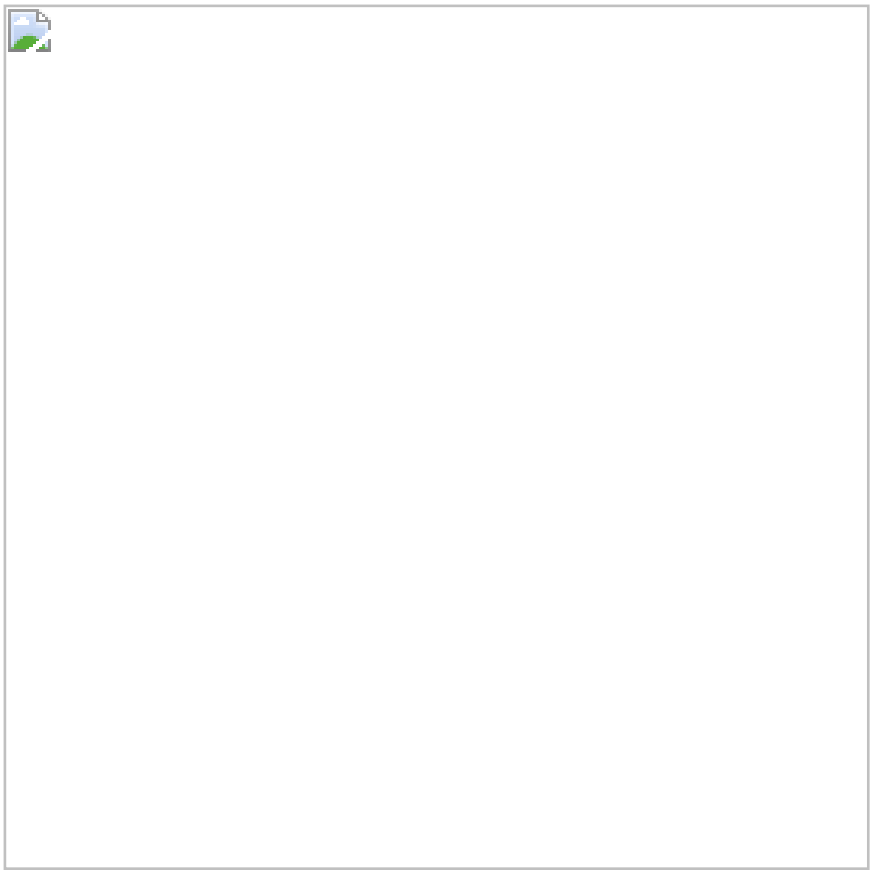

New records of earthstar fungi (Basidiomycota) for different physiognomies of the Cerrado biome, Brazil1

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New records of earthstar fungi (Basidiomycota) for different physiognomies of the Cerrado biome, Brazil[1]

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Abstract. In the present study, six new records of fungi of the genus *Geastrum* Pers. are described in four different physiognomies of the Cerrado *stricto sensu*: *Geastrum fimbriatum, G. lageniforme, G. morganiii*, and *G. hirsutum* are the first records for the Brazilian Cerrado, being collected, respectively, in Typical Cerrado, Rupestrian Cerrado, Sparse Cerrado and Dense Cerrado. The specimen described as *G.* aff. *rusticum* is also the first record for the biome and was founded in Typical Cerrado. *G. triplex* is the second record for the Brazilian Cerrado and the first for the state of Bahia, found in physiognomies of Dense Cerrado. The taxa described present plates with photographs and micrographs for each species and a map for the collection locations.

Key words: Gasteroid fungi, *Geastrum*, *Geastraceae*, hotspots, neotropical, taxonomy

The genus *Geastrum* Pers. is a gasteroid fungus popularly known as "earthstar fungi" because it presents the peridium dehiscence in rays at maturity, showing a starry shape; and has its spores dispersed through a bellows-type mechanism by the impact of raindrops, wind, or trampling of small animals (Miller and Miller 1988, Sunhede 1989, Soto and Wright 2000).

Geastrum representatives are commonly found in humid environments such as tropical and temperate forests (Pegler *et al.* 1995, Calonge 1998). However, they also inhabit semi-arid regions such as the Brazilian Caatinga and Cerrado (Baseia *et al.* 2003, Silva *et al.* 2011), as well as arid regions such as the deserts of North America (Bates 2004, Moreno *et al.* 2010). *Geastrum* has significant importance in forest ecosystems, participating in nutrient cycling, ecological balance, and the decomposition of organic matter in the soil (Pegler *et al.* 1995, Calonge 1998, Kuhar *et al.* 2016). The genus has great biochemical potential and can be used in the pharmaceutical industry or the production of antibiotics, as its representatives have bioproducts with anti-inflammatory, antioxidant, and cytotoxic properties (Guerra-Dore *et al.* 2007, Mustafa *et al.* 2017, Sevindik *et al.* 2017). In addition, specimens of *Geastrum* can also be used in the decomposition of contaminants from textile effluents, such as the synthetic dye Remazol Brilliant Blue R (RBBR) (Santana *et al.* 2016).

The Cerrado biome is considered a global biodiversity and endemism hotspot (Myers *et al.* 2000, Strassburg *et al.* 2017, Gomes *et al.* 2018), being one of the 36 priority regions for preservation according to International Conservation, only behind the Amazon biome when compared to other Brazilian biomes. The Cerrado is the second largest biome in South America, with about 2 million km^2, which corresponds to almost 22% of the

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Brazilian territory. Despite this, in recent years the rate of deforestation has increased dramatically, and only 2.2% of the Cerrado area is legally protected (Klink and Machado 2005). The biome has been suffering constant threats to the extinction of species due to the increase in unnatural fires, excessive human occupation, and the disorderly use of land, as well as logging and the direct action of the agricultural, urban, and industrial big sectors (Brannstrom *et al*. 2008, Mueller and Martha 2008, Ribeiro and Walter 2008, Mazzeto-Silva 2009, Carneiro-Filho and Costa 2016, Strassburg *et al*. 2017, MMA 2018).

The Cerrado features physiognomies that encompass forest, savannah, and grassland formations, constituting a vegetational complex of ecological, physiognomic, historical, and geological relationships with other regions of South America, Africa, and Australia (Beard 1953, Cole 1958, Eiten 1972, 1994, Allem and Valls 1987). The phytophysiognomy of the Cerrado that composes the Western Bahia (Northeastern region of Brazil) specifically covers the Cerrado *stricto sensu*, characterized by the presence of shrubs and subshrubs in addition to small trees, generally inclined, tortuous, or branched (Ribeiro and Walter 2008). Due to xeromorphism, some species have trunks with thick cork bark, called "suber"; some others have perennial underground organs, or "xylopods," that allow efficient regrowth soon after burning or cutting. The leaves in general are more rigid or leathery, being densely pilose, to protect themselves (Ribeiro and Walter 2008).

The Cerrado *stricto sensu* is composed of different phytophysiognomies and may have deep soils with high aluminum content, acidic pH, lack of nutrients, low organic matter content, and frequent fires (Waibel 1948, Beard 1953, Goodland 1971, Goodland *et al.* 1979, Ab'Saber 1977, Coutinho 1992, Felfili and Silva 1993, Eiten 1994, Felfili *et al.* 1998). The set of these factors reflects on the structure and spatial distribution of the vegetation, originating distinct subdivisions of Cerrado *stricto sensu* such as, for example, Dense Cerrado, Typical Cerrado, Sparse Cerrado, and Rupestrian Cerrado (Ribeiro and Walter 2008).

According to Ribeiro and Walter (2008), the Dense Cerrado (Fig. 1A) is characterized by a predominantly arboreal type of vegetation, with vegetation cover between 50% and 70% and an average height of 5–8 m, being the densest and highest form of the Cerrado *stricto sensu*. Shrubs and herbs, in general, are thinner, due to shading resulting from the canopy of trees, and it is a type of vegetation that occurs mainly in purple, dark red, red-yellow latosols, and cambisols. Despite this, in general, the soil is moderately acidic, with elevated levels of aluminum and pH between 4.5 and 5.5, in addition to a lack of essential nutrients, mainly nitrogen and phosphorus (Ribeiro and Walter 2008). The Typical Cerrado (Fig. 1B) is a predominantly tree-shrub vegetation, with vegetation cover between 20% to 50% and an average height of 3–6 m, which can be understood as an intermediate form between the Dense Cerrado and the Scarce Cerrado. This type of vegetation occurs in dark red, red-yellow latosols, cambisols and quartz sands, in addition to lithosols or concretionary soils (Ribeiro and Walter 2008).

The Sparse Cerrado (Fig. 1C) is characterized by predominantly tree-shrub vegetation, like a Typical Cerrado, with vegetation covering 5–20% and an average height of 2–3 m. This is the lowest and least dense phytophysiognomy of the Cerrado *stricto sensu* and occurs mainly in red-yellow latosols, cambisols, quartz sands, concretionary, hydromorphic, and lithologic soils (Ribeiro and Walter 2008). Finally, the Rupestrian Cerrado (Fig. 1D) is characterized by a predominantly arboreal-shrubby vegetation of rupestrian environments of lithologic or rocky soils, and having vegetation cover that varies between 5% and 20% with an average height of 2–4 m. This type of vegetation can occur in continuous stretches and mosaics, including other types. The Rupestrian Cerrado is often confused with the Sparse Cerrado; however, the substrate is easily differentiated by having little soil between the rocky outcrops. Litholic soils where this type of vegetation occurs originate from the decomposition of sandstones and quartzites, and are often acidic, poor in nutrients, and with low levels of organic matter (Ribeiro and Walter 2008).

