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Article

Bioecology of mites associated with cocoa trees (*Theobroma cacao*: Malvaceae) in the Bragantina microregion of the state of Pará, Eastern Amazon, Brazil

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Abstract

This study aimed to understand the diversity of associated mites in cocoa growing areas in the municipalities of Bragança and Augusto Corrêa, state of Pará, as well as their distribution in rainy and dry periods. A total of 1,178 mites were collected and the most abundant families were Phytoseiidae, Tetranychidae, Tuckerellidae, Iolinidae and Cunaxidae, in addition to the unidentified taxa of the suborder Oribatida. The most abundant species were *Oligonychus* sp. (13.9%), *Tuckerella ornata* (12.2%), *Amblyseius* **n. sp.** 1 (12.1%) and *Parapronematus* sp. (10.5%). Among the predatory mites, the phytoseiid mites were more abundant and prevalent, with *Amblyseius* **n. sp.** 1 and *Armascirus amazoniensis* standing out. *Amblyseius* **n. sp.** 1 showed greater abundance in the rainy season than in the dry season, in both municipalities. Great diversity did note, mainly for predatory mites, while phytophagous mites were more abundant.

Key words: Acariformes, Biodiversity, Parasiformes, Seasonality

Introduction

The cocoa tree, *Theobroma cacao* L. (Malvaceae), is a fruit tree of great importance in the Amazon, as its production chain generates income for family-based producers and cooperatives. Furthermore, it is a sought-after commodity on the international market, as it serves not only the food sector, especially chocolate, but also the fertilizer, cosmetics, cleaning and animal feed sector (Filgueiras 2002; Chepote 2003). The state of Pará is one of the main cocoa producers in Brazil, occupying first place in the ranking of national cocoa bean productivity, with 145,994 tons in the year 2022 (IBGE 2022).

In Brazil, the phytophagous mites *Aceria reyesi* (Nuzacci) (Eriophyidae) and *Tetranychus mexicanus* (McGregor) (Tetranychidae) have been reported in association with cultivation in the state of Bahia (Maia & Valverde 2017; Carvalho *et al*. 2018). *Aceria reyesi*, the cocoa bud mite, has been considered an emerging agricultural pest in the states of Bahia and Rondônia (Oliveira & Navia

2013). The first report of *A. reyesi* in Rondônia was made at the Ouro Preto Experimental Station (ESTEX-OP), of the Executive Commitee of the Cacau Farming Plan – CEPLAC, in the ESTEX-OP germplasm bank, where severe damages from shortening of internodes and death of terminal branches were observed (Trevisan *et al*. 2012).

Several species of tetranychid mites are reported in *T. cacao* (Migeon & Dorkeld 2006-2020). *Brevipalpus yothersi* Baker (Tenuipalpidae), *Tuckerella ornata* (Tucker), *T. pavoniformis* (Ewing) and *T. knorri* Baker & Tuttle (Tuckerellidae) have been reported causing damage to cocoa crops in Peru (Escobar-Garcia *et al*. 2021). *Tuckerella ornata* did report in cocoa leaves and stems in Brazil (Flechtman 1979). In a recent study, *T. ornata* was reported causing damage to cocoa fruits in the state of Pará (Brito *et al*. 2023).

There are few studies on mite diversity in this culture and little is known about the acarofauna present. Some predator mite species can be used in applied biological control programs, while understanding the phytophagous that cause damage to agricultural crops is of fundamental importance to farmers and the state's economy. Thus, this studyaimed to understand the mite diversity associated with cocoa crops cultivated in the Amazon region, Pará State, Brazil, as well as its distribution in rainy and dry periods.

Materials and methods

Study location and sampling procedure

The collections were carried out in commercial areas, at farm *Alto Arajivu* (1º10'18.6"S, 46º43'49.3"W), at 41 m altitude, and small farm *Jiquiri* (1°03'59.8"S 46°44'40.0"W) 16 m above sea level, in Bragança, and at small farm *Coisas da Roça* (1º03'58.91"S 46º66'23.30"W) and farm *Bacuri* (1º04'11.10"S 46º66'33.82"W) in Augusto Corrêa (Figure 1). Collections took place in Bragança, the dry period corresponded to September and December the 2021 and the rainy period, between January and June the 2022, and in Augusto Corrêa, in the dry season, between September and December 2021, in the period rainy period, between February and May 2022. The plants measured two to three meters in height, aged between three and six years. Twenty plants per location were assessed by automatic draw, from which five leaves and one fruit were randomly collected per plant.

