An Acad Bras Cienc (2021) 93(Suppl. 3): e20201442 DOI 10.1590/0001-3765202120201442
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

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1916 • 2021

ECOSYSTEMS

Insect galls and associated fauna in two areas of Cerrado *sensu stricto* in the State of Bahia, Brazil

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Abstract: This study inventoried and characterized the richness of galling insects based on gall morphotypes and their host plants in two Cerrado *sensu stricto* areas of Caetité municipality in Bahia State, Brazil, to aid the identification of galling insects and their host plants, as well as to contribute to the knowledge and conservation of local biodiversity. The survey was conducted in the Moita dos Porcos archaeological site and João Barroca Farm site, adopting the random walking methodology for sampling, during 12 months. We recorded 98 gall morphotypes on 42 plant species belonging to 36 genera and 22 families. Leguminosae, Malpighiaceae and Myrtaceae demonstrated the greatest richness of galls, and the *Copaifera langsdorffii* was the super-host species, with 16 gall morphotypes. Most galls occur on leaves, and may be globoid, glabrous, grouped, and are usually unilocular, and brown. The galling insects identified belonged to Coleoptera, Diptera, Lepidoptera, and Thysanoptera. Eight plant host species and eight gall morphotypes were recorded for the first time in Cerrado areas in Brazil. The areas surveyed demonstrated high richness of gall morphotypes and host plants, evidencing the importance of studying and preserving different areas of the same biome.

Key words: *Copaifera* galls, gall morphotypes, Malpighiaceae, savanna.

INTRODUCTION

Brazilian Cerrado is a hostpost of biodiversity, which is formed by mosaic of different phytophysiognomy, demonstrating elevated levels of species richness. It hosts more than 12,330 plant species (BFG 2018, 2021) and one third of Brazilian biodiversity, with a high level of endemism, making it the most biodiverse savanna in the world (Klink & Machado 2005). In the state of Bahia, the Cerrado covers an area of approximately 9.1 million hectares (Faleiro 2015) distributed mainly in the western region of the state (Harley 1995). In addition, the Cerrado of Bahia is also distributed in higher regions forming small patches interspersed by Campos Rupestres, Caatinga and Seasonal Forests and transition areas, as occurs in Chapada Diamantina (Harley et al. 2005), and Serra Geral of the Caetité municipality (Bahia State, Brazil).

The Brazilian Cerrado is also one of the most threatened biomes, due to continuing deforestation. It is estimated that 43% of its native vegetation has already been removed or transformed (MMA 2015). The Cerrado areas of the Caetité municipality have been subjected to constant environmental impacts (Rodrigues et al. 2017) due to iron ore and limestone rock extraction (DNPM 2014), the construction of wind farms (Prudente et al. 2017), and amethyst mining.

Cerrado vegetation has several interactions among plants and herbivores (Ribeiro & Fernandes 2000, Furtado et al. 2003, Cintra et al.

2020). Among the different forms of herbivory, the endophytic habit of galling insects is by far the most sophisticated (Shorthouse et al. 2005). Galling insects are capable of inducing galls through disordered processes of hyperplasia, hypertrophy, and cellular differentiation in plant tissues (Ferreira & Isaias 2013). The structures resulting from those interactions provide shelter for the gall-inducing insect against abiotic and biotic factors, allowing its successful development, and energetic resources for nutrition of the inducers (Price et al. 1987, Stone & Schönrogge 2003).

The Brazilian Cerrado has been the subject of in-depth studies on the richness of galls, mainly in state of Minas Gerais (*e.g.,* Gonçalves-Alvim & Fernandes 2001, Urso-Guimarães et al. 2003, Carneiro et al. 2009a, Araújo & Guilherme 2012, Coelho et al. 2013, Cintra et al. 2020). The richness of gall studies in the Cerrado of Bahia State has been little studied; only five has yet been undertaken in the municipalities of Caetité (Nogueira et al. 2016, Vieira et al. 2018, Silva et al. 2018, Santana et al. 2020) and Barreiras (Lima & Calado 2018). These studies in the Cerrado of Bahia recorded a total of 144 different types of galls in 103 plant species.

Studies of galling insect richness have demonstrated the usefulness of that insect guild as a measure of environmental conservation and quality (Santos et al. 2012, Santana & Isaias 2014, Brito et al. 2018). The entomofauna associated with galls responds to environmental disturbances, with resulting losses of species richness and abundance (which also impact their natural enemies) (Oliveira 2009). As such, inventories of gall-inducing insect richness can assistance in urban planning, design, and management (Julião et al. 2005) as well as for environmental monitoring and conservation activities (Santana & Isaias 2014, Melo-Júnior et al. 2018). Here, we realized an inventory of the richness of galling insects in two Cerrado *sensu stricto* areas of the Caetité municipality (Bahia) and a similarity analysis between areas based on gall morphotypes and their host plants to contribute to the knowledge and conservation of local biodiversity.

MATERIALS AND METHODS

Study area

The study was carried out in two localities of Cerrado *sensu stricto* vegetation in the municipality of Caetité, Bahia State, Brazil: João Barroca Farm (JB) (14°19’23.96” S and 42°33’’7.91” W) situated about 40 km of Caetité’s center, and the Moita dos Porcos archaeological site (MP) (14°10’1.52” S and 42°31’’16.05” W) approximately 15 km from the city center. The areas studied were selected on the basis of accessibility for sampling, the distance from previously sampled areas, and the presence of preserved vegetation (Costa et al. 2014a, b, Nogueira et al. 2016, Vieira et al. 2018, Silva et al. 2018, Santana et al. 2020). The JB comprises approximately 105 hectares of preserved area at 950 m elevation, while the MP covers approximately 300 hectares of preserved area at 920 m elevation. The vegetation is composed of many herbaceous and woody species, with a palm (*Syagrus werdermannii* Burret, Arecaceae) and sparse trees from 2 to 3 m tall (*e.g.*, *Hymenaea courbaril* L., Leguminosae). The soil is sandy to sandy with rock outcrops on the higher elevation sites (Alves 2008). The regional climate is *Aw* (Alvares et al. 2013), with a mean annual temperature of 21.4°C and mean annual rainfall of 862 mm (IBGE 2015).