Even with the presence of high levels of biodiversity and endemism in the Cerrado, the known diversity of macrofungi for the Western region of Bahia, a state located in the Northeast region of Brazil, is extremely scarce, with entire areas without any record, except for the surroundings of the city of Barreiras, which contains only a single published record of a gasteroid fungus of the genus *Tulostoma* Pers.: *Tulostoma irregulireticulatum* Dourado-Barbosa, R.L. Oliveira, A.A. Lima, Baseia & R. Cruz (Barbosa *et al.* 2023). In this sense, the present study aims to expand the knowledge about gasteroid fungi from Cerrado

FIG. 1. Phytophysiognomies of the Cerrado of Western Bahia found in the studied localities. A. Dense Cerrado. B. Typical Cerrado. C. Sparse Cerrado. D. Rupestrian Cerrado.

areas in western Bahia, Brazil, using morphological data, photographs, and illustrations to contribute to a better understanding of the diversity of these organisms in the Brazilian Cerrado.

Materials and Methods. The collections were carried out in the rainy period of 2020 (March and April) and February 2023, in four locations distributed in two municipalities in the Western region of Bahia – Brazil: Barreiras and São Desidério (Fig. 2): a forestry area at Universidade Federal do Oeste da Bahia (UFOB - Campus Reitor Edgard Santos), municipality of Barreiras (12° 8′59.22″S, 45°01′07.22″W); *Família Barbosa* Farm road, municipality of Barreiras (12°08′47.2″S, 45°01′40.2″W); *Família Barbosa* Farm, municipality of Barreiras (12°08′11.10″S, 45°04′28.7″W); *Lagoa Azul* Municipality Park, municipality of São Desidério (12°22′16″S, 45°52′09″W); and *Acaba Vida* Waterfall, in the limits of the municipality of Barreiras and Luís Eduardo Magalhães (11°53′37″S, 45° 36′4″W).

Field specimen collection followed the modified protocol by Lodge *et al.* (2004), Baseia *et al.* (2014) and Fortuna (2020), following preexisting trails in search of substrates capable of growth for the genus *Geastrum*, such as decomposing trunks or wood, litter, herbivore manure, and soil. The specimens were photographed and removed from the substrate using a pocketknife. The fruiting bodies were packed in compartmentalized plastic cases. Samples taken from the substrate were tagged with collection information, collector's name, and geographic position. Basidiomata colors were obtained in the field with fresh samples, following the codes and names of Kornerup and Wanscher (1978) color chart. At the laboratory, samples were dehydrated at 40 °C for a period of 24 to 48 hr, depending on the size of the basidiome.

The characterization of the macroscopic and microscopic structures of *Geastrum* was based on specific literature for the genus, such as the work by Sunhede (1989), Zamora *et al.* (2014), Miller and Miller (1988) and Sousa (2015). The macroscopic characterization was performed with the aid of Leica EZ4 and Nikon SMZ1500 stereomicroscopes, and microscopic analyses were performed using a Nikon Eclipse Ni light microscope, both with a Nikon DS-Ri1 camera attached and the NIS-Elements AR v.4.51.00 software. The assembly and preparation of the microscopic slides to obtain the exoperidium layers and measurements of the basidiospores were carried out in 5% potassium hydroxide (KOH). The scanning electron microscopy (SEM) analysis to visualize the ornamentation of basidiospores and capillitia was performed on a Shimadzu SSX-550, following the protocol by Silva *et al.* (2011). The measurements of all analyzed structures followed the acronyms used by Sousa (2015) and Bates (2004), with n = number of analyzed samples. Thirty spores were randomly selected and measured, and the mean and standard deviation were calculated (χ and $\pm$, respectively), both for diameter and height (including ornamentation), in addition to the average height/width ratio (Qm). The collected specimens were deposited in the fungal collection of the BRBA Herbarium at the Universidade Federal do Oeste da Bahia (UFOB), city of Barreiras, Bahia, Brazil.

Results. ***Geastraceae*** Corda, Icones fungorum hucusque cognitorum 5: 25 (1842)

Geastrum fimbriatum Fr., Systema Mycologicum 3: 16 (1829) (Fig. 3)

ETYMOLOGY. Based on the distinctly fimbriated peristome.

DESCRIPTION. Immature basidiomata absent. Expanded basidiome saccate, 12 mm height (including peristome) × 36 mm width. Exoperidium formed by 5–6 rays, planar to revolute, slightly curved to the basidiome direction, triangular, non-hygroscopic. Mycelial layer orange white (5A2) when fresh, to greyish orange (5B3) when dehydrated, with a papyraceous surface, encrusted, persistent, falling off slightly with maturation. Fibrous layer orange white (5A2–6A2) when fresh, to pale orange (6A3) when dehydrated, surface papyraceous. Pseudoparenchymatous layer greyish red to brownish orange (7B3–6C3) when fresh, to brown (5E4) when dehydrated, slightly rimous and falling off at the base of the rays. Endoperidium subglobose, light brown to brown (7D4–7E5), 10 mm height (including peristome) × 21 mm width, sessile, glabrous. Peristome fimbriate to lacerated, not delimited, slightly mammiform to flattened, slightly darker than endoperidium. Gleba greyish brown (7F3). Rhizomorph absent.

Basidiospores brownish, globose, 4.5–5.9 × 4.2–5.7 μm [χ = 5.1 ± 0.4 × 5.0 ± 0.4, Qm = 1.03, n = 30], conspicuous ornamentation under LM

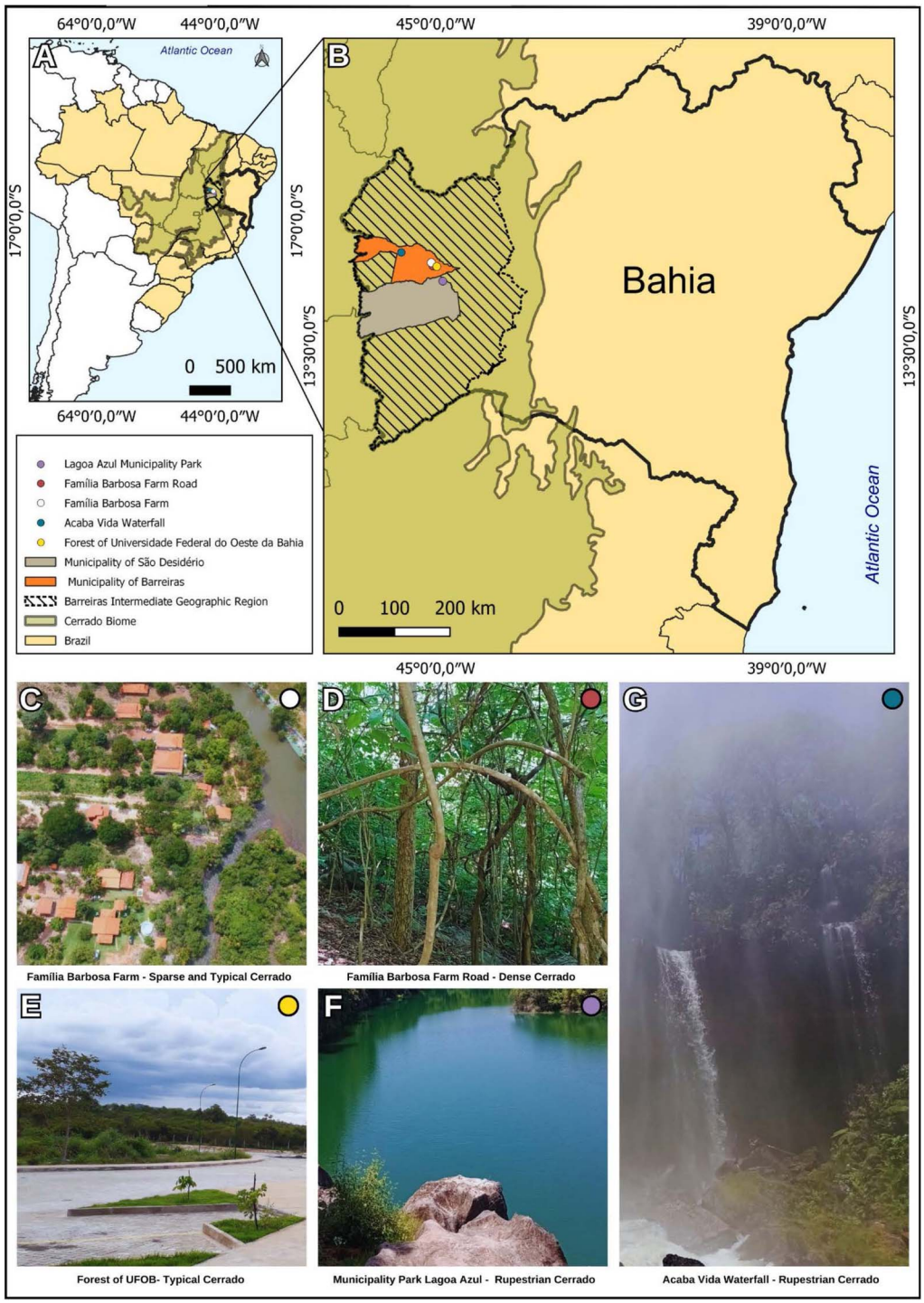

FIG. 2. Collection area map. A. Greater enlargement of the area, showing the collection points. B. Map of the state of Bahia, with emphasis on Barreiras Intermediate Geographic Region and the municipalities of Barreiras and São Desidério, northeast region of Brazil. C–G. Collection areas: C. *Família Barbosa* Farm. D. *Família Barbosa* Farm road. E. Federal University of Western Bahia (UFOB). F. *Lagoa Azul* Municipality Park. G. *Acaba-vida* Waterfall.