The region's climate is hot and humid equatorial (Amw'), according to the Köppen classification, characterized by a rainy season, between December and May, and a dry season, in the other months of the year. The average annual rainfall is 2,500 mm and the relative humidity varies between 80 and 91%. The average temperature is 27.7 ºC, which can vary from 20.4 to 32.8 ºC (Martorano *et al*. 1993).

Sample processing and mite identification

All leaves collected were placed in paper bags, kept in a cooler with Gelox® at a low temperature (ca. 15 °C), being sent to the biology laboratory of the Federal Institute of Education of Pará (IFPA) for screening. The mites were observed using a stereomicroscope (Zeiss Stemi 305) and mounted on microscope slides in Hoyer's medium (Jeppson *et al*. 1975) and placed in a kiln for 10 days at 50-60°C. Species identification was carried out in the Acarology laboratory at Universidade do Vale do Taquari – Univates. The prepared specimens were examined with aphase contrast microscope (Axio Scope. A1-Zeiss) through taxonomic keys (e.g. Baker & Tuttle 1994; Kazmierski 1998; Chant & McMurtry 2007; Mesa *et al*. 2009; Johann *et al*. 2013; Skvarla *et al*. 2014 and Wurlitzer *et al*. 2020). Voucher specimens of the mite species collected in the study were deposited in the Museum of Natural Sciences (ZAUMCN) at UNIVATES, Lajeado, Rio Grande do

Sul. Environmental data on temperature, relative humidity, atmospheric pressure and precipitation were collected at the National Institute of Meteorology (INMET).

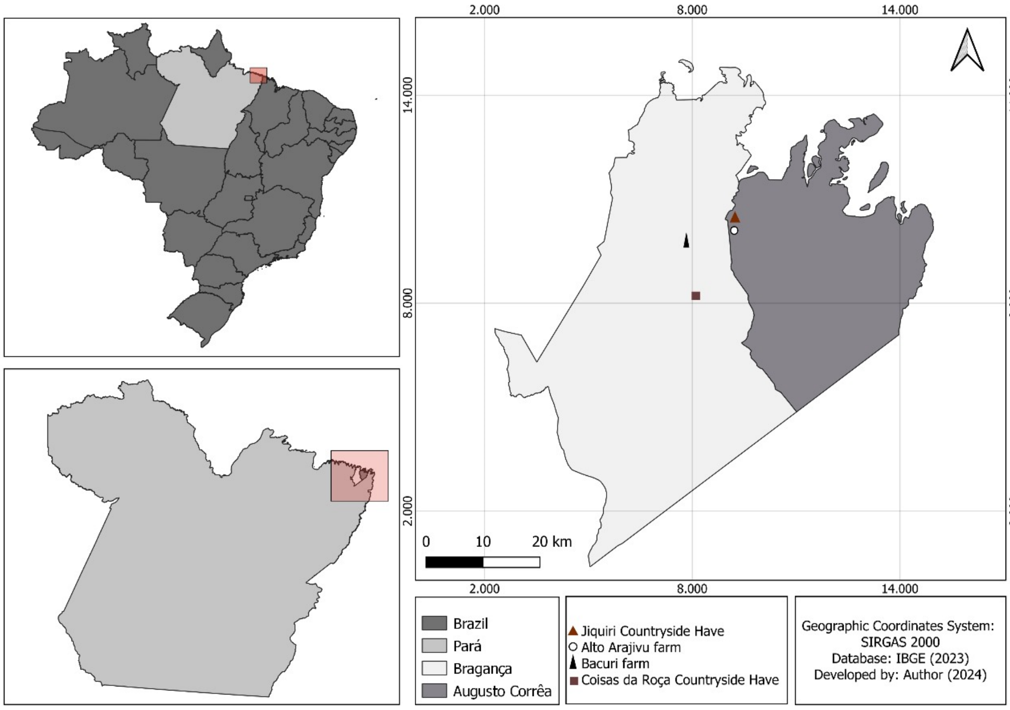

FIGURE 1. Location of cocoa crops assessed in the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará State, Brazil.

Statistical analysis

Sampling effort and diversity. To determine whether the sampling effort was sufficient to observe the diversity of mites present between periods and municipalities, species rarefaction curves were used for Chao1 diversity valuesafter 99 permutations (Chao & Jost 2015). This metric estimates species richness in a biological sample based on the number of rare and unique species present in the sample. It considers species observed only once (singular species) and those observed twice (dual species) to make an estimate of total richness. Therefore, Chao1 is robust when there are many rare species that may not have been detected in the sample. Including unique species in the estimate helps correct bias caused by under sampling. The observed and estimated richness were generated using the 'spec pool' function of the vegan package (Oksanen *et al*. 2018) through the statistical programming language R (Ihaka & Gentleman 1996; R Development Core Team 2020). To evaluate the effectiveness of sampling in capturing the total diversity of mite species, species rarefaction curves were made based on the abundance of specimens per species/taxon, using the `iNEXT´ function of the iNEXT package (Hsieh *et al*. 2016) in R. The dispersion measure was calculated in 95% confidence intervals.

