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ARTICLE

Gall-inducing arthropods in a Neotropical savanna area in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil): effects of plant species richness and super-host abundance

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Abstract. Several plant-related factors can influence the diversity of gall-inducing species communities. In the present study we performed an inventory of gall-inducing arthropods and we tested if the plant species richness and the abundance of super-host plants *(Copaifera oblongifolia)* influenced positively in the diversity of gall-inducing arthropod species. The study was realized in an area of Neotropical savanna (cerrado *sensu stricto*) in the Environmental Protection Area (EPA) of Rio Pandeiros, Minas Gerais, Brazil. Host-plant species and gall-inducing arthropods were sampled in 18 10 × 10 m plots distributed in the vegetation. In total we found 40 arthropod gall morphotypes, distributed on 17 botanical families and 29 plant species. Cecidomyiidae (Diptera) induced the most arthropod galls (85%), and the plant family Fabaceae had the greatest richness of gall morphotypes (16). The plant species *Copaifera oblongifolia* and *Andira humilis* (Fabaceae) were the most important host species with five and three morphotypes, respectively. Galling species richness was not affected by none of explanatory variables (plant species richness and abundance of super-host plants). On the other hand, galling species per plant species was negatively affected by plant species richness and positively affected by abundance of super-host plants. This is the first study of arthropod-induced galls conducted in EPA of Rio Pandeiros, Brazil. Our results corroborate previous studies that highlight the importance of super-host plants for galling arthropod diversity on a local scale.

Key-Words. *Arthropod-plant interactions;* Cecidomyiidae; Cerrado; *Copaifera;* Fabaceae.

INTRODUCTION

Plant-animal interactions between herbivorous arthropods and their host plants encompass the greatest diversity of terrestrial species (Price, 2002). Among herbivorous arthropods, gall-inducing species represent the most specialized guild (Araújo *et al.,* 2019a), because they are the only arthropods capable of manipulating physiological and anatomical plant structures inducing the formation of galls (review in Miller III & Raman, 2019). Arthropod galls are structures formed by hyperplasia and hypertrophy of plant tissues, inside which the inductor development and feed (Fernandes *et al.,* 2014). In addition, galls can provide shelter for galling arthropods against attack by natural enemies and environmental weathering (Miller III & Raman, 2019). Due to the intimate association between gall-inductors and their host plants, galling arthropod communities tend to be strongly influenced by host plant assemblages (Araújo *et al.,* 2013; Altamirano *et al.,* 2016; Costa & Araújo, 2019).

One of the main factors of plant assemblages that can influence galling communities is the richness of plant species (review in Araújo, 2013). Plant species richness represents a greater di-

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versity of resources for the use of gall-inducing species (Cuevas-Reyes *et al.,* 2004). In this sense, several evidences point that gall-inducing species richness increases as more potential host plant species are available (*e.g.,* Wright & Samways, 1998; Gonçalves-Alvim & Fernandes, 2001; Cuevas-Reyes *et al.,* 2004). On the other hand, there is also evidence that some galling communities are little influenced by richness of plant communities, because plant species vary greatly in their susceptibility to gall induction (Blanche, 2000; Araújo *et al.,* 2013).

In tropical environments, many plant species have few or no gall-inducing species (Blanche, 2000), but some plant species can host many species of galling arthropods (Araújo *et al.,* 2013). The existence of super-host plants, *i.e.,* plant species with a high number of gall-inducing species, indicates that the composition of plant assemblages also is important for the galling community (Araújo *et al.,* 2013). Therefore, the occurrence of super-host plants may increase the diversity of arthropod galls, regardless of the number of plant species (Veldtman & McGeoch, 2003; Araújo *et al.,* 2014a). For Brazilian savannas, some super-host plants are recorded, such as *Baccharis dracunculifolia* DC. (Fernandes *et al.,* 1996), *Copaifera langsdorffii* Desf. (Costa *et al.,* 2010; Ribeiro *et al.,* 2019), and *Qualea parviflora* Mart. (Araújo *et al.,* 2013), but few studies have investigated the effect of the presence of these taxa on the local diversity of galling species.

In the present study we performed an inventory of gall-inducing arthropods and their host plants in an area of Neotropical savanna (cerrado *sensu stricto*) located in the Environmental Protection Area (EPA) of Rio Pandeiros (Bonito de Minas, MG, Brazil). Additionally, we tested if the plant species richness and the abundance of super-host plants influenced positively in the diversity of gall-inducing arthropod species.

MATERIAL AND METHODS

Study area

The study was performed in an area of Neotropical savanna (cerrado *sensu stricto*) in the Environmental Protection Area (EPA) of Rio Pandeiros (15°21′37.2″S and 44°54′45.9″W), which englobe the municipalities of Bonito de Minas, Cônego Marinho and Januária in the North of Minas Gerais State, Brazil. The reserve has an area of 431.401 hectares and was created in 1995 with objective to preserve the hydric resources and biodiversity in the valley of Pandeiros river. This area has been classified as of extreme biological importance, priority for scientific research and biodiversity conservation (Drummond *et al.,* 2005). The EPA of Pandeiros river is located in an ecotone zone between the domains of Caatinga and Cerrado and has a remarkable floristic diversity, characteristic of this transitional effect (Bahia *et al.,* 2009; Fagundes *et al.,* 2019a). The cerrado *sensu stricto* is the predominant physiognomy of the EPA, but seasonally dry tropical forest and palm swamps are very common in the area (Bahia *et al.,* 2009). Soils are classified as Quartzarenic Neosol, with sandy texture, Dystrophic Haplic Cambisol and Latosol with high water storage capacity, acid and low fertility (EMBRAPA, 2013). The climate of the region is tropical dry (Aw in the Köppen system), characterized by well-defined rainy periods, an average temperature of 24.2°C, and an average annual rainfall of 1,000 mm (Alvares *et al.,* 2013).

Arthropod gall survey

Arthropod gall sampling was performed in a rapid ecological study realized in November of 2019. The sampling was realized in 18 plots of 10 × 10 m distributed in the study area (Araújo *et al.,* 2013). In each plot all woody plants with a circumference ≥ 10 cm at 1.3 m above ground were sampled. The botanical material was herborized and identified according to the botanical literature and/or the recommendation of experts. In the plots arthropod galls were sampled by active searches up to a height of 2.5 m in all plants. All sampled galls were classified into morphotypes using the host plant species and external morphology (organ of occurrence, shape, color, pubescence and size) (Carneiro *et al.,* 2009). To designate gall morphotypes we use the terminology proposed by Isaias *et al.* (2013). Gall-inducing arthropods were determined from dissection of galls in field or laboratory and also using the arthropod gall literature from Neotropic and Brazil (*e.g.,* Maia & Fernandes, 2004; Carneiro *et al.,* 2009; Gagné, 2014; Araújo *et al.,* 2013; Araújo *et al.,* 2014b; Araújo *et al.,* 2019b). In the area, we recorded the host-plant species *Copaifera oblongifolia* DC. (Fabaceae), which has been recently listed as a super-host plant harboring 15 different species of gall-inducing insects (Coutinho *et al.,* 2019).

