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Vertical extratification of phytophagous and predator mites (Acari) on *Caryocar brasiliense* (Caryocaraceae) tree canopies

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The distribution of *Caryocar brasiliense* Camb. (Caryocaraceae) trees is wide in the Brazilian Cerrado biome and its fruits are used by humans for food and as the main income source of many communities. Herbivorous mites damage this plant and their abundance and their predator mites were recorded in three separate parts of *C. brasiliense* canopies. The number of *Eutetranychus* sp. (Tetranychidae) individuals was highest in the apical parts of the canopy and those of *Proctolaelaps* sp. (Ascidae) and *Tetranychus* sp. 1 (Tetranychidae) in the basal part. This knowledge is important to sample phytophagous and predator mite's in future commercial plantations of this plant.

Caryocar brasiliense trees, with wide distribution in the Brazilian savanna (Pinheiro and Monteiro 2010; Santos *et al*. 2018), can reach over 10 m high and 6 m of canopy width. Their fruits are rich in oil, vitamins, proteins and compounds of medicinal importance, used by humans as food, in cosmetics, lubricant production and in the pharmaceutical industry, and are the main income source of many communities (Leite *et al*. 2006). Isolated *C. brasiliense* trees in the agro-landscape are subject to higher leaf damage by mites (Acari) (Leite *et al.* 2021a, b) than in native areas. Despite the biological and social importance of *C. brasiliense*, the vertical distribution of its associated mite species is unknown.

Vertical distribution of the herbivores in the *C. brasiliense* canopy needs further studies because sampling plans are needed to define the mite pest and its natural enemy distribution in plant tree canopies (Lamien *et al*. 2008). The arrangement of the branches on a tree and the parts of their leaves can affect the diversity and abundance of mites (Roda *et al*. 2012). The objective was to study the vertical distribution of phytophagous and predator mites on *C. brasiliense* tree canopy.

This study was carried out in the campus of the Instituto de Ciências Agrárias da Universidade

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Federal de Minas Gerais in the municipality of Montes Claros, Minas Gerais, Brasil (June 2015 through June 2018). This region has dry winters and rainy summers, with Aw climate: tropical savanna, according to Köppen. The area has 6,800 m^2 and 272 ten-year-old (monoculture) *C. brasiliense* trees, spaced 5 × 5 m, with gardens in the surrounding ~300 m. These trees are 3.85 ± 0.18 m high with 1.81 ± 0.15 m canopy width (average ± standard error). The weeds between plant rows were removed by manual weeding. The research design was in 15 blocks, each with one tree. Canopy heights represented the three treatments (basal, median, and apical parts). The 15 trees selected were marked. Phytophagous and predator mites were collected during three consecutive years. The average number of individuals per canopy part per tree were evaluated.

The distribution of mites (phytophagous and predators) was recorded on four fully-expanded leaves at the basal, median and apical parts of 15 *C. brasiliense* trees per month (over 36 months). Mites were identified by Dr. A.L. Matioli (several families) and Dr. Eddie A. Ueckermann (*Agistemus* spp.). These *C. brasiliense* leaves were collected and transported to the laboratory. The numbers of nymphs and adults (sum) of mites were counted on these leaves, using a 12.5× magnifying lens, starting earlier than two hours after their collection. These organisms were counted on three fields in the central part of each leaf, on both the abaxial and adaxial surfaces. Each field (0.60 mm^2) was distributed per leaf part (distal, median, and proximal, near the petiole).

Means of mites' numbers were used per canopy tree part. The number of individuals per phytophagous and predator species on the canopy heights was evaluated with the statistical model: $y_{ij} = m + a_i + b_j + e_{ij}$, where: m is the general average analyzed; a_i, the effect of the i-th plant considered random; bj, the effect of the j-th plant part (j = 1, 2, ..., 3) considered to be fixed; e_{ij}, the effect of the experimental error associated with j-th part of the i-th plant. R software was used for statistical analysis. The lme function (linear mixed-effects models) of the nlme package was used with the restricted maximum likelihood method. The means were compared using the Tukey's test ($P < 0.05$) with the aid of the glht function of the multcomp package (R Core Team 2014).

The numbers of *Tetranychus* sp. 1 (Tetranychidae) (Fig. 1A) were highest on the basal and that of *Eutetranychus* sp. (Tetranychidae) (Fig. 1B) on the apical of *C. brasiliense* tree canopies. The numbers of *Tetranychus* sp. 2 (Tetranychidae), *Histiostoma* sp. (Histiostomidae), and Acaridae did not differ between canopy parts (Fig. 1C–E).

