

# Relationship between host plant diversity and gall-inducing insect's richness in the Brazilian Cerrado

## Relações entre a diversidade de plantas hospedeiras e a riqueza de insetos galhadores no Cerrado brasileiro

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### Abstract

Several hypotheses have been proposed to explain the diversity patterns of gall-inducing insect species. Some of them take into consideration the influence of host plants on these patterns, mainly in relation to plant community richness and composition. In the present study, we intended to answer three questions: (i) Is gall richness dependent of the host plant family size?, (ii) This relationship also occurs for the plant genus size?, and (iii) Does the composition of host taxa influence gall richness? We carried out inventories of gall-inducing insect diversity in different areas of the Cerrado region in the state of Goiás, in the Midwestern Region of Brazil. Gall richness was positively correlated to host plant family size in number of species. Larger families presented higher richness of gall morphotypes, such as Fabaceae, a family that exhibits the highest number of plants in the Cerrado area. Also, plant community composition influenced gall richness and the presence of some super-host taxa incremented gall diversity. Our results indicate that plant community composition may be as determinant of gall-inducing insect species diversity as host plant richness.

**Key words:** floristic composition, galls, host plant richness, super-hosts.

### Resumo

Várias hipóteses têm sido propostas para explicar os padrões de diversidade de insetos galhadores. Algumas delas têm levado em consideração a influência das plantas hospedeiras nesses padrões, sobretudo em relação à riqueza e composição da comunidade. No presente estudo, nós respondemos às seguintes questões: (i) a riqueza de galhas é proporcional ao tamanho da família de plantas? (ii) essa relação também ocorre para o tamanho dos gêneros de plantas? e (iii) a composição dos táxons hospedeiros pode influenciar a riqueza de galhas? Inventários da diversidade de insetos galhadores foram realizados em diferentes regiões do estado de Goiás, centro-oeste do Brasil. A riqueza de galhas foi positivamente correlacionada com o tamanho da família de plantas hospedeiras, em número de espécies. Famílias maiores apresentaram uma maior riqueza de morfotipos de galhas, como Fabaceae, a família que exibe o maior número de espécies de plantas no Cerrado. Do mesmo modo, a composição do táxon vegetal influenciou a riqueza de galhas e a presença de alguns táxons super-hospedeiros incrementou a diversidade de galhas. Esses resultados indicam que a composição da comunidade de plantas pode ser tão determinante para a diversidade de insetos galhadores quanto a riqueza de plantas hospedeiras.

**Palavras-chave:** composição florística, galhas, riqueza de plantas hospedeiras, super-hospedeiras.

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## Introduction

A variety of studies have been performed to search for factors that account for gall-inducing insect diversity patterns, mainly in the last 10 years (Espírito-Santo *et al.*, 2007). Among them, the idea that host plants influence richness of gall-inducing insects is highly spread and presents several trends in the literature, as to plant architecture (Lawton, 1983; Araújo and Santos, 2009), plant type (Fernandes and Price, 1988; Gonçalves-Alvim and Fernandes, 2001), host plant richness (Cuevas-Reyes *et al.*, 2004; Dalbem and Mendonça, 2006), or host plant family size (Fernandes, 1992; Veldtman and McGeoch 2003). This last hypothesis indicates that larger families are more likely to host more gall-inducing species than smaller ones (Fernandes, 1992), since each host plant species represents a potential niche for gall-inducing insects, thus permitting large families to support high diversity of these insects (Mendonça, 2007). If this is true, a similar idea can be applied to other taxonomic level of host plants, such as orders or genera.

Plant family size hypothesis was tested just a few times (Fernandes, 1992; Gonçalves-Alvim and Fernandes, 2001; Mendonça, 2007; Araújo 2011). Nevertheless, the theoretical framework that supports the hypothesis is quite robust, since the larger the number of species in one family, the greater the probability of occurrence of plant species potentially hosts of galls (Fernandes, 1992). On the other hand, it also matters the number of species, families with high species diversity represent greater amount of natural groups with physiological and ecological similarities as well (Araújo, 2011). Structural and ecological synchronism is considered an important factor in the diversification of galling insect species (Mendonça, 2001).