Sampling method

The Cerrado vegetation was examined during 12 months, between May 2016 to April 2017 throughout the MP site and between August 2017 to July 2018 at the JB site, adopting the random walking methodology for sampling (Julião et al. 2002, Oliveira & Maia 2005, Coelho et al. 2009). In these areas, the galls and the host plants were collected once a month by two people working for four person-hours along pre-existing trails, totaling 96 hours of total collecting efforts. All plant architectural types (herbaceous, shrub, arboreal, tree and vines) up to 2 m tall were inspected. Each gall morphotype was photographed in field, and characterized based on shape, color, presence or absence of trichomes, number of internal chambers (Isaias et al. 2013). Specimens of the host plants were collected, pressed, and deposited in the Caetité Collection of the HUNEB herbarium. The plants were identified by consulting the taxonomic literature and contacting botanical specialists, and by comparisons with herbarium collections at the Universidade do Estado da Bahia (HUNEB, Caetité collection) and the Universidade Estadual de Feira de Santana (HUEFS). Plant nomenclature was verified in the Flora do Brasil 2020 (www.floradobrasil.jbrj.gov.br) and, the names are presented in alphabetical order by family, following APG IV (2016). The circumscription of the Leguminosae family was based on classification proposed by LPWG (2017).

The samples of each gall morphotypes collected in the field were analyzed in laboratory. Galls were dissected under a stereomicroscope to retrieve any larvae of the gall-inducing insects and/or associated fauna, as well as observation the number of larval chamber. To obtain adults, samples of each gall morphotype were held separately in labeled plastic containers (lined with paper) and inspected daily. All of the insects obtained were conserved in 70% alcohol and sent to be identified at the Diptera Laboratory of the National Museum at the Universidade Federal do Rio de Janeiro.

Statistical Analysis

Sørensen's similarity index (S= 2c/a+b) (Sørensen 1948) was used to compare the two localities in relation to the host plants (c = number of host plant species common to JB and MP, a = number of species in JB and b = number of species in MP) and gall morphotypes (c= number of gall morphotypes common to JB and MP, a = number of gall morphotypes in JB and b = number of gall morphotypes in MP).

RESULTS

We recorded 98 gall morphotypes on 42 plant species belonging to 36 genera and 22 families (Table I; Figures 1-5). Galls were recorded for the first time on the plant species *Alchornea tiliifolia* (Benth.) Müll. Arg. (Euphorbiaceae, Fig. 1m), *Byrsonima correifolia* A. Juss. (Malpighiaceae, Fig. 4c), *Dalbergia acuta* Benth. (Leguminoseae-Papilionoideae, Fig. 3m), *Erythroxylum stipulosum* Plowman (Erythoxylaceae, Fig. 1l), *Eugenia lucidifolia* Barb. Rodr. (Myrtaceae, Fig. 5b), *Pseudobrickellia brasiliensis* (Spreng.) R. M. King & Rob. (Asteraceae, Fig. 1h), *Senna cana* (Nees & Mart.) H. S. Irwin & Barneby var. *cana* (Leguminoseae- Caesalpinioideae, Fig. 2f), and *Lippia origanoides* Kunth (Verbenaceae, Fig. 5p).

A total of 73 gall morphotypes were found on the JB farm on 35 plant species belonging to 31 genera and 20 families (Table I). The species of the families Leguminosae, Malpighiaceae and Myrtaceae hosted the greatest gall richness, with 31, nine, and nine morphotypes, respectively. The plant genera with the greatest richness of gall morphotypes were *Copaifera* L. (Leguminosae-Detarioideae) (n = 13, n = 2 host species) and *Byrsonima* Rich. ex Kunth (Malpighiaceae) (n = 7, n = 4 host species). The super-host species with the greatest richness of gall morphotypes

Table I. Insect galls of areas of Cerrado *sensu stricto* vegetation in the municipality of Caetité, Bahia State, Brazil. Abbreviations: JB, the João Barroca farm; MP, the Moita dos Porcos Archaeological Site.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
ANACARDIACEAE											
Anacardium humile A. St. -Hil	Leaf	Abaxial	Green or brown	Globoid	No	Grouped	1	Cecidomyiidae	-	JB	1a
	Leaf	Adaxial	Brown	Lenticular	No	Isolated or grouped	1	-	-	MP	1b
ANNONACEAE											
Annonaceae Indet. 1	Stem	-	Brown	Globoid	No	Isolated	1	-	-	MP	1c
Annona leptopetala (R. E. FR.) H. Rainer	Leaf	Adaxial	Green	Globoid	Yes	Isolated	1	-	-	JB	1d
Duguetia furfuracea (A. St-Hil.) Saff.	Leaf	Adaxial	Green	Globoid	No	Grouped	Various	Cecidomyiidae	Hymenoptera	JB, MP	1e
	Leaf	Adaxial	Brown	Amorphous	No	Grouped	Various	-	-	JB, MP	1f
ASTERACEAE											
Moquiniastrum paniculatum (Less). G. Sancho	Leaf	Adaxial	White	Globoid	Yes	Grouped	1	Cecidomyiidae	Hymenoptera	JB	1g
Pseudobrickellia brasiliensis (Spreng.) R. M.King & H.Rob	Stem	Adaxial	Green	Globoid	No	Isolated	1	-	-	JB	1h
CELASTRACEAE											
Maytenus sp.	Stem	-	Black	Amorphous	No	Grouped	1	-	-	JB	1i
COMBRETACEAE											
Combretum leprosum Mart.	Leaf	Adaxial	Yellow	Globoid	No	Isolated	1	Cecidomyiidae	-	JB, MP	1j
ERYTHROXILACEAE											
Erythroxylum suberosum A. St.-Hil.	Leaf	Adaxial	Red	Globoid	Yes	Grouped	1	*Myrciaryiamia admirabilis* Maia, 2007 (Diptera, Cecidomyiidae)	Formicidae	JB, MP	1k
Erythroxylum stipulosum Plowman	Leaf	Adaxial	Green	Lenticular	No	Isolated	1	-	-	JB	1l
EUPHORBIACEAE											
Alchornea tiliifolia (Benth.) Müll. Arg.	Leaf	Abaxial	Brown	Globoid	No	Isolated	1	-	-	MP	1m

