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Does environmental diversity affect hymenopteran galling insects and their natural enemies on *Caryocar brasiliense* trees (Caryocaraceae)?

¿La diversidad ambiental puede afectar los himenópteros de agallas y sus enemigos naturales en árboles de *Caryocar brasiliense* (Caryocaraceae)?

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Abstract: *Caryocar brasiliense* (Malpighiales: Caryocaraceae) trees, protected by Brazilian federal laws, are the main income source in many communities. The transformation of the Cerrado (savanna biome) into grazing or agricultural areas has been isolating these trees species in an agro-urban landscape. We studied the effects of environmental diversity on the abundance of galling insect communities inhabiting *C. brasiliense* trees in three different environments: Cerrado, pasture, and an urban area. *Eurytoma* sp. (Hymenoptera: Eurytomidae) adults and their galls, its parasitoid *Sycophila* sp. (Hymenoptera: Eurytomidae) and the predator *Zelus armillatus* (Hemiptera: Reduviidae) were present in larger numbers on the *C. brasiliense* leaflets in the urban area. The percentages of totally galled leaflets (exhibiting all kinds of galls) and the number of trees were negatively correlated. Greater habitat diversity favored that of galling insect species and their natural enemies.

Keywords: *Ablerus magistretti*, *Bruchophagus* sp., *Eurytoma* sp., parasitoids, predators.

Resumen: Los árboles de *Caryocar brasiliense* (Malpighiales: Caryocaraceae), que representan la principal fuente económica para muchas comunidades, están protegidas por leyes federales brasileñas. La transformación de la sabana de El Cerrado en áreas de pastoreo o agrícolas da como resultado un escenario de árboles de esta especie aislados en un paisaje agro-urbano. La presente investigación tuvo como objeto estudiar los efectos de la diversidad ambiental sobre la abundancia de comunidades de agallas en árboles de *C. brasiliense* en tres diferentes ambientes: cerrado, pastoreo y área urbana. La frecuencia de adultos de *Eurytoma* sp. (Hymenoptera: Eurytomidae) y sus agallas, del parasitoide *Sycophila* sp. (Hymenoptera: Eurytomidae) y del depredador *Zelus armillatus* (Hemiptera: Reduviidae) fue más frecuente en hojas de *C. brasiliense* en el área urbana. Se observó una correlación negativa entre porcentajes de hojas con presencia de las agallas (todos los tipos) y el número de árboles. El hábitat de los árboles favoreció la diversidad de especies de agallas y sus enemigos naturales.

Palabras clave: *Ablerus magistretti*, *Bruchophagus* sp., *Eurytoma* sp., parasitoides, depredadores.

Introduction

The galling insects are among the most sophisticated in this group because they modify the host plant tissues to produce highly specialized structures where their larvae develop protected from harsh external environment, endophytically, while feeding on a rich material (Silva *et al.* 2016). These abnormal plant cell growths are called galls and vary in color, aspect, size, phenology, hardness, chemistry, and anatomical structure, besides being rare, univoltine or multivoltine (e.g. Fernandes and Santos 2014).

Galling insects are extremely abundant in all major ecosystems in the world, with many of them damaging plant species of economic importance. Theses insects are totally dependent on the nutrients obtained from the host plant tissues. Thus, they need to manipulate their host plant physiology to adjust their feeding (Espírito-Santo *et al*. 2012).

Large-scale distribution of galling insects has been studied and some mechanisms may explain their trends. Changes in habitat conditions affect the interactions between gallers and their host plants, transforming their diversity and abundance. These insects are diverse in more complex environments (*i.e.* higher floristic diversity) (Price 2005), but the factors affecting galling community and population trends, such as host traits mediated by habitat interactions, require further studies (Price 2005).

The system composed by a common and economically important Cerrado (savanna biome) tree species, *Caryocar brasiliense* Camb. (Malpighiales: Caryocaraceae) (Leite *et al*. 2006), and its four main galling herbivores in central Brazil is adequate to evaluated their interactions. Four different hymenopterans species, very distinct in shape, morphology and abundance induce galls on *C. brasiliense* (Leite *et al*. 2009, 2011a, 2011b, 2011c).