Statistical analyses

For the statistical analyses, galling species richness (total number of arthropod gall morphotypes in each plot) and galling species per plant species (mean number of arthropod gall morphotypes by host plant species in each plot) were used as response variable. We used the plant species richness and abundance of super-host plants as explanatory variables at plot level in generalized linear models (GLM's) built for each response variable. In the present study we used the abundance of *Copaifera oblongifolia* as a measure of abundance of super-host plants. All models were submitted to a residual analysis to determine the adequacy of error distribution and had a Gaussian error distribution assumed. All statistical analyses were performed in the software R version 3.4.1 (R Development Core Team, 2015).

RESULTS

We found a total of 40 arthropod gall morphotypes distributed on 29 species and 17 families of host-plants in the study area (Table 1; Figs. 1-5). The mean number

Table 1. Characterization of arthropod galls recorded in a Neotropical savanna area in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil).

Host family	Host plant	Organ	Shape	Color	Pubescense	Size (mm)	Gall-inductor	Figure
Anacardiaceae	*Anacardium humile* A. St.-Hil.	Leaf	Globoid	Brown	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 1A
Apocynaceae	*Aspidosperma macrocarpon* Mart.	Leaf	Lenticular	Green	Glabrous	5	*Pseudophacopteron* sp. (Psylloidea, Hemiptera)	—
Bignoniaceae	*Handroanthus ochraceus* (Cham.) Mattos	Leaf	Lenticular	Green	Pilose	2	Cecidomyiidae (Diptera)	Fig. 1B
Calophyllaceae	*Kielmeyera speciosa* A. St.-Hil.	Leaf	Amorphous	Yellow	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 1C
Caryocaraceae	*Caryocar brasiliense* A. St.-Hil.	Leaf	Lenticular	Brown	Glabrous	1	Cecidomyiidae (Diptera)	Fig. 1D
Combretaceae	*Terminalia fagifolia* Mart.	Leaf	Conical	Green	Pilose	2	Cecidomyiidae (Diptera)	Fig. 1E
Connaraceae	*Connarus suberosus* Planch.	Leaf	Globoid	Brown	Glabrous	4	Cecidomyiidae (Diptera)	Fig. 1F
Connaraceae	*Connarus suberosus* Planch.	Leaf	Globoid	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 1G
Dilleniaceae	*Davilla elliptica* A. St.-Hil.	Stem	Fusiform	Brown	Glabrous	8	Lepidoptera	Fig. 1H
Dilleniaceae	*Davilla elliptica* A. St.-Hil.	Leaf	Lenticular	Brown	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 2A
Ebenaceae	*Diospyros hispida* A. DC.	Leaf	Amorphous	Green	Pilose	10	Eriophyidae (Acari)	Fig. 2B
Erythroxylaceae	*Erythroxylum suberosum* A. St.-Hil.	Leaf	Amorphous	Red	Pilose	4	*Myrciaryiamia admirabilis* Maia, 2007	Fig. 2C
Fabaceae	*Andira humilis* Mart. exBenth.	Leaf	Amorphous	Green	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 2D
Fabaceae	*Andira humilis* Mart. exBenth.	Leaf	Globoid	Yellow	Glabrous	1	Cecidomyiidae (Diptera)	Fig. 2E
Fabaceae	*Andira humilis* Mart. exBenth.	Leaf	Fusiform	Yellow	Glabrous	3	*Lopesia* sp. (Cecidomyiidae)	Fig. 2F
Fabaceae	*Copaifera luetzelburgii* Harms	Leaf	Lenticular	Yellow	Pilose	5	Cecidomyiidae (Diptera)	Fig. 2G
Fabaceae	*Copaifera oblongifolia* Mart.	Stem	Globoid	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 2H
Fabaceae	*Copaifera oblongifolia* Mart.	Stem	Convex	Brown	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 3A
Fabaceae	*Copaifera oblongifolia* Mart.	Leaf	Lenticular	Brown	Glabrous	4	Cecidomyiidae (Diptera)	Fig. 3B
Fabaceae	*Copaifera oblongifolia* Mart.	Leaf	Rosette	Green	Glabrous	6	Cecidomyiidae (Diptera)	Fig. 3C
Fabaceae	*Copaifera oblongifolia* Mart.	Stem	Globoid	White	Glabrous	11	Cecidomyiidae (Diptera)	Fig. 3D
Fabaceae	*Hymenaea stigonocarpa* Hayne	Leaf	Lenticular	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 3E
Fabaceae	*Machaerium opacum* Vogel	Leaf	Lenticular	Yellow	Glabrous	5	Cecidomyiidae (Diptera)	Fig. 3F
Fabaceae	*Machaerium opacum* Vogel	Leaf	Lenticular	Green	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 3G
Fabaceae	*Machaerium acutifolium* Vogel	Leaf	Lenticular	Green	Glabrous	2	Cecidomyiidae (Diptera)	—
Fabaceae	*Sclerolobium denudatum* Vogel	Leaf	Lenticular	Green	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 3H
Fabaceae	*Sclerolobium denudatum* Vogel	Leaf	Lenticular	Green	Glabrous	3	Cecidomyiidae (Diptera)	—
Fabaceae	*Tachigali alba* Ducke	Leaf	Amorphous	Green	Pilose	2	Cecidomyiidae (Diptera)	Fig. 4A
Malpighiaceae	Malpighiaceae undentified	Leaf	Conical	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 4B
Malvaceae	*Eriotheca gracilipes* (K. Schum.) A. Robyns	Leaf	Amorphous	Green	Glabrous	2	Eriophyidae (Acari)	Fig. 4C
Myrtaceae	*Eugenia dysenterica* DC.	Leaf	Amorphous	Green	Pilose	5	Cecidomyiidae (Diptera)	Fig. 4D
Myrtaceae	*Eugenia* sp.	Leaf	Cylindrical	Yellow	Glabrous	3	Cecidomyiidae (Diptera)	Fig. 4E
Myrtaceae	*Psidium* sp.	Leaf	Lenticular	Brown	Glabrous	3	Psylloidea (Hemiptera)	Fig. 4F
Ochnaceae	*Ouratea hexasperma* (A. St.-Hil.) Baill.	Leaf	Lenticular	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 4G
Ochnaceae	*Ouratea spectabilis* (Mart. ex Engl.) Engl.	Leaf	Lenticular	Brown	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 4H
Salicaceae	*Casearia sylvestris* Sw.	Leaf	Lenticular	Yellow	Glabrous	2	Cecidomyiidae (Diptera)	—
Vochysiaceae	*Qualea grandiflora* Mart.	Leaf	Lenticular	Green	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 5A
Vochysiaceae	*Qualea grandiflora* Mart.	Leaf	Lenticular	Brown	Glabrous	2	Cecidomyiidae (Diptera)	Fig. 5B
Vochysiaceae	*Qualea parviflora* Mart.	Leaf	Amorphous	Green	Glabrous	8	Eriophyidae (Acari)	Fig. 5C
Vochysiaceae	*Qualea parviflora* Mart.	Leaf	Marginal roll	Green	Glabrous	8	Cecidomyiidae (Diptera)	Fig. 5D