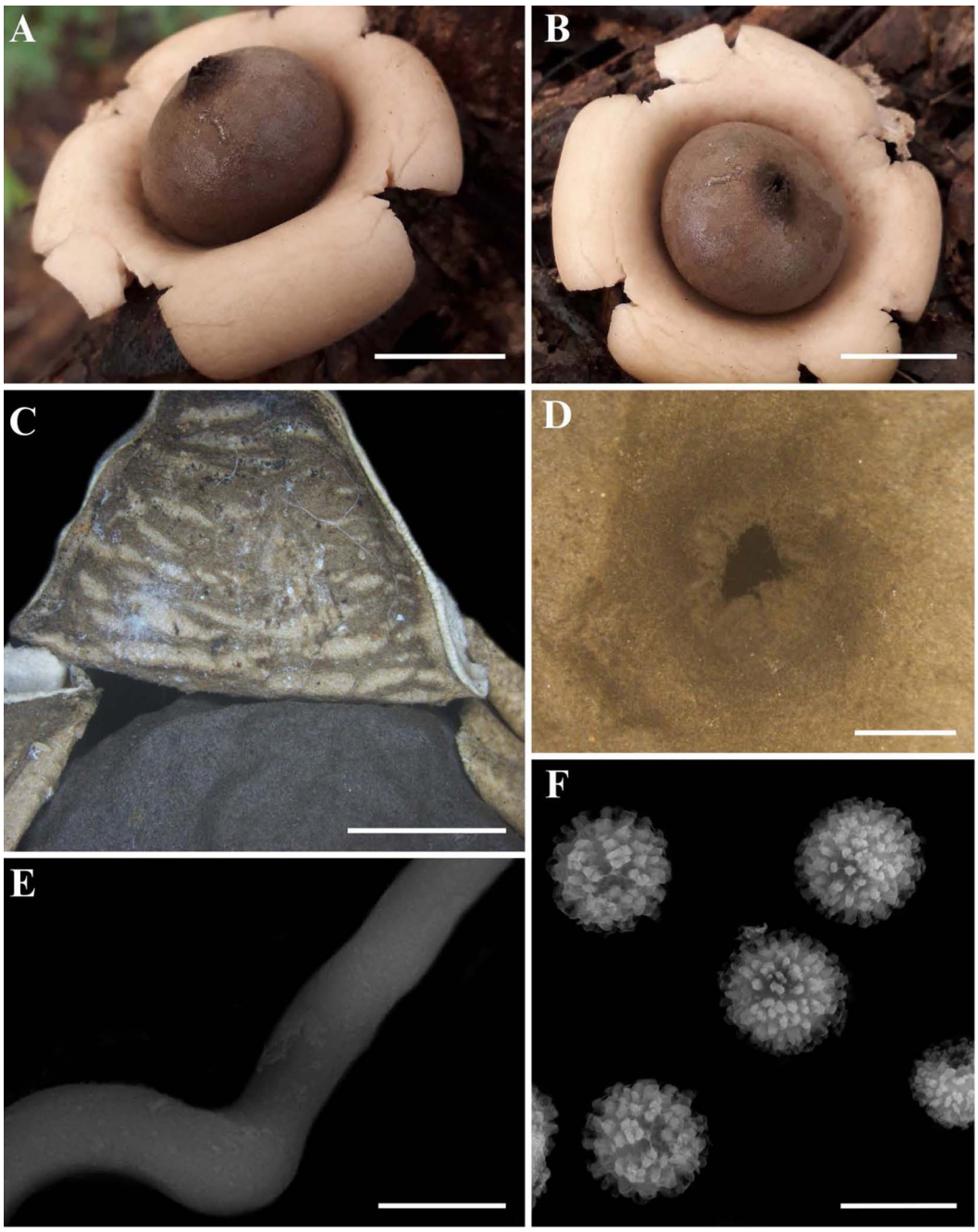

FIG. 3. *Geastrum fimbriatum* (BRBA-Fungos 0028). A–B. Mature basidiome in field. C. Detail of the exoperidium. D. Detail of the fimbriate peristome. E. Capillitium under SEM. F. Basidiospores under SEM. Scale: A–B = 10 mm; C = 4 mm; D = 1 mm; D = 10 mm; E = 4 μm; F = 4 μm.

(< 1 μm) and verrucous under SEM, verrucae short and columnar, truncated, rounded to flattened at the apex, pedicel inconspicuous. Eucapillitium yellowish brown, 2.6–7.3 (−8.3) μm diam., thin-walled (0.4–1.0 μm width), surface slightly encrusted, lumen evident, not septate, unbranched. Mycelial layer composed of hyaline hyphae, 1.3–3.3 μm diam., thin-walled (0.3–0.7 μm width), surface slightly encrusted, lumen evident, slightly sinuous, unbranched. Fibrous layer formed by hyaline hyphae, 3.3–7.6 (–10.7) μm

diam., thin- to thick-walled (0.6–1.9 μm width), surface encrusted, slightly sinuous, lumen evident, not septate, unbranched. Pseudoparenchymatous layer composed of hyaline hyphae, 0.5–1.6 μm diam., thin- to thick-walled, ranging from subglobose, pyriform to irregular, 13.7–51.0 × 10.3–41.6 μm.

HABITAT. Soil with litter, solitary.

DISTRIBUTION. Cosmopolitan (Ponce de Leon 1968). In Brazil, this species was recorded previously in the states of Bahia (Trierveiler-Pereira *et al*. 2009), Pará (Leite *et al*. 2011, Trierveiler-Pereira *et al*. 2011); Paraíba (Trierveiler-Pereira *et al*. 2011), Pernambuco (Leite *et al*. 2007, Trierveiler-Pereira *et al*. 2011), Rio de Janeiro (Berkeley and Cooke 1876), Rio Grande do Norte (Sousa *et al*. 2014b) and Rio Grande do Sul (Rick 1961). This sample is the first record for the Cerrado biome.

PHYTOPHYSIOGNOMY. Typical Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, Barreiras, *Família Barbosa* Farm, Cerrado *stricto sensu*, 12° 07′13.301″S, 45°04′38.023″W, 13 April 2020. Barbosa, K.D., KD0039 (BRBA-Fungos 0028).

NOTES. *Geastrum fimbriatum* Fr. is characterized by having a heavily encrusted mycelial layer, globose to subglobose endoperidium with protuberant hyphae, and a distinctly fimbriated, non-delimited peristome (Sousa *et al.* 2014b, Sousa 2015). The species also names the section *Fimbriata*, which groups species by having an endoperidium covered by small salient hyphae and basidiospores ≤ 4.5 diam. (Zamora et al. 2014). *Geastrum fimbriatum* resembles *G. setiferum* Baseia & Milanez and *G. fornicatum* (Huds.) Hook, (both from the sect. *Fornicata*) by the presence of globose and brownish basidiospores (Baseia and Milanez 2002, Leite *et al.* 2007). However, some authors state that *G. fornicatum* has an ephemeral mycelial layer that forms a kind of cup in the mature basidiome (Zamora *et al.* 2014, Baseia and Milanez 2002, Bates 2004), while *G. setiferum* has a distinctly grooved peristome and endoperidium covered by cymbiform setae.

Two other morphologically related species to *G. fimbriatum* are *G. rusticum* Baseia, B.D.B. Silva & T.S. Cabral, and *G. rufescens* Pers., as both have indistinctly delimited peristome (Carlsson and Hæggström 2005, Cabral *et al.* 2014). However, *G. rusticum* has basidiospores with distinct ornamentation (Cabral *et al.* 2014). *G. rufescens*, on the other hand, has arched and much more robust basidiomata, reaching almost 60 mm in width (Bates 2004, Zamora *et al.* 2014). *G. fimbriatum* is here recorded for the first time for the Brazilian Cerrado biome, and this is the first collection from the phytophysiognomy of Typical Cerrado.

Geastrum hirsutum Baseia and Calonge, Mycotaxon 95: 302 (2006) (Fig. 4)

ETYMOLOGY. In reference to the tomentose and hairy exoperidium.

DESCRIPTION. Immature basidiomata epigeous, globose to subglobose, reddish-orange to burnt sienna (7A7–7D8), 5–8 mm height × 7–9 mm width, caespitose, growing on a subiculum, yellowish white (1A2), formed by rigid, elongated hairs (0.5–1.5 mm long). Expanded basidiomata saccate, 6.1–18.2 mm height (including peristome) × 17–20 mm width. Open exoperidium formed by 6–7 rays, triangular to revolute, hygroscopic when dried. Mycelial layer greyish orange (5B3–5B4) when fresh, to chocolate brown (6E4) when dehydrated, hirsute surface completely covered with rigid hairs, teak brown (6F5), elongated (0.5–1.2 mm long), not encrusted, persistent. Fibrous layer pale yellow to orange grey (4A3–5B2) when fresh, to orange grey (5B3) when dehydrated, papyraceous surface. Pseudoparenchymatous layer coffee to brown (5F7–6E4) when fresh, and hair brown (5E4) when dehydrated, persistent. Endoperidium globose to subglobose, reddish brown (8D4–8E4), 3–6 mm height (including peristome) × 4–6 mm width, sessile, glabrous. Peristome finely fimbriate, distinctly delimited, reddish grey (8B2), slightly conical to flattened, slightly darker than the endoperidium. Gleba brown (6E4). Rhizomorph whitish (1A2), 4–9 mm long.