Caryocar brasiliense trees, which are protected by Brazilian federal laws, are the main income source of many communities (Leite *et al*. 2006; Santos *et al.* 2018). Hence, these trees are left in the Cerrado areas even after being converted to pasture, urban or agricultural areas, with a common scenario of isolated plants in the agro-urban landscape. The effects of habitats on the diversity and abundance of galling insects and of their natural enemies on *C. brasiliense* trees were evaluated in three environments: i) preserved Cerrado; ii) Cerrado cleared for pasture; and iii) Cerrado converted into an urban development area. The hypothesis tested was that the diversified of galling insects is higher in more diverse habitats. Therefore, the diversity of galling insects was expected to be higher on trees in the Cerrado compared to the other two habitat types.

Materials and methods

Study sites. This study was performed in the municipality of Montes Claros, Minas Gerais state, Brazil, during 3 consecutive years (June 2008 through June 2011). This region has dry winters and rainy summers with a Aw: tropical savanna climate, according to Köppen. The study was developed in three distinct environments: 1) ***sensu stricto*** **Cerrado,** (16º44'55.6"S 43º55'7.3"W, at an elevation of 943 masl, with dystrophic yellow red oxisol soil with sandy texture); 2) **pasture,** formerly with Cerrado vegetation (16º46'16.1"S 43º57'31.4"W, at an elevation of 940 masl, with dystrophic yellow red oxisol soil with loamy texture); and 3) an **urban** area in the campus of the "Instituto de Ciências Agrárias da Universidade Federal de Minas Gerais (ICA/UFMG)", (16º40'54.5"S 43º50'26.8"W, at an elevation of 633 masl, with dystrophic red oxisol with medium texture which was described by Leite *et al.* (2006). Permission to collect insects and galls in these locations/activities was granted by the landowner (Universidade Federal de Minas Gerais) and the collected arthropods are neither endangered nor protected species.

The Cerrado area was of the *sensu stricto* type (a species-rich biome of shrubs and trees 8-10 m high, with a dense understory) in an area with 44.9 % of soil covered by grass, 5.8 % by shrubs, 23.5 % by small trees and 8.8 % by large ones and an average of 17 *C. brasiliense* trees per ha. The pasture area has 84.2 % of the soil covered by African grass (*Brachiaria decumbens* (Stapf)), 0.2 % by shrubs, 4.8 % by small trees, 2.8 % by large ones and with 42.3 *C. brasiliense* trees per ha. The urban area has 100 % of the soil covered by grass (*Paspalum notatum* Flüggé) with 100 *C. brasiliense* trees per ha (see Leite *et al*. 2006). The native Cerrado vegetation is the most diverse habitat, followed by the pasture and the urban habitat, respectively. The high number of *C. brasiliense* trees per ha in the urban area is explained by it's use as a designed landscape and as shade source. The Cerrado and pasture were 10 km apart and 20-30 km apart, respectively, from the urban area.

Study host plants and galling species. Adult *C. brasiliense* trees (reproductive stage) in the Cerrado, pasture and urban environment were 4.1 ± 0.2 m, 2.9 ± 0.1 m and 3.8 ± 0.2 m high (average ± SE) with crown width of 5.2 ± 0.2 m, 4.0 ± 0.1 m and 1.7 ± 0.1 m (average ± SE) (Leite *et al.* 2006).