Table I. Continuation.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
Manihot tripartita (Spreng.) Müll. Arg	Leaf	Adaxial	Green	Fusiform	No	Grouped	1	Cecidomyiidae	-	JB	1n
LAURACEAE											
Ocotea lancifolia (Schott) Mez	Stem	-	Brown	Globoid	No	Isolated	Various	-	-	JB	1o
LEGUMINOSAE											
LEGUMINOSAE- CAESALPINIOIDEAE											
Calliandra dysantha Benth.	Stem	-	Brown	Globoid	No	Grouped	1	-	Hymenoptera	JB, MP	1p
	Stem	-	Brown	Fusiform	No	Isolated	Various	-	-	MP	1q
	Leaf	Adaxial	Brown	Leaf fold	No	Isolated	1	-	Thysanoptera	JB	1r
Calliandra macrocalyx Harms	Stem	-	Brown	Fusiform	No	Isolated	1	-	Hymenoptera	JB	1s
Mimosa gemmulata Barneby	Stem	-	Brown	Fusiform	Yes	Isolated	Various	-	Lepidoptera	JB	1t
	Leaf	Adaxial	Green	Bivalve-shaped	Yes	Isolated or grouped	1	Cecidomyiidae	-	JB	2a
	Leaf	Adaxial	Brown	Clavate	Yes	Isolated	1	-	-	JB	2b
	Leaf	Adaxial	Brown	Bivalve-shaped	Yes	Isolated or grouped	1	*Lopesia* sp. (Diptera, Cecidomyiidae)	-	JB, MP	2c
	Leaf	Adaxial	Green	Bivalve-shaped	No	Isolated or grouped	1	Cecidomyiidae	-	JB	2d
Senegalia langsdorffii (Benth.) Seigler & Ebinger	Stem	-	Brown	Globoid	No	Isolated	Various	-	-	JB	2e
Senna cana (Ness & Mart) H. S. Irwin & Barneby	Leaf	Adaxial	Red	Lenticular	No	Isolated	1	-	-	JB	2f
LEGUMINOSAE- CERCIDOIDEAE											
Bauhinia acuruana Moric.	Leaf	Adaxial	Green	Bivalve-shaped	No	Isolated	Various	-	-	JB	2g
	Leaf	Adaxial	Brown	Globoid	Yes	Grouped	Various	-	Araneae	MP	2h
	Leaf	-	Green	Marginal roll	No	Isolated	1	-	-	JB	2i
Bauhinia pulchella Benth.	Stem	-	Brown	Fusiform	No	Grouped	1	Lepidoptera	-	JB	2j

Table I. Continuation.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
	Leaf	-	Green	Leaf fold	No	Isolated	1	Cecidomyiidae	-	JB	2k
	Leaf	Adaxial	Brown	Globoid	No	Grouped	1	Cecidomyiidae	-	JB	2l
LEGUMINOSAE- DETARIOIDEAE											
Copaifera langsdorffii Desf.	Stem	-	Orange	Globoid	No	Grouped	Various	-	Araneae	JB, MP	2m
	Stem	-	Red	Globoid	No	Grouped	1	-	Hymenoptera	JB, MP	2n
	Stem	-	Green	Globoid	No	Isolated	1	-	-	JB	2o
	Stem	-	Brown	Globoid	No	Isolated	Various	Curculionidae (Coleoptera)	-	MP	2p
	Leaf	Adaxial	Pink	Lenticular	No	Isolated	1	-	-	JB	2q
	Leaf	Abaxial	Brown	Globoid	Yes	Grouped	1	-	Hymenoptera	JB. MP	2r
	Leaf	Adaxial	Yellow	Lenticular	No	Grouped	1	-	-	JB	2s
	Leaf	Abaxial	Brown	Globoid	No	Isolated	1	-	-	JB, MP	2t
	Leaf	Abaxial	Green	Globoid	No	Isolated	Various	-	-	JB, MP	3a
	Leaf	Abaxial	Red	Rosette	No	Isolated	1	-	-	JB	3b
	Leaf	-	Green	Leaf fold	No	Grouped	1	Cecidomyiidae	Hemiptera	JB	3c
	Leaf	Adaxial	Red	Globoid	No	Grouped	1	Cecidomyiidae	-	JB	3d
	Leaf	Adaxial	Black	Rosette	No	Isolated	1	-	-	JB	3e
	Leaf	Adaxial	Orange	Leaf fold	No	Isolated	1	-	-	MP	3f
	Leaf	Adaxial	Red	Globoid	No	Isolated	1	-	-	MP	3g
	Leaf	Adaxial	Red	Globoid	No	Isolated	1	-	Thysanoptera	MP	3h
Copaifera luetzelburgii Harms	Leaf	Abaxial	Green	Lenticular	No	Isolated or grouped	1	-	-	MP	3i
Hymenaea coubaril L.	Leaf	Adaxial	Brown	Globoid	Yes	Isolated or Grouped	1	-	-	JB, MP	3j
	Leaf	Abaxial	Green	Cylindrical	No	Isolated	1	-	-	JB	3k
LEGUMINOSEAE-PAPILIONOIDAE											
Andira parvifolia Mart. ex Benth.	Leaf	Abaxial	Green	Fusiform	No	Grouped	1	Cecidomyiidae	-	MP	3l
Dalbergia acuta Benth.	Bud	-	Yellow	Conical	Yes	Grouped	1	-	-	JB	3m
Dalbergia miscolobium Benth.	Stem	-	Brown	Fusiform	No	Isolated	1	Cecidomyiidae	-	JB	3n

