Acta Botanica Brasilica 27(3): 537-542. 2013.

Host plants of insect-induced galls in areas of *cerrado* in the state of Goiás, Brazil

Walter Santos de Araújo[1,2,4,5], Isadora Portes Abraham Silva[2], Benedito Baptista dos Santos[2] and Vera Lúcia Gomes-Klein[3,4]

Received: 17 November, 2010. Accepted: 19 July, 2013

ABSTRACT

Most studies of the interactions between plants and gall-inducing (galling) insects have focused on the entomological aspects, few having addressed the diversity of galls in relation to the characteristics of the host plants. The objective of this study was to analyze the richness and composition of the community of host plants of galls in areas of *cerrado* (savanna) in the state of Goiás, Brazil. To that end, we inventoried the galls in different regions of the state and within various types of vegetation formations, between 2005 and 2007. We registered 80 gall morphotypes in 58 species of host plants (30 families and 47 genera). The host family with highest diversity of galls was Fabaceae, with 17 morphotypes, followed by Styracaceae, with seven. In the *cerrado*, Fabaceae is the plant family with the highest number of species. Our results show that the composition of a plant community is a determinant of the distribution of galling insects. At the family or genus level, the presence of certain taxa increases the species richness of the population of galling insects.

Key words: botanical families; floristic composition; galling insects; superhosts

Introduction

Insect-induced galls are caused by interactions between insects and plants that results in hypertrophy or hyperplasia of plant tissues (Fernandes *et al.* 1988). The relationships between species of gall-inducing (galling) insects and their host plants are intimate and specific (Carneiro *et al.* 2009), each gall morphotype being unique (Stone & Schönrongger 2003). Most studies investigating this type of insect-plant interaction have examined it from an entomological point of view, with various objectives, such as to characterize distribution patterns and quantify diversity (Fernandes & Price 1988; Cuevas-Reyes *et al.* 2004); to identify preferences related to host plants (Espírito-Santo & Fernandes 2007; Araújo & Santos 2009a); and to elucidate ecological and evolutional dynamics (Price 2005; Espírito-Santo *et al.* 2007). Few studies have addressed the diversity of galls by investigating the characteristics of the host plants.

Species of host plants of insect-induced galls have been identified in many botanical families (Gagné 1994). Certain characteristics of those families might increase the species richness of the population of galling insects. For example, the size of the plant family (Fernandes 1992; Mendonça 2007; Araújo 2011) and the geological age of the family (Fernandes 1992), as well as the presence of species or genera that present "superhost" phenotypes (Vedtman & McGeoch 2003; Araújo *et al.* 2013), can be determinants of galling insect species richness. The systematic investigation of the composition of the host plant communities is fundamental to demonstrating the importance of each of these factors.

The families that have been shown to harbor the greatest diversity of galls in Brazil are Asteraceae, Fabaceae and Myrtaceae (Mendonça 2007). Those families have been identified in studies of different regions, vegetation formations and biomes within the country. Although such studies have focused on various regions of the country, the floristic patterns of the host plants of galls in Brazil remain practically unknown. Therefore, the objective of the present study was to analyze the effects that the richness and composition of the community of host plants has on galling insect species richness in areas of *cerrado* (savanna) within the state of Goiás.

[1] Instituto de Pesquisas Ambientais e Ações Conservacionistas, Departamento de Ecologia, Goiânia, GO, Brazil
[2] Universidade Federal de Goiás, Instituto de Ciências Biológicas, Departamento de Biologia Geral, Laboratório de Entomologia, Goiânia, GO, Brazil
[3] Universidade Federal de Goiás, Instituto de Ciências Biológicas, Departamento de Biologia Geral Laboratório de Morfologia e Taxonomia Vegetal, Goiânia, GO, Brazil
[4] Universidade Federal de Goiás, Pós-Graduação em Ecologia e Evolução, Goiânia, GO, Brazil
[5] Author for correspondence: walterbioaraujo@yahoo.com.br

Material and methods

Study area

The study was carried out in different areas of the state of Goiás, which is in the central-west region of Brazil, within a macro-region dominated by *cerrado*. According to the Köppen climate classification system, the climate of the region is type Aw, tropical hot and humid, with rainy summers (October through March) and dry winters (April through September). The average annual rainfall is 1500 mm (range, 750-2000 mm), and the average temperature in the coolest month is above 18°C (Ribeiro & Walter 1998).

