Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v43i1.50164

CROP PROTECTION

Habitat complexity and mite population on *Caryocar brasiliense* trees

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ABSTRACT. The objective was to study the habitat complexity of mite populations on *Caryocar brasiliense* trees under natural and cultivated field conditions. The study was performed in the municipality of Montes Claros, in the state of Minas Gerais, Brazil, over 3 years. Three types of areas were studied: 1) Cerrado, 2) pasture, and 3) a university Campus. Several chlorotic spots were detected on leaves with larger populations of *Tetranychus* sp. and *Eutetranychus* sp. (Tetranychidae). The greatest numbers of *Agistemus* sp. (Stigmaeidae) on leaves and *Histiostoma* sp. (Histiostomidae) and *Proctolaelaps* sp. (Ascidae) on fruits were observed in the pasture, and that of *Histiostoma* sp. on leaves in the pasture and on the university Campus. In general, the herbivorous mites (e.g., *Tetranychus* sp.) found on *C. brasiliense* plants were correlated with more clayey soils with a higher cationic exchange capacity; larger populations of mites (e.g., *Agistemus* sp. and *Histiostoma* sp.) were found on the *C. brasiliense* trees with the largest crown sizes; and associations between predator mites (e.g., *Agistemus* sp.) and phytophagous mites (e.g., *Tetranychus* sp.1) were observed. Greater habitat diversity and more complex plant architectures favored the mite populations. The positive effect of loamier soil on herbivorous mites indicates that these species are adapted to Cerrado conditions. Some recorded species of herbivorous mites can be pests in commercial plantations of *C. brasiliense*.

Keywords: acari; Cerrado; pequi; soil.

Received on October 2, 2019.
Accepted on May 5, 2020.

Introduction

The Cerrado occupies approximately 2 million km^2 of the Brazilian territory, in which *Caryocar brasiliense* Camb. (Malpighiales: Caryocaraceae) trees are widely distributed (Pinheiro & Monteiro, 2010; Santos et al., 2018). The fruits of this tree are used as food and lubricants and are employed in the pharmaceutical industry and the production of cosmetics (Moura, Chaves, & Naves, 2013). *Caryocar brasiliense* flowers are important as food for *Agouti paca* (L.) (Rodentia: Agoutidae) and *Mazamagoua zoupira* (G. Fischer) (Artiodactyla: Cervidae) and the flowers of this plant are pollinated by bats, bees, and moths, and its fruits dispersed by *Didelphisal biventris* (Lund) (Mammalia: Marsupialia) and *Cyanocorax cristatellus* (Temminck) (Passeriformes: Corvidae) (Oliveira, 1997; Almeida, Proença, Sano, & Ribeiro, 1998; Macedo & Veloso, 2002). *Caryocar brasiliense* trees are protected by federal law and left isolated in deforested areas of the Cerrado. This situation increases leaf and fruit damage by mites. Despite the biological and social importance of *C. brasiliense*, its associated mite species are unknown.

The diversity and abundance of mites can vary between environments. This has been attributed to the fact that the numbers of herbivorous mite species (e.g., species richness) and their predators associated with a host plant are generally lower (e.g., abundances) in more complex environments (1) (Eichelberger, Johann, Majolo, & Ferla, 2011), while soil characteristics that are more favorable to trees increase phytophagous mite numbers (e.g., nutritional quality) (2) (Carvalho et al., 2013; Chacon-Hernandez et al., 2018).

The objective here was to study mites on *C. brasiliense* trees and the effect of more complex environments and soil characteristics on the diversity and abundance of phytophagous mites and their predators under three habitat conditions: preserved Cerrado (1), Cerrado cleared for pasture (2), and Cerrado converted for urban development (a university Campus) (3).

Material and methods

The study was conducted in the municipality of Montes Claros, Minas Gerais State, Brazil, during three consecutive years (Jun. 2015 through Jun. 2018). The region is characterized by dry winters and rainy summers and an Aw climate (tropical savanna according to Köppen classification) (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). The studied three areas consisted of Cerrado *stricto sensu*(1) (16º 44' 55.6" S 43º 55' 7.3" W at 943 m asl with dystrophic yellow red oxisol with sandy texture), a pasture formerly containing Cerrado vegetation (2) (16º 46' 16.1" S 43º 57' 31.4" W at 940 m as l with red dystrophic yellow oxisol with loamy texture), and a university Campus of the "Instituto de Ciências Agrárias of the Universidade Federal de Minas Gerais (ICA/UFMG)" (3) (16º 40' 54,5" S, 43º 50' 26,8" W at 633 m asl with dystrophic red oxisol with medium texture). These sites, soils, and the height and crown widths of *C. brasiliense* were described (Leite, Veloso, Zanuncio, Fernandes, & Almeida, 2006; Leite et al., 2011).