Table I. Continuation.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
LORANTHACEAE											
Struthanthus sp.	Leaf	Abaxial	Green	Lenticular	No	Isolated	1	-	-	JB	3o
MALPIGHIACEAE											
Malpighiaceae Indet. 1	Leaf	Adaxial		Lenticular	No	Isolated	1	-	-	JB	3p
Malpighiaceae Indet. 2	Leaf	Adaxial	Brown	Lenticular	No	Grouped	1	-	-	JB	3q
Malpighiaceae Indet. 3	Leaf	Adaxial	Brown	Lenticular	No	Grouped	1	Cecidomyiidae	-	JB	3r
Malpighiaceae Indet. 4	Leaf	Adaxial	Brown	Globoid	No	Isolated	1	-	-	MP	3s
Malpighiaceae Indet. 5	Leaf	Adaxial	Brown	Lenticular	No	Grouped	1	-	-	MP	3t
Banisteriopsis malifolia (Ness & Mart) B. Gates	Leaf	-	Green	Marginal roll	Yes	Isolated	1	Lepidoptera	-	JB	4a
	Leaf	-	Brown	Globoid	Yes	Isolated	1	-	-	JB	4b
Byrsonima correifolia A. Juss.	Stem	-	Brown	Globoid	No	Grouped	1	-	-	MP	4c
Byrsonima gardneriana A. Juss.	Leaf	Adaxial	Brown	Globoid	No	Isolated	1	Cecidomyiidae	-	JB	4d
	Leaf	Adaxial	Green	Conical	Yes	Isolated	1	-	-	MP	4e
Byrsonima sericea DC.	Stem	-	Brown	Fusiform	Yes	Isolated	Various	-	-	MP	4f
	Bud	Adaxial	Orange	Globoid	No	Isolated	1	-	-	JB	4g
	Leaf	Adaxial	Brown	Fusiform	Yes	Isolated	1	-	-	MP	4h
Byrsonima sp.	Stem	-	Brown	Globoid	No	Isolated	1	-	-	MP	4i
Diospyros sp.	Leaf	Adaxial	Orange	Globoid	No	Isolated	1	-	-	MP	4j
Diplopterys pubipetala (A. Juss.) W. R. Anderson & C. Davis	Leaf	Adaxial	Green	Lenticular	No	Isolated	1	-	-	JB	4k
Stigmaphyllon paralias A. Juss.	Leaf	Adaxial	Pink	Lenticular	No	Isolated	1	-	-	JB	4l
MALVACEAE											
Helicteres sp.	Leaf	Adaxial	White	Globoid	Yes	Grouped	1	-	-	MP	4m

Table I. Continuation.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
MORACEAE											
Moraceae Indet.	Stem	-	Brown	Globoid	No	Grouped	1	-	-	JB	4n
	Leaf	-	Green	Marginal roll	No	Isolated	1	-	-	JB	4o
MYRTACEAE											
Myrtaceae Indet. 1	Stem	-	Brown	Globoid	No	Isolated	Various	-	-	MP	4p
Myrtaceae Indet. 2	Leaf	-	Green	Marginal roll	No	Isolated	1	-	-	JB	4q
Myrtaceae Indet. 3	Leaf	Adaxial	Red	Globoid	Yes	Grouped	Various	-	-	MP	4r
Eugenia sp.	Leaf	Adaxial	Red	Lenticular	No	Grouped	1	-	-	JB	4s
Eugenia dysenterica DC.	Stem	-	Brown	Globoid	No	Isolated	1	-	-	JB	4t
	Leaf	Adaxial	Green	Lenticular	No	Isolated	1	Cecidomyiidae	Hymenoptera	JB	5a
Eugenia lucidifolia Barb. Rodr.	Leaf	Adaxial	Red	Conical	Yes	Grouped	1	Cecidomyiidae	Araneae	MP	5b
Eugenia punicifolia (Kunth) DC.	Bud	-	Orange	Fusiform	No	Isolated	Various	-	Hymenoptera	JB	5c
	Leaf	Adaxial	Black	Lenticular	No	Isolated	1	-	-	JB	5d
	Leaf	-	Pink	Marginal roll	Yes	Isolated	1	-	-	JB	5e
Myrcia tomentosa (Aubl.) DC.	Bud	-	Black	Globoid	No	Grouped	1	-	-	JB	5f
	Bud	Abaxial	Pink	Marginal roll	No	Grouped	1	Thysanoptera	-	JB	5g
NYCTAGINACEAE											
Guapira laxa (Netto) Furlan	Leaf	Adaxial	Green	Lenticular	No	Grouped	1	Cecidomyiidae	Hemiptera	MP	5h
OCHNACEAE											
Ouratea semiserrata (Mart. & Ness) Engl.	Stem	-	Brown	Fusiform	No	Isolated	1	-	-	JB	5i
	Leaf	Adaxial	Green	Lenticular	No	Isolated	1	-	-	JB,MP	5j

Table I. Continuation.