The hymenopteran galls studied on *C. brasiliense* leaves were: i) *Eurytoma* sp. globoid galls, with 2.53, 1.28, and 0.90 mm of height, length and width, respectively, with walls covered by yellowish trichomes with one larval chamber and one galling larva each; ii) *Bruchophagus* sp. vein galls, with 1.91, 2.04, and 5.56 mm of height, length and width, respectively, greenish and glabrous; iii) Eulophidae spherical galls, with 1.61 and 1.84 mm of diameter and height, respectively, brownish and glabrous; and iv) Hymenopteran discoid galls, with 3.70 and 0.57 mm of diameter and height, respectively, greenish and glabrous. For detailed information on the natural history of the galling insects and their distribution within trees, as well as descriptions of the natural enemies in this system, see Leite (2014). There, the following summary of these species is shown. I) Predators: The spiders *Cheiracanthium inclusum* Hentz, 1847 (Miturgidae); *Peucetia rubrolineata* (Keyserling, 1877) (Oxyopidae); *Anelosimus* sp., *Achaearanea hirta* (Taczanowski, 1873) (Theridiidae); *Gastromicans albopilosa* Simon, 1903; *Chira bicirculigera* Soares and Camargo, 1948; *Rudra humilis* Mello-Leitão, 1945; *Thiodina melanogaster* Mello-Leitão, 1917 and *Lyssomanes pauper* (Mello-Leitão, 1945) (Salticidae); *Dictyna* sp. and sp.1 (Dictynidae); *Tmarus* sp. and sp.1 (Thomisidae); *Argiope argentata* (Fabricius, 1775); *Gasteracantha cancriformes* (L., 1758); *Argiope* sp.; *Parawixia* sp. and sp.1 (Araneidae); and Anyphaenidae are important generalist predators (see Leite *et al*. 2013). The ants *Crematogaster* sp., *Pseudomyrmex termitarius* Smith, 1855, and *Camponotus novograndensis* Mayr, 1870 (Hymenoptera: Formicidae) and the predatory thrips *Holopothrips* sp., *Trybonia intermedius* Bagnall, 1910 and *Trybonia mendesi* Moulton, 1933 (Thysanoptera: Phlaeothripidae) can reduce defoliation by lepidopteran leaf miners and/or sucking insects (Leite *et al.* 2012a, 2012b, 2012c), and this factor may favor the colonization of the leaves on *C. brasiliense* by galling insects (free space). *Zelus armillatus* (Lepeletier & Serville, 1825) (Hemiptera: Reduviidae) is an important predator of *Eurytoma* Illiger, 1807 galls as well as defoliators and leaf-mining insects (Leite *et al.* 2012a, 2012c, 2013). *Epipolops* sp. (Hemiptera: Geocoridae) can also prey on defoliators and leaf-mining insects (Leite *et al*. 2012a). II) Parasitoids: *Sycophila* sp. (Hymenoptera: Eurytomidae) is the major parasitoid of *Eurytoma* sp. (Leite *et al*. 2013), but *Ablerus*

magistretti Blanchard, 1942 (Hymenoptera: Aphelinidae) is also a parasitoid of this galling insect and apparently competition occur between these two species for their galling host (Leite *et al*. 2013). III) Hyperparasitoids: *Quadrastichus* sp. (Hymenoptera: Eulophidae) is a possible hyperparasitoid of *Sycophila* sp. (Leite *et al*. 2013). IV) Inquiline: *Eurytoma* occupy the galls belonging to the Alycauline (Diptera) (Leite *et al*. 2013).

Study design. The study design was completely randomized, with 12 replicates (12 trees) and 3 treatments (habitats). Data were collected on *C. brasiliense* adult trees at every 50 m along a 600 m transect at each site (Cerrado, pasture and urban area). For the 12 replicates, we collected data during 3 consecutive years, collecting samples of all insects' species (i.e., rare species) per year and area. No fertilizers or pesticides were used in these three areas.

The distribution of galling insects and their galls, predators, parasitoids and inquilines, and the percentage of leaves infested with galls, was recorded on 4 fully expanded leaves (three leaflets/leaf) of each 12 *C. brasiliense* trees per area. Sampling was performed in the morning (7:00-11:00 a. m.) by direct visual observation once a month. Insects were collected with tweezers, brushes, or aspirators and preserved in vials with 70 % alcohol for identification by taxonomists. The leaves were collected and transported to the laboratory. Gall size was measured by using a digital caliper (accurate to the nearest 0.1 mm). Leaves were scanned and the leaf area and that occupied by each galling species calculated using the Sigma Scan Pro software (SPSS 1999). Subsequently, the leaves were placed inside a white plastic pot (temperature 25 °C) and the emergence of galling insects, parasitoids, hyperparasitoids and inquilines were evaluated per sample every two days during 30 days. The emerged insects were collected and preserved as described for identification. The voucher number for spiders and insects are IBSP 36921-36924 (Instituto Butantan, São Paulo state, Brazil) and 1595/02 - 1597/02 (CDZOO, Universidade Federal do Paraná, Paraná state, Brazil), respectively.

