.9–39.3 µm in diam., thin-walled (< 1 µm). Eucapillitium hyaline 3–6 µm in diameter, thin-walled (> 1 µm), non-encrusted, slightly sinuous, lumen evident, unbranched. Rhizomorphs absent. Basidiospores globose to slightly elliptical, yellowish to brownish ($Q = 1.00\text{--}1.25$), 5.3–8.5 × 4.8–7.8 µm [$x = 6.9 \pm 0.6 \times 6.4 \pm 0.6$, $Q_m = 1.10$, $n = 30$], conspicuous ornamentation (0.2–0.9 µm in height) under LM, verrucose to irregularly pilate under SEM.

COMMENTS

Geastrum complanatum sp. nov. is a unique species growing unusually on the top of termite mounds in areas of the Brazilian Cerrado biome. The species is characterized by the presence of a flattened pedicle and “farinaceous” crystalline matter on the surface of the endoperidium, with the presence

of pupa-shaped (pupiform) oxalate crystals under SEM, an exclusive crystal shape described for the first time for the genus *Geastrum*.

Phylogenetically, *Geastrum complanatum* sp. nov. fits with the representatives of Sect. *Geastrum*, Subsect. *Sulcostomata*, characterized by having species with grooved peristome, well-developed mesoperidium and powdery/pruinose layer formed by small crystals with generative hyphae on the surface of the endoperidial and pseudoparenchymatous layers (Zamora *et al.* 2014; Zamora *et al.* 2015). In our phylogeny, *G. complanatum* sp. nov. groups in this Section and Subsection, together with *G. meridionale* J.C. Zamora (100 bs MP/ 52 bs ML/ 60 Bayesian pp), forming a sister-group with the species *G. biplicatum* Berk. & M.A. Curtis and *G. tenuipes* Berk. (100 bs MP/ <50 bs ML/ 59 Bayesian pp).

Geastrum complanatum sp. nov. morphologically resembles the specimens of *G. pectinatum* Pers., *G. meridionale*, *G. plicatum* Berk., *G. glaucescens* Speg., *G. parvistriatum* J.C. Zamora & Calonge, *G. papinuttii* J.C. Zamora, *G. striatum* DC and *G. tenuipes* (Table 2), because all these species present a grooved peristome and the presence of crystalline matter on the endoperidial surface (Zamora *et al.* 2015). However, the peristome of *G. complanatum* sp. nov. presents very discreet grooves and little development compared to the other species with grooved peristomes.

Geastrum pectinatum differs from *G. complanatum* sp. nov. by the presence of more robust basidiomata measuring 20–135 mm in diameter, while *G. complanatum* sp. nov. has delicate basidiomata measuring 17–28 mm in diameter (Zamora *et al.* 2015). In addition, the endoperidium of *G. pectinatum* is formed by crystalline matter with calcium oxalate dihydrate (COD) bipyramidal crystals in the mesoperidium, with sizes ranging from 5–15 µm in diameter (Zamora *et al.* 2015), while *G. complanatum* sp. nov. has crystals that resemble a pupa, with sizes ranging from 4.1–18 µm in diameter. *Geastrum meridionale* J.C. Zamora is also similar to *G. complanatum* sp. nov., however the endoperidium of *G. meridionale* is much larger than that of *G. complanatum*