Methodology and data analysis

Data were compiled from a series of inventories related to gall host plants and the diversity of gall morphotypes, conducted between 2005 and 2007 in areas of the Serra dos Pireneus State Park, near the city of Pirenópolis; the Itanhangá quarter of the (capital) city of Goiânia, a semi-urban area; another semi-urban area within the city of Caldas Novas; and the campus of the Federal University of Goiás, in Goiânia. The characteristics of the four study sites are shown in Tab. 1. These semi-urban areas are remnants of native vegetation, generally located on tracts of land or housing developments that are only partially inhabited.

The sampling was done through censuses and active searches in each of the vegetation formations of the studied areas (Fernandes *et al.* 1988). We sampled every plant that hosted galls, including trees, bushes and shrubs. All of the observed galls and host plants were described, registered, photographed and identified. Three or four exemplars of each host plant were collected, part of the material being sent for botanical identification, the remainder being used in order to create a photographic record and written description, as well as to obtain the adult insect, in the laboratory.

From the data collected at the various sites, we compiled a list of host plants and galls, including the morphological descriptions of the latter. The relationship between the size of the plant family and galling insect species richness was tested through simple linear regression analysis. Information about the diversity and size of botanic *taxa* was obtained from the *Flora Vascular do Bioma Cerrado* ("Vascular Flora of the Cerrado Biome") inventory taken by Mendonça *et al.* (1998). The families of host plants were categorized according to the classification system established in the Angiosperm Phylogeny Group II guidelines (APG II 2003).

Results and discussion

We registered 80 morphotypes of galls in 58 species of host plants (Tab. 2). Those species were distributed among 30 families and 47 genera. Many of the gall morphotypes sampled represent new records for the neotropical region. Some of the galls found are depicted in Fig. 1.

We observed a relevant pattern of galling insect species richness, by taxonomic level. At the order level, the plant species that were hosts of galls were distributed across 17 orders (Fig. 2a), those with the highest numbers of host species and galls being Fabales, Malpighiales and Myrtales. Within the order Fabales, which is particularly species rich in the tropics, especially in the neotropical region (Mendonça *et al.,* 1998), we identified 12 host species (all belonging to the family Fabaceae) and 17 gall morphotypes. The orders Malpighiales and Myrtales also showed great species richness among the population of galling insects, each with 13 gall morphotypes (Fig. 2a), on plant species belonging to one of seven and three families, respectively. Fabales, Malpighiales and Myrtales collectively accounted for 53.7% of the gall morphotypes sampled in the present study, which suggests that these orders are highly important to galling insects. However, the galling insect species richness was also relatively high among the orders Ericales, Sapindales and Rosales, which presented with nine, six and four gall morphotypes, respectively.

Various authors, such as Gagné (1994) and Mendonça (2007), have analyzed the importance of gall host taxa at the family level. In the present study, the families most commonly represented, in descending order, were Fabaceae, Styracaceae, Vochysiaceae, Myrtaceae, Euphorbiaceae,

Table 1. Areas and vegetation formations within which galls were sampled in the state of Goiás, Brazil. 2005-2007.

Study area	Type(s) of vegetation formation(s)*	Municipality	Geographic coordinates
Serra dos Pireneus State Park	*Cerrado* (savanna) *stricto sensu,* rocky *cerrado*, dry semideciduous forest, gallery forest	Pirenópolis, Goiás	15°47'34.4"S; 48°50'16.3"W
Semi-urban region	*Cerrado stricto sensu, cerradão* (woodland savanna)	Goiânia, Goiás	16°35'53.98"S; 49°16'51.1"W
Semi-urban region	*Cerrado stricto sensu*	Caldas Novas, Goiás	17°44'41.9"S; 48°37'29.8"W
Campus of the Federal University of Goiás	Dry semideciduous forest	Goiânia, Goiás	16°36'12.9"S; 49°15'41.7"W

*Classifications based on Ribeiro & Walter (1998).

Table 2. Number of host plant species and gall morphotypes per host plant family in different areas of the *cerrado* (savanna) in the state of Goiás, Brazil.