Basidiospores brownish, globose to subglobose, 3.81–5.9 × 3.2–5.8 μm [$\chi = 4.9 \pm 0.6 \times 4.7 \pm 0.6$, Qm = 1.06, n = 30], conspicuous ornamentation under LM (< 1 μm) and verrucous under SEM, verrucae short and columnar, truncated, rounded to pointed at the apex, pedicel discreet. Eucapillitium brownish-yellow, 2.8–48 μm diam., thin- to thick-walled (0.4–1.6 μm width), surface lightly encrusted, lumen evident, sinuous,

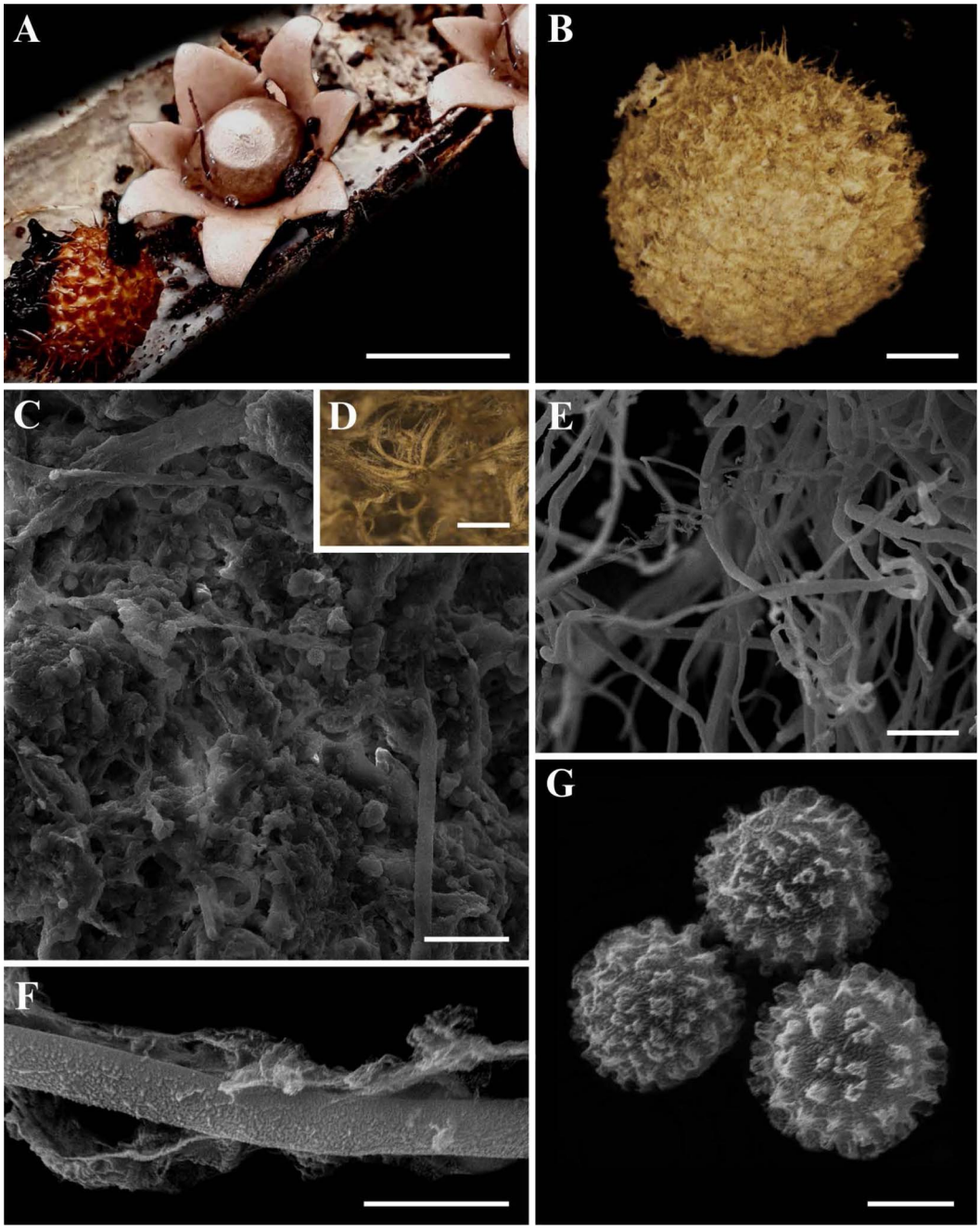

FIG. 4. *Geastrum hirsutum* (BRBA-Fungos 0050). A. Mature basidiomata in field. B. immature basidiome C. Peridium hyphae under SEM. D. Tomentum details, with hirsute hairs. E. Rhizomorph under SEM. F. Capillitium under SEM. G. Basidiospores under SEM. Scale: A = 10 mm; B = 20 mm; C = 20 μm; D = 0.5 mm; E = 5 μm; F = 5 μm; G = 2 μm.

not septate, unbranched. Mycelial layer composed of hyaline hyphae, with 3.9–7.3 (–8.2) μm diam., thin- to thick-walled (0.3–1.9 μm width), surface lightly encrusted, lumen evident, slightly sinuous, unbranched. Fibrous layer formed by hyaline hyphae, 2.1–6.2 μm diam., thin-walled (0.4–0.8 μm width), encrusted surface, slightly sinuous, evident lumen, not septate, unbranched.

Pseudoparenchymatous layer composed of brownish-yellow to hyaline hyphae, 0.4–1.0 µm diam., thin- to thick-walled, ranging from subglobose, pyriform to irregular, 23.9–58.1 × 10.8–32.1 µm.

HABITAT. Lignicolous, on decaying wood, in a gregarious growth pattern.

DISTRIBUTION. French Guyana and Brazil. The species was previously recorded in the states of Pernambuco (Baseia and Calonge 2006, Trierveiler-Pereira *et al*. 2011), Pará (Sotão *et al*. 2009) and Paraíba (Sousa *et al*. 2014a). This one is the first record for the state of Bahia, and for the Cerrado biome.

PHYTOPHYSIOGNOMY. Dense Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, *Família Barbosa* Farm road, Cerrado *stricto sensu*, Dense Cerrado, lignicolous, on decaying wood, with gregarious growth, 12°08′11.10″S, 45°04′28.7″W, 23 April 2020. Barbosa, K.D. (BRBA–Fungos 0050).

NOTES. *G. hirsutum* is characterized by presence of a brownish hirsute mycelial layer, with elongated hairs (1.0–3.0), rigid and non-persistent, saccate basidiome, peristome fibrillose and distinctly delimited, and basidiospores with short ornamentation, verrucous under SEM (Sousa 2015). Specimens of *G. hirsutum* morphologically resemble species with the presence of hairs in the exoperidial layer, a characteristic that is particularly recurrent in species with subiculum such as *G. brunneocapillatum* J.O. Sousa, Accioly, M.P. Martín & Baseia, *G. pusillipilosum* J.O. Sousa, Alfredo, R.J. Ferreira, M.P. Martín & Baseia e *G. rubellum* P.-A. Moreau & C. Lécuru (Accioly *et al.* 2019). However, *G. brunneocapillatum* has longer hairs (0.5–2.0 mm long) and smaller basidiospores (2.8–4.0 µm diam.) compared to *G. hirsutum*. The mycelial layer of *G. pusillipilosum* and *G. rubellum* has even smaller hairs (0.3–0.68 mm long). Furthermore, in *G. pusillipilosum* the exoperidium is hairless and the basidiospores are much larger (5.0–6.5 µm diam.) when compared to *G. hirsutum* (4.7–4.9 µm diam.), while in *G. rubellum* the exoperidium is formed by smaller hairs with a reddish to brownish color (Accioly *et al.* 2019).

It is worth mentioning that *G. brunneocapillatum*, *G. rubellum*, and *G. hirsutum* are characterized as semi-cryptic species, even though they are not sister species (Vondrak *et al.* 2009, Hodkinson and Lendemer 2011, Korshunova *et al.* 2017). This statement further reinforces that the presence of hair in the exoperidial layer is not a morphologically reliable characteristic for describing new species or delimiting existing species, strongly suggesting that this character represents an evolutionary convergence within *Geastrum* (Accioly *et al.* 2019).

Geastrum lageniforme Vittad., Mem. Accad. Torino 5: 16 (1842) (Fig. 5)

ETYMOLOGY. Based on the flask-like shape of the mature basidiomata.

DESCRIPTION. Immature basidiome epigeous, lageniform, dark blonde (5D4), 29–31 mm height × 16–20 mm width. Non-encrusted surface. Rhizomorph absent. Expanded basidiome 12–21 mm height (including peristome) × 29–52 mm width. Open exoperidium formed by 6–7 rays, revolute, hygroscopic, arachnoid, tapering at the tips and twisting below the basidiome, 12–27 mm. Mycelial layer persistent, not encrusted, papyraceous, detaching with age and forming distinct longitudinal grooves, greyish brown "nougat" (5D3) when fresh, and nutria (5F3) when dehydrated. Fibrous layer greyish red (7B3) when fresh, to pale orange (5A3) when dehydrated, papyraceous. Pseudoparenchymatous layer slightly rimose, falling off at the base in some basidiomes, reddish grey (7B2) when fresh, to brown (7E4) when dehydrated. Endoperidium mammiform, sessile, depressed globose to subglobose, surface glabrous, dark brown (6F3), 9–19 mm height (including peristome) × 14–25 mm width. Apophysis and pedicel absent. Peristome mammiform to conical, finely fimbriate, delimited, 2.0–3.0 mm high, slightly darker than endoperidium at the apex. Gleba chocolate brown (6F4). Rhizomorph absent.