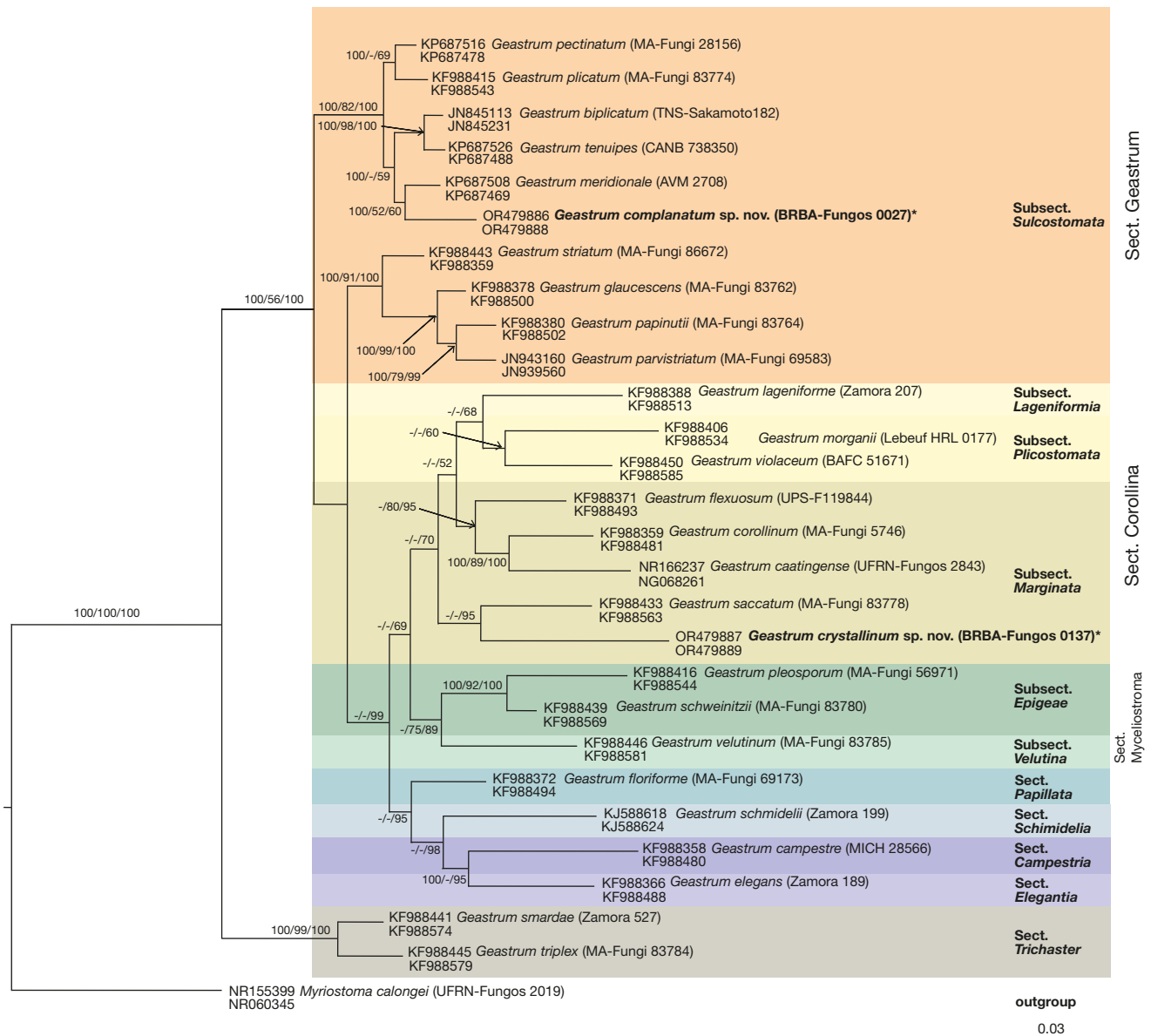


FIG. 2. — *Geastrum* ITS and LSU nrDNA sequences obtained from a Maximum Parsimony, Maximum Likelihood and Bayesian analysis, through the CIPRES Science Gateway. Maximum Parsimony and Maximum Likelihood bootstrap support ($\geq 50\%$) is indicated in the branches, followed by the Bayesian posterior probability. Sections and Subsections according to Zamora et al. (2015). Sequences obtained from *Geastrum complanatum* sp. nov. Holotype (BRBA-Fungos 0027) and *Geastrum crystallinum* sp. nov. Holotype (BRBA-Fungos 0137) in bold.

sp. nov. specimens, with 12-33 mm in diameter and 5-13 mm in diameter, respectively. Furthermore, the exoperidium of *G. meridionale* is four times larger (45-125 mm in diameter) than that of *G. complanatum* sp. nov., with 17-28 mm in diameter (Zamora et al. 2015).