Hill Diversity Profile. The analysis of mite communities from periods, which behave under different compositions of rare and dominant species, was carried out using Hill's diversity profile analysis (Hill 1973). This analysis, generated by the Renyi index in different orders of magnitude, provides a comprehensive view of the distribution of diversity in a community. This profile is especially useful for understanding the relative contribution of abundant species compared to less abundant ones. Each order in the profile (x-axis) highlights different aspects ofdiversity, allowing detailed analysis of mite community structure and insights into species richness, evenness, and sensitivity to dominant species. This analysis was done with the `renyi´ function (hill = TRUE) in the vegan package(Oksanen *et al*. 2018) in R. Therefore, Hill's diversity profile helps in inferring how and which mite community is more diverse than another, in this case, dry vs. rainy. In the parameters of this scale (x-axis), the values on the left side are sensitive to rare species, while the values on the right side are sensitive to abundant, common species (Tóthmérész 1995).

Mite community structure. An ordination analysis using non-metric multidimensional scaling (NMDS) was performed to evaluate the dissimilarity of mite communities between the two periods. To address the numerical predominance that may occur with some taxa, the species matrix was standardized using the `decostand´ function (method = Hellinger) in the vegan package (Oksanen *et al*. 2018) in R. Then, this standardized matrix was transformed into a dissimilarity matrix with the Bray-Curtis method using the `vegdist´ function and NMDS orderingwas performed using the `metaMDS´ function (k = 3 dimensions) both from vegan (Oksanen *et al*. 2018) in R. The resulting stress value (< 0.2) was considered an adequate fit of the NMDS.

Differences in mite community structure. The differences among mite communities in both periods were tested using analysis of variance with permutations (n=99) (PERMANOVA) using the `adonis2' function of the vegan package (Oksanen *et al*. 2018) in R. Permutations were restricted / stratified according to collection campaigns (1st, 2nd, 3rd). As PERMANOVA is sensitive to data dispersion, a multivariate homogeneity analysis of group dispersions was also carried out using the vegan 'betadisper' function (Oksanen *et al*. 2018) in R, which calculates theaverage distance of the groups using from its centroid to analyze the most significant species and ecological data (temperature, relative humidity, atmospheric pressure and precipitation) contributing to the ordering of the NMDS. In short, this function adjusts environmental vectors in the NMDS to assess how environmental variables influence community structure. Therefore, it is possible to infer how different environmental conditions can affect the distribution and abundance of mite species between periods. The interpretation of the results from this analysis involves the evaluation of the direction and magnitude of the environmental vectors (i.e. coefficient of variation) significant in relation to the dispersion of the samples in the ordination space.

Results

In total, 1,178 mites belonging to 67 species, 46 genera and 21 families were collected (Table 1; Figure 2). Among the families observed, Phytoseiidae (31.6%), Tetranychidae (16.9%), Tuckerellidae (12.8%), Iolinidae (11.4%) and Cunaxidae (6.5%) stood out, in addition to those unidentified taxa from the Oribatida suborder (6.1%). The most of sampled species were predators, while phytophagous mites showed greater abundance. It's with unknown feed behavior were rare and with low abundant. The most abundant species were *Oligonychus* sp. (13.9%), *T. ornata* (12.2%), *Amblyseius* **n. sp.** 1 (12.1%) and *Parapronematus* sp. (10.5%). The other species had smaller proportions. The number of mites sampled seems to have been quite satisfactory, since the Chao1 estimate richness calculated a larger number (75 ± 5 s.e.) of taxa, very close to the richness found in this work, indicating low probability of new taxa in sample according to sampling effort increases, or to having had an extremely low abundance.

Quantity and diversity of mites. The greatest mite abundance was observed in the dry period (67.23%) compared to the rainy period (32.76%), or approximately 105% more mites in the dry period (Figure 3A, Tables 1, Table 2, Table 3. The average number of mites was μ = 2.87 ± 10.9 s.d.

in the dry period and μ = 1.40 ± 6.94 s.d. in the rainy.Furthermore, the largest population was sampled from leaves (86.7%) than from fruits (13.3%).