Basidiospores brownish, subglobose, 4.6–5.7 × 4.3–5.4 µm [$\chi = 5.1 \pm 0.3 \times 4.8 \pm 0.3$, Qm = 1.07, n = 30], conspicuous ornamentation under LM (< 1 µm) and verrucous under SEM, verrucae long and columnar, truncated, rounded to flattened at the apex, pedicel discreet. Eucapillitium brownish, 2.7–6.4 µm diam., thin-walled (< 1 µm width), surface not encrusted, lumen evident, septate, and unbranched. Mycelial layer composed of hyaline hyphae, 2.2–7.8 µm diam., thin-walled (< 1.1 µm

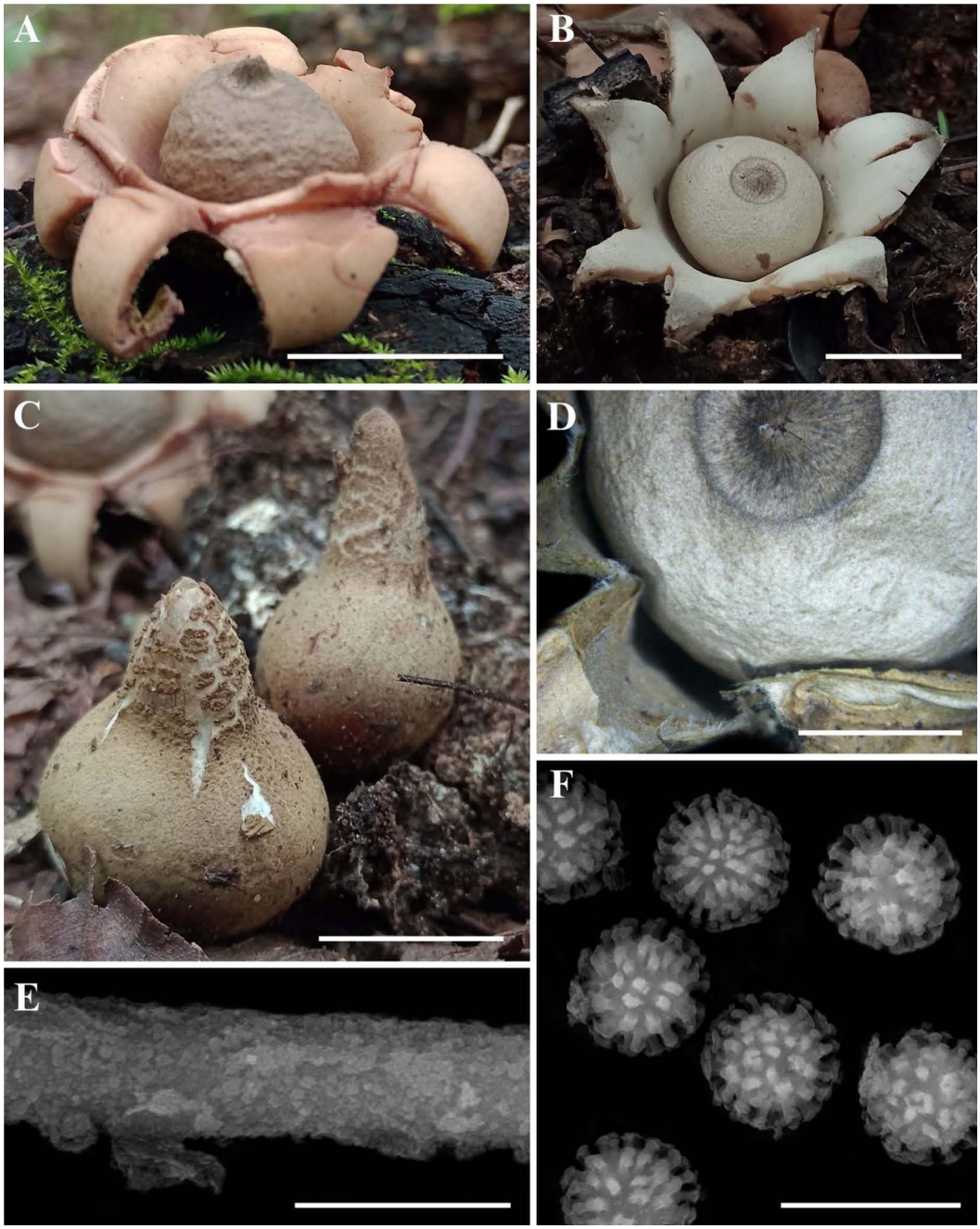

FIG. 5. *Geastrum lageniforme* (BRBA-Fungos 0126). A–B. Mature basidiome in field. C. Immature basidiomata in field. D. Peridium hyphae under SEM. D. Details of the rays, endoperidium, and the delimited peristome. E. Capillitium under SEM. F. Basidiospores under SEM. Scale: A = 20 mm; B = 10 mm; C = 20 mm; D = 4 mm; E–F = 5 μm.

width), not encrusted, slightly sinuous, unbranched. Fibrous layer composed of hyaline hyphae, 2.7–5.9 μm diam., thick-walled (> 1 μm width), slightly sinuous, with evident lumen, non-septate and unbranched. Pseudoparenchymatous layer formed by hyaline cells, thick-walled (> 1.3 μm width), ranging from globose, cylindrical to ellipsoid, 22.6–73.5 × 14.0–44.7 μm.

HABITAT. On decaying wood, in a gregarious growth pattern.

DISTRIBUTION. Africa (Dissing and Lange 1962, Dring 1964), Americas (Calonge *et al*. 2005, Bates 2004, Trierveiler-Pereira *et al*. 2011, Cortez *et al*. 2008, Rick 1961), and Europe (Calonge 1998, Sunhede 1989). In Brazil, this species was recorded previously in the states of Amazonas (Cabral *et al*. 2014), Bahia (Trierveiler-Pereira *et al*. 2009), Ceará (Sousa *et al*. 2014b), Pará (Leite *et al*. 2011), Paraíba (Sousa *et al*. 2014b), Pernambuco (Trierveiler-Pereira *et al*. 2011), Rio de Janeiro (Hennings 1904), Rio Grande do Norte (Sousa *et al*. 2014b), and Rio Grande do Sul (Rick 1961, Cortez *et al*. 2008). This sample is the first record for the Cerrado biome.

PHYTOPHYSIOGNOMY. Rupestrian Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, São Desidério, *Lagoa Azul* Municipality Park, Cerrado *stricto sensu*, Rupestrian Cerrado, on decaying wood, in a gregarious growth pattern, 12°22′16″S, 45° 52′09″W, 23 February 2023. Cruz, R.H.S.F., Barbosa, K.D., KD0066 (BRBA-Fungos 0126).

NOTES. *Geastrum lageniforme* Vittad. is characterized by having a mature basidiome saccate with long rays, horizontally distributed and tapered at the end, in addition to a distinctly delimited fimbriated peristome and verrucous basidiospores on SEM (Sousa 2015). Specimens of *G. lageniforme* are commonly confused with *G. saccatum* Fr. and *G. triplex* Jungh., as both species can present a kind of collar around the endoperidium during the basidiome maturation (Zamora *et al.* 2013). However, *G. saccatum* belongs to subsection *Marginata,* characterized by presenting fibrillose, non-folded, thickened and distinctly delimited peristome, and rhizomorphs with acicular crystals with rare horn-like crystals mixed (Zamora *et al.* 2014); *G. triplex* belongs to the section *Trichaster,* characterized by presenting exoperidium saccate to arched, or even pseudo-fornicated, and rhizomorphs with rosette-shaped bipyramidal crystal aggregates (Zamora *et al.* 2014); while *G. lageniforme* belongs to the subsection *Lageniformia,* characterized by presenting a pseudoparenchymatous layer that does not react with syringaldazine, saccate exoperidium and rhizomorphs with horn-like crystals often grouped in candelabrum-like structures (Zamora *et al.* 2014). Furthermore, both species are easily distinguishable in the field from *G. lageniforme*. Representatives of *G. saccatum* differ by not having a mycelial layer with longitudinal grooves, arachnoid rays and lageniform immature basidiomata (Sousa *et al*. 2014b, Sousa 2015), while *G. triplex* have much larger basidiomes, measuring up to 150 mm, in addition to a distinct strongly prominent collar formed from the pseudoparenchymatous layer (Calonge 1998, Zamora *et al.* 2013). *Geastrum lageniforme* is the first record for the Brazilian Cerrado biome and the first collected in phytophysiognomies of the Rupestrian Cerrado.

Geastrum morganii Lloyd, Mycological Writings 1(8): 80 (1902) (Fig. 6)

ETYMOLOGY. In reference to the American botanist Andrew Price Morgan.

DESCRIPTION. Immature basidiome epigeous, mammiform, cinnamon brown (6D6), with gregarious growth, 7.1–13 mm height × 5.2–9.8 mm width. Surface not encrusted, rhizomorph evident 7.76–10.63 mm long. Expanded basidiomata saccate, 8.0–17.7 mm height (including peristome) × 15.9–25.1 mm width. Open exoperidium formed by 5–6 arched rays, involute, non-hygroscopic, 7.3–11.2 mm. Mycelial layer single-layered, orange grey (6B2) when fresh, to clay (5D5) to honey yellow (5D6) when dehydrated, persistent and not encrusted, with a papyraceous consistency. Fibrous layer pale orange (5A3), papyraceous. Pseudoparenchymatous layer slightly rimous, yellowish grey (4B2) when fresh, to linoleum brown (5E7) when dehydrated. Endoperidium mammiform, brownish grey (5C2), 8.7–10.4 mm height (including peristome) × 6.6–11.4 mm width, sessile, surface glabrous. Apophysis and pedicel absent. Peristome mammiform, irregularly sulcate, not delimited, concolor with the endoperidium, slightly darker at apex. Gleba brownish gray (6F2). Rhizomorph absent.