In a recent study, Araújo (2011) investigated the relationship between diversity of gall-midges (Cecidomyiidae)

and size and identity of plant taxa in the Brazil. According to the author, the size of the orders and families of plants was a good predictor of the galling diversity. However, the size of plant genera showed no significant relationship with the richness of Cecidomyiidae, being the plant genera with the greatest diversity of galling insects not necessarily the same in ranking of plant diversity. These results have shown that both the number of species and composition of plant taxa may have important roles in the gall-midge diversity, however, have raised questions about how these patterns are given to other groups of galling insects. In the present study, we aimed at answering three questions: (i) Is gall richness dependent of the host plant family size? (ii) Does this relationship also occur for the plant genus size? and (iii) Does the composition of host taxa influence gall richness?

## Material and methods

### Area of study

This study was carried out in different areas of the state of Goiás, in the Midwestern Region of Brazil, in a macroregion of Cerrado. Inventories were performed in following locations: Parque Estadual da Serra dos Pireneus (gallery forest, semidecidual forest, typical cerrado, rocky cerrado), municipality of Pirenópolis (15°48'45" S, 48°50'39" W); semi-urban region of Itanhangá (typical cerrado), municipality of Goiânia (16°35'53" S, 49°16'51" W); campus of the Universidade Federal de Goiás (semidecidual forest), municipality of Goiânia (16°36'12" S, 49°15'41" W); semi-urban region of the Del Rey District (typical savanna), municipality of Caldas Novas (17°44'41" S, 48°37'29" W) (Figure 1). All these areas are characterized by two well-defined seasons, with dry winter and rainy summer, category Aw according to the Köppen climate classification (tropical rainy). The average annual

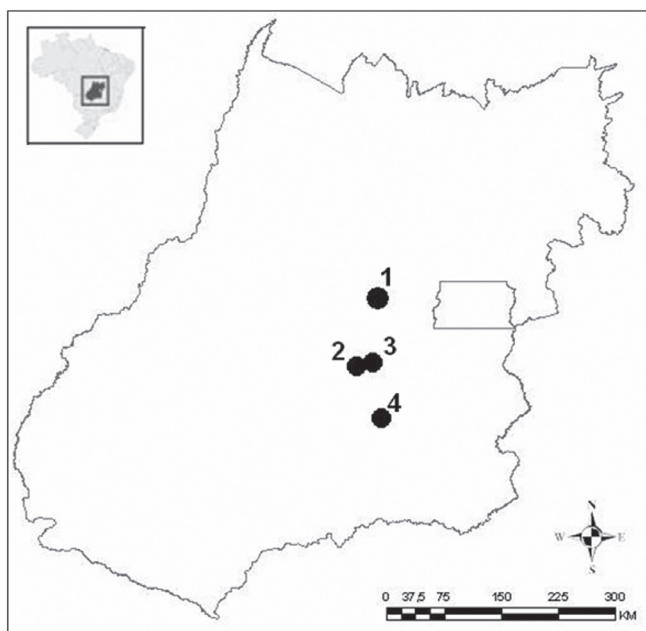
precipitation is around 1500 mm, ranging from 750 mm to 2000 mm. The rainy season extends from October to March and the average temperature of the coldest month is above 18°C (Ribeiro and Walter, 1998).

### Sampling

Samples were taken from July 2005 to August 2007 by random walks that covered the local vegetation in all the above mentioned sites, searching for host plant species and galls (Fernandes *et al.*, 1988). The sampling was bimonthly and had an average duration of 2 hours. All the galls found were registered, photographed, and classified according to their external morphology. Gall-inducing insect richness was measured based on the study of gall morphotypes sampled (Carneiro *et al.*, 2009a). Articles with the descriptions of the galls from each of the localities have been published separately (Araújo *et al.*, 2007; Santos *et al.*, 2010; Araújo *et al.*, 2011) or are in the confection process. Gall-inducing insects present species-specific relationship and gall morphology that are unique for each species (Stone and Schönrogge, 2003), which facilitates gall identification in natural habitat and constitute reliable parameters to estimate gall-inducing insect richness (Espírito-Santo and Fernandes, 2007).

### Data analyses

Data from different areas of this study were grouped in morphotypes according to the families and genera of host plants. Information on botanical taxon diversity was obtained in the inventory carried out in the Cerrado region by Mendonça *et al.* (1998). Some gall morphotypes were observed in different sampling areas and in different host species. In these situations, morphotypes and host species were registered only once to avoid duplicating results. When we tested the plant family size hypothesis it was observed a nonlinear pattern where half the fa-