Geastrum biplicatum resembles *G. complanatum* sp. nov. by the exoperidium with non-hygroscopic rays, brownish endoperidium with crystalline matter and a slightly delimited and sulcate peristome (Zamora et al. 2015). However, *G. biplicatum* has crystals with bipyramidal shape measuring 6-15 μm in diameter, while *G. complanatum* sp. nov. has pupa-shaped crystals with (4.1-) 5.5-18.0 μm in diameter. Furthermore, *G. biplicatum* has a peristome with fewer folds (up to 19 folds), while the new species presented up to 21 folds. Two other species

that are part of Subsect. *Sulcostomata* and resembles morphologically *Geastrum complanatum* sp. nov. are *G. plicatum* and *G. glaucescens*. However, the exoperidium of *G. plicatum* sp. nov. is a little more than twice the size of *G. complanatum* sp. nov., 38-62 mm in diameter, while *G. glaucescens* has pedicels that are commonly brownish, a characteristic not observed in *G. complanatum* sp. nov. which, in addition to presenting a yellowish white pedicel, has a flat conformation with up to 0.6 mm in diameter (Zamora et al. 2015).

Geastrum parvistriatum and *Geastrum papinutii* also resemble *G. complanatum* sp. nov. by the presence of farinaceous crystalline matter on the endoperidial surface and pedicellate endoperidium (Zamora et al. 2015). However, both species have pyramidal COD crystals and do not have