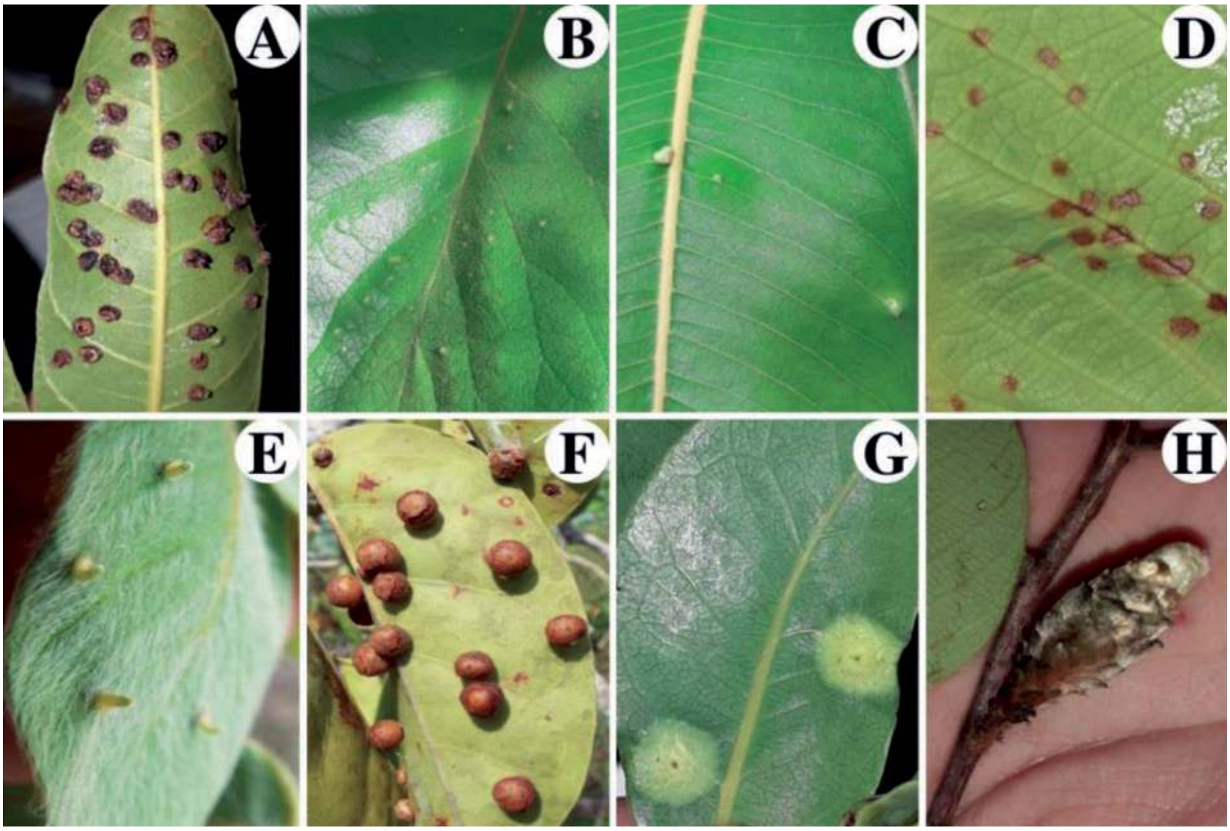

Figure 1. Gall morphotypes in host plants in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil). (A) Anacardiaceae = *Anacardium humile,* (B) Bignoniaceae = *Handroanthus ochraceus,* (C) Calophyllaceae = *Kielmeyera speciosa,* (D) Caryocaraceae = *Caryocar brasiliense,* (E) Combretaceae = *Terminalia fagifolia,* (F-G) Connaraceae = *Connarus suberosus,* (H) Dilleniaceae = *Davilla elliptica.*