Family/species	Organ	Face	Color	Shape	Pilosity	Occurrence	Nº larval chambers	Inductor	Associated fauna	Area	Fig.
Ouratea sp.	Stem	-	Brown	Globoid	No	Isolated	1	-	-	JB	5k
PASSIFLORACEAE											
Turnera harleyi Arbo	Leaf	-	Green	Marginal roll	No	Isolated	1	-	-	JB	5l
PROTEACEAE											
Roupala montana Aubl.	Leaf	-	Green	Marginal roll	No	Isolated	1	-	-	JB	5m
RUBIACEAE											
Rubiaceae Indet.	Bud	-	Brown	Globoid	No	Grouped	Various	-	-	JB	5n
TRIGONIACEAE											
Trigonia nivea Cambess.	Leaf	Abaxial	White	Globoid	Yes	Isoleted or grouped	1	Cecidomyiidae	-	JB, MP	5o
VERBENACEAE											
Lippia origanoides Kunth	Leaf	Adaxial	Gray	Globoid	Yes	Isolated	1	-	-	JB	5p
VOCHYSIACEAE											
Qualea grandiflora Mart.	Leaf	Adaxial	Brown	Lenticular	No	Grouped	1	-	-	JB, MP	-
Qualea parviflora Mart.	Leaf	Adaxial	Orange	Globoid	No	Grouped	1	Cecidomyiidae	Hymenoptera	JB	5q
	Leaf	Adaxial	Brown	Lenticular	Yes	Grouped	1	-	-	MP	5r

Figure 1. Insect galls in two areas of Cerrado *sensu stricto* vegetation in Caetité, Bahia State, Brazil. a-b. *Anacardium humile*; c. Annonaceae Indet. d. *Annona leptopetala*; e-f. *Duguetia furfuracea*; g. *Moquiniastrum paniculatum*; h. *Pseudobrickellia brasiliensis*; i. *Maytenus* sp.; j. *Combretum leprosum*; k. *Erythroxylum suberosum*; l. *Erythroxylum stipulosum*; m. *Alchornea tiliifolia*; n. *Manihot tripartita*; o.*Ocotea lancifolia*;p-r. *Calliandra dysantha*; s. *Calliandra macrocalyx*; t. *Mimosa gemmulata*.

was *Copaifera langsdorffii* Desf (n = 12 gall morphotypes; Figs. 2m-o, 2q-t, 3a-e).

On the MP archaeological site, 40 gall morphotypes were found on 29 plant species belonging to 18 genera and 13 families (Table I). The plant families that hosted the greatest richness of gall morphotypes were Leguminosae and Malpighiaceae (n = 16 and n = 8, respectively). The plant genera with the greatest richness of galls were *Copaifera* L. (n = 10 gall morphotypes, n = 2 host species) and *Byrsonima* Rich. ex Kunth (n = 5 gall morphotypes, n = 3 host species). The super-host species with the greatest richness of gall morphotypes was *Copaifera langsdorffii* (n = 9 gall morphotypes; Figs. 2m-n, p, r, t, 3a, f-h).

The galls were found only on vegetative organs: leaves (n = 88, 57 in JB and 32 in MP), stems (n = 23, 15 in JB and eight in MP), and buds

Figure 2. Insect galls in two areas of Cerrado *sensu stricto* vegetation in Caetité, Bahia State, Brazil. a-d. *Mimosa gemmulata*; e. *Senegalia langsdorffii*; f. *Senna cana* var. *cana*; g-i. *Bauhinia acuruana*; j-l. *Bauhinia pulchella*; m-t. *Copaifera langsdorffii*.

(n = 4 in JB). Most gall morphotypes occurred on a single plant organ; only one gall morphotype induced on *Moquiniastrum paniculatum* (Less.) G. Sancho (Asteraceae) was observed on both stems and leaves (Table I, Fig. 1g).

The most frequent gall shapes were globoid (n = 54, 32 in JB and 22 in MP), lenticular (n = 23, 15 in JB and 8 in MP), and fusiform (n = 12, 7 in JB and 5 in MP). Most galls were glabrous (n = 101, 67 in JB and 34 in MP), unilocular (n = 94, 64 in JB and 30 in MP), and solitary (n = 58, 41 in JB and 17 in MP) or grouped (n = 55, 32 in JB and 23 in MP). Gall color were green, brown, red, yellow, orange, gray, white, black or purple, being the brown color the most frequent (n = 44, 26 in JB and 18 in MP). The globoid leaf galls of *Combretum leprosum* Mart. (Combretaceae) could be green, yellow (Fig. 1j) red, or brown.

The inducer insects that emerged (from only 33 gall morphotypes) belonged to the orders Diptera, Cecidomyiidae (n = 27, 19 in JB, eight in MP), Lepidoptera (n = 2 in JB), Thysanoptera (n = 1 in JB), and Coleoptera (n = 1 in MP). The associated fauna was found in 17 gall morphotypes (n = 13 in JB, 10 in MP), and composed by parasitoids (Hymenoptera, n = 9, 9 in JB, four in MP), predators (Araneae, n = 3, one in JB, three in MP), inquilines (Hemiptera [n = 2, one in JB, one in MP] and Thysanoptera [n = 2, one in JB, one in MP]), and successors (Formicidae n = 1 in JB and MP).