Statistical analyses. Averages were used to reduce the data per leaflet/tree in each area. Correlations between the number of galling insects and their galls with floristic diversity (number of trees/ha) (see Leite *et al*. 2006) were subjected to variance (ANOVA) ($P < 0.05$) and simple regression analysis ($P < 0.05$). The richness and species diversity of galling insects and their parasitoids and predators were calculated per tree and habitat. The diversity was calculated using Hill´s formula (Hill 1973), and the species richness with Simpson indices (Lazo *et al.* 2007). The effect of the habitat on the numbers of galling insects and their galls, natural enemies and inquilines (transformed to $\sqrt{x} + 0.5$ or arcsine for percentage data) was determined with ANOVA ($P < 0.05$), with subsequent mean separation by Tukey's test ($P < 0.05$).

Results

The richness of galling insects per leaflet was greater on the *C. brasiliense* trees in the Cerrado and pasture habitats than on the urban habitat and diversity of galling insects higher in the Cerrado habitat (Table 1). The highest richness and diversity for both parasitoids and predators of the galling insects were higher on *C. brasiliense* trees in the pasture and urban areas (Table 1). The numbers of trees/ha (floristic diversity) was negatively correlated with the percentages of leaflets, the total number of all kinds of galls/leaflets, of leaflet area with total number of all kinds of galls/leaflets, area of globoid galls, and length and width of the conglomerate of globoid galls and positively with the area of discoid galls (Fig. 1).

The total numbers of adults emerged per area, in laboratory, were: a) Cerrado: *Eurytoma* sp. (globoid galls)= 12, *Bruchophagus* sp. (vein galls)= 1, Eulophidae (spherical galls)= 1, and Hymenopteran (discoid galls)= 22, respectively; b) pasture: *Eurytoma* sp. (globoid galls)= 499, Eulophidae (spherical galls)= 1, and Hymenopteran (discoid galls)= 2; and urban area: only *Eurytoma* sp. (globoid galls)= 3,328. The numbers of *Eurytoma* sp. adults emerged from galls induced on *C. brasiliense* in the urban habitat was five times higher than in the other two habitats. The numbers of *Bruchophagus* sp. galls, Eulophid and hymenopteran gallers were highest on *C. brasiliense* leaflets in the Cerrado habitat. The *C. brasiliense* trees in the urban environment were exclusively galled by *Eurytoma* (Tables 2-3).

The percentages of leaflets, the total number of galls/leaflet (4 galling species) and the length and width of the conglomerate globoid galls (*Eurytoma* sp.) were greater on *C. brasiliense* leaflets in the pasture and urban habitats than in the Cerrado. The numbers and size of globoid galls (*Eurytoma* sp.), the percentages of leaflet area and the total number of galls/leaflets were greater in the urban habitat. The numbers of vein galls (*Bruchophagus* sp.) of the largest size and discoid galls (Hymenopteran galls) were highest on *C. brasiliense* leaflets in the Cerrado. The size of discoid galls (Hymenopteran) and the number of spherical galls (Eulophidae) were similar ($P > 0.05$) in the pasture and Cerrado habitats; however, the vein galls (*Bruchophagus* sp.) on *C. brasiliense* leaflets were larger in the Cerrado habitat (Table 3).

The numbers of the parasitoid *Sycophila* sp. (Hymenoptera: Eurytomidae) and of the predator, *Zelus armillatus* (Hemiptera: Reduviidae) were 2.5 and 8 times higher on

Table 1. Ecological indexes of galling insects and their natural enemies per leaflet on *Caryocar brasiliense*, Montes Claros, Brazil, during autumn 2008 to autumn 2011.

Indexes	Cerrado	Pasture	Urban	F	P
Richness of galls*	2.75 ± 0.25 a	2.33 ± 0.22 a	1.00 ± 0.00 b	27.77	0.00000
Diversity of galls*	4.10 ± 0.57 a	2.30 ± 0.18 b	1.44 ± 0.00 b	16.83	0.00004
Richness of parasitoids*	0.25 ± 0.13 b	1.33 ± 0.18 a	1.58 ± 0.22 a	20.06	0.00001
Diversity of parasitoids*	0.36 ± 0.18 b	1.77 ± 0.24 a	1.75 ± 0.25 a	1.97	0.00006
Richness of predators*	1.92 ± 0.37 b	4.58 ± 0.48 a	3.08 ± 0.25 a	19.30	0.00001
Diversity of predators*	3.20 ± 0.73 b	8.15 ± 1.35 a	5.52 ± 0.74 ab	8.64	0.00171

Means followed by the same letter (± standard error) per line do not differ by the test of Tukey (* = $P < 0.01$).