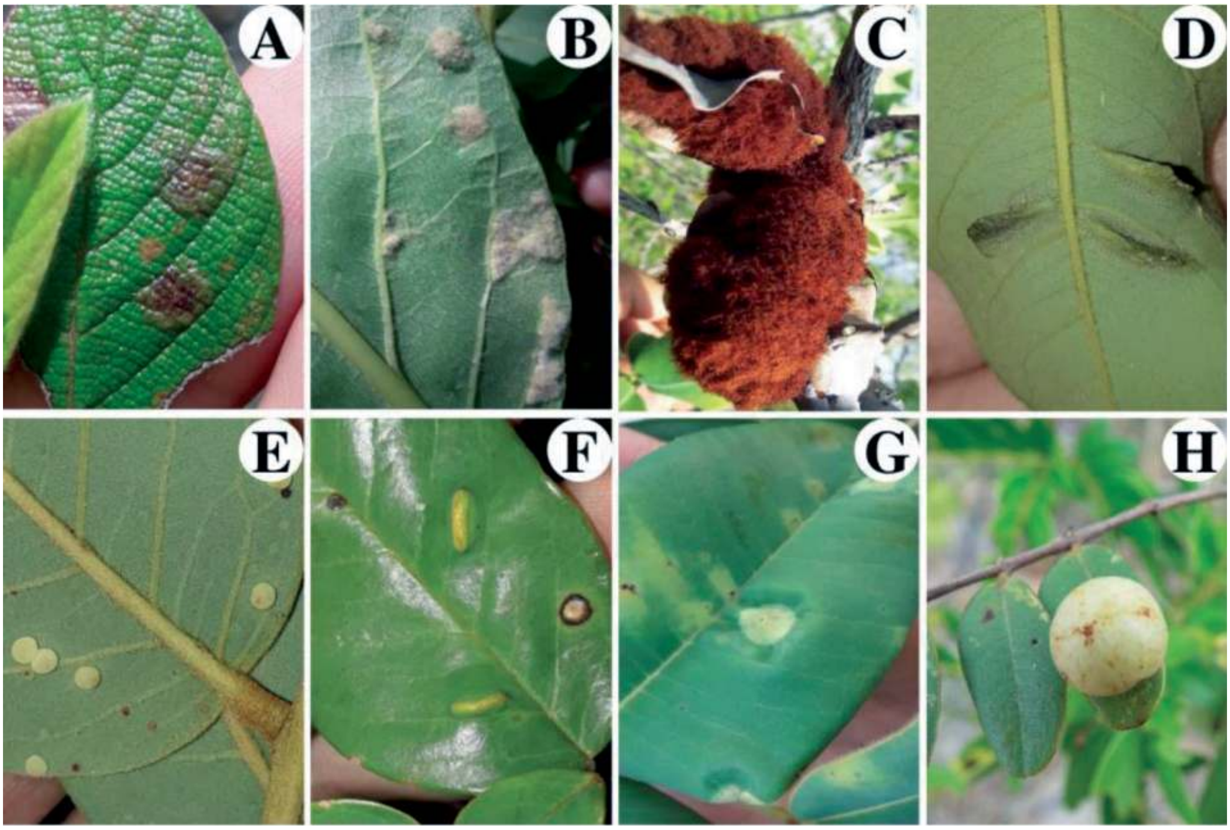

Figure 2. Gall morphotypes in host plants in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil). (A) Dilleniaceae = *Davilla elliptica,* (B) Ebenaceae = *Diospyros hispida,* (C) Erythroxylaceae = *Erythroxylum suberosum,* (D-F) Fabaceae = *Andira humilis,* (G) Fabaceae = *Copaifera luetzelburgii,* (H) Fabaceae = *Copaifera oblongifolia.*

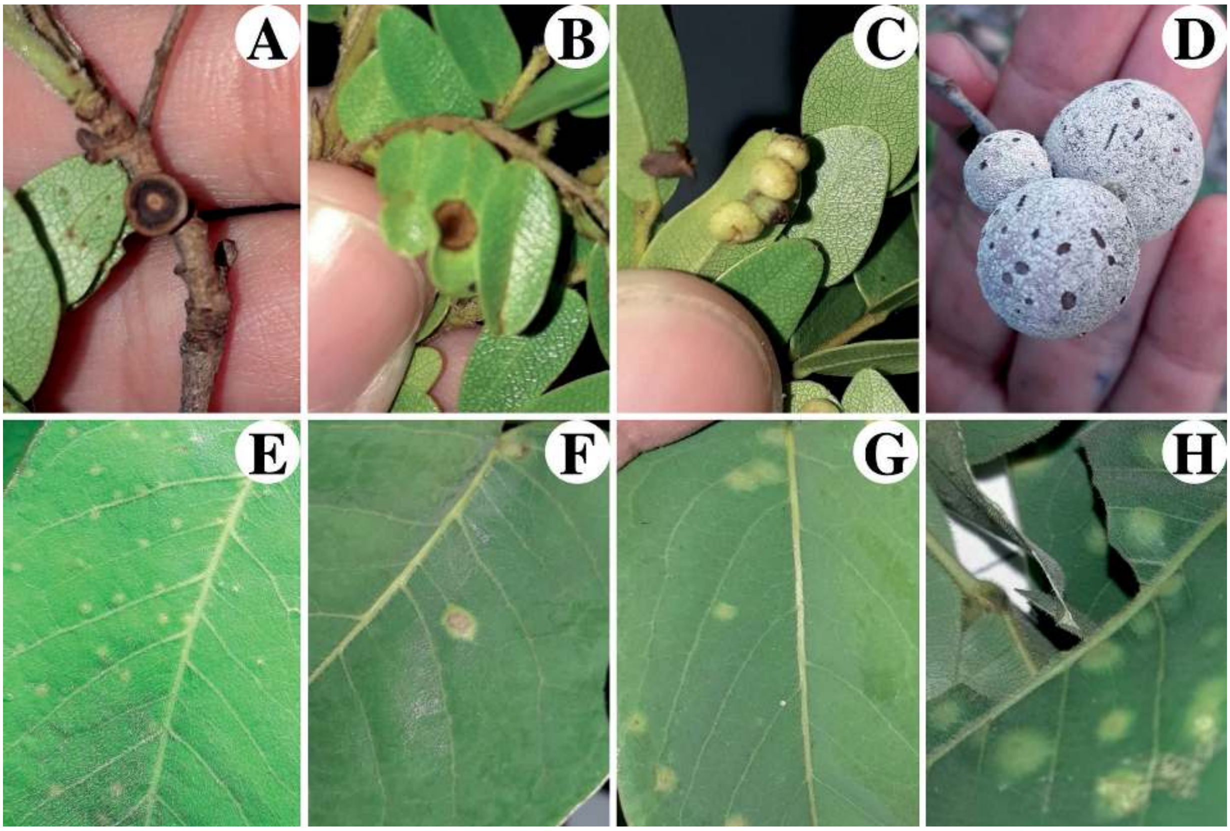

Figure 3. Gall morphotypes in host plants in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil). (A-D) Fabaceae = *Copaifera oblongifolia,* (E) Fabaceae = *Hymenaea stigonocarpa,* (F-G) Fabaceae = *Machaerium opacum,* (H) Fabaceae = *Sclerolobium denudatum.*