Basidiospores brownish, globose to slightly elliptical, 2.5–3.7 × 2.5–3.1 µm [$\chi = 3.2 \pm 0.4 \times 2.9 \pm 0.3$, Qm = 1.12, n = 30], conspicuous ornamentation under LM (< 1 µm) and verrucous under SEM, verrucae long and columnar, truncated, rounded to flattened at the apex, pedicel discreet. Eucapillitium brownish, 1.88–4.38 µm diam., thin-walled (< 1 µm width), surface not

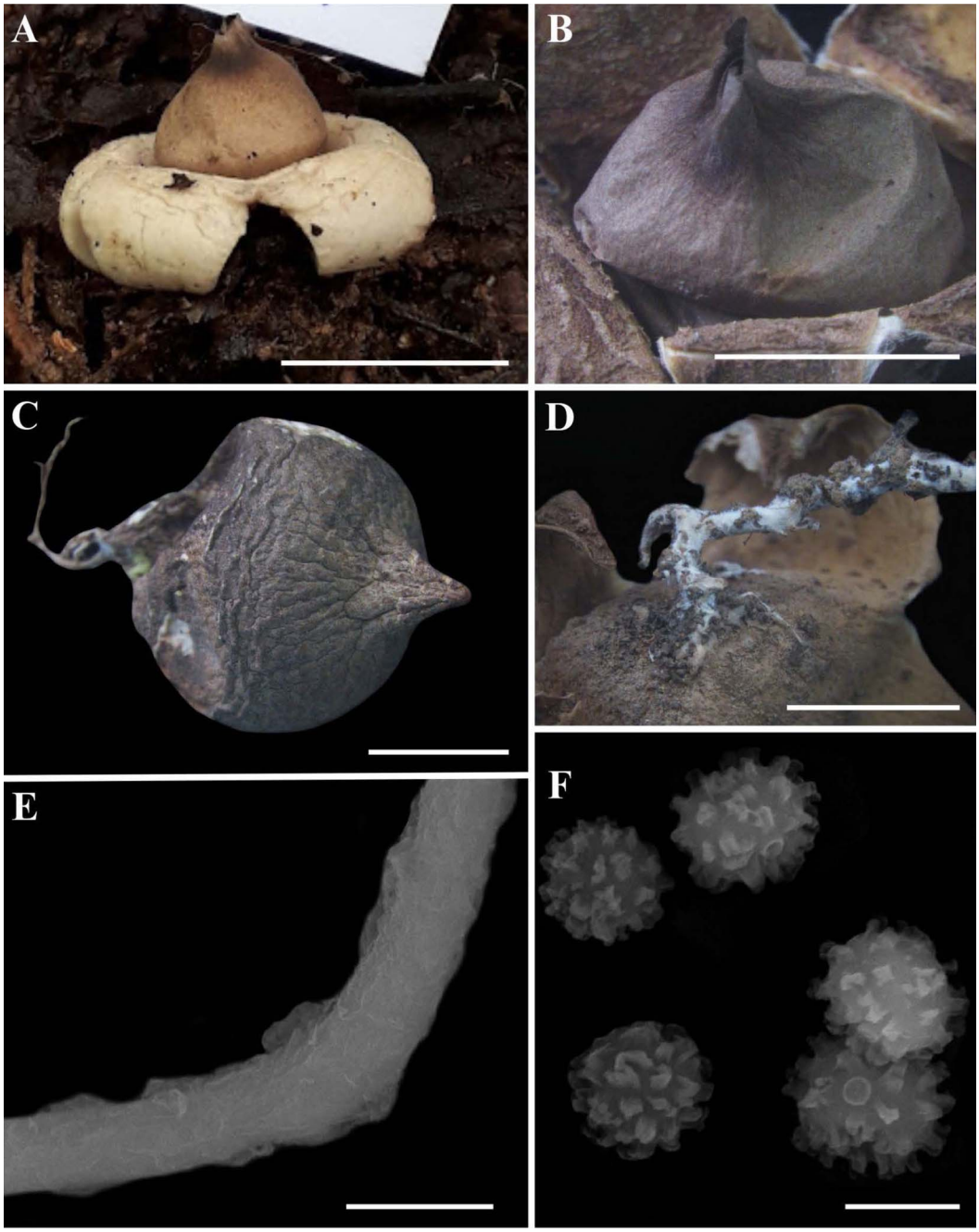

FIG. 6. *Geastrum morganii* (BRBA-Fungos 0034). A. Mature basidiome in field. B. Details of the peridium, and non-delimited peristome. C. Immature basidiome mammiform. D. Details of the rhizomorph. E. Capillitium under SEM. F. Basidiospores under SEM. Scale A = 15 mm; B, C–D = 5 mm; D = 5 mm; E = 5 μm; F = 2 μm.

encrusted, lumen evident, unbranched. Mycelial layer composed of greenish hyphae, 1.9–3.7 μm diam., thin-walled (< 1 μm width), not encrusted, slightly sinuous, unbranched. Fibrous layer formed by hyaline hyphae, 1.9–3.8 (–5) μm diam., thick-walled (> 1 μm width), not encrusted, lumen evident, slightly sinuous, unbranched. Pseudoparenchymatous layer composed of hyaline to brownish

cells, thick-walled (> 1 µm width), ranging from globose, cylindrical to ellipsoid, 12.3–22.5 × 6.9–15.2 µm. Rhizomorph composed of hyaline hyphae, greenish yellow, 1.9–2.5 µm diam., thin-walled (< 1 µm width), surface encrusted, lumen evident, slightly sinuous.

HABITAT. Growing over termite mound, in a gregarious growth pattern.

DISTRIBUTION. Africa (Dissing and Lange 1962); America (Coker and Couch 1928, Calonge and Mata 2006, Hemmes and Desjardin 2011, Caffot *et al*. 2013); Europe (Sunhede 1989). In Brazil, this species was previously recorded in the state of Rio Grande do Norte (Sousa *et al*. 2014a).

PHYTOPHYSIOGNOMY. Sparse Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, Barreiras, *Família Barbosa* Farm, Cerrado *stricto sensu*, Sparse Cerrado, over termite mound, with gregarious growth, 12°8′11.10.0″S, 45°04′28.7″W, 25 March 2020. Barbosa, K.D., KD0034 (BRBA–Fungos 0034).

NOTES. *G. morganii* is characterized by having a saccate basidiomata at maturity, a sessile endoperidium, and an irregularly sulcate and non-delimited peristome, in addition to having basidiospores with columnar warts flattened at the apex (Sousa *et al.* 2014a, Sousa 2015). *G. morganii* is morphologically similar to *G. violaceum* Rick, as it has a sessile endoperidium and an irregularly sulcate peristome (Sousa *et al.* 2014c, Sousa 2015). Both species belong to section *Corollina*, subsection *Plicostomata*, characterized by having an irregularly sulcate peristome, not thickened, and indistinctly delimited (Zamora *et al.* 2014). However, *G. violaceum* has a color with shades that vary from lilac to pink (Sousa *et al.* 2014a), while *G. morganii* has a chestnut-like brown, brownish, or yellowish-brown color (Sousa *et al.* 2014a). Another species similar to *G. morganii* is *G. elegans* Vittad, which also has an irregularly sulcate peristome; however, in specimens of *G. morganii*, the delimitation is not as evident as the delimitation of *G. elegans*, which has a greater number of grooves (10–20) and an endoperidium with a little amount of crystalline matter (Sunhede 1989, Calonge and Mata 2006). Furthermore, *G. elegans* is phylogenetically grouped in the section *Elegantia*, characterized by having a well-developed mesoperidium and a distinctly sulcate peristome (Zamora *et al.* 2014).

Geastrum morganii can also be compared to specimens of *G. reticulatum* Desjardin & Hemmes, as both species have conical or mammiform immature basidiomata and saccate mature basidiomata. However, *G. reticulatum* is distinguished by having an exoperidial surface covered by a reticulated network of raised hairs and a regularly sulcate and distinctly delimited peristome (Hemmes and Desjardin 2011), while *G. morganii* has an irregularly sulcate and indistinctly delimited peristome (Sousa *et al.* 2014a, Sousa 2015). Finally, *G. triplex* is another species morphologically related to *G. morganii* in that it has a collar around the endoperidium formed by the pseudoparenchymatous layer; however, *G. triplex* has more robust basidiomata, a distinctly delimited endoperidium, and a fibrillose peristome (Sunhede 1989, Kuhar and Papinutii 2009). This is the first record of *Geastrum morganii* for the state of Bahia, and for the Brazilian Cerrado biome.

Geastrum* aff. *rusticum Baseia, B.D.B. Silva and T.S. Cabral, Nova Hedwigia 98: 267 (2012)
(Fig. 7)

ETYMOLOGY. Based on the rustic appearance of basidiomata.