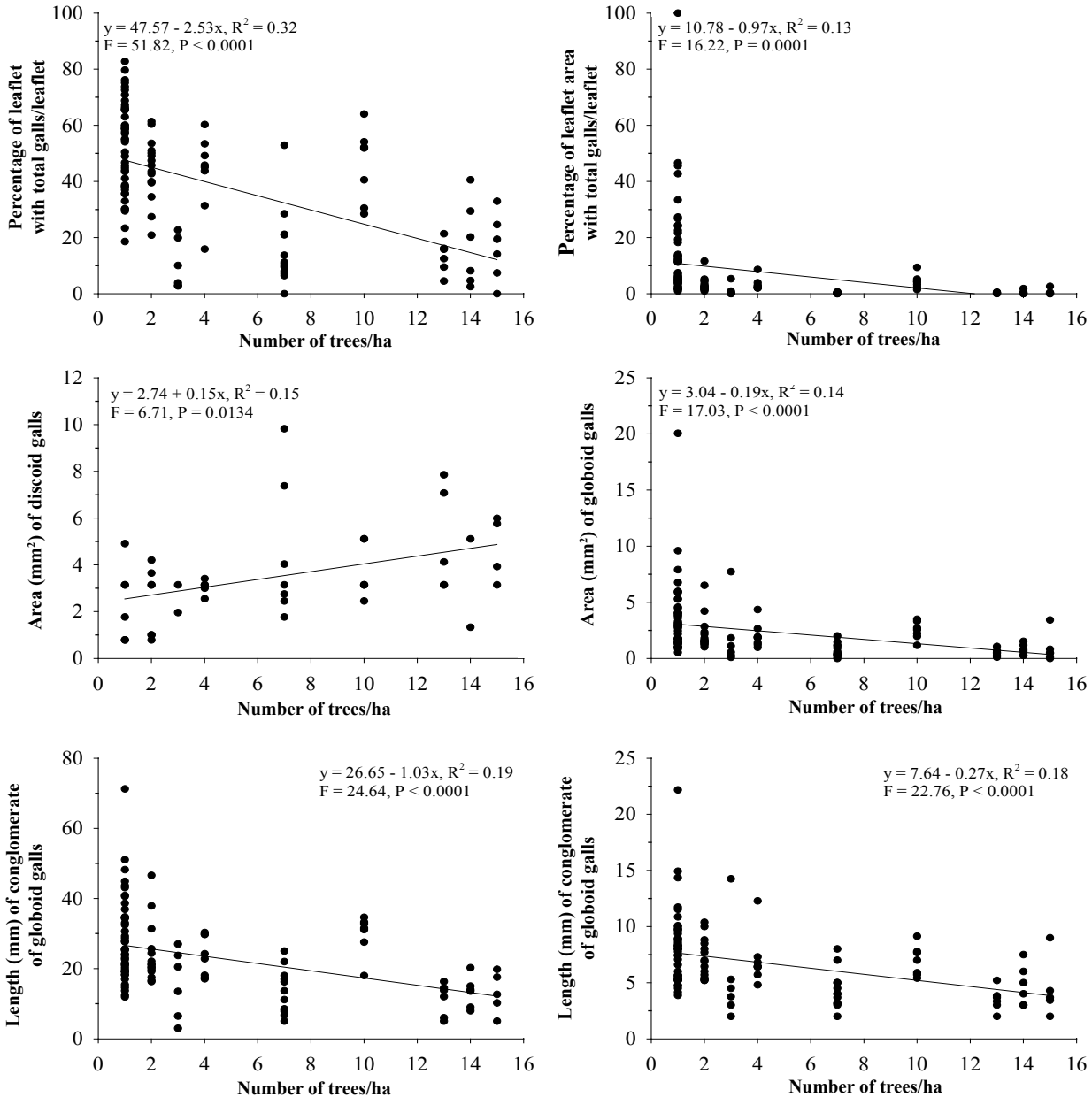

Figure 1. Relationships between number of trees/ha with percentages of leaflets and with total number of all kinds of galls and leaflet area with total number of all kinds of gall/leaflet, areas (mm^2) of globoid and discoid galls, lengths and widths (mm) of conglomerate globoid galls on *Caryocar brasiliense* trees in Montes Claros, Minas Gerais State, Brazil.