The study design was completely randomized with 10 replications (10 trees) and three treatments (areas) with the goal of testing the effect of environment complexity. The hypothesis regarding soil characteristics was tested considering each tree evaluated as a replication (30 trees and replications). We walked (~600 m) in straight lines in each area, and every 50 m, one randomly selected adult *C. brasiliense* tree (producing fruits) was sampled per collection time, except on the lawn of the university Campus, where the same trees were evaluated every time. Four expanded leaves, four flowers (Aug.-Sep.), and four fruits (Oct.-Jan.) from each stratum of the canopy (bottom, medium, and apical part) and from each cardinal orientation of the branches (North, South, West, and East) were collected from 30 trees monthly (in the morning) during each of the three years. These plant materials were placed in transparent white plastic bags, which were sealed and transported to the laboratory, where the numbers of the nymphs and adults (sum) of mites (phytophagous and predators) were counted. The counting started within 2 h after material collection on average and was performed by examining the leaves and flowers under a binocular microscope with 12.5X magnification, while the mites on the fruits were directly counted (without using a lens). The mites were counted in three fields located in the central area (equidistant between the principal vein and the margin) of each leaf (abaxial and adaxial surface) and randomly distributed on the flowers. The mites present on each whole fruit were counted. The mites on *C. brasiliense* leaves, flowers, and fruits were collected with a brush and preserved in vials with 70% alcohol for identification by Dr. A.L. Matioli (several families) and Dr. Eddie A. Ueckermann (*Agistemus*).

The correlations of the numbers of individuals of each predator species with each herbivorous mite species, the chemical characteristics of the soils and plant height and crown size (see Leite et al., 2006; 2011; same areas) were subjected to principal component regression (PCR) ($p < 0.05$). The applied regression model uses principal component analysis based on the covariance matrix to perform regression. Thus, it can exclude the dimensions that contribute to multicollinearity problems (e.g., the linear relationships between independent variables) to reduce the regression dimensions. The parameters used in these regressions were those that were considered significant ($p < 0.05$) after selection via the ''stepwise'' method. The effects of the three different areas and the host plant attributes on the number of individuals of each species of herbivorous mite and their predators were subjected to $\sqrt{x} + 0.5$ transformation and tested with ANOVA ($p < 0.05$) and Tukey's test ($p < 0.05$).

Results and discussion

The populations of *Tetranychus* sp.1 and sp.2 and *Eutetranychus* (Tetranychidae) were larger on *C. brasiliense* leaves with chlorotic spots, and they probably reduced photosynthetic leaf area, particularly during the dry period; these mite genera are pests of other plants as well (e.g., rose and apple) (Silva et al., 2009; Carvalho et al., 2013; Hardman et al., 2013; Chacon-Hernandez et al., 2018). The abundance of *Histiostoma* sp. (Histiostomidae) was high, especially on fruits, but this may not pose a problem for *C. brasiliense* because these mites consume the tissue around the seeds without injuring the fruit skin (e.g., crack or groove) or reducing its size. *Histiostoma* sp. was associated with fruit peel decomposition, and its populations were large on the fruits stored in the lab with rotting skin (data not shown). *Histiostoma polypori* (Oud.) is necromenic with the earwig *Forficula auricularia* (De Geer) (Dermaptera: Forficulidae), *H. piceae* Scheucher is a phoretic mite associated with *Ipstypographus* L. (Curculionidae: Scolytinae), and *H. polypori* and *H. feroniarum*

(Dufour)are phoretic mites associated with *F. auricularia* (Chmielewski, 2009; Takov, Pilarska, & Moser, 2009; Wirth, 2009).

The populations of predatory *Agistemus* sp. (Stigmaeidae) mites were largest on the *C. brasiliense* trees with the largest crown size (height x width) and greatest populations of predatory *Proctolaelaps* sp. (Ascidae) and *Tetranychus* sp.1 mites. However, the number of *Agistemus* sp. was lowest on the trees with the tallest or widest crowns, in soils with the highest percentage of loamier soil and the largest populations of *Tetranychus* sp.2, Acaridae, and *Histiostoma* sp. The greatest numbers of Acaridae, *Tetranychus* sp.2 and the predatory *Agistemus* sp. mites and the lowest number of *Tetranychus* sp.1 were associated with an increase in the population of predatory *Proctolaelaps* sp. mites on *C. brasiliense* trees, independent of the soil or tree crown characteristics. The number of *Tetranychus*sp.1 was highest on *C. brasiliense* trees in soils with the highest pH and cationic exchange capacity and the lowest percentage of soil base saturation with the cationic exchange capacity at pH 7.0. The numbers of *Tetranychus* sp.2 and Acaridae mites were highest on *C. brasiliense* trees in the soils with the highest percentage of loamier soil and pH levels, respectively (Table 1).

Table 1. Relationships of physical and chemical soil characteristics and the size of *Caryocar brasiliense* tree crowns with mites in Montes Claros, Minas Gerais State, Brazil.

Equations of the principal components regressions	R^2	*F*	*P*
Agistemus sp. = 0.32 + 1.87 x *Proctolaelaps* sp. + 1.11 x *Tetranychus* sp.1 + 0.03 x treecrown - 4.05 x *Tetranychus* sp.2 -3.29 x Acaridae-0.28 x *Histiostoma* sp. -0.15 x crown width - 0.06 x crown height - 0.0005 x loamier	0.99	1026.8	0.00
Proctolaelaps sp. = -0.002 + 1.61 x Acaridae +1.49 x *Tetranychus* sp.2 + 0.77 x *Agistemus* sp. - 0.45 x *Tetranychus* sp.1	0.93	24.10	0.00
Eutetranychus sp. = 0.00009 + 0.24 x Acaridae	0.45	8.03	0.01
Tetranychus sp1. = - 0.19 + 0.04 x pH + 0.01 x capacity of cationic exchange - 0.002 x percentage of soil base saturation of the capacity of cationic exchange to pH 7.0	0.77	8.78	0.00
Tetranychus sp2. = -0.002 + 0.0001 x loamier	0.39	6.31	0.03
Acaridae = -0.007 + 0.001 x pH	0.48	9.04	0.01

The correlations between the predatory (e.g., *Agistemu s*sp.) and phytophagous (e.g., *Tetranychus* sp.1) mites on *C. brasiliense* leaves were positive in the studied areas. Predatory mites are important for the biological control of herbivorous mites in native and cultivated areas (e.g., orange orchard), and an increase in their prey and floristic diversity maintain or increase their populations (Saber & Rasmy, 2010; Eichelberger et al., 2011). Competition was not observed among the herbivorous and predatory mites on *C. brasiliense* trees, but competition among predatory mites for free space (Hammen, Montserrat, Sabelis, Roos, & Janssen, 2012; Strodl & Schausberger, 2012) and among females of *Tetranychus urticae* (Koch) (Tetranychidae) (Macke et al., 2012) has been reported.

Mites were not found on *C. brasiliense* flowers. The number of *Agistemus* sp. mites was highest on leaves (F = 3.075, P = 0.0467, df = 6989), while the numbers of *Histiostoma* sp. (F = 10.170, P = 0.00000, df = 691) and *Proctolaelaps* sp. (F = 8.820, P = 0.00007, df = 691) were highest on fruits in the pasture, and the numbers of *Histiostoma* sp. (F = 5.556, P = 0.00390, df = 5282) were highest on leaves in the pasture and the university Campus. The abundance of *Eutetranychus* sp., *Tetranychus* sp.1 and sp.2, *Proctolaelaps* sp. and Acaridae was similar (p > 0.05) on leaves on *C. brasiliense* in the three areas (Table 2).

Table 2. Number of mites per cm^2/leaf or per *Caryocar brasiliense* fruit (mean ± SE) in the Cerrado, pasture and university Campus areas. Montes Claros, Minas Gerais State, Brazil.

	Areas		
Per cm^2/leaf	Cerrado	Pasture	Campus
Acari$^{n.s.}$	0.0000 ± 0.0000A	0.0004 ± 0.0002A	0.0056 ± 0.0012A
Agistemus sp. **	0.0041± 0.0019B	0.0110 ± 0.0026A	0.0058 ± 0.0013AB
Eutetranychus sp.$^{n.s.}$	0.0000 ± 0.0000A	0.0006 ± 0.0005A	0.0008 ± 0.0004A
Histiostoma sp.*	0.0355 ± 0.0131B	0.0674 ± 0.0073A	0.0691 ± 0.0089A
Proctolaelaps sp.$^{n.s.}$	0.0000 ± 0.0000A	0.0098 ± 0.0048A	0.0041 ± 0.0015A
Tetranychus sp.1$^{n.s.}$	0.0004 ± 0.0003A	0.0063 ± 0.0018A	0.0134 ± 0.0027A
Tetranychus sp.2$^{n.s.}$	0.0015 ± 0.0011A	0.0061 ± 0.0017A	0.0021 ± 0.0008A
Per fruit			
Histiostoma sp.*	0.0000 ± 0.0000B	76.76 ± 18.67A	0.0000 ± 0.0000B
Proctolaelaps sp.*	0.0000 ± 0.0000B	2.80 ± 0.79A	0.0000 ± 0.0000B

Means followed by the same letter per line do not differ by the test of Tukey (*p < 0.01 and **p < 0.05). n.s. = non-significant by ANOVA.

The greater numbers of species of phytophagous mites and, consequently, their predators found on *C. brasiliense* trees in the pasture than in the Cerrado or in the university Campus may be explained by a combination of factors: the *C. brasiliense* trees in the pasture environment grew in the presence of grass and other trees and shrubs (see Leite et al., 2006; 2011); the crowns of these trees were wider with more complex structures, and fruit production was higher in the pasture than in the other two areas (Leite et al., 2006); and the soil characteristics (e.g., loamier, higher aluminum levels and lower pH levels) in the pasture were more favorable to *C. brasiliense* trees (Leite et al., 2006), thereby indirectly favoring herbivorous mites and their predators. Both habitat complexity and host-plant attributes (e.g., architecture and nutritional quality) influence the diversity of herbivores and predatory mites (Silva et al., 2009). The number of species associated with a given host in a less complex environment may be lower, and the abundance of each species may generally be higher, increasing the likelihood that herbivores of economically valuable plants will become pests (Benaoun, Elbakkey, & Ferchichi, 2014; Pollier, Guillomo, Tricault, Plantegenest, & Bischoff, 2018). The wind currents may have influenced the larger mite populations (e.g., *Agistemus* sp. and *Histiostoma* sp.) found on the *C. brasiliense* trees with the largest crown sizes (pasture area) because the dispersion of these small arthropods, is probably strongly influenced by the wind (Kumar, Raghuraman, & Singh, 2015). A larger tree canopy could favor the migration of mites carried by the wind, as reported for winged termites on *C. brasiliense* (Leite et al., 2011). In addition, the supply of food available (leaves and fruits) to herbivorous mites and their predators is greater on larger trees. The herbivorous mites (e.g., *Tetranychus* sp.1 and sp.2) found on *C. brasiliense* plants were correlated with more clayey soils with a higher cationic exchange capacity. The damage caused by *Tetranychus* sp. on *Lippia sidoides* Charm (Verbenaceae) on seedlings was higher on plants that were not supplied with calcium and magnesium but were fertilized with nitrogen (Silva et al., 2009). Phosphorus and magnesium deficiency may block protein synthesis in plants, resulting in the accumulation of free amino acids and, thus, better nutrition available to mites (Silva et al., 2009). The presence of lepidopteran leaf miners and defoliation (%) on *C. brasiliensis* trees were positively and negatively correlated with the aluminum and pH levels of the soil, respectively (Leite et al., 2012 b). On the other hand, the mortality of *C. brasiliense* trees caused by Cossidae (Lepidoptera) and *Phomopsis* sp. fungi was higher in soils with lower aluminum and higher pH levels (Leite et al., 2012a).

Conclusion

Greater habitat diversity and more complex plant architectures increased the number of mite species. The positive effect of loamier soil on herbivorous mites indicates that these species are adapted to Cerrado conditions. Some of the recorded species of herbivorous mites can be pests in commercial plantations of *C. brasiliense*.

Acknowledgements

The authors acknowledge the Brazilian agencies "Conselho Nacional de Desenvolvimento Cientifico e Tecnológico (CNPq), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/PELD- Finance Code 001), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)" and "Programa Cooperativo sobre Proteção Florestal (PROTEF) of the Instituto de Pesquisas e Estudos Florestais (IPEF)" for scholarships and financial support. JCZ and SPR are granted researcher from CNPq.

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