The highest numbers of *Eutetranychus* sp. and *Tetranychus* sp. 1 on the apical and basal parts of *C. brasiliense* canopy, respectively, is possibly, due to the hotter and drier conditions (e.g. higher radiation) in the apical than in the basal part (Ribeiro and Basset 2007), favoring the first, but not the second species, in a semi-arid environment (Leite *et al.* 2006). The hot and dry climatic conditions favored *Aculops lycopersici* Tryon (Eriophyidae), *Tetranychus evansi* Baker & Pritchard and *Tetranychus urticae* Koch (Tetranychidae) on *Solanum melongena* L. (Solanaceae) and *Tetranychus* spp. on *Vigna unguiculata* (L.) Walpers (Fabaceae) (Leite *et al*. 2003; Lemtur and Choudhary 2016). Temperature preference by mite species of the family Tetranychidae differed with *T. evansi* which is adapted to a wide range of summer temperatures explaining its current distribution and the global warming may favor its spread and expand its distribution (Ghazy *et al.* 2019). The performance of *Tetranychus ludeni* Zacher (Tetranychidae) is best at 22–28 °C and worst at 29–35 °C, suggesting that this mite is less likely to invade regions with warmer weather (Ristyadi *et al.* 2019). *Eutetranychus* sp. and *Tetranychus* sp. 1 may use different feeding sites (e.g. apical and basal parts) to reduce competition among them. Competition between females of *T. urticae* fed with *Cucumis sativus* L. (Cucurbitaceae) (Macke *et al.* 2012), predatory mites *Iphiseius degenerans* (Berlese) and *Neoseiulus cucumeris* (Berlese) (Phytoseiidae) (pollen and thrips larvae feeding) (Hammen *et al.* 2012), and nymphal life stages of *Phytoseiulus persimilis* Evans (Phytoseiidae) fed with *T. urticae* of mixed life stages, reared on whole bean of *Phaseolus vulgaris* L. (Fabaceae) (Strodl and Schausberger 2012) was recorded in laboratory. The numbers of *Raoiella indica* Hirst (Tenuipalpidae) individuals was highest in the median part than in the apical and basal parts of *Cocos nucifera* (L.) (Arecaceae), indicating that the competition, predation and other behavioral traits of a particular species can affect the spatial distribution pattern of mites (Roda *et al.* 2012). Nymphs and adults of *A. lycopersici* and *T. evansi* attacked, mainly, on the apical and middle leaves of *S. melongena*, and the first mite species, on the same canopy parts on *Solanum lycopersicon* Mill. (Solanaceae), was explained by the tenderness of these leaves with higher nutritional quality (e.g. N) favoring mite feeding by these species (Leite *et al.* 1999, 2003). On the other hand, the higher number of *T. urticae* eggs in the apical and medium leaves and their nymphs and adults in the medium and lower thirds of these plants may be due to a lower movement capacity of *T. urticae* compared to *T. evansi* and, while the plant continues to grow, the mobile stages tend to concentrate in the middle and lower third of eggplants (Leite *et al.* 2003).