DESCRIPTION. Immature basidiome absent. Expanded basidiome saccate, 8–11 mm height (including peristome) × 22–25 mm width. Open exoperidium formed by 5–7 rays, horizontal, triangular to revolute, non-hygroscopic. Mycelial layer pale orange (5A3) when fresh and greyish orange (5B3) when dehydrated; papyraceous surface, encrusted, persistent; falling off slightly in irregular portions during the maturation process. Fibrous layer platinum blonde (4B3) when fresh to brownish orange (5C3) when dehydrated, coriaceous surface. Pseudoparenchymatous layer brownish orange to greyish red (6C3–7B3) when fresh, and brownish gray (5D3–5E4) when dehydrated; persistent, falling off at the base of basidiome rays with age. Endoperidium globose to subglobose, greyish brown to brown (7D3–7F4), 9–13 mm height (including peristome) × 12–16 mm width, sessile, surface glabrous. Apophysis and pedicel absent. Peristomium fimbriate to lacerated, not delimited, slightly mammiform, concolor with the endoperidium,

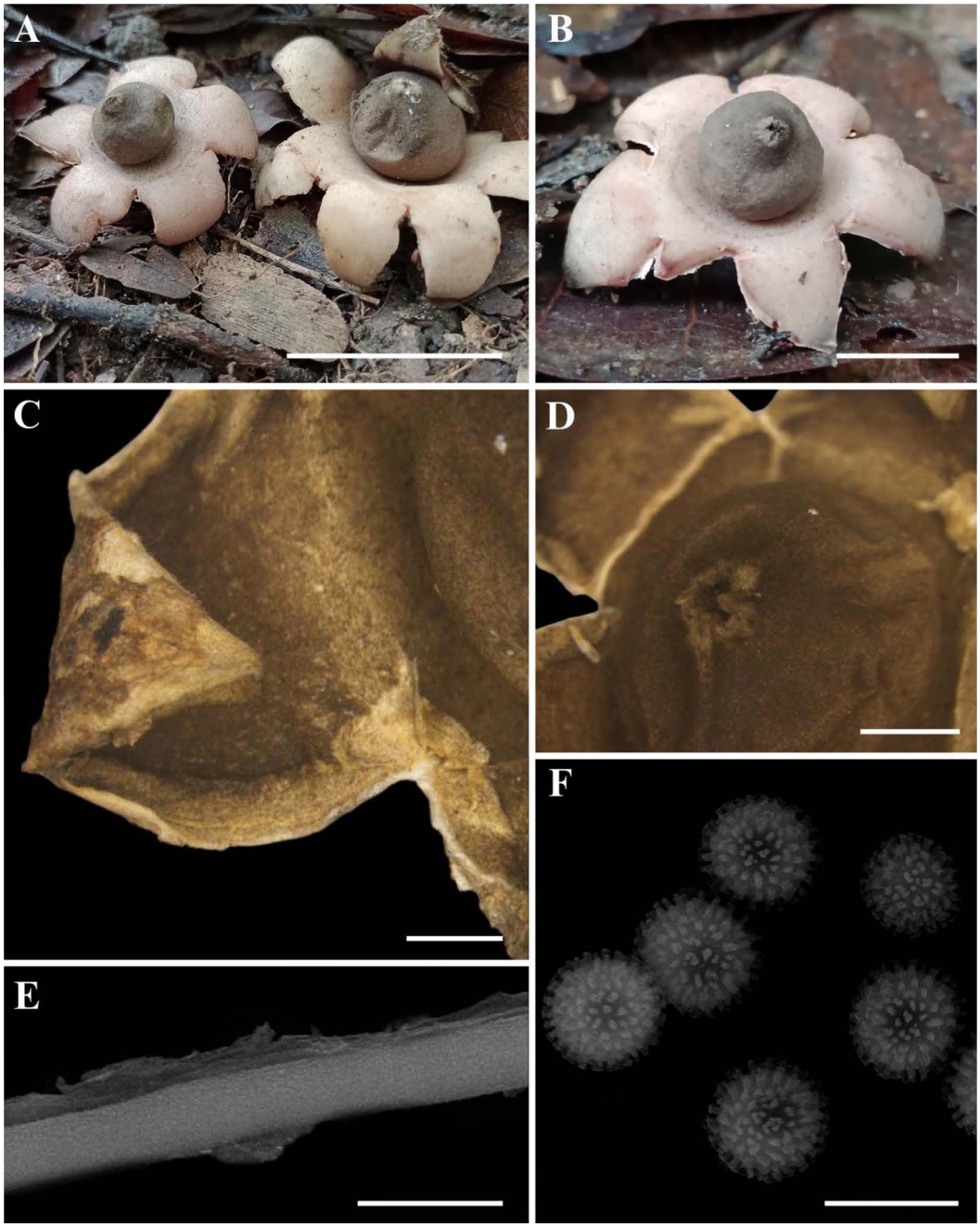

FIG. 7. *Geastrum* aff. *rusticum* (BRBA-Fungos 0112). A–B. Mature basidiomata in field. C. Details of the peridium. D. Details of the endoperidium, and non-delimited peristome. E. Capillitium under SEM. F. Basidiospores under SEM. Scale: A = 15 mm; B = 10 mm; C = 1.5 mm; D = 3 mm; E = 5 μm; F = 5 μm.

and sometimes slightly darker. Gleba dark brown (7F8). Rhizomorph absent.

Basidiospores chestnut brown, globose to subglobose, 6.2–6.7 (–7.3) × 5.1–5.8 μm [$\chi = 6.1 \pm 0.3 \times 5.4 \pm 0.3$, Qm = 1.05, n = 30], conspicuous ornamentation under LM (<1 μm) and verrucous under SEM, verrucae short and columnar, truncated, rounded to flattened at the apex, pedicel

discreet. Eucapillitium yellowish-brown, 3.2–7.4 µm diam., thick-walled (> 1 µm width), surface slightly encrusted, lumen evident, not septate, unbranched. Mycelial layer composed of hyaline, thin-walled hyphae (< 1 µm width), 1.2–4.1 µm in diam., surface slightly encrusted, lumen evident, sinuous, coiled, unbranched. Fibrous layer formed by hyaline hyphae, 3.5–7.1 µm diam., thin- to thick-walled (0.7–3.3 µm width), surface encrusted, slightly sinuous, lumen evident, not septate, unbranched. Pseudoparenchymatous layer composed of thin-walled hyaline hyphae (< 1 µm width), ranging from subglobose, pyriform, to irregular, 22.2–77.6 × 18.2–47.5 µm.

HABITAT. Soil covered by litter and decaying wood, in a gregarious growth pattern.

DISTRIBUTION. Brazil. The species was previously recorded in the states of Rio Grande do Norte (Cabral *et al.* 2014), Ceará (Sousa *et al*. 2014b) and Paraíba (Sousa *et al*. 2014b).

PHYTOPHYSIOGNOMY. Rupestrian Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, Barreiras, Municipal Park of Life, *Acaba Vida* Waterfall, Cerrado *stricto sensu*, Soil covered by litter and decaying wood, in a gregarious growth pattern, 11° 53′37″S, 45°36′4″W, 19 February 2023. Barbosa, K.D. & Cruz, R.H.S.F. (BRBA–Fungos 0112).

NOTES. *Geastrum rusticum* Baseia, B.D.B. Silva & T.S. Cabral is characterized by having mature basidiomata saccate to slightly arched, and a semi-hypogeous immature basidiome, in addition to a heavily encrusted mycelial layer, a peristome lacerated and non-delimited, and basidiospores verrucous with short ornamentations (Cabral *et al.* 2014, Sousa 2015). The basidiomata of the sample collected in the Cerrado were found growing in fresh soil covered by litter, while the type species has a registered habit as a lignicolous. Together with this, the sample from the Cerrado has basidiomata with measurements remarkably similar to the type material, with 22–25 mm in diameter in the mature sample in the new record, while the original material has 23–26 mm in diameter (Cabral *et al.* 2014). The difference that makes this sample like "aff." is that the Cerrado materials have slightly larger basidiospores (6.2–6.7 µm diam., reaching up to 7.3 µm diam.), while the holotype described for the Atlantic Forest areas in Brazil (type locality) has relatively smaller basidiospores (3.5–5.1 µm diam.). Due to this being the unique difference found between both species, together with the substrate, it was reasonable to indicate the sample described here as *species affinis* of *Geastrum rusticum*.

G. aff. *rusticum* is morphologically similar to specimens of *G. fimbriatum* Fr. by the presence of an encrusted mycelial layer, and saccate to arched basidiomata (Fazolino 2009, Sunhede 1989); however, *G.* aff. *rusticum* is distinguished by not having an endoperidium with protuberant hyphae (Sunhede 1989, Cabral *et al.* 2014). Another species quite similar to *G.* aff. *rusticum* is *G. echinulatum* T.S. Cabral, B.D.B. Silva & Baseia, as both species also have a mature basidiome saccate and non-delimited peristome (Silva *et al*. 2013, Cabral *et al.* 2014, Sousa 2015). Still, *G. echinulatum* differs by the presence of a subiculum, basidiospores with distinct ornamentation, and a pinkish pseudoparenchymatous layer (Silva *et al.* 2013, Sousa 2015).

G. aff. *rusticum* can also be compared to specimens of *G. hieronymi* Henn., as both species present an encrusted mycelial layer, a fibrillose and non-delimited peristome, and immature basidiomata that are relatively hypogeous (Bates 2004, Cabral *et al.* 2014, Sousa 2015); however, specimens of *G. hieronymi* have pedicels and protuberant hyphae in the endoperidium (Bates 2004, Cabral *et al.* 2014, Sousa 2015). Another close species is *G. floriforme* Vittad., based on the phylogenetic position; however, *G. floriforme* is distinguished by the presence of a non-persistent mycelial layer, larger basidiospores (5.0–7.0 µm in diameter), and an endoperidium with a furfuraceous surface (Cabral *et al.* 2014, Sousa 2015). No records of *G. rusticum*, or any similar or *affinis* specimen, are registered for the Brazilian Cerrado biome, so this is the first record for the Cerrado in a Typical Cerrado phytophysiognomy.

Geastrum triplex Jungh., Tijdschr. Nat. Gesch. Physiol. 7: 287 (1840) (Fig. 8)

ETYMOLOGY. Based on the well-observed three layers (fibrous, pseudoparenchymatous, and mycelial) in the peridium, with the pseudoparenchymatous layer forming a collar.