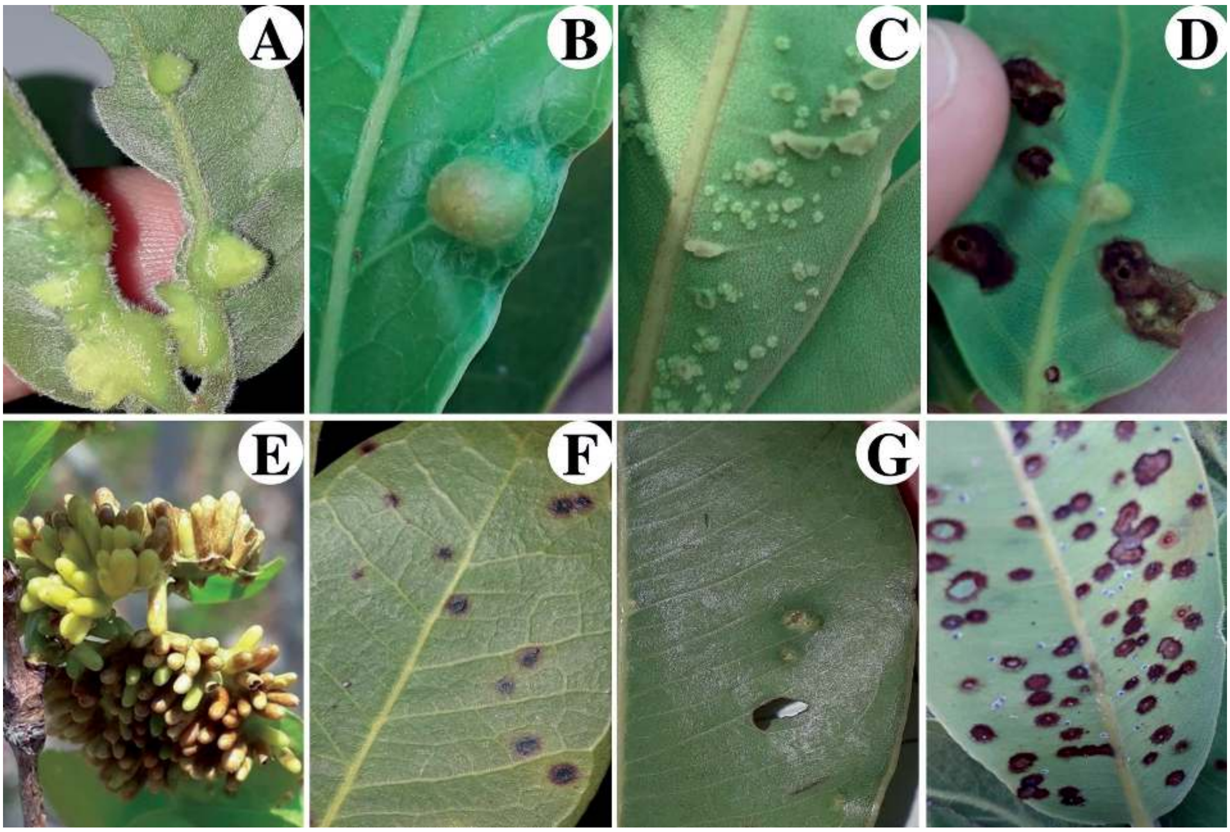

Figure 4. Gall morphotypes in host plants in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil). (A) Fabaceae = *Tachigali alba,* (B) Malpighiaceae = Malpighiaceae sp., (C) Malvaceae = *Eriotheca gracilipes,* (D) Myrtaceae = *Eugenia dysenterica,* (E) Myrtaceae = *Eugenia* sp., (F) Myrtaceae = *Psidium* sp., (G) Ochnaceae = *Ouratea hexasperma,* (H) Ochnaceae = *Ouratea spectabilis.*

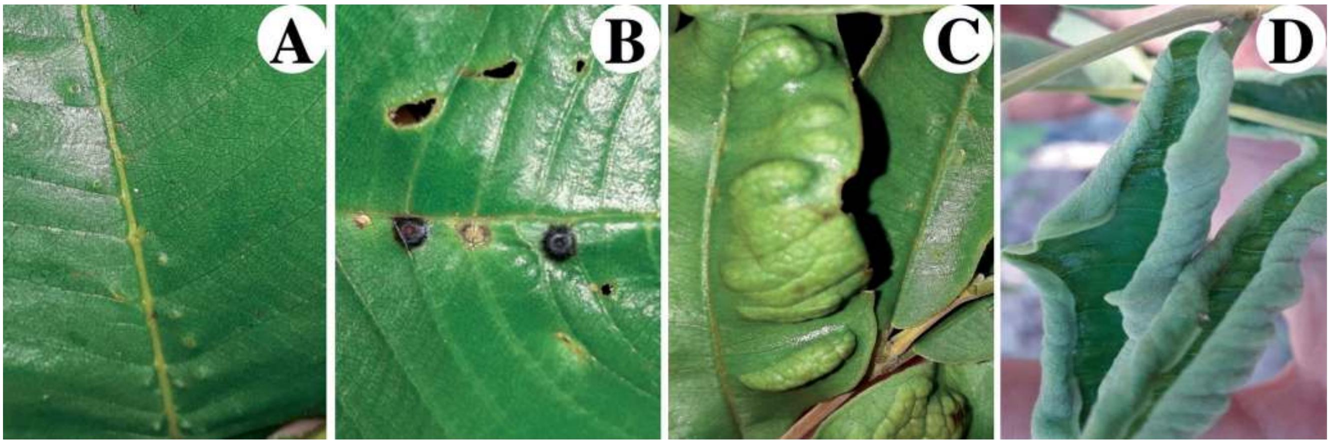

Figure 5. Gall morphotypes in host plants in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil). (A-B) Vochysiaceae = *Qualea grandiflora,* (C-D) Vochysiaceae = *Qualea parviflora.*

of gall morphotypes per host plant species was 1.37. Gall-inducing arthropods belonged to Acari, Diptera, Hemiptera and Lepidoptera. The most important gall-inducing arthropods were Cecidomyiidae (Diptera) having induced 34 (85.0%) gall morphotypes. In the sequence were Eriophyidae (Acari) inducing three (7.5%) morphotypes, Psylloidea (Hemiptera) inducing two (5.0%) morphotypes, and Lepidoptera inducing a single (2.5%) morphotype.

The plant families that showed the greatest richness of arthropod galls were Fabaceae, with 16 (40.0%) morphotypes, Vochysiaceae with four (10.0%) and Myrtaceae (7.5%) with three morphotypes (Table 1). The plant species *Copaifera oblongifolia* and *Andira humilis* Mart. ex Benth. (Fabaceae) were the most important host species with five and three morphotypes, respectively. All other host plant species had two or one morphotypes (Table 1). Most of the arthropod galls occurred on leaves (90.0%), and was lenticular (45.0%), green (52.5%) and glabrous (82.5%).

Galling species richness was not affected by none of explanatory variables (Table 2), despite the tendency of a positive effect of abundance of super-hosts on the gall richness ($p = 0.057$). Already the galling species per plant species was significantly influenced both by plant species richness ($p = 0.011$) and abundance of super-host plants ($p = 0.020$) (Table 2). We found that galling species per plant species was negatively affected by plant species richness (Fig. 6) and positively affected by abundance of super-host plants (Fig. 7).