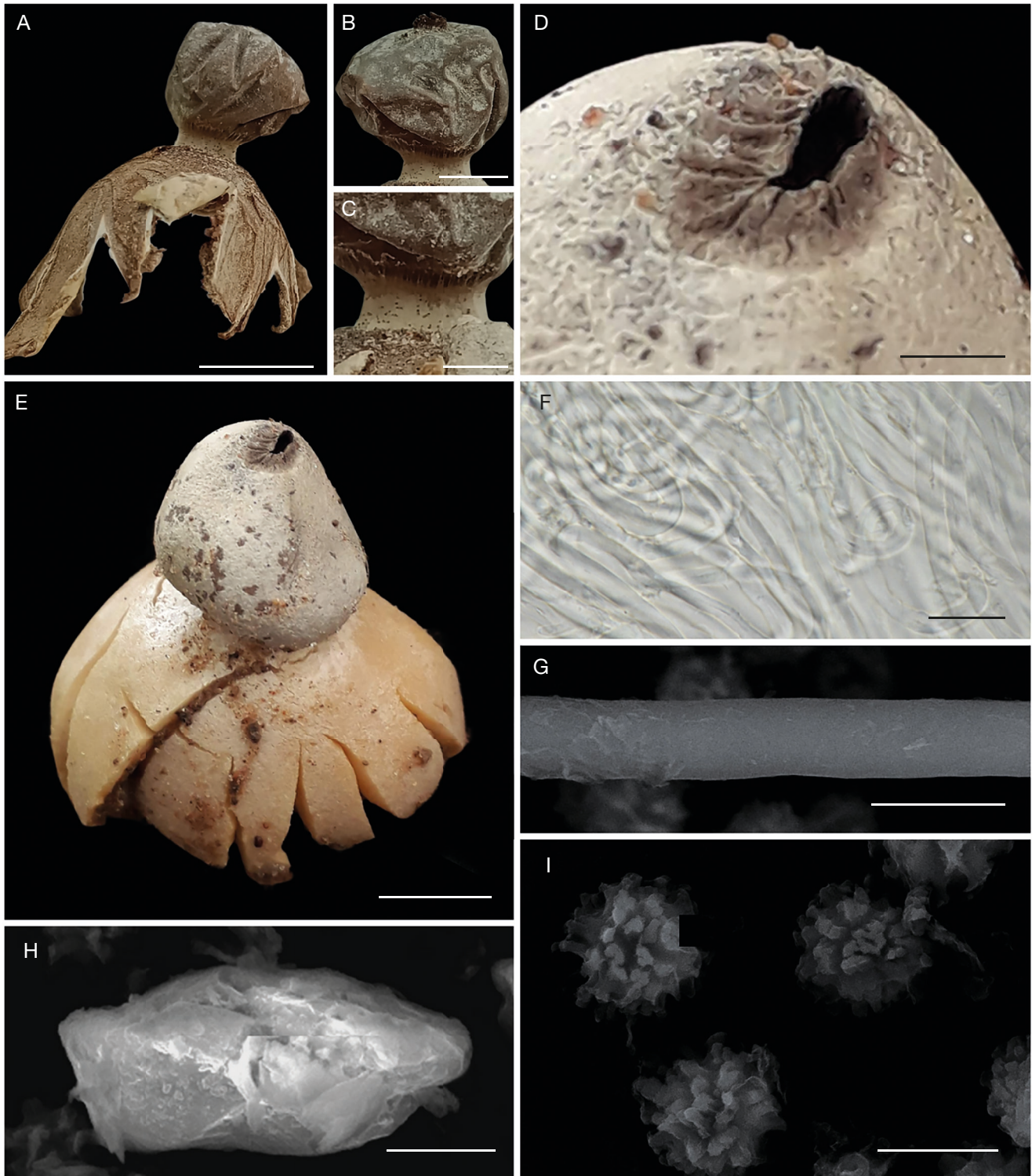


FIG. 3. — *Geastrum complanatum* sp. nov. (BRBA-Fungos 0027): **A, E**, mature basidiome; **B**, endoperidium with presence of crystalline matter; **C**, details of the flattened pedicel; **D**, details of the discreetly grooved peristome; **F**, hyaline fibrous layer under light microscope; **G**, capillitium under SEM; **H**, crystals under SEM; **I**, basidiospores with verrucose to irregularly pilate ornamentation under SEM. Scale bars: A, 10 mm; B, 6 mm; C, 3 mm; D, 1,5 mm; E, 6 mm; F, 20 μ m; G, 5 μ m; H, 10 μ m; I, 5 μ m.

the pupal-shape observed in *G. complanatum* sp. nov. under SEM (Zamora *et al.* 2015). The specimens of *G. striatum* and *G. tenuipes* also have morphological characters remarkably similar to *G. complanatum* sp. nov., such as the presence of

a clear pedicel, farinaceous crystalline matter and globose basidiospores, however the exoperidium of the first two species is about three times larger, with diameters of 21-85 and 25-82 mm, respectively (Zamora *et al.* 2015).

TABLE 3. — Morphological comparison of *Geastrum crystallinum* sp. nov. and close related species based on descriptions by Baseia *et al.* (2003); Trierveiler-Pereira *et al.* (2011); Kuhar *et al.* (2012); Sousa *et al.* (2014, 2019) and Assis *et al.* (2019). In **bold**, characteristics of the new species.

<i>Geastrum triplex</i> Jungh.	<i>Geastrum smardae</i> V.J. Stanek	<i>Geastrum saccatum</i> Fr.	<i>Geastrum corollinum</i> (Batsch) Hollós	<i>Geastrum caatingense</i> J.O. Sousa, M.P. Martín & Baseia	<i>Geastrum hyalinum</i> Freitas-Neto, N.M. Assis, J.O. Sousa & Baseia	<i>Geastrum lageniforme</i> Vittad.	<i>Geastrum floriforme</i> Vittad.	<i>Geastrum crystallinum</i> sp. nov.
Exoperidi								
47-64 mm diam., 5-8 saccate, forming a prominent collar around the endoperidium, rays involute, non-hygroscopic	25-30 mm diam., 6-8 saccate, forming a collar around the endoperidium, rays revolute, splitting, to about the middle non-hygroscopic	8-50 mm diam., 6-8 saccate, some rays are split at the apex, involute or not, non-hygroscopic	6-19 mm diam., saccate to slightly arched, 8-11 strongly hygroscopic rays that cover the endoperidial body	7-29 mm diam., 6-10 rays revolute when fresh, involute, rolling up above the endoperidial body or planar when dry, hygroscopic	28-34 mm diam., 5-7 triangular rays, revolute, non-hygroscopic	7-45 mm diam., 6-8 saccate, long rays, slender and with longitudinal ridges on the external layer, non-hygroscopic	9-mm diam., 6-8 saccate, revolute rolling up under basidioma, non-hygroscopic	5-17 mm diam., 7-9 triangular rays, revolute, non-hygroscopic
Endoperidium								
18-25 mm, sessile, globose, yellowish brown to dark brown when fresh	Sessile, dark blond	5-16 mm, without crystalline matter, depressed-globose, sessile, greyish green	Sessile, globose, greyish beige	6-16 mm, sessile, with glabrous surface with presence of crystalline matter, orangish gray, brownish gray to yellowish white	6-17 mm, sessile, with protruding hyphae, orange white to pale orange	8-13 mm, sessile, without crystalline matter, pale orange when fresh, to blond	5-17 mm, sessile, without crystalline matter, subglobose to pyriform, violet brown to greyish brown	3.5-6 mm, sessile, with small protruding hyphae, whitish to orange
Peristome								
Fibrillose, delimited distinctly	Fibrillose	Fibrillose, distinctly delimited, slightly darker than endoperidium	Fibrillose, distinctly delimited	Fibrillose, strongly conical, distinctly delimited	Fibrillose, flat, distinctly delimited	Fibrillose, concolor with endoperidium, distinctly delimited	Irregularly pliate, becoming fibrillose to lacerate with age, not delimited, conic	Fibrillose, flat to mammiform, not delimited distinctly
Gleba								
Not observed	Not observed	Not observed	Brown	Grayish brown	Yellowish white	Not observed	Brownish grey	Whitish
Capillitium								
Yellowish to brownish hyphae straight, solid or with narrow lumen, 2.0-6.0 µm diam., covered or not with amorphous material	Light brown, unbranched or shortly branched, 3.0-4.0 µm diam.	Yellowish to slightly brownish hyphae straight, with wide or narrow lumen, covered with amorphous material, 2.0-6.0 µm diam.	Hyphae thick walled	Yellowish, thin-walled, 3.8-6.7 µm diam., surface encrusted	Hyaline, thin-walled, 2.7-4.7 µm diam., surface encrusted	Yellowish, thin-walled, 2.5-7.0 µm diam. hyphae straight to more or less sinuous, with narrow lumen, covered with amorphous material	Brownish, walls straight, thick 4.6-7.1 µm diam., surface light encrusted, glabrous, lumen evident, not branched	Hyaline, thin-walled, 1.3-4.3 µm diam., surface encrusted