Greater richness was observed in the dry period (65 species) than in the rainy season (36) (Figure 3B). In relation to the Hill diversity profile, the dry period was more diverse, presenting higher values along the entire x axisfor the Hill diversity order parameters (Figure 3C, Table 4, Table 5). This result can be attributed to the greater number of individuals sampled, reflecting a greater contribution to diversity in all aspects of this analysis. However, this trend suggests that mite community dynamics in the dry period exhibited higher diversity compared to the rainy season, especially at smaller scales of the Hill diversity profile, where rare species exert greater influence. As this scale increases (towards the right), the difference in diversity between the two periods decreases considerably, suggesting that more abundant species gained greater relevance.

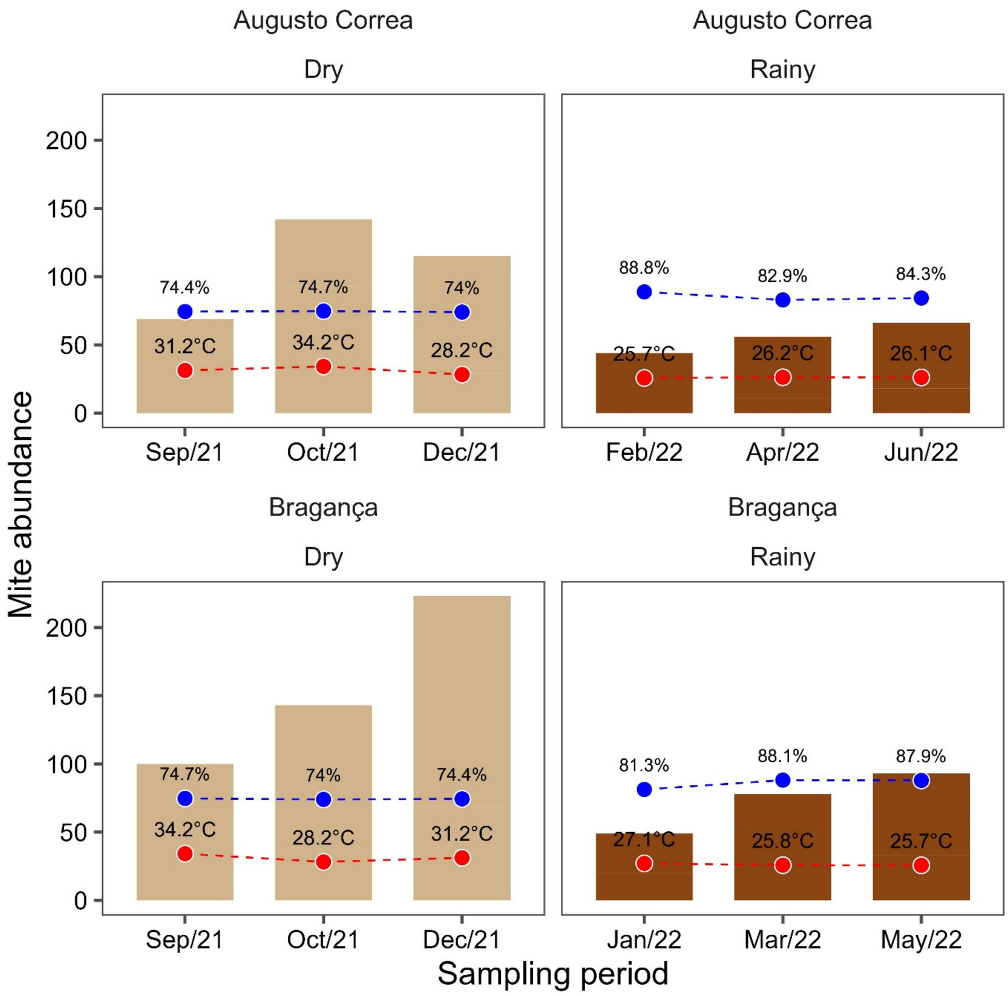

FIGURE 2. Mite abundance, temperature (°C) and relative air humidity (%) observed in cocoa cultivation in the dry and rainyperiods in the municipalities of Bragança and Augusto Corrêa, state of Pará, Brazil. *Bars represent the total mite abundance, blue lines represent humidity and red lines, temperature.

TABLE 1. Mite fauna associated with cocoa cultivation in the dry and rainy periods, in the municipalities of Augusto Corrêa and Bragança, state of Pará, Brazil. Food habits: P—Predator; F—Phytophagous and HI—Indeterminate habit.

Families (N)	Genre and species	Augusto Corrêa				Bragança				Total	%
		Dry		Rainy		Dry		Rainy			
		Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit		
Acaridae (2)	*Tyrