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Original Article

Sucking insects and their predators on tree canopies of a monocultural stand of *Caryocar brasiliense*

Insetos sugadores e seus predadores na copa de *Caryocar brasiliense* em sistema de monocultura

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Abstract

Caryocar brasiliense Camb. (Malpighiales: Caryocaraceae) trees are widely distributed throughout the Cerrado ecosystem. The fruits of *C. brasiliense* trees are used by humans for food and as the main income source in many communities. *C. brasiliense* conservation is seriously threatened due to habitat loss caused by the land-use change. Sucking insects constitute an important ecological driver that potentially impact *C. brasiliense* survival in degraded environments. In addition, insects sampling methodologies for application in studies related to the conservation of *C. brasiliense* are poorly developed. In this study, sucking insects (Hemiptera) and their predators were recorded in three vertical strata of *Caryocar brasiliense* canopies. The distribution of sucking species showed vertical stratification along the canopy structure of *C. brasiliense*. The basal part of the canopy had the highest numbers of sucking insects *Aphis gossypii* (Glover 1877) (Hemiptera: Aphididae) and *Bemisia tabaci* (Genn. 1889) (Hemiptera: Aleyrodidae), and their predators *Chrysoperla* sp. (Neuroptera: Chrysopidae), spiders (Araneae), and *Zelus armillatus* (Lep. & Servi., 1825) (Hemiptera: Reduviidae). Predators' distribution follows the resource availability and preferred *C. brasiliense* tree parts with a higher abundance of prey.

Keywords: aphids, *Bemisia tabaci*, Brazilian Cerrado, *Dikrella caryocar*, Hemiptera, *Pseudococcus* sp., vertical stratification.

Resumo

Caryocar brasiliense Camb. (Malpighiales: Caryocaraceae) é amplamente distribuído por todo o ecossistema de cerrado. Os frutos de *C. brasiliense* são utilizados na alimentação humana e constitui uma importante fonte de renda para muitas comunidades. A perda de habitat provocada pelas mudanças de uso da terra coloca em risco a conservação de *C. brasiliense*. Insetos sugadores constituem um importante fator ecológico que, potencialmente, afeta o fitness de *C. brasiliense* em ambientes degradados. Além disso, as metodologias de amostragem de insetos para aplicação em estudos relacionados à conservação de *C. brasiliense* são pouco desenvolvidas. Neste estudo, o número de insetos sugadores (Hemiptera) e seus predadores foram avaliados em três estratos verticais do dossel de *C. brasiliense*. A distribuição das espécies sugadoras apresentou estratificação vertical ao longo da estrutura do dossel. O estrato basal do dossel apresentou o maior número de insetos sugadores *Aphis gossypii* (Glover 1877) (Hemiptera: Aphididae) e *Bemisia tabaci* (Genn. 1889) (Hemiptera: Aleyrodidae), e seus predadores *Chrysoperla* sp. (Neuroptera: Chrysopidae), aranhas (Araneae) e *Zelus armillatus* (Lep. & Servi., 1825) (Hemiptera: Reduviidae). Os predadores distribuíram-se de acordo com a disponibilidade de recursos, ocorrendo em maior número nas partes do dossel com maior abundância de suas presas.

Palavras-chave: pulgões, *Bemisia tabaci*, Cerrado Brasileiro, *Dikrella caryocar*, Hemiptera, *Pseudococcus* sp., estratificação vertical.

1. Introduction

Caryocar brasiliense Camb. (Malpighiales: Caryocaraceae) is a perennial plant widely distributed throughout the Cerrado ecosystem, which covers approximately 23% of the Brazilian territory (Araújo, 1995; Ratter et al., 1997). The fruits of *C. brasiliense* trees are rich in oil, vitamins, proteins, and compounds of medicinal importance used

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by humans as food, cosmetics, lubricant production, and pharmaceutical products. Due to this vast utility to human society, *C. brasiliense* is the main income source of many traditional communities (Leite et al., 2006). This species is protected by federal laws in Brazil, and, as a result, is maintained in degraded areas of the Brazilian Cerrado. Nevertheless, conservation of *C. brasiliense* is serious threatened due to habitat loss caused by land-use change during the expansion of agricultural activities (Ratter et al., 1997; Collevatti et al., 2001; Leite et al., 2006; Melo Junior et al., 2012). Isolated *C. brasiliense* individuals embedded in agro-landscapes are subject to higher leaf, flower and fruit damage by sucking insects than those located in native areas (Leite et al., 2012a, 2015a, b, 2016). Thus, sucking insects constitute an important ecological driver that potentially negatively affect *C. brasiliense* survival in degraded environments. Despite the environmental and social importance of *C. brasiliense*, the occurrence of antagonistic insects on *C. brasiliense* as well as what factors may affect their distribution in *C. brasiliense* canopies is poorly debated.

Several studies suggested that resources (Dáttilo et al., 2012; Wardhaugh, 2014; Ballarin et al., 2019), competition (Camarota et al., 2020), predation (Pringle and Fox-Dobbs, 2008), edaphoclimatic conditions (Hikosaka, 2005; Araújo and Haridasan, 2007; Sousa-Souto et al., 2018), and habitat degradation (Stone et al., 2018; Basset et al., 2001) are important drivers of niche partitioning in plant-dwelling arthropods. These factors might impose a vertical stratification in arthropod communities that inhabit and interact with plant tree species (Basset et al., 2003). Vertical stratification of the arthropods along the canopy tree in plants from tropical, subtropical, and humid tropical forests (Summerville et al., 2003; Novotny and Basset, 2005; Campos et al., 2006; Wardhaugh et al., 2006; Neves et al., 2013; Wardhaugh, 2014; Basset et al., 2015; McCaig et al., 2020) have been vastly recorded.

In seasonal environments such as Brazilian Cerrado and Caatinga, the vertifical stratification of arthropod assemblage can be extremely common. Once variations in edaphoclimatc conditions across the year can markedly affect the leaf nutrient content along with the vertical structure of the canopy, which in turn, can affect the nutritional quality of the resources available to arthropods (Hikosaka, 2005; Araújo and Haridasan, 2007; Sousa-Souto et al., 2018). For example, the number of flowers and fruits produced is differentially distributed in *C. brasiliense* canopy, in both vertical and horizontal layers. This heterogeneity of plant resources distribution in *C. brasiliense* trees are probably related to environmental factors such as predominant wind direction and level of exposure to the sun, which in turn, might also affect arthropods distribution within the canopy (Leite et al., 2006, 2021, 2022; Ribeiro and Basset, 2007). Indeed, the abundance of *Proctolaelaps* sp. (Mesostigmata: Ascidae), a predator mite, and the distribution of the gall parasitoid, *Sycophila* sp. (Hymenoptera: Eurytomidae), are spatially stratified on the *C. brasiliense* crowns and reliant of the distribution and abundance of its preys (Leite et al., 2021).

The development of insects sampling methodologies is one of the most important steps to offer representative results for application in studies related to biodiversity conservation and insect pest management in agroecossystem (Basset et al., 2015; Nakamura et al., 2017; McCaig et al., 2020). Despite some studies have investigated arthropod assemblage in *C. brasiliense* (Leite et al., 2012a, b, 2015a, b, 2016, 2021, 2022), the vertical arthropod distribution in the *C. brasiliense* canopy located in human-modified landscapes needs further investigation because sampling plans are necessary to define insect pest and natural enemy distribution in plant tree canopies (Lamien et al., 2008). To fill this gap, we investigated arthropod vertical stratification in *C. brasiliense* using a novel insect sampling protocol. As edaphoclimatic factors affect seasonal plant species such as *C. brasiliense*, we also tested the hypothesis that sucking insects avoid the upper strata of the *C. brasiliense* canopy due to excessive sunlight and wind exposure, which make this canopy layer more stressful. Furthermore, we tested whether sucking insects and their predators were more abundant in canopy layers offering more plant resources (resource availability hypothesis), as resource availability affects plant-interacting arthropods (Dáttilo et al. 2012; Wardhaugh, 2014; Ballarin et al. 2019).

2. Material and Methods

This study was conducted 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, 633 m.a.s.l., with medium texture dystrophic red oxisol) in the municipality of Montes Claros, Minas Gerais state, Brazil, from June 2009 to June 2012. This region has dry winters and rainy summers, with Aw climate: tropical savanna, according to Köppen (Alvares et al., 2013). The area encompasses a monodominat *C. brasiliense* stand with 6,800 m^2. 272 *C. brasiliense* trees with 10 years old (monoculture) (e.g, 400 *C. brasilense* ha^{-1}), are distributed homogeneously, spaced 5 × 5 m, with gardens surrounding ~300 m. These trees were 3.85 ± 0.18 m high with 1.81 ± 0.15 m canopy width. The weeds between plant rows were removed by manual weeding. We selected 15 trees and counted arthropod species number in the basal (0 to 33%), median (34 to 66%) and apical regions (67 to 100% of total plant height) of the canopy in each plant individual. The relative frequency was calculated as F= (n/N)*100, where n= number of individuals per specie and per taxon collected and N= total number of individuals collected in each part of the canopy.

The distribution of sucking insects and their predators was recorded in the morning (7:00-11:00 AM) by direct visual observation on four fully-expanded leaves at the basal, median and apical parts (0 to 33%, 33 to 66% and 66 to 100% of total plant height, respectively) (Leite et al., 2015b, 2016) of 15 *C. brasiliense* trees per month (over 36 months). Insects were collected with tweezers, brushes, or aspirators and preserved in vials with 70% alcohol for identification by taxonomists (see acknowledgments). A total of 6,480 trifoliate leaves were sampled in the three canopy parts during the 3 years (12 leaves/tree/month).

Means of arthropod numbers were used per canopy tree part. To evaluate whether number of herbivore and predator species on the canopy differ in basal, medium, and apical regions of the tree individuals we performed Linear mixed models, considering the region of the tree canopy as fixed factor and accounting for intraspecific variation on tree canopy as random effect. For this, the lme function (linear mixed-effects models) of the nlme package (Pinheiro et al., 2021) was used. The means were compared using the Tukey test (P< 0.05) with the aid of the glht function of the multcomp package (Hothorn et al., 2008). All analyzes were performed by the R software (R Core Team, 2014).

3. Results

In this study, despite the *C. brasiliense* grew in monodominat stands, the distribution of two sucking insect species and all predator species was spatially stratified along with the vertical *C. brasiliense* canopy. The numbers of sucking insects Hemiptera *Aphis gossypii* (Glover, 1877) (Aphididae) (Figure 1A) and *Bemisia tabaci* (Genn., 1889) (Aleyrodidae) (Figure 1B) were highest on the basal of *C. brasiliense* tree canopies (statistical results with significance testing) with total individuals and relative frequency (%) of 33023 and 78.76% and 652 and 75.12%, respectively, in this plant part (Table 1). *Dikrella*

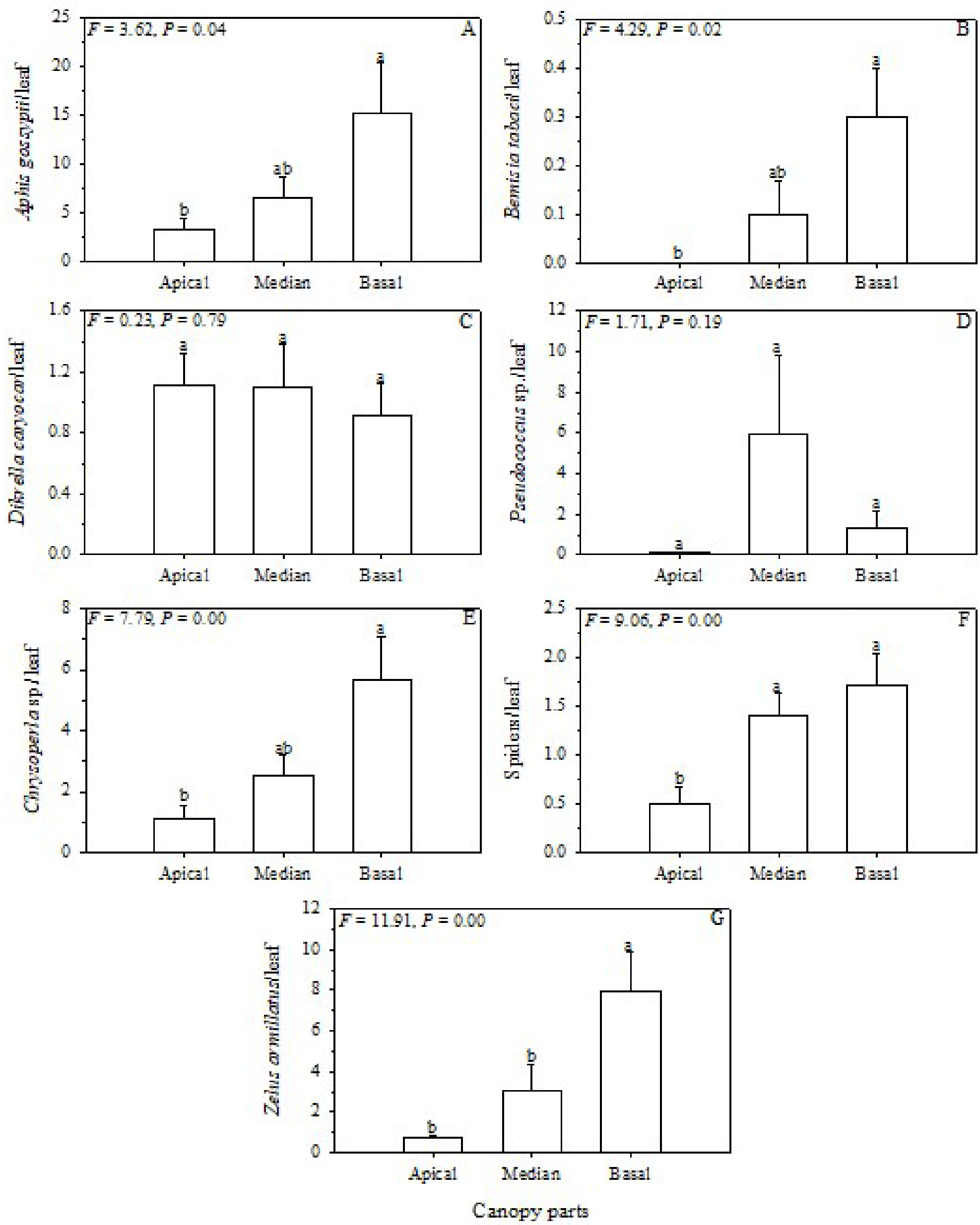

Figure 1. Number of sucking insects and their predators per leaf/canopy part of *Caryocar brasiliense* trees (means ± standard error). Means followed by the same letter per line do not differ by the Tukey test. ANOVA obtained values of F and P. df's of treatments, blocks, and errors were 2, 14, and 28, respectively.

Table 1. Total number of arthropods species and of their groups and their specific relative frequency (%) on *Caryocar brasiliense* trees.

Arthropods	Canopy part			Total per specie
	Apical	Median	Basal	
Dikrella caryocar	2405 (35.70%)	2376 (35.27%)	1956 (29.03%)	6737
Aphis gossypii	7432 (17.73%)	1472 (3.51%)	33023 (78.76%)	41927
Bemisia tabaci	0 (0.00%)	216 (24.88%)	652 (75.12%)	868
Pseudococcus sp.	219 (1.39%)	12744 (80.72%)	2825 (17.89%)	15788
Total sucking insects	10056 (15.39%)	16808 (25.73)	38456 (58.87%)	65320
Spiders	1093 (13.99%)	3024 (38.71%)	3694 (47.29%)	7811
Zelus armillatus	1530 (6.03%)	6696 (26.37%)	17163 (67.60%)	25389
Chrysoperla sp.	2448 (12.14%)	5472 (27.14%)	12240 (60.71%)	20160
Total predators	5071 (9.50%)	15192 (28.47%)	33097 (62.03%)	53360

caryocar (Coelho, Leite & Da-Silva, 2014) (Cicadellidae) and *Pseudococcus* sp. (Pseudococcidae) numbers did not differ between canopy parts (Figures 1C, 1D). The total number of sap-sucking insects and its frequency were 38456 and 58.86%, respectively, in the basal part of the canopy (Table 1). Stratified vertical distribution was also observed for predatory arthropods (statistical results with significance testing). The numbers of predators *Chrysoperla* sp. (Neuroptera: Chrysopidae), spiders (Araneae), and *Zelus armillatus* (Lep. & Servi., 1825) (Hemiptera: Reduviidae) were less significant in the apical part of the *C. brasiliense* canopy (Figures 1E-G) (statistical results with significance testing) with total individuals and relative frequency (%) of 2448 and 12.14%, 1093 and 13.99%, and 1530 and 6.03%, respectively, in this plant part. The total number of predators and its frequency were 5071 and 9.50%, respectively, in the apical part of the canopy (Table 1).

4. Discussion

In this study, we evaluated vertical stratification of arthropods in *C. brasiliense*. Despite some studies that have investigated their abundance in several different contexts, to our knowledge, this is study is the first to reveal a clear spatial partition of the arthropods that cohabit the *C. brasiliense* canopy. We observed that there is a vertical stratification of arthropods in *C. brasiliense* canopy, but also that this spatial configuration follows a species-specific pattern, in which some herbivores and their predators use the same niche space.

Resource available for insects on the canopy structure can be influenced by sunlight exposure that affects host plant tissue quality, leaf sclerophylly (Lamien et al., 2008), and microclimate (Stoeckli et al., 2008). Usually, insects move to preferred host parts using gustatory, olfactory, tactile and visual stimuli and identifying vertical objects based on polarized light (Doane and Leonard, 1975). The highest numbers and frequencies of the sucking insects *A. gossypii* and *B. tabaci* in the basal part of the *C. brasiliense* canopy, probably, is due to tender tissues (e.g., fewer sclerophyll leaves) and lower radiation (e.g., desiccant effect) than the apical parts, favoring these soft insects occurrence (Rao et al., 2000; Chau et al., 2005; Ribeiro and Basset, 2007).

Moreover, the prevailing wind direction in Montes Claros is from the northeast to the east (Leite et al., 2006) and the prevailing sunlight radiation is on the north side in the Southern Hemisphere (Vianello and Alves, 2012). Both features might have strong desiccant effects in this municipality, with low relative humidity and high temperature (Leite et al., 2006), which in turn, can influence sucking insect populations (Leite et al., 2015a). These factors should explain the non-preference of sucking insects to attack the north side (horizontal axis), apical part (vertical axis), and adaxial surface leaf, resulting in a lower diversity of species, as related for *Aethalion reticulatum* (L., 1767) (Hemiptera: Aethalionidae), *Dalbulus maidis* (DeLong & Wolcott, 1923) (Hemiptera: Cicadellidae), and *Mahanarva posticata* (Stal., 1855) (Hemiptera: Cercopidae) on *Acacia mangium* (Willd.) (Fabales: Fabaceae) and *Leucaena leucocephala* (Lam. de Wit) (Fabales: Fabaceae) trees, and *Edessa rufomarginata* (De Geer1, 1773) (Hemiptera: Pentatomidae) on *C. brasiliense* trees, in Montes Claros areas (Silva et al., 2014; Leite et al., 2015a; Damascena et al., 2017).

Additionally, a study reported by Leite et al. (2022) found that in monoculture environments, apical strata of the *C. brasiliense* crown are more attacked by gall-forming insects [e.g., *Eurytoma* sp. (Hymenoptera: Eurytomidae)] and *Eutetranychus* sp. (Trombidiformes: Tetranychidae), which, in turn, can make this strata more stressed due to interspecific competition for space and food. The greater number of *A. gossypii* and *B. tabaci* in the basal region may be strongly influenced not only by climatic factors but also by competition between herbivores in the canopy of *C. brasiliense* as well as by predator avoidance elicited by *Chrysoperla* sp., predatory bugs, and spiders, which are important herbivore consumers on *C. brasiliense*. The higher number and frequency of the predators *Chrysoperla* sp., spiders, and *Z. armillatus* in the basal part of *C. brasiliense* agree with the resource availability hypothesis that insect distribution follows the resource abundance in the *C. brasiliense* crown. Distribution models for natural enemies indicate the preference for canopy parts with higher numbers of their prey, with their populations being dependent on the numbers of these organisms (Oberg et al., 2008; Venturino et al., 2008; Leite et al., 2021). Therefore, despite the monodominant stands of *C. brasiliense* provides huge resource display that attract abundant antagonistic species, these arthropods from higher trophic levels (e.g., spiders) may control herbivores abundance through top-down effects, which in turn may allow *C. brasiliense* to survive. But the net effects of herbivory and herbivore predator occurrence on *C. brasiliense* survival should be further investigated.

5. Conclusions

Distribution of sucking species *A. gossypii* and *Bemisia tabaci* are vertically stratified along with the canopy structure of *C. brasiliense* and occur in greater number in the basal strata. These species have the potential for becoming a pest of this plant. Predators' distribution follows the resource availability and preferred *C. brasiliense* tree parts with a higher abundance of prey, which might diminish the impact of herbivores on this *C. brasiliense* monodominant stand. This knowledge will be important to carry out the sucking insects and their predators sampling in future commercial plantations of this plant. It suggests as preliminary sampling plan for sucking insects and their predators on *C. brasiliense* leaf the following: assess eight new leaves, with completely expanded blade (two per cardinal orientation) in the basal part in 10 plants per plot (1000 plants/plot).

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