DISCUSSION

The number of galling species observed in the area of EPA of Rio Pandeiros (40 morphotypes) is intermediary compared to other studies performed in Neotropical savannas (Table 3). For example, Urso-Guimarães *et al.* (2003) recorded only 22 gall morphotypes in cerrado fragments, rupestrian field and gallery forest in Delfinópolis, Minas Gerais State. In other study, Maia & Fernandes (2004) recorded 137 morphotypes of insect galls in an area of rupestrian fields and cerrado in the Serra de São José, Minas Gerais. These numbers extremely variable in the diversity of galling species can be explained by several factors, among which are different sampling efforts employed in the studies, as well as variations in the structural characteristics and diversity of the studied vegetation. The stan-

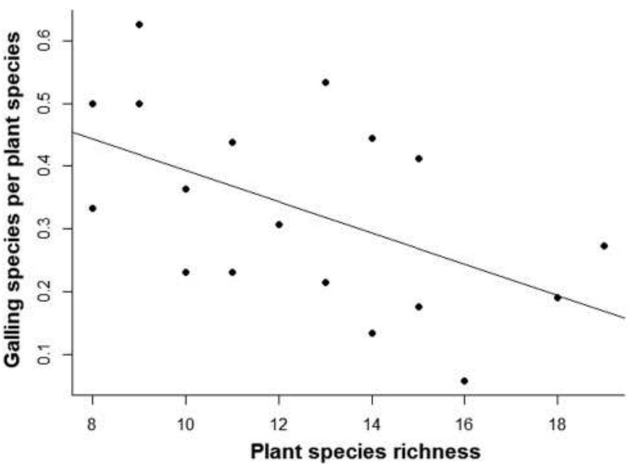

Figure 6. Effect of plant species richness on the galling species per plant species in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil).

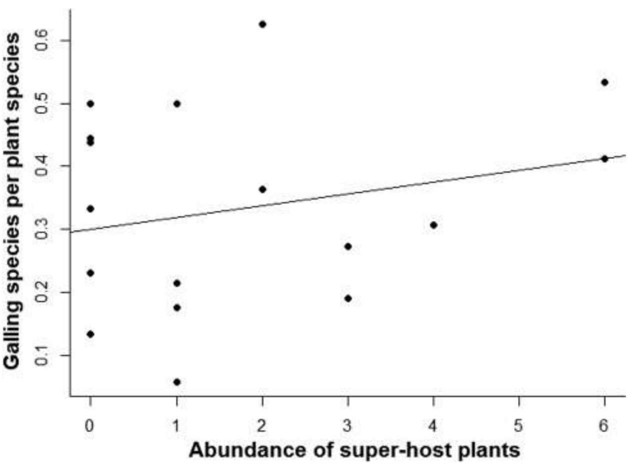

Figure 7. Effect of abundance of super-host plants on the galling species per plant species in an area of Neotropical savanna in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil).

Table 2. Generalized linear models testing for effects of explanatory variables (plant species richness and abundance of super-host plants) on diversity of gall-inducing arthropods (galling species richness and galling species per plant species) in a Neotropical savanna area in the EPA of Rio Pandeiros (Bonito de Minas, MG, Brazil).

Response variables	Explanatory variables	Deviance Resid.	Df	Resid. Dev	*F*-value	*p*-value
Galling species richness	Plant species richness	1.660	16	94.840	0.337	0.570
	Abundance of super-host plants	20.943	15	73.898	4.251	0.057
Galling species per plant species	Plant species richness	0.114	16	0.296	8.401	0.011
	Abundance of super-host plants	0.092	15	0.204	6.784	0.020

Values of *F* and *p* are those of the regression coefficients in the general model.

Table 3. Richness of insect gall morphotypes, host plant species and host plant families and mean number of galls per host plant species in different localities of the Brazilian Cerrado.

Locality	Richness of insect gall morphotypes	Richness of host plant species	Number of host plant families	Reference
EPA of Rio Pandeiros – MG	40	29	17	Present study
Delfinópolis – MG	22	19	19	Urso-Guimarães *et al.* (2003)
Santa Rita do Passa Quatro – SP	36	24	15	Urso-Guimarães & Scareli-Santos (2006)
Campus Pampulha – MG	37	22	11	Fernandes *et al.* (1988)
Serra do Cabral – MG	47	39	21	Coelho *et al.* (2013)
Caldas Novas – GO	56	34	21	Santos *et al.* (2012)
Estação Ecológica de Pirapitinga – MG	92	62	28	Gonçalves-Alvim & Fernandes (2001)
Parque Nacional das Emas – GO	97	44	24	Araújo *et al.* (2014b)
Serra de São José – MG	137	73	30	Maia & Fernandes (2004)

dardized measure of galling species per plant species obtained in the present study (1.37) can also be considered intermediate. In a recent review, Araújo *et al.* (2019b) founded that the mean number of insect gall morphotypes per plant species for Brazilian inventories was 1.72 (± 0.43), ranging between 1.16 and 3.50.

Gall-inducing arthropod fauna recorded in the EPA of Rio Pandeiros was composed of distinct and important galling groups such as gall-midges (Cecidomyiidae) and eriophyids (Eriophyidae), which induced 85% and 7.5% of the gall morphotypes, respectively. Gall-midges are the largest and most diverse group of galling insects in the world (Gagné, 2014). In gall surveys conducted in Brazil this family has shown to be quite diverse and abundant (review in Araújo *et al.,* 2019b). Eriophyids are galling mites than can induce galls in more than 500 host plant species (Petanovíc & Kielkiewicz, 2010). In Brazil eriophyids are rarely include in gall inventories, but in other parts of globe some studies have highlighted the importance of the group for galling fauna (*e.g.,* Nasareen & Ramani, 2014; Araújo *et al.,* 2019a). According review of Maia (2006) gall-inducing insects of the orders Hemiptera and Lepidoptera are less common in the Neotropical region, which corroborates the results of the present study where these groups represented less of 8% of gall-inducers.

The plant family with higher gall richness was Fabaceae with 16 morphotypes, being this also the family with the largest number of host species (eight in total). The recent review about Brazilian gall inventories points that Fabaceae is the most important host family of Brazil, appearing as a super-host in 68.6% of the studies (Araújo *et al.,* 2019b). The great intrinsic galling insect richness of this plant family may be due to the great diversity of species it presents (Mendonça, 2007). The host-plant species with higher diversity of gall morphotypes also were of family Fabaceae: *Copaifera oblongifolia* and *Andira humilis*. Recent studies have pointed *Copaifera oblongifolia* (Fabaceae) as a super-host plant of galling insects with 15 different gall morphotypes recorded (Coutinho *et al.,* 2019; Fagundes *et al.,* 2019b). Species of the genus *Andira* have also been listed as important hosts of galling insects in other areas of neotropical savannas, such as *Andira paniculata* Benth. (Santos *et al.,* 2012).