TABLE . — Continuation

<i>Geastrum triplex</i> Jungh.	<i>Geastrum smardae</i> V.J. Stanek	<i>Geastrum saccatum</i> Fr.	<i>Geastrum corollinum</i> (Batsch) Hollós	<i>Geastrum caatingense</i> J.O. Sousa, M.P. Martín & Baseia	<i>Geastrum hyalinum</i> Freitas- Neto, N.M. Assis, J.O. Sousa & Baseia	<i>Geastrum lageniforme</i> Vittad.	<i>Geastrum floriforme</i> Vittad.	<i>Geastrum crystallinum</i> sp. nov.
Basidiospores								
Basidiospores Globose, 4.0- golden brown to brownish, densely orna- mented with more or less columnar pro- cesses, 4.5- 6.0 µm diam.	Globose, 4.0- 5.5 µm diam.	Globose, brownish, ornamented with dense high columns, 4.0-5.5 µm diam.	globose, 3.5- 4.0 µm wide, verrucose, with ≤0.4 µm long colum- nar verrucae	Subglobose, brownish, ver- rucose (apex slightly pointed or rounded, with some inconspicu- ous apex with confluent tips), 5.7-6.2 µm diam.	Globose to subglo- bose, hyaline (sometimes flattened with a semi-ellip- tical shape), 3.6-5.0 × 3.6- 4.9 µm diam.	Globose, yel- lowish brown, with colum- nar ornamen- tation, 4.0- 5.0 µm diam.	Globose, brownish, warts incon- spicuous, finely verru- cose, 2.7-3.1 µm diam.	Globose to subglo- bose, hya- line (some- times flat- tened with a semi- elliptical shape), 3.8-4.9 µm diam.

Geastrum crystallinum Dourado-Barbosa, R. L. Oliveira,
A. A. Lima, P. Marinho, Baseia & R. Cruz, sp. nov.
(Fig. 4)

DIAGNOSIS. — Basidiomata small and completely whitish in the field, from exoperidium, mesoperidium, endoperidium, peristome and gleba. Hyaline basidiospores under light microscope, showing bipyramidal crystals of calcium oxalate in the gleba.

ETYMOLOGY. — Based on the presence of crystals in the hyaline gleba under optical light microscopy.

MATERIAL EXAMINED. — **Brazil** • Bahia, Barreiras, *Familia Barbosa* Farm, Cerrado *stricto sensu*; found on sandy soils in a gregarious growth; 12°7'11.25"S, 45°4'26.43"W; 27.II.2021; *K.D. Barbosa, KD 0055*; Holotype: BRBA-Fungos 0137; Isotype: UFRN-Fungos 3682.