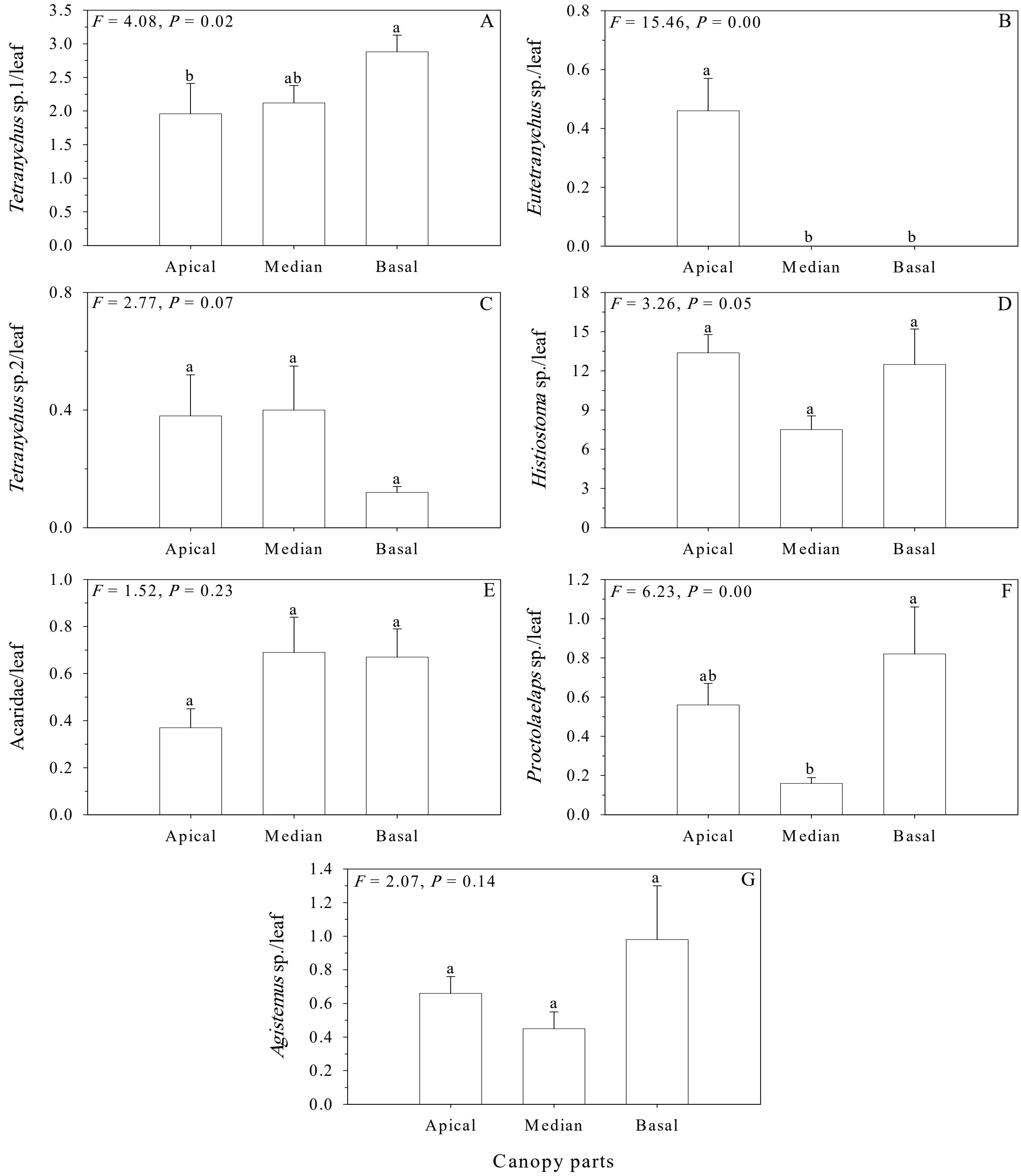

Figure 1. Number of phytophagous and predator mites per leaf/canopy part of *Caryocar brasiliense* trees (means ± standard error). Means followed by the same letter per line do not differ by the Tukey's test. Values of *F* and *P* were obtained by ANOVA. df's of treatments, blocks, and errors were 2,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

The numbers of predator *Proctolaelaps* sp. (Ascidae) (Fig. 1F) were greatest in the apical and basal of *C. brasiliense* canopies, but that of the predator *Agistemus* sp. (Stigmaeidae) (Fig. 1G) were similar between tree canopy parts. The highest numbers of the predators *Proctolaelaps* sp. in the apical and basal *C. brasiliense* canopies agree with the known patterns for natural enemies, preferring canopy parts with higher numbers of their prey, with their populations being dependent on the numbers of these organisms (Leite *et al. in press* a, b). Predatory mites are important on *C. brasiliense* as well as in other ecosystems (Leite *et al.* 2021a, b).

The high number of species of the Tetranychidae family, as *Tetranychus* sp. 1, agrees with results for this mite group on leaves of *C. brasiliense* trees (Leite *et al.* 2021a, b), and shows that the potential of this mite to becoming a pest of this plant. *Eutetranychus* sp. and *Tetranychus* sp. 1 preferred the apical and basal parts, respectively, on *C. brasiliense* trees. Predator mites (e.g. *Proctolaelaps* sp.) preferred *C. brasiliense* tree parts with a higher abundance of their prey. This knowledge is important to sampling phytophagous and predatory mite's in future commercial plantations of this plant. A sampling plan for mites (phytophagous and predator) on *C. brasiliense* should be as follow: assessing 1 cm^2 (pocket magnifying lens) of four leaves (one per cardinal orientation) from the apical (e.g. *Eutetranychus* sp.), median (e.g., *Tetranychus* sp. 2 and *Agistemus* sp.), and basal (e.g. *Tetranychus* sp. 1 and *Proctolaelaps* sp.) parts of 10 *C. brasiliense* plants/plot.

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