DESCRIPTION. Immature basidiome absent. Expanded basidiome 27.9–33.3 mm height (including

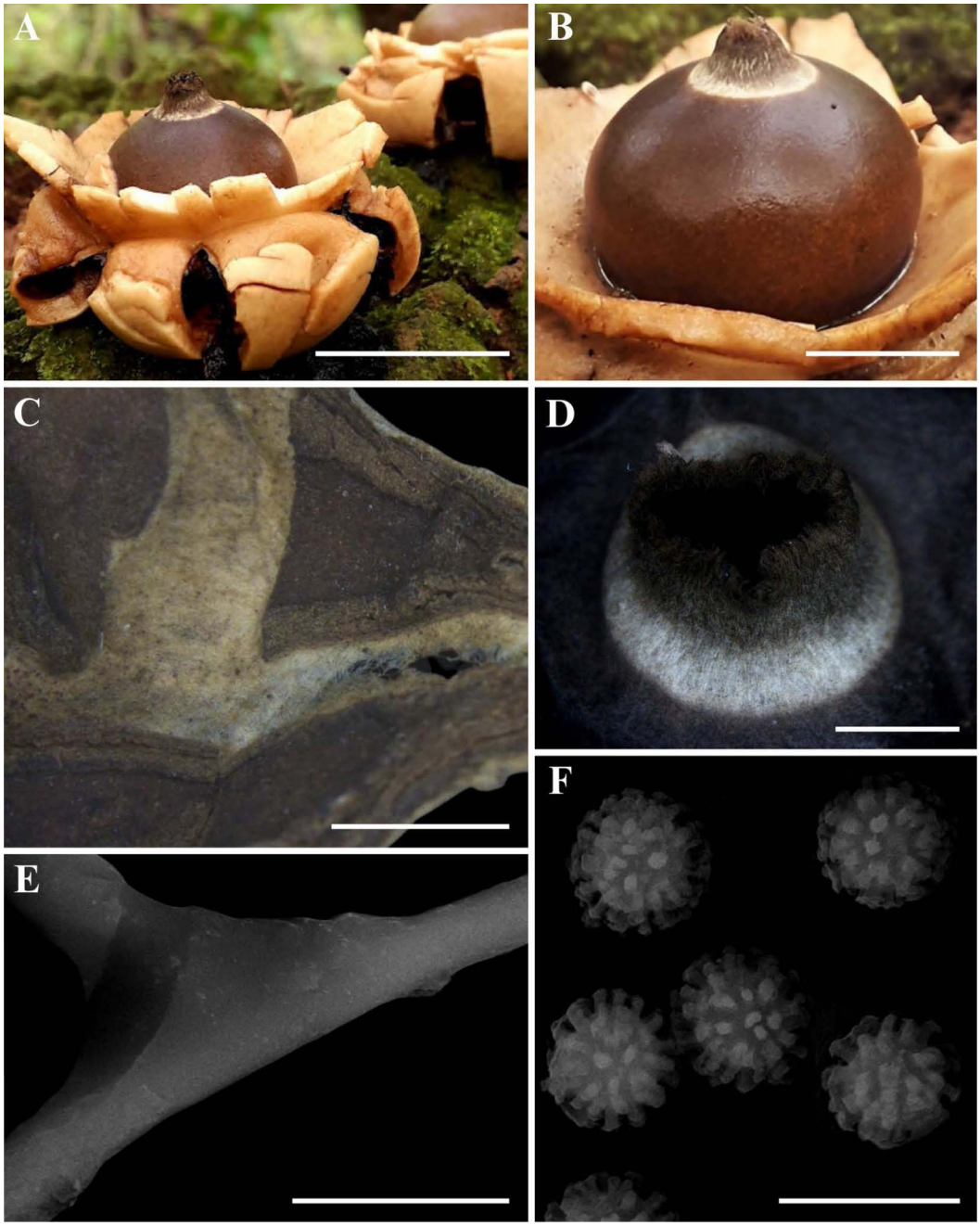

FIG. 8. *Geastrum triplex* (BRBA-Fungos 0009). A. Mature basidiomata in field. B. Details of the endoperidium with delimited peristome. C. Details of the exoperidium. D. Delimited peristome. E. Capillitium under SEM. F. Basidiospores under SEM. Scale: A = 2.5 mm; B = 1 mm; C = 3 mm; D = 1 mm; E = 10 μm; F = 5 μm.

peristome) × 45.7–48.7 mm width. Open exoperidium formed by 6–7 arched rays, involute, non-hygroscopic, 25.2–21.3 mm. Mycelial layer persistent, not encrusted, coriaceous, orange gray (6B2) when fresh, and golden blonde (5C4) when dehydrated. Fibrous layer coriaceous, orange white (5A2). Pseudoparenchymatous layer slightly rimose, with the presence of a brownish collar (6E7). Endoperidium globose, sessile, surface glabrous, chocolate brown (6F4), 23.8–26.1 mm height × 22.9–24.7 mm width.

Apophysis and pedicel absent. Peristome conical, fimbriate, delimited, orange gray (6B2) to brownish (6E7) at apex, 2.6–2.3 mm in height. Gleba dark brown (7F4). Rhizomorph absent.

Basidiospores brownish, globose to subglobose, 4.7–6.0 × 4.1–5.8 µm [$\chi = 5.1 \pm 0.3 \times 4.8 \pm 0.4$, Qm = 1.07, n = 30], conspicuous ornamentation under LM (<1 µm) and verrucous under SEM, verrucae long and columnar, truncated, rounded to flattened at the apex, pedicel discreet. Eucapillitium brownish, thick-walled 3.1–6.4 µm diam., (> 1 µm width), surface encrusted, strongly verrucous, lumen evident, unbranched. Mycelial layer composed of hyaline hyphae, 3.1–7.6 µm diam., thick-walled (> 1 µm width), surface encrusted, lumen evident, slightly sinuous, branched. Fibrous layer formed by hyaline hyphae, 4.2–8.3 µm diam., thick-walled (1.3–2.1 µm) width, surface not encrusted, septate, slightly curved, lumen evident. Pseudoparenchymatous layer composed of hyaline hyphae, thin- to thick-walled, (0.7–1.3 µm width), ranging from subglobose, pyriform, oblong, to oval, 32.9–82.5 × 15.9–48.5 µm.

HABITAT. Soil covered by litter and over termite mound, in a gregarious growth pattern.

DISTRIBUTION. Cosmopolitan (Dissing and Lange 1962, Sunhede 1989, Grgurinovic 1997, Calonge 1998, Bates 2004, Leite and Baseia 2007, Hemmes and Desjardin 2011). In Brazil, this species was previously recorded in the states of Amazonas (Cabral *et al*. 2014), Ceará (Sousa *et al*. 2014b), Paraíba (Sousa *et al*. 2014), Paraná (de Meijer 2006), Pernambuco (Drechsler-Santos *et al*. 2008, Trierveiler-Pereira *et al*. 2011), Rio Grande do Norte (Leite and Baseia 2007), Rio Grande do Sul (Rick 1961), Santa Catarina (Sobestiansky 2005), and São Paulo (Baseia *et al*. 2003).

PHYTOPHYSIOGNOMY. Dense Cerrado.

EXAMINED MATERIAL. Brazil, Bahia, Barreiras, *Família Barbosa* Farm road, Cerrado *stricto sensu*, soil covered by litter and over termite mound, in a gregarious growth pattern, 12°08′47.2″S, 45°01′40.2″W, 15 April 2020. Barbosa, K.D., KD0041 (BRBA–Fungos 0138); KD0042 (BRBA–Fungos 0009).

NOTES. *Geastrum triplex* Jungh. is characterized by the prominent collar formed from the opening of the pseudoparenchymatous layer, robust basidiomata in the field, a relatively squamulose mycelial layer, a fibrillose peristome, and a well-delimited sessile endoperidium (Sousa *et al.* 2014b, Sousa 2015). Commonly, the specimens of *G. triplex* from South America are much smaller (4.7–35 mm in diam.) compared to species from Europe, which are much larger, reaching up to 150 mm in diameter (Calonge 1998). This comparison can be easily observed in the descriptions of *G. triplex* for Brazil, as evidenced in the works of Trierveiler-Pereira *et al.* (2011), Sousa *et al.* (2014b), and Sousa (2015). *G. triplex* specimens morphologically resemble *G. saccatum* Fr., *G. lageniforme* Vittad., and *G. rufescens* Pers. because all these species present a pseudoparenchymatous collar in the mature basidiome. However, contrary to the representatives of *G. triplex*, these species are distinguished by having a small and much less conspicuous collar (Sunhede 1989).

Like *G. triplex*, specimens of G. *melanocephalum* (Czern.) V.J. Staněk also have a collar around the endoperidium and squamous mycelial layer, being phylogenetically close in the section *Trichaster*. However, *G. melanocephalum* differs by presenting a pedicellate endoperidium (Kasuya *et al.* 2012, Zamora *et al.* 2014). Other species, such as *G. fimbriatum*, and *G. litchiforme* Desjardin & Hemmes, also morphologically resemble *G. triplex*; however, *G. fimbriatum* is distinguished by having a non-delimited peristome and an encrusted mycelial layer, while *G. litchiforme* has an ephemeral mycelial layer with pyramidal tufts and a non-delimited peristome. *Geastrum triplex* is the second record of this species for the Brazilian Cerrado (the first one was described by Baseia *et al*. 2003 in an area of vegetational transition in the state of São Paulo, Brazil), and the first for the state of Bahia.

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