The Sørensen's index values indicated high similarity in host plants between JB farm and MP archaeological site (S=0.66). These localities shared 15 host plant species (Table I). In relation to the morphotypes galls, the similarity is low (S=0.36), with only 15 gall morphotypes common to both areas, showing that these localities differed in relation to the gall composition species.

DISCUSSION

The gall richness in JB and MP were high in comparison to other areas with Cerrado *sensu stricto* vegetation (Araújo et al. 2007, Urso-Guimarães et al. 2003, Coelho et al. 2013, Nogueira et al. 2016), corroborating other studies that indicate that the Cerrado has the richest fauna of galling insects in Brazil (Araújo 2018, Cintra et al. 2020).

The plant families with the greatest numbers of species in a given area generally correspond to those that host the greatest gall richness (Araújo et al. 2014, Santos-Silva & Araújo 2020). Leguminosae, Malpighiaceae and Myrtaceae were the main host plant families of galls in the two Cerrado *s.s.* areas, a result similar to reports of other inventories realized in the Bahia Cerrado (Nogueira et al. 2016, Vieira et al. 2018). Those botanical families together with Asteraceae and Melastomataceae hosting a rich diversity of gall-inducing insects in the Cerrado (n = 468 gall morphotypes), with many species bearing galls (n = 263 spp.) (Cintra et al. 2020).

In addition to those super-host plant families, gall richness can be influenced by presence of super-host species that hosted more than double the number of gall morphotypes compared to other species (Mendonça 2007, Araújo et al. 2013), as is evidenced to *Copaifera langsdorffii* is this study. This species is frequent in the study area and is considered one of the principal super-hosts of galls in the Brazilian Cerrado (Costa et al. 2010, Lima & Calado 2018, Fagundes et al. 2018). According to Araújo et al. (2013), the plant species richness explains more than 49 % of the gall inducing insect species richness in the Neotropical savannas, because their important role in the attraction of natural enemies and adaptive radiation of galling species.

Galls induced principally on leaves followed by stems is similar to the patterns seen throughout Brazil (Fernandes & Negreiros 2006, Santos et al. 2011b, 2012a, Toma & Mendonça Junior 2013, Santana & Isaias 2014, Nogueira et al. 2016, Silva et al. 2018). Leaves are considered to be more plastic host organs as compared to stems (Isaias et al. 2013). Additionally, it has been proposed that greater incidence of leaf galls reflects higher levels of nutritional reserves available in the leaves and their photosynthetic capacities (Castro et al. 2012). Almost all galls occurred on a single plant organ, confirming the gall-inducer specificity for the host plant organ (Dreger- Jauffret & Shorthouse 1992).

Globoid, lenticular, and fusiform galls are generally the predominate shapes in inventories in the Neotropical region (*e.g.,* Urso-Guimarães et al. 2003, Maia 2013a, b, Costa et al. 2014b, Vieira

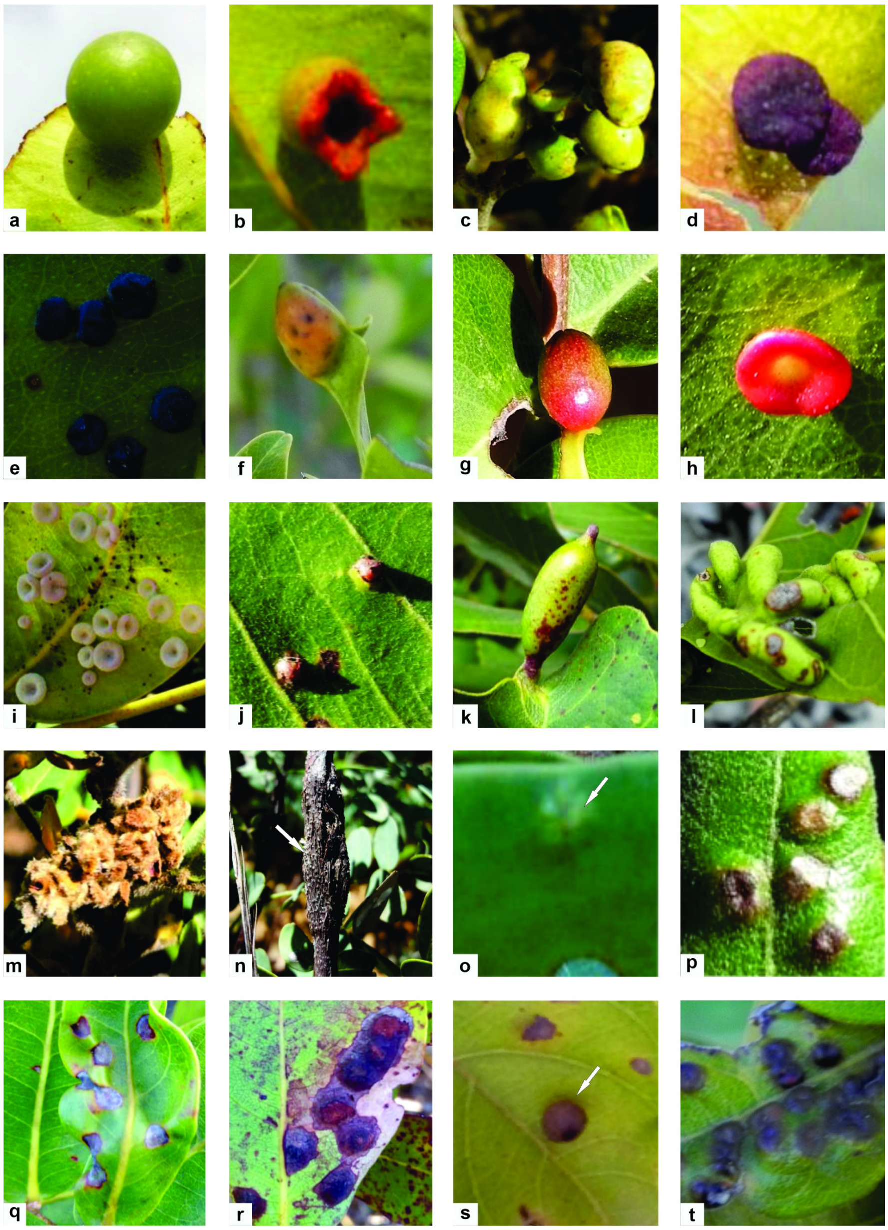

Figure 3. **Insect galls in two areas of Cerrado *sensu stricto* vegetation in Caetité, Bahia State, Brazil. a-h. *Copaifera langsdorffii*; i. *Copaifera luetzelburgii*; j-k.*Hymenaea courbaril*; l. *Andira parvifolia*; m. *Dalbergia acuta*; n. *Dalbergia miscolobium*; o. *Struthanthus* sp.; p-q. Malpighiaceae Indet. 1; r. Malpighiaceae Indet. 2; s. Malpighiaceae Indet. 3.; t. Malpighiaceae Indet. 4.**

et al. 2018, Silva et al. 2018). The association between gall morphotypes and host organs was observed, with most globoid and lenticular galls being found on leaves, while fusiform shapes were most common on host stems. Stem galls are often elongated and/or appressed to that organ, following length (Isaias et al. 2013, Ferreira & Isaias 2013, Santana & Isaias 2014). While leaf galls tend to distributed equally over the leaf blade, making maximum and efficient use of that surface as well as its total volume, which the cell expansions can occur in all directions (Isaias et al. 2013).

The gall color were predominantly brown, similar to the colors reported in Cerrado and Caatinga-Cerrado transition sites in the Serra Geral at Caetité (Nogueira et al. 2016). The brown color of leaf galls often indicates their final stages of development (Carneiro et al. 2017). In addition, the gall color can also indicate the

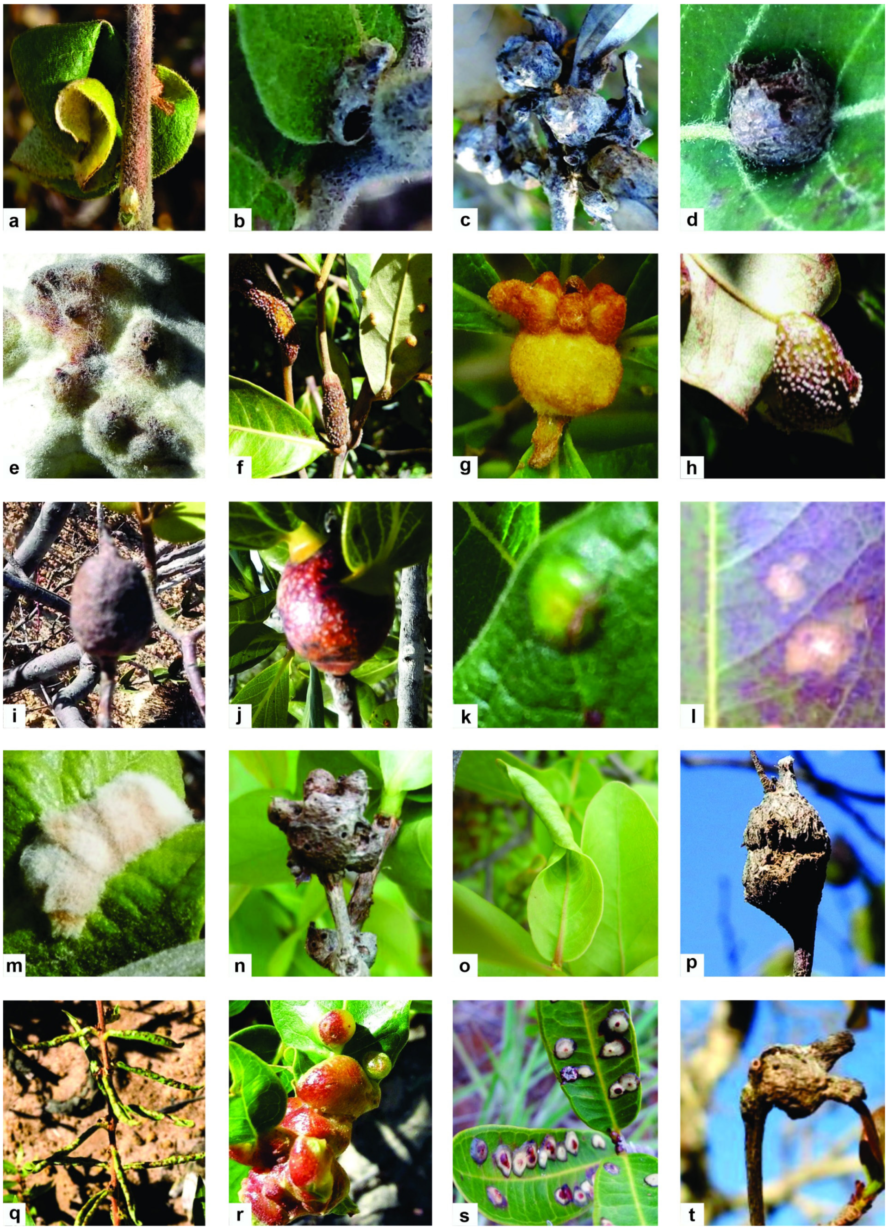

Figure 4. Insect galls in two areas of Cerrado *sensu stricto* vegetation in Caetité, Bahia State, Brazil. a-b. *Banisteriopsis malifolia*; c. *Byrsonima correifolia*; d-e. *Byrsonima gardneriana*; f-h. *Byrsonima sericea*; i. *Byrsonima* sp.; j. *Diospyros* sp. k. *Diplopterys pubipetala*; l. *Stigmaphyllon paralias*; m. *Helicteres* sp.; n-o. Moraceae Indet. 1.; p. Myrtaceae Indet. 1; q. Myrtaceae Indet. 2; r. Myrtaceae Indet. 3; s. *Eugenia* sp.; t. *Eugenia dysenterica*.

presence of parasitoids or aposematism (Inbar et al. 2010, Dias et al. 2013). As such, gall color variations represent an open field for research, and their colors may serve to alert predators to the possible presence of toxic compounds (Inbar et al. 2010).

In spite of numerous inventories of galls in different Brazilian ecosystems, our lack of knowledge about the inducer insect species is a barrier to more comprehensive studies (Melo-Júnior et al. 2018). That situation reflects the difficulty of obtaining specimens of galling insects (including immature and adult phases of both sexes, necessary for species determinations), the prevalence of galls that have already been abandoned by their inducer, our general lack of knowledge of the life histories of the gall inducers, the limited number of taxonomists specialized in gall-inducing groups, and the high mortality rates to the host

Figure 5. Insect galls in two areas of Cerrado *sensu stricto* vegetation in Caetité, Bahia State, Brazil. a. *Eugenia dysenterica*; b. *Eugenia lucidifolia*; c-e. *Eugenia punicifolia*; f-g. *Myrcia tomentosa*; h. *Guapira laxa*; i-j. *Ouratea semiserrata*; k. *Ouratea* sp.; l. *Turnera harleyi*; m. *Roupala montana*; n. Rubiaceae Indet.; o. *Trigonia nivea*; p. *Lippia origanoides*; q-r. *Qualea parviflora*.

galler larvae, due the incidence of parasitoids (Espírito-Santo & Fernandes 2007, Carneiro et al. 2009b, Gagné & Jaschhof 2017, Melo-Júnior et al. 2018). Of the 98 gall morphotypes recorded in the present work, the insect inducers were identified in only 26 (24 insects to family, one to genus, and just one to species level [*Myrciaryiamia admirabilis* Maia, 2007, Diptera, Cecidomyiidae]). The Cecidomyiidae (Diptera) were found to be the principal gall inducers, as expected. Cecidomyiidae stands out in the literature as one of the principal gall-inducing groups in the Neotropics (*e.g.*, Carneiro et al. 2009b, Santos et al. 2011a, 2012a, b, Maia 2013a, b, Costa et al. 2014b, Nogueira et al. 2016, Gagné & Jaschhof 2017, Silva et al. 2018, Santana et al. 2020, Santos-Silva & Araújo 2020).

The parasitoids were more frequent than inquilines, predators, and successors - another pattern recovered in our results. Plant galls are preyed upon by a diverse group of parasitoids belong to Hymenoptera. These organisms frequently cause high mortality rates to the host gall-inducing larvae (Weis & Abrahamson 1985, Price & Clancy 1986). The parasitoid community associated with host plant from Cerrado vegetation had already been widely reported in other inventories (Maia 2001, Maia & Fernandes 2004).

Our results add evidences to the plant diversity hypothesis, the leaves as mainly host organ, the predominance of globoid gall, and Cecidomyiidae as one of the principal gall-inducing groups in Cerrado of Caetité, Bahia. We report new species of host plants and new gall morphotypes for the Brazilian Cerrado, which contribute to the understanding of the distribution and diversity of galls in the Cerrado. The great richness of gall morphotypes and host plants found and the high incidence of galling insects of uncertain taxonomic identities indicate that many of them must represent new records for the region, which suggests for the conservation of the two study areas. Additionally, the galling insect guild and the host plant composition varied among Cerrado localities, evidencing the importance of studying and preserving different areas of the same biomes.

Acknowledgments

The authors are grateful to Msc. Jamile Jorge Ferreira, Cleiton Couto, and Jaqueline Teixeira for their help with the field collections; to Dr. Luciano Paganucci, Dr. Flávio França, and Dr. Efigênia de Mello at the Universidade Estadual de Feira de Santana (UEFS) for their help in identifying the botanical material; and to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq 406111/2016-2), the Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB 9648/2015) and the Universidade do Estado da Bahia (Propublic - 015/2019) for financial support. JSS is grateful to Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro - FAPERJ (E-26/202.501/2019) and CNPq (160015/2019-7) for her research grant.

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How to cite

CAMPOS GBD, COSTA EC, SANTOS DLS, CARVALHO-FERNANDES SP & SANTOS-SILVA J. 2021. Insect galls and associated fauna in two areas of Cerrado *sensu stricto* in the State of Bahia, Brazil. An Acad Bras Cienc 93: e20201442. DOI 10.1590/0001-3765202120201442.

Manuscript received on September 8, 2020; accepted for publication on February 16, 2021

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Author contributions

Gabriela Campos contributed to data collection and to manuscript preparation; Elaine Costa contributed to data analysis and interpretation and to manuscript preparation; Débora Santos contributed to data collection; Sheila Carvalho-Fernandes contributed to data analysis and interpretation; Juliana Santos contributed in the concept and design of the study and acquisition of the financial support for the project leading to this publication.