HABIT. — Gregarious, growing on sandy soils.

MYCOBANK. — MB#849826.

GENBANK ACCESSION NUMBER. — OR479887 (ITS), OR479889 (LSU).

DESCRIPTION

Unexpanded basidiomata absent. Expanded basidiomata saccate, 5-6 mm high (including peristome), 11-17 mm wide. Exoperidium with 7-9 triangular rays, revolute, non-hygroscopic. Mycelial layer cottony to furfuraceous, encrusted with debris, completely whitish (1A1) when fresh and ivory when dry (4B3). Fibrous layer coriaceous, persistent, completely whitish (1A1) when fresh and grayish orange (5B3) when dried. Pseudoparenchymatous layer showing a pattern that varies from slightly rimose in newly expanded basidiomata to extremely rimose in older expanded basidiomata, white (1A1) when fresh and light brown (5D5) when dehydrated, collar absent. Endoperidium globose, 3.5-6 mm high (including peristome) × 3-5.5 mm wide, surface non-pruinose, with small vermiform hyphae, entirely white (1A1) when fresh and whitish orange (5A2) when dry. Apophysis and stalk

absent. Peristome fibrillose, flat to mammiform, concolour to slightly darker than the endoperidium, 0.1-0.2 mm high, whitish yellow (1A2) to pale yellow (2A2). Gleba whitish (1A1), with bipyramidal crystals (4.2-7.3 µm diam). Mycelial layer composed of hyaline hyphae, 1.8-3.7 µm in diameter, thick walled (0.3-0.6 µm), not encrusted, slightly sinuous, unbranched, with lumen evident. Fibrous layer composed by hyaline hyphae, 1.8-3.7 (5) µm in diameter, thick-walled, 0.3-1.2 (1.88 µm), not encrusted, slightly sinuous, unbranched, lumen evident. Pseudoparenchymatous layer composed of subglobose, globose to ellipsoid cells, hyaline, 24.7-66.1 × 19.2-36.6 µm in diameter, thin-walled (< 1 µm). Eucapillitium hyaline, 1.3-4.3 µm in diameter, thin-walled (< 1 µm), encrusted, slightly sinuous, unbranched, lumen evident. Basidiospores globose to slightly elliptical, hyaline (Q = 1.00-1.25), 3.8-5.1 × 3.7-4.9 µm [x = 4.4 ± 0.4 × 4.2 ± 0.3. Qm = 1.06, n = 30], conspicuous ornamentation (0.2-0.9 µm in height) under LM and verrucose under SEM.

COMMENTS

Geastrum crystallinum sp. nov. (Table 3), is characterized by having a small basidioma, being completely whitish in the field, both in the rays, endoperidium, peristome and gleba, in addition to presenting hyaline basidiospores and the presence of bipyramidal crystals in the gleba.

Geastrum crystallinum sp. nov. groups phylogenetically with the Sect. *Corollina*, Subsect. *Marginata*, forming a group with *G. saccatum* Fr. (<50 bs MP/ <50 bs ML/ 95 Bayesian pp), at the base of other species in the Subsect. *Marginata* (*G. flexuosum* (L.S. Domínguez & Castellano) Jeppson & E. Larss., *G. corollinum* (Batsch) Hollós and *G. caatingense* J.O. Sousa, M.P. Martín & Baseia). This Subsection is characterized by the presence of fibrillose, non-folded, thickened and distinctly delimited peristome (Zamora *et al.* 2014, 2015; Sousa *et al.* 2019). However, contrary to these characteristics present in the other species of Subsect. *Marginata*, *G. crystallinum* sp.

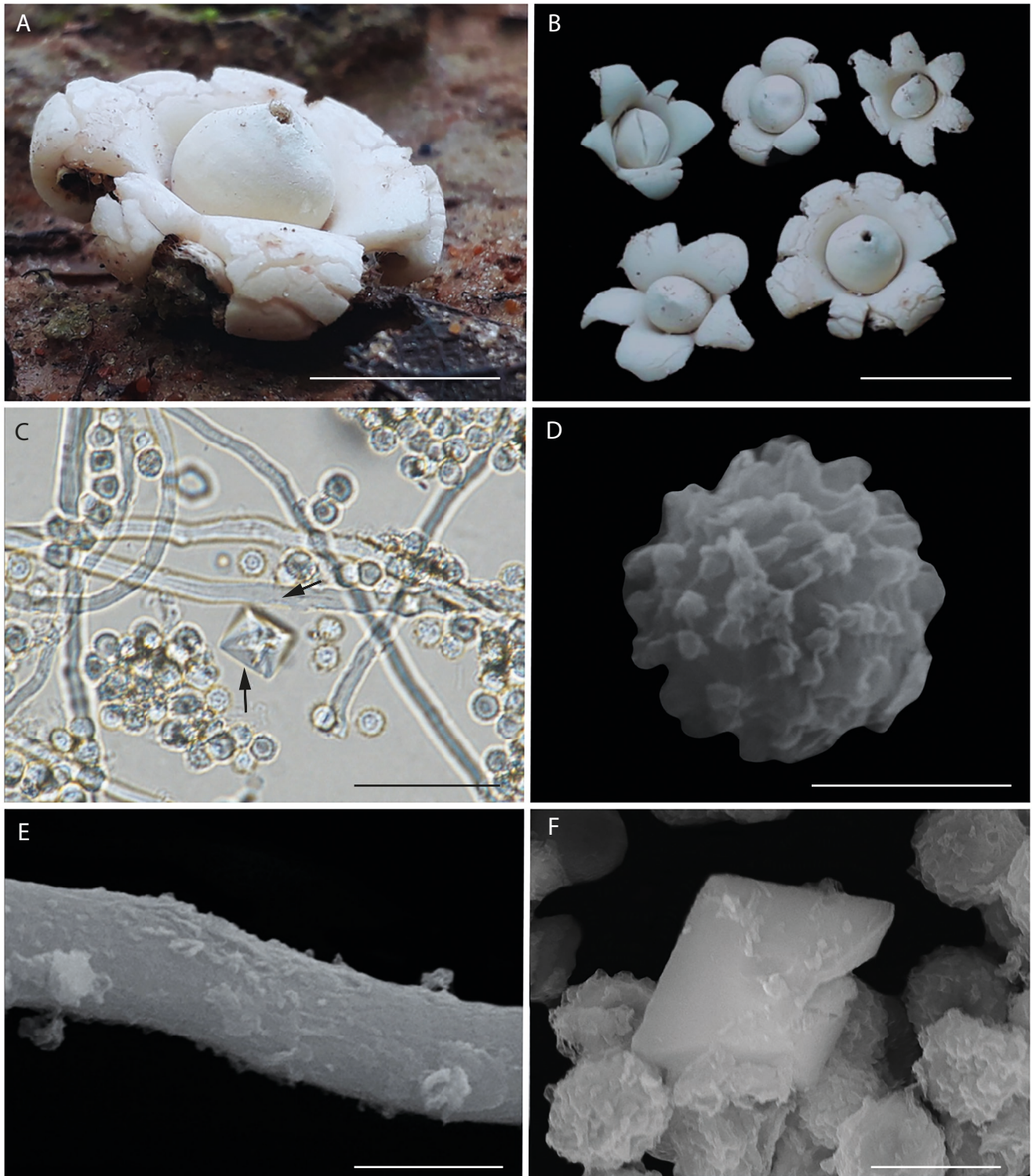


FIG. 4. — *Geastrum crystallinum* sp. nov. (BRBA-Fungi 0137): **A, B**, mature basidiomata in field; **C**, gleba with capillitium, bipyramidal crystals and basidiospores under light microscope; **D**, basidiospores with verrucose ornamentation under SEM; **E**, capillitium under SEM; **F**, basidiospores and bipyramidal crystals under SEM. Scale bars: A, 10 mm; B, 20 mm; C, 20 μ m; D, 2,5 μ m; E, 2,5 μ m; F, 5 μ m.

nov. have a non-delimited peristome, which is the unique character that distinguishes the new species in this Subsection.