C. brasiliense leaflets in the urban habitat compared to the other ones (Table 2). The numbers of the hyperparasitoids of *Sycophila* sp., *Ablerus magistretti* Blanchard, 1942 (Hymenoptera: Aphelinidae), and *Quadrastichus* sp. (Hymenoptera: Eulophidae), and adults of the *Eurytoma* gall inquiline (Alycauline: Diptera) were similar between habitats ($P > 0.05$; Table 2).

The numbers of the predators *Epipolops* sp. (Hemiptera: Geocoridae), *Trybonia* spp. *(T. intermedius* Bagnall 1910 and *T. mendesi* Moulton 1933: Thysanoptera: Phlaeothripidae), the ants (Hymenoptera: Formicidae) and the sap-sucking hemipterans were larger on *C. brasiliense* trees in the pasture habitat and those of the predators *Holopothrips* sp. (Thysanoptera: Phlaeothripidae) and spiders similar between habitats (Table 2).

Discussion

Caryocar brasiliense trees can reach over 10 m in height and 6 m in canopy width in the Cerrado (Leite *et al*. 2006). Its fruits have an internal mesocarp rich in oil, vitamins and proteins, and contain many compounds of medicinal importance. Moreover, it is used by humans for food, production of cosmetics, lubricants and in the pharmaceutical industry (Bezerra *et al*. 2015).

The diversity of leaf-galling species (all kinds of galls) on *C. brasiliense* trees increased with the floristic diversity, as higher numbers of trees, shrubs and herbs were found in the Cerrado and pasture habitats than on the university campus (the urban area). The galling species are not linearly distributed among the habitats with trends in their distribution

Table 2. Average number of adult galling insects, their natural enemies, and inquilines per leaflet on *Caryocar brasiliense* at Montes Claros, Minas Gerais, Brazil (2008 to 2011).

Kinds of insects	Cerrado	Pasture	Urban	F	P
Galling insects					
Eurytoma sp.*	0.01 ± 0.01 b	0.19 ± 0.09 ab	1.03 ± 0.48 a	5.95	0.009
Bruchophagus	0.001 ± 0.001	0.0 ± 0.0	0.0 ± 0.0	1.00	0.390
Eulophidae	0.0006 ± 0.0005	0.0003 ± 0.0002	0.0 ± 0.0	1.00	0.390
Hymenoptera	0.017 ± 0.016	0.001 ± 0.001	0.0 ± 0.0	0.97	0.388
NE/inquilines					
Ablerus magistretti	0.0 ± 0.0	0.0 ± 0.0	0.001 ± 0.001	2.57	0.099
Alycaulini	0.0 ± 0.0	0.0 ± 0.0	0.001 ± 0.001	1.00	0.390
Epipolops sp.**	0.001 ± 0.001 b	0.02 ± 0.01 a	0.0 ± 0.0 b	15.39	0.000
Holopothrips sp.	0.003 ± 0.001	0.01 ± 0.01	0.01 ± 0.01	2.84	0.080
Quadrastichus sp.	0.001 ± 0.001	0.004 ± 0.002	0.002 ± 0.001	1.52	0.241
Spiders	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	1.90	0.174
Sycophila sp.**	0.001 ± 0.001 b	0.04 ± 0.01 ab	0.09 ± 0.03 a	3.58	0.045
Total ants*	0.06 ± 0.01 ab	0.10 ± 0.02 a	0.02 ± 0.01 b	9.70	0.001
Trybonia spp.**	0.003 ± 0.001 b	0.09 ± 0.04 a	0.0 ± 0.0 b	4.36	0.025
*Zelus armillatus***	0.002 ± 0.001 b	0.01 ± 0.01 ab	0.08 ± 0.03 a	4.74	0.019

Means followed by the same letter (± standard error) in each row are not different by the test of Tukey (* = P < 0.01 and ** = P < 0.05).

and impacts between them (Leite *et al*. 2006). The density of *Eurytoma* sp. (globoid gall), the most abundant species, and consequently, the richness and diversity of its natural enemies (*i.e*. *Sycophila* sp. and *Z. armillatus*) was highest in an environment with the lowest floristic diversity (*i.e*., the urban area).

The emergence and percentage of survival of *Eurytoma* sp. were higher in the urban area and lowest in the Cerrado area. This galling insect colonized up to 70 % of the leaf area of *C. brasiliense* trees in an urban area (Leite *et al*. 2009). On the other hand, a positive correlation between floristic diversity and the area of discoid galls was observed, and these galls showed the highest emergence of adults per this gall type in the Cerrado area. Discoid galls species were not observed in the urban area. This shows that changing the environment promotes a complete change in the structure of galling insect communities, with a single species completely dominating the available resources. The increase in the environmental simplification positively influenced the most common species, *Eurytoma* sp., corroborating to report that plant species richness is one of the most important factors explaining the variation in galling richness on the regional scale (Araújo *et al*. 2013). The combination of plant richness and plant abundance, on the regional level, is the best model to explaining galling insect richness (Araújo *et al*. 2014).

The higher richness and diversity of natural enemies of the galling insects in *C. brasiliense* trees in the pasture and urban areas, including that of *Eurytoma* sp., confirms the natural enemies' patterns - their populations depend on their prey/hosts and follow those of the herbivorous insects (Oberg *et al*. 2008; Venturino *et al*. 2008). These natural enemies, such as spiders, predatory bugs and *Sycophila* sp., are important in *C. brasiliense* and other ecosystems (Oberg *et al.* 2008; Venturino *et al*. 2008; Leite *et al*. 2012a, 2012b, 2012c, 2013).

Table 3. Galling insects and their damage per leaflet on *Caryocar brasiliense*, Montes Claros, Brazil, during autumn 2008 to autumn 2011.

Indexes	Cerrado	Pasture	Urban	F	P
Leaflet galled (%)	14.74 ± 2.56 b	45.11 ± 2.33 a	52.98 ± 4.48 a	39.22	0.000
Leaflet area taken by all galls (%)	0.48 ± 0.21 b	3.63 ± 0.50 b	17.01 ± 3.98 a	14.16	0.000
Leaf area occupied by *Eurytoma* globoid galls (mm^2)	0.92 ± 0.30 b	2.23 ± 0.21 ab	3.68 ± 0.74 a	8.40	0.002
Leaf area occupied by *Bruchophagus* vein galls (mm^2)	4.08 ± 1.23 a	0.72 ± 0.50 b	---	9.82	0.010
Leaf area occupied by Eulophid spherical galls (mm^2)	0.12 ± 0.06	0.48 ± 0.23	---	2.49	0.143
Leaf area occupied by hymenopteran discoid galls (mm^2)	2.40 ± 0.63	1.75 ± 0.32	---	1.42	0.256
Length (mm) of conglomerate of globoid galls*	12.63 ± 1.49 b	28.73 ± 3.12 a	25.31 ± 1.15 a	17.11	0.000
Width (mm) of conglomerate of globoid galls**	4.24 ± 0.58 b	8.15 ± 0.81 a	7.05 ± 0.38 a	10.09	0.001

Means followed by the same letter (± standard error) per line do not differ by the test of Tukey (* = P < 0.01 and ** = P < 0.05).

Conclusions

Greater environmental diversity (*i.e*. floristic diversity) favored the diversity of galling insect species and of their natural enemies, but decreased that of *Eurytoma* sp. and their natural enemies numbers, with the habitat impact having different effects in the structure of galling insect communities. *Eurytoma* sp. is the galling insect species with greatest potential to become a pest in commercial *C. brasiliense* plantations, based on the abundant and premature abscission caused to *C. brasiliense* leaves.

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Author contribution

R. V. S. Veloso, G. L. D. Leite and N. A. Oliveira carried out the experiments. G. L. D. Leite and M. A. Soares analyzed the data and performed the interpretation of the results. G. L. D. Leite, M. A. Soares, G. W. Fernandes, V. C. dos Santos Júnior and J. C. Zanuncio wrote the manuscript. J. C. Zanuncio and G. W. Fernandes translated to English. G. L. D. Leite supervised the project.