Plant family	Number of host species	Number of gall morphotypes
Fabaceae	12	17
Styracaceae	2	7
Vochysiaceae	3	6
Myrtaceae	4	5
Euphorbiaceae	4	4
Malpighiaceae	4	4
Ulmaceae	2	4
Bignoniaceae	2	3
Sapindaceae	1	3
Malvaceae	2	2
Melastomataceae	2	2
Asteraceae	2	2
Burseraceae	1	2
Piperaceae	1	2
Dilleniaceae	1	2
Anacardiaceae	1	1
Annonaceae	1	1
Apocynaceae	1	1
Araliaceae	1	1
Caryocaraceae	1	1
Chrysobalanaceae	1	1
Clusiaceae	1	1
Ebenaceae	1	1
Erytroxylaceae	1	1
Lauraceae	1	1
Loranthaceae	1	1
Monimiaceae	1	1
Ochnaceae	1	1
Proteaceae	1	1
Sapotaceae	1	1
Total	58	80

Malpighiaceae, Ulmaceae, Bignoniaceae, Sapindaceae and Malvaceae (Fig. 2b). Many of those are the families with the greatest numbers of neotropical species, especially within the *cerrado* biome (Mendonça *et al.* 1998). According to Gagné (1994), Fabaceae is the family in which the diversity of morphotypes of galls induced by Cecidomyiidae (Diptera) in the neotropical region is greatest. Fabaceae has also been shown to have higher species richness than does any other family within the *cerrado* biome (Mendonça *et al.* 1998).

Although Styracaceae and Vochysiaceae were well represented in the present study, neither Gagné (1994) nor Mendonça (2007) mentioned them among the most representative families. Within the *cerrado*, Styracaceae and Vochysiaceae are represented by only nine and 36 species, respectively (Mendonça *et al.* 1998). Nevertheless, in the present study, they were among the families showing the greatest galling insect species richness, because of the number and diversity of galls affecting the genera *Styrax* and *Qualea,* respectively. In terms of the number of gall morphotypes, the family Myrtaceae ranked fourth in the present study, whereas it ranked fifth and second in the studies conducted by Gagné (1994) and Mendonça (2007), respectively. Myrtaceae is the seventh most diverse family in the *cerrado* (Mendonça *et al.* 1998).

We found a positive correlation between the size of the plant family (in number of species) and galling insect species richness (Fig. 3), plant family size explaining 49% of the variation in the number of galls (r^2=0.49, N = 30, p<0.001). This pattern was strongly influenced by Fabaceae, which showed the greatest species richness, in terms of host plants of galls in the *cerrado* (Mendonça *et al.* 1988). These results support the plant family size hypothesis, which states that the

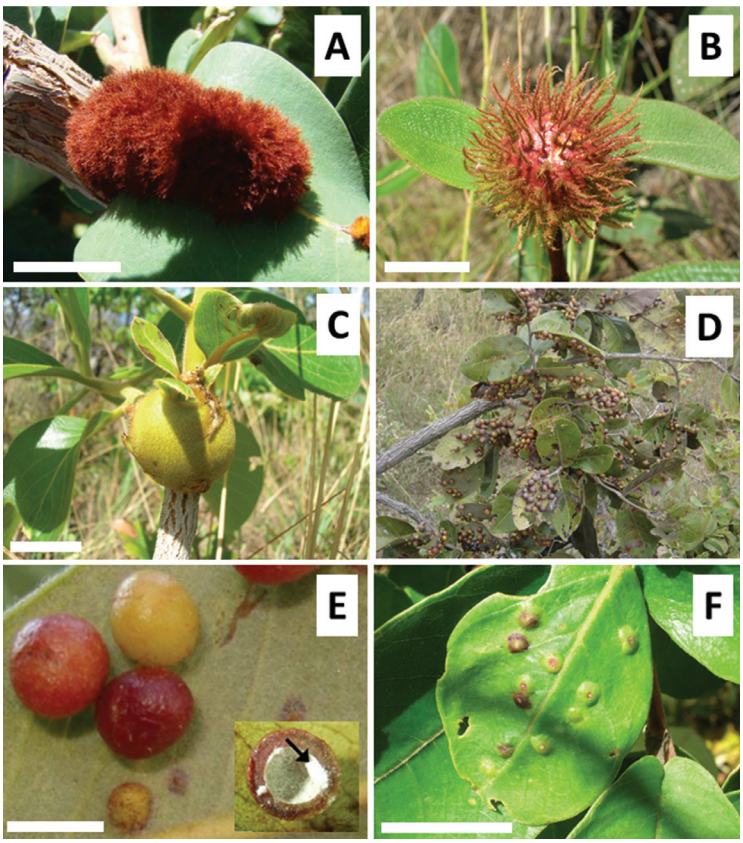

Figure 1. Examples of insect-induced galls found in different areas of *cerrado* (savanna) in the state of Goiás, Brazil: A) globose leaf gall of Cecidomyiidae (Diptera) on *Erythroxylum suberosum*; B) globose leaf gall of Gelechiidae (Lepidoptera) on *Macairea radula*; C) globose stem gall of Lepidoptera on *Diospyros hispida*; D) general aspect of the plant *Psidium pohlianum* replete with leaf galls of Psyllidae (Hemiptera); E) open gall on *Psidium pohlianum* showing the inner compartment with the insect nymph (arrow); and F) on *Qualea parviflora*, discoid leaf galls caused by parasitoids (Hymenoptera), rather than galling insects. Scale bar: 2 cm in A-D and F; 0.5 cm in E.

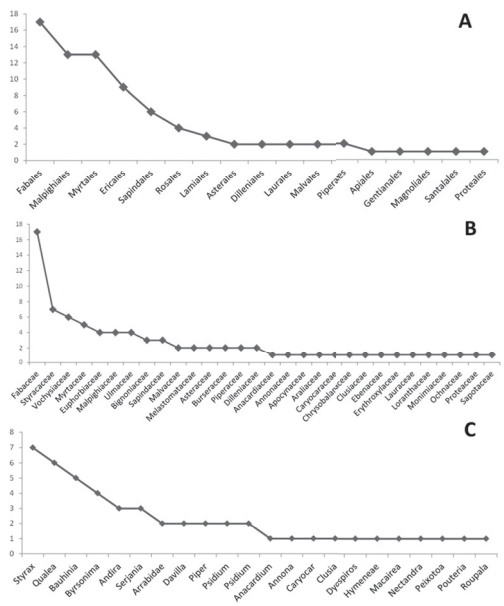

Figure 2. Distribution of galling insect species richness (number of galling species per host plant taxon) in various areas of the *cerrado* (savanna) in the state of Goiás, Brazil: a) by order; b) by family; and c) by genus.

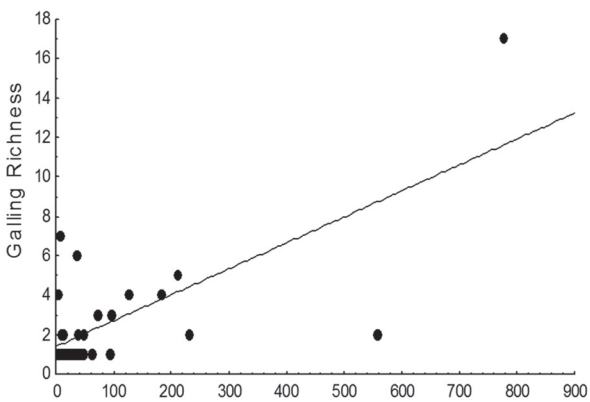

Figure 3. Linear regression between galling insect species richness per plant taxon and plant family size in number of species (y=1.39 + 0.01x, r^2=0.49, N = 30, p<0.001. Data on family size taken from Mendonça *et al.* (1998).

diversity of galling insects should be greater among the host plant families with the highest numbers of species (Fernandes 1992; Araújo 2011; Araújo *et al.* 2012). A high number of species within a family creates a greater availability of niches available for galling (Mendonça 2007). Gonçalves-Alvim & Fernandes (2001) found galling insect species richness to be higher among plant families that comprise more species. The authors showed that 50% of the variation in galling insect species richness was explained by the size of the plant family and that the five major families (Leguminosae, Asteraceae, Myrtaceae, Malpighiaceae, and Erythroxylaceae) harbored more than 65% of the galls identified.

Among the 47 genera of host plants of galls sampled in the present study, galling insect species richness was found to be highest for the genera *Styrax*, *Qualea*, *Bauhinia* and *Inga* (Fig. 2c). *Styrax* was the only representative of the family Styracaceae with seven morphotypes of galls, six of them being on *Styrax pohlii* DC, a species known to present great galling insect species richness (Araújo & Santos 2009b; Araújo *et al.* 2012). Likewise, *Qualea* was the only Vochysiaceae genus of presenting six morphotypes. *Qualea parviflora* Mart. hosted five of the six morphotypes of galls of that genus, confirming the results recently reported by Araújo *et al.* (2013), who classified the genus *Qualea* as a "superhost" of insect galls.

All of these observations indicate that the diversity of galls depends on a local component: the composition of the plant community (Vedtman & McGeoch 2003). The composition of the plant community is a qualitative character given by the identity of the taxon (Begon *et al.* 2006), which is considered a determinant of the character of different communities and vegetation formations (Scarano 2002). In addition, at the family or genus level, the presence of certain taxa appears to increase galling insect species richness (Gonçalves-Alvim & Fernandes 2001; Araújo *et al.* 2012).

Certain plants families have been frequently identified in studies of insect-induced gall diversity in Brazil, indicating their importance as host groups. For example, the family Myrtaceae is frequently listed in surveys of galls in the Atlantic Forest of southeastern Brazil (Maia 2001; Maia *et al.* 2008). it has been reported that, for the southern region of Brazil, which is dominated by Atlantic Forest and Pampas, galling insect species richness is greatest among host plants of the family Asteraceae (Mendonça 2007), whereas, in the *cerrado*, it is greatest among those of the family Fabaceae (Gonçalves-Alvim & Fernandes 2001; Maia & Fernandes 2004; Araújo *et al.* 2012). In a preliminary study of gall diversity in Goiás, Araújo *et al.* (2007) also found galling insect species richness to be highest among host plants of the family Fabaceae. These patterns are repeated at the genus level. In a broad revision of the galling fauna associated with the genus *Baccharis* (Asteraceae), Fernandes *et al.* (1996) registered 121 gall morphotypes. Mendonça (2007) found 19 and 15 gall morphotypes on host plants of the genera *Mikania* (Asteraceae) and *Eugenia* (Myrtaceae), respectively. Araújo *et al.* (2013) recently reported 19 gall morphotypes on host plants of the genus *Qualea* (Vochysiaceae) occurring in diverse areas of the *cerrado*. In the present study, the number of gall morphotypes was found to be highest (n = 7) for host plants of the genus *Styrax* (Styracaceae). The high diversity of galls on host plants of these genera can have a considerable influence on the local diversity of galling insects (Oyama *et al.* 2003; Araújo *et al.* 2012; Araújo *et al.* 2013).

According to Moreira (2006), approximately 40% of all studies of insect-induced galls in Brazil are related to insect taxonomy and diversity, whereas another 40% deal with the biology and ecology of galling. The diversity of insect-induced galls, with an emphasis on the composition and structure of plant communities, has come to be studied only recently in Brazil (Mendonça 2007). We recommend that botanists and plant ecologists collect data on insect-induced galls during their fieldwork. The galls are easy to collect, and the insects they harbor can be bred to maturity (for identification) in the laboratory, a process that, albeit laborious, is not expensive or complicated (see methodologies of sampling in Price *et al.* 1998). During the collection of botanical specimens, the occurrence of galls is often ignored, which limits our knowledge of the variety of these interactions and contributes to the lack of data in the literature. Studies of the occurrence and characteristics of galls are fundamental to understanding the diversity patterns of galling insects and their host plants. In addition, the gall morphotypes are extremely specific and could be used for taxonomic differentiation between closely related or similar plant species (Abranhamson *et al.* 1998).

The host plants of galls are determinants of galling insect diversity, because the former provide the conditions and fundamental resources necessary for the development of the offspring of the latter, especially habitat and food (Mendonça 2001). Each species of host plant represents a potential niche for galling insects (Mendonça 2007), some of them being considered "superhosts" of galls (Vedtman & McGeoch 2003). All of this underscores the need to seek a deeper knowledge of the flora that hosts galls, in terms of its composition and diversity. Therefore, efforts to identify the diversity patterns of galling insects must also consider that of their host plants.

Acknowledgments

The authors are grateful to Frederico Augusto Guimarães Guilherme, of the *Universidade Federal de Goiás* (UFG, Federal University of Goiás), and to the peer reviewers, for their suggestions to improve the manuscript, as well as to the UFG Biological Sciences Institute, for the logistical support provided. This study received financial support from the Brazilian *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES, Office for the Advancement of Higher Education; grant to WSA).

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