In addition to this characteristic that separates all these species, representatives of *G. saccatum* and *G. corolinum*

commonly present elongated, non-faceted and circular calcium oxalate monohydrate (COM) crystals, almost filiform or even in arachnoid structures with radial patterns that are often abundant, forming substantial amounts of powdery masses

(Zamora *et al.* 2013). The specimens of *G. caatingense*, on the other hand, have color patterns in the basidiome that are completely different from those of *G. crystallinum*, with a pale orange (5A3) micelial layer, white orange (5A2) fibrous layer, a dark brown (6E4) pseudoparenchymatous layer, a grayish orange (6B2) endoperidium, and a brownish gray (6C2) to yellowish white (5A2) gleba, while specimens of *G. crystallinum* are completely whitish in colors (Sousa *et al.* 2019).

Geastrum crystallinum sp. nov. resembles *G. flexuosum* in the presence of globose and verrucose basidiospores, with similar sizes between 4.0 to 5.0 μm in diameter (Kers 1976; Domínguez de Toledo & Castellano 1996). Both species have hyaline eucapillitium, with thin, sinuous walls covered in debris (Jeppson *et al.* 2013). However, *G. flexuosum* has a rounded semi-hypogeous basidiome that open irregularly at maturity and not like a typical star with rays, as observed in *G. crystallinum* and other species of the genus (Domínguez de Toledo & Castellano 1996; Jeppson *et al.* 2013). Although the basidiome of *G. flexuosum* also has a whitish color like *G. crystallinum*, its representatives can also have a brownish color and irregular rupture of the peridium (Jeppson *et al.* 2013), a characteristic not observed in the specimens of *G. crystallinum*. Additionally, *G. flexuosum* has a dark brown gleba without crystals (Kers 1976), while *G. crystallinum* has a whitish gleba with bipyramidal crystals.

Another strongly similar species is *Geastrum hyalinum* Freitas-Neto, N.M. Assis, J.O. Sousa, & Baseia by the mature basidioma saccate, whitish gleba and hyaline spores under light microscopy (Assis *et al.* 2019). However, the gleba of *G. hyalinum* has a more whitish yellow color (1A2) (Assis *et al.* 2019), instead of the completely white color (1A1) when fresh and only whitish yellow (1A2) in dehydrated basidiomata of *G. crystallinum*. Another similar feature in *G. crystallinum* and *G. hyalinum* is the morphology of the endoperidium, that varies from globose to subglobose, also showing prominent small vermiform hyphae, absence of crystalline matter and apophysis (Assis *et al.* 2019). However, in *G. crystallinum* the size of this structure is almost four times smaller than in *G. hyalinum*. The peristome of both species is fibrillose and flattened, but in specimens of *G. hyalinum* the peristome is delimited, which is completely different from the non-delimited peristome of *G. crystallinum* (Assis *et al.* 2019). Both species have hyaline, globose basidiospores with conspicuous ornamentation, but in *G. crystallinum* there is no presence of bipyramidal crystals in the gleba (Assis *et al.* 2019). Unfortunately, no molecular data are available for the species *G. hyalinum* to be used in a genetic comparison, forcing us to compare the samples based solely on the morphological features.

Geastrum crystallinum sp. nov. also morphologically resembles two other species that have saccate basidiomata: *Geastrum floriforme* Vittad. and *G. lageniforme* Vittad. (Fries 1829; Vittadini 1842). However, *G. floriforme* has a strongly hygroscopic exoperidium and a yellowish-brown gleba (5E4), while *G. crystallinum* has a non-hygroscopic exoperidium and a whitish gleba (Vittadini 1842; Sousa 2015). In *G. lageniforme*, the species has long rays with thin ends, a mycelial layer with distinct longitudinal grooves, and basidiospores

with prominent columnar warts up to 1.2 μm in height, while *G. crystallinum* has short rays that do not taper at the base, absence of longitudinal grooves in the mycelial layer, and short verrucose ornamentations, smaller than 1 μm in height (Vittadini 1842; Sousa 2015). Thus, *G. crystallinum* sp. nov. is a unique and characteristic species, both in its macroscopic form in the field and microscopically in the laboratory.

CONCLUSION

These newly described species from the Brazilian Cerrado highlight the importance of taxonomic studies of gasteroid fungi. This not only advances our understanding of the biodiversity conservation, but also underscores the critical need to protect these organisms in their natural habitat, where historically gasteroid fungi have played a vital role as decomposers of organic matter in the soil, enhancing nutrient absorption for plants, and serving as a valuable food source for a diverse range of vertebrate and invertebrate species.

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