**Figure 1.** Distribution of the areas under study in the state of Goiás, Midwestern Region of Brazil: (1) Parque Estadual da Serra dos Pireneus, municipality of Pirenópolis (15°48'45" S, 48°50'39" W); (2) Semi-urban region of Itanhangá, municipality of Goiânia (16°35'53" S, 49°16'51" W); (3) Campus of the Universidade Federal de Goiás, municipality of Goiânia (16°36'12" S, 49°15'41" W); (4) Semi-urban region of Del Rey District, municipality of Caldas Novas (17°44'41" S, 48°37'29" W).

families had a single morphotype of gall, so we used a logistic regression model (Logit model) to test whether the probability of hosting more than one morphotype of gall depends on the family size. The same was done to test the hypothesis for the genera of plants. For the relationship between the plant genus size and galling richness the variables were processed by function logarithmic ( $\log x$ ). We also tested separately the plant genus size only with taxa richest, in which we detected three or more gall morphotypes (which we call super-hosts). To test the effect of size of the super-host genera on the diversity of galls, as data showed a pattern of linearity and normality, we use a simple linear regression model. All analysis was done in the software Statística 7.1.

## Results

We registered 80 gall morphotypes in 58 species, 30 families, and 47 genera

of host plants (Table 1). The most important families, in decreasing order, were Fabaceae, Styracaceae, Vochysiaceae, Myrtaceae, Euphorbiaceae, Malpighiaceae, Ulmaceae, Bignoniaceae, Sapindaceae, and Malvaceae. These 10 families accumulated 68.7% of gall richness and 54.3% of host species. Families Fabaceae, Styracaceae, Vochysiaceae, and Myrtaceae presented 17 (21.2% of total galls), seven, six, and five morphotypes, respectively. Among the 47 host plant genera sampled, *Styrax*, *Qualea*, *Bauhinia*, and *Inga* presented the highest gall richness, with seven, six, five, and four morphotypes, respectively. Gall-inducing insect richness depends of the host plant family size in terms of number of species (Table 2). We observed that half of the plant families had only one gall morphotype, being that the probability of hosting two or more morphotypes increases 18.2% with the genus size. Excluding family Fabaceae (the most frequent in this

study) from the analysis, the relationship continued statistically significant but has lost some strength (Table 2), showing the relative importance this family.

Besides Fabaceae, others plant taxa observed in our study were particularly rich in gall-inducing insects. For instance, *Styrax* was the only genus of the family Styracaceae found in this study and presented seven gall morphotypes, six of them in *Styrax pohlii* DC. Similarly, *Qualea* was the only genus of the family Vochysiaceae registered in our study, with six morphotypes, five of them in *Qualea parviflora* Mart. The plant genus size was positively correlated with the richness of galling, explaining 20.3% of the variation (Table 2). When analyzed, only the richest plant genera (super-host) had a negative marginal correlation between genus size and gall-inducing insect richness (Figure 2).

## Discussion

The diversity pattern of gall-inducing insect species observed in the present study corroborates the host plant family size hypothesis (Fernandes, 1992). This pattern is highly influenced by families which has a relative importance both in the regional flora composition as in the local number of species of herbivores (Veldtman and McGeoch, 2003; Mendonça, 2007). For instance, Fabaceae is a family that presents the highest diversity of both plant species in the Cerrado area (Mendonça *et al.*, 1998) and gall-inducing insects in the Neotropical region (Gagné, 1994). Gonçalves-Alvim and Fernandes (2001) observed a similar pattern in the Cerrado region located in the state of Minas Gerais, in the Southeastern Region of Brazil. The authors reported that gall-inducing insect richness was also positively correlated to the host plant family size and Fabaceae was the most important family, both in gall richness and host plant diversity. Altogether, these results reveal that in the Brazilian Cerrado, Fabaceae is undoubte-

**Table 1.** Number of host plant species and gall morphotypes per family of host plant obtained from gall samples collected in four different areas of Cerrado in the state of Goiás, Midwestern Region of Brazil.

Family	Total species (no.) <sup>1</sup>	Species sampled (no.) <sup>2</sup>	Gall morphotypes (no.) <sup>3</sup>	Gall morphotypes (%)
Fabaceae	777	12	17	21.25
Styracaceae	9	2	7	8.75
Vochysiaceae	36	3	6	7.50
Myrtaceae	211	4	5	6.25
Euphorbiaceae	183	4	4	5.00
Malpighiaceae	126	4	4	5.00
Ulmaceae	5	2	4	5.00
Bignoniaceae	96	2	3	3.75
Sapindaceae	72	1	3	3.75
Malvaceae	48	2	2	2.50
Melastomataceae	231	2	2	2.50
Asteraceae	557	2	2	2.50
Burseraceae	12	1	2	2.50
Piperaceae	38	1	2	2.50
Dilleniaceae	11	1	2	2.50
Anacardiaceae	20	1	1	1.25
Annonaceae	45	1	1	1.25
Apocynaceae	95	1	1	1.25
Araliaceae	16	1	1	1.25
Caryocaraceae	3	1	1	1.25
Chrysobalanaceae	32	1	1	1.25
Clusiaceae	38	1	1	1.25
Ebenaceae	9	1	1	1.25
Erythroxylaceae	24	1	1	1.25
Lauraceae	62	1	1	1.25
Loranthaceae	48	1	1	1.25
Monimiaceae	12	1	1	1.25
Ochnaceae	30	1	1	1.25
Proteaceae	10	1	1	1.25
Sapotaceae	20	1	1	1.25
Total	2876	58	80	100.00

Notes: <sup>1</sup>Number of host plant species in each family inventoried by Mendonça *et al.* (1998) in the Brazilian Cerrado. <sup>2</sup>Number of host plant species in each family inventoried in this study. <sup>3</sup>Number of different gall morphotypes registered per host plant family inventoried in the present study.

dly a preponderant family to account for gall diversity. In other regions of Brazil, or even in other parts of the world, several other plant families have presented a considerably large number of galls as well (Blanche and Westoby, 1995; Oyama *et al.*, 2006). Recently, Mendonça (2007) studied gall diversity in the Southern Region of Brazil and found a strong correlation between host plant family size and gall richness. Also, the author re-

ported that this pattern was influenced by the presence of the family Asteraceae, which is particularly rich in galls in the region studied. Therefore, he concluded that host plant family size is an important factor for regional prediction of gall-inducing insect species richness.

In the Cerrado, the plants species present congruence high of development, principally because of fire, what lead the vegetation to a state of symphenol-

ogy (Mistry, 1998). As gall-inducing insects generally exhibit opportunistic adaptive irradiation (Price, 2005), the conditions may favor the change of the host plant, causing speciation (Craig *et al.*, 1994; Singer and Stireman, 2005). These processes are related to an ecological synchronism of plant species, however, can be increased in natural botanical families that present chemical, structural, and ecological similarities (Mendonça, 2007). One of the principles of the plant family size hypothesis is that larger families have a higher number of plant species and, consequently, are more likely to present species developing synchronically (Araújo, 2011). At plant communities where species have different phenological patterns, for example the rainforests, host-shift process would occur more frequently in species presenting symphenology (Craig *et al.*, 1994), generally found in phylogenetically related species. Thus, the phylogenetic proximity of host plants and their synchronical development, more likely to happen in larger families, facilitates the occurrence of these irradiation events (Banks and Paterson, 2005).

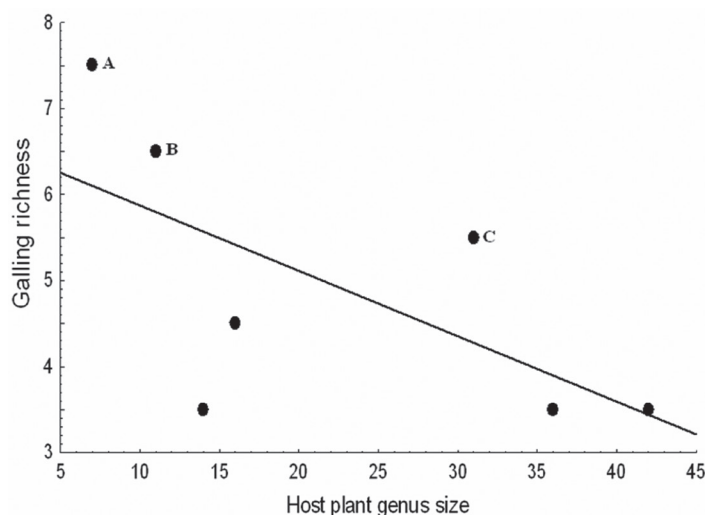
Plant community composition was an important factor in generating richness of gall-inducing insects as well. In addition, Fabaceae has shown to be a megadiverse family (both in plant species as in galling species), Styracaceae and Vochysiaceae, presenting a high richness of gall-inducing insect species. This was a consequence of the great richness of genera *Styrax* and *Qualea*, in general, and the species *Styrax pohlii* and *Qualea parviflora*, in particular, respectively. This confirms the trend certain groups of host taxa exhibit to be super-hosts (Veldtman and McGeoch, 2003). Mendonça (2007) affirms that the term super-host refers to plant species or taxa that host a large number of gall-inducing insect species and their distribution plays a decisive role in local and regional diversity of gall-inducing insects.

We analyzed the relationship between

**Table 2.** Results of logistic regression between gall-inducing insects richness and plant taxa size (family and genus)\* in four different areas of Cerrado in the state of Goiás, Midwestern Region of Brazil.

	Parameter estimate	Chi-square	P
Family size (all)	2.57	5.08	0.02
Family size no Fabaceae	2.43	3.89	0.04
Genus size (all)	4.72	11.85	0.001

Note: (\*) Size of the families and genera obtained in Mendonça *et al.* (1998).

**Figure 2.** Relationship between gall richness and super-host plant genus size in terms of number of species ( $y = 1.09 - 0.36x$ ;  $r^2 = 0.47$ ;  $N = 7$ ;  $p = 0.08$ ). Letters A, B, and C in the both graphics represent *Styrax*, *Qualea*, and *Bauhinia*, respectively, the genera presenting the highest richness of gall-inducing insect species in different areas of Cerrado in the state of Goiás, Midwestern Region of Brazil. Data on host plant genus size were obtained in Mendonça *et al.* (1998).

genus size and gall richness, the general pattern we observed was interesting: the positive relationship taken when analyzed all genera is reversed when we analyzed only the richest genera. The positive effect of the genus size observed for analysis of all genera is not repeated when only the richest genera in gall-inducing insects are analyzed. Thus, those genera presenting the highest diversity regarding number of species were not the richest in terms of gall morphotypes, corroborating Araújo (2011). This evidences that the presence of some super-host taxa may increase gall diversity regardless of the number of plant species (Mendonça, 2007).

The observed results suggest that the plant family size hypothesis appears

to be strongly dependent on one or few botanical families sampled, which shows a high diversity at regional level (Mendonça, 2007). Local processes such as the composition of plant community seem to influence the galling diversity in local level (e.g. the frequent presence of the genus *Styrax* in our samples placed the family Styrcaceae among the richest in galls, regardless of the low number of species of this family in the Cerrado region). Mendonça (2007) reports that local processes might present stronger effects on the diversity of gall-inducing insect species and their host plants when compared with regional processes. However, considering several areas of study simultaneously, local patterns, existing in one or some of

them, such as local richness of plant species, may influence gall-inducing insect diversity (Oyama *et al.*, 2003). Veldtman and McGeoch (2003) studied gall-inducing insect species richness in non-scleromorphic vegetation in South Africa. The authors concluded that the selection of insects by the most advantageous plant species varies according to the vegetation or the biome considered. This can be explained based on the fact that host species may have different values for gall-inducing insects, depending on their historical-evolutionary relationships (Price, 2005). According to Araújo (2011), factors like the development synchrony and the sympatric occurrence of species may be responsible for the appearance of super-host taxa. Therefore, plant community composition, especially the presence of super-host species and families presenting high diversity of galls, is the factor that best accounts for local richness of gall-inducing insect species (Veldtman and McGeoch, 2003).

Inventories on galling insect's diversity have found empirical results that confirm the observations made by us. For example, Carneiro *et al.* (2009b) studied gall insects in rocky fields of the Serra do Espinhaço, MG, and found both a high diversity of galling on large plant families (Asteraceae) and taxa independently of its size (*Baccharis* and *Byrsonima*), also had many galls. Santos *et al.* (2010) observed a great diversity of galls in the family Fabaceae (very diverse) and in the genus *Styrax* (which presents a few species) in Semideciduous Forest, in Goiânia. Similar patterns were also observed in other studies (Gonçalves-Alvim and Fernandes, 2001; Maia *et al.*, 2008; Araújo *et al.*, 2011). Thus, both studies that test explicit ecological hypothesis such as descriptive inventories have found similar patterns. Our findings allow us to conclude that the host plant family size was important for gall-inducing insect species richness in the Cerrado region. Nevertheless, it is important to report that families with high diversity, as Fab-

ceae in this study, can strongly influence the results. Anyway, both the occurrence of megadiverse families as super-host taxa presence, indicate the importance of host plant community composition for the diversity of gall-inducing insects. Further studies designed to evaluate host plant influence on gall richness are highly recommended and must be conducted to verify whether these patterns are repeated, clarifying the real importance of plant communities in the diversity of gall-inducing insect species. We suggest what hypothesis to assess the species identity and community composition of host plants can be biologically more relevant to understanding the diversity of gall-inducing insects, than those with a quantitative approach based only on the number of host species.

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