Contrary to the expected the galling species richness was not affected by plant species richness and abundance of super host plants, despite the tendency of a positive effect of the abundance of *Copaifera oblongifolia* on the arthropod gall richness. A possible explanation for these results may be environmental factors, such as environmental stress and soil fertility, which were not measured in the present study, but may also influence the distribution of galling species (Gonçalves-Alvim & Fernandes, 2001; Ramos *et al.,* 2019). On the other hand, we found that galling species per plant species was negatively affected by plant species richness and positively affected by abundance of super-host plants, corroborating our expectations. The negative relationship between plant species richness and galling species per plant species likely is a mathematical effect of increment in the number of host plant species (denominator) more accelerated than the number of galling species (numerator). However, the positive effect of the abundance of super-host plants on this measure may be indicative that each individual of *Copaifera oblongifolia* add new species of galling species to the community. Our results highlight the importance of super-host plants for galling arthropod diversity on a local scale, corroborating previous studies (*e.g.,* Araújo *et al.,* 2014a).

This is the first study of arthropod-induced galls conducted in EPA of Rio Pandeiros, Minas Gerais, Brazil. Considering that our sampling was done through a rapid ecological study, medium- and long-term sampling, considering different seasonal periods, will probably result in the recording of a greater diversity of arthropod galls. Nevertheless, compared to other areas of cerrado *sensu stricto* in Brazil the diversity recorded in the present study can be considered intermediate. Previous studies have shown that different factors can affect the diversity of gall-inducing arthropods in Neotropical savannas (Gonçalves-Alvim & Fernandes, 2001; Araújo *et al.,* 2013; Araújo *et al.,* 2014a). Contrary to expectations, we did not find effects of the plant species richness and abundance of super-host plants on the galling species richness but found that these explanatory variables affected significantly the number of galling species per plant species. Thus, we believe that future studies can investigate the extent to which the occurrence of other super-host species influences the local diversity of galling arthropods.

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AUTHOR'S CONTRIBUTIONS

All authors participated in the field data collection. The laboratory procedures were made by Kelly Christie dos Santos Costa, Luana Teixeira Silveira and Érica Vanessa Durães de Freitas. The analyzes were performed by Walter Santos de Araújo. All authors participated in the writing of the manuscript.

REFERENCES

Altamirano, A.; Valladares, G.; Kuzmanich, N. & Salvo, A. 2016. Galling insects in a fragmented forest: incidence of habitat loss, edge effects and plant availability. *Journal of Insect Conservation,* 20(1): 119-127.

Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M. & Sparovek, G. 2013. Köppen's climate classifcation map for Brazil. *Meteorologische Zeitschrift,* 6: 711-728.

Araújo, W.S. 2013. Different relationships between galling and non-galling herbivore richness and plant species richness: a meta-analysis. *Arthropod-Plant Interactions,* 7(4): 373-377.

Araújo, W.S.; Scareli-Santos, C.; Guilherme, F.A.G. & Cuevas-Reyes, P. 2013. Comparing galling insect richness among Neotropical savannas: effects of plant richness, vegetation structure and super-host presence. *Biodiversity and Conservation,* 22: 1083-1094.

Araújo, W.S.; Cuevas-Reyes, P. & Guilherme, F.A.G. 2014a. Local and regional determinants of galling-insect richness in Neotropical savanna. *Journal of Tropical Ecology,* 30(3): 269-272.

Araújo, W.S.; Sobral, F.L. & Maracahipes, L. 2014b. Insect galls of the Parque Nacional das Emas (Mineiros, GO, Brazil). *Check List,* 10(6): 1445-1451.

Araújo, W.S.D.; Freitas, É.V.D.D.; Kollár, J.; Pessoa, R.O.; Corgosinho, P.H.C.; Valério, H.M.; Falcão, L.A.D.F.; Fagundes, M.; Pimenta, M.A.S.; Faria, M.L.; Borges, M.A.Z. & Martins, W.P. 2019a. Host Specialization in Plant-galling Interactions: Contrasting Mites and Insects. *Diversity,* 11(10): 180.

Araújo, W.S.; Fernandes, G.W. & Santos, J.C. 2019b. An overview of inventories of gall-inducing insects in Brazil: looking for patterns and identifying knowledge gaps. *Anais da Academia Brasileira de Ciências,* 91(1): 1-19, e20180162.

Bahia, T.D.O.; Luz, G.R.; Braga, L.L.; Menino, G.C.O.; Nunes, Y.R.F.; Veloso, M.D.M.; Neves, W.V. & Santos, R.M. 2009. Florística e fitossociologia de veredas em diferentes estágios de conservação na APA do Rio Pandeiros, norte de Minas Gerais, MG. *Biota,* Belo Horizonte, 2(3): 14-21.

Blanche, K.R. 2000. Diversity of insect-induced galls along a temperature-rainfall gradient in the tropical savannah region of the Northern Territory, Australia. *Austral Ecology,* 25: 311-318.

Carneiro, M.A.A.; Branco, C.S.A.; Braga, C.E.D.; Almada, E.D.; Costa, M.B.M.; Maia, V.C. & Fernandes, G.W. 2009. Are gall midge species (Diptera, Cecidomyiidae) host-plant specialists? *Revista Brasileira de Entomologia,* 53(3): 365-378.

Coelho, M.S.; Carneiro, M.A.A.; Branco, C.A. & Fernandes, G.W. 2013. Gall-inducing insects from Serra do Cabral, Minas Gerais, Brazil. *Biota Neotropical,* 13: 102-109.

Costa, F.V.D.; Fagundes, M. & Neves, F.S. 2010. Arquitetura da planta e diversidade de galhas associadas à Copaifera langsdorffii (Fabaceae). *Ecología Austral,* 20: 9-17.

Costa, K.C.D.S. & Araújo, W.S. 2019. Distribution of gall-inducing arthropods in areas of deciduous seasonal forest of Parque da Sapucaia (Montes Claros, MG, Brazil): effects of anthropization, vegetation structure and seasonality. *Papéis Avulsos de Zoologia,* 59(31): 1-10.

Coutinho, R.D.; Cuevas-Reyes, P.; Fernandes, G.W. & Fagundes, M. 2019. Community structure of gall-inducing insects associated with a tropical shrub: regional, local and individual patterns. *Tropical Ecology,* 60(1): 74-82.

Cuevas-Reyes, P.; Quesada, M.; Hanson, P.; Dirzo, R. & Oyama, K.E.N. 2004. Diversity of gal-inducing insects in a Mexican tropical dry forest: the importance of plant species richness, life-forms, host plant age and plant density. *Journal of Ecology,* 92: 707-716.

Drummond, G.M.; Martins, C.S.; Machado, A.B.M.; Sebaio, F.A. & Antonini, Y. 2005. *Biodiversidade em Minas Gerais: um atlas para sua conservação.* 2.ed. Belo Horizonte, Fundação Biodiversitas. 222p.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). 2013. *Sistema brasileiro de classificação de solos.* 3.ed. Brasília, EMBRAPA. 353p.

Fagundes, N.C.A.; Ávila, M.A.; Souza, S.R.; Azevedo, I.F.P.; Nunes, Y.R.F.; Fernandes, G.W.; Fernandes, L.A.; Santos, R.M. & Veloso, M.D.M. 2019a. Riparian vegetation structure and soil variables in Pandeiros river, Brazil. *Rodriguésia,* 70: 1-13, e0182017.

Fagundes, M.; Barbosa, E.M.; Oliveira, J.B.; Brito, B.G.; Freitas, K.T.; Freitas, K.F. & Reis-Junior, R. 2019b. Galling inducing insects associated with a tropical shrub: The role of resource concentration and species interactions. *Ecología Austral,* 29(01): 012-019.

Fernandes, G.W.; Carneiro, M.A. & Isaias, R.M. 2014. Gall-inducing insects: From anatomy to biodiversity. *In:* Panizzi, A.R. & Parra, J.R.P. (Eds.). *Insect bioecology and nutrition for integrated pest management.* Boca Raton, FL. p. 369-395.

Fernandes, G.W.; Carneiro, M.A.A.; Lara, A.C.F.; Allain, L.R.; Andrade, G.I.; Julião, G.R.; Reis, T.R. & Silva, I.M. 1996. Galling insects on neotropical species of Baccharis (Asteraceae). *Tropical Zoology,* 9: 315-332.

Fernandes, G.W.; Tameirão-Neto, E. & Martins, R.P. 1988. Ocorrência e caracterização de galhas entomógenas na vegetação do Campus

Pampulha da Universidade Federal de Minas Gerais. *Revista Brasileira de Zoologia,* 5: 11-29.

Gagné, R.J. 2014. *Update for a catalog of the Cecidomyiidae (Diptera) of the world. Digital version.* 3.ed. Available at: http://www.ars.usda.gov. Access in: 03/13/2019.

Gonçalves-Alvim, S.J. & Fernandes, G.W. 2001. Biodiversity of galling insects: historical, community and habitat effects in four neotropical savannas. *Biodiversity & Conservation,* 10(1): 79-98.

Isaias, R.M.D.S.; Carneiro, R.G.S.; Oliveira, D.C. & Santos, J.C. 2013. Illustrated and annotated checklist of Brazilian gall morphotypes. *Neotropical Entomology,* 42(3): 230-239.

Maia, V.C. 2006. Galls of Hemiptera, Lepidoptera e Thysanoptera from Central and South America. *Publicações Avulsas do Museu Nacional,* 110: 1-24.

Maia, V.C. & Fernandes, G.W. 2004. Insect galls from Serra de São José (Tiradentes, MG, Brazil). *Brazilian Journal of Biology,* 6: 423-445.

Mendonça, M.S. 2007. Plant diversity and galling arthropod diversity-searching for taxonomic patterns in an animal-plant interaction in the Neotropics. *Boletin de la Sociedad Argentina de Botanica,* 42: 347-357.

Miller III, D.G. & Raman, A. 2019. Host-Plant Relations of Gall-Inducing Insects. *Annals of the Entomological Society of America,* 112: 1-19.

Nasareen, P.N.M. & Ramani, N. 2014. Survey on gall forming Eriophyid Mites (Acari: Eriophyidae) associated with economically important plants of North Kerala. *Journal of Entomology and Zoology Studies,* 2(5): 126-133.

Petanovíc, R. & Kielkiewicz, M. 2010. Plant-eriophyoid mite interactions: specific and unspecific morphological alterations. Part II. *Experimental and Applied Acarology,* 51: 81-91.

Price, P. 2002. Resource-driven terrestrial interaction webs. *Ecological Research,* 17: 241-247.

R Development Core Team. 2015. *R: a language and environment for statistical computing.* Vienna, R Foundation for Statistical Computing.

Ramos, L.F.; Solar, R.R.; Santos, H.T. & Fagundes, M. 2019. Variation in community structure of gall-inducing insects associated with a tropical plant supports the hypothesis of competition in stressful habitats. *Ecology and Evolution,* 9(24): 13919-13930.

Ribeiro, A.N.; Balbi, M.I.P. & Urso-Guimarães, M.V. 2019. Characterization of insect galls from a vegetation area in Altinópolis, São Paulo State, Brazil. *Papéis Avulsos de Zoologia,* 59(4): 1-9, e20195904.

Santos, B.B.; Ribeiro, B.A.; Silva, T.M. & Araújo, W.S. 2012. Galhas de insetos em uma área de cerrado sentido restrito na região semi-urbana de Caldas Novas (Goiás, Brasil). *Revista Brasileira de Biociências,* Porto Alegre, 10(4): 439-445.

Urso-Guimarães, M.V. & Scareli-Santos, C. 2006. Galls and gall makers in plants from Pé-de-Gigante Cerrado Reserve, Santa Rita do Passa Quatro, SP, Brazil. *Brazilian Journal of Biology,* 66, 357-369.

Urso-Guimarães, M.V.; Scareli-Santos, C. & Bonifácio-Silva, A.C. 2003. Occurrence and characterization of entomogen galls in plants from natural vegetation areas in Delfnópolis, MG, Brazil. *Brazilian Journal of Biology,* 63: 705-715.

Veldtman, R. & Mcgeoch, M.A. 2003. Gall-forming insect species richness along a non-scleromorphic vegetation rainfall gradient in South Africa: the importance of plant community composition. *Ecological Society of Australia,* 28: 11-13.

Wright, M.G. & Samways, M.J. 1998. Insect species richness tracking plant species richness in a diverse flora: gall-insects in the Cape Floristic Region, South Africa. *Oecologia,* 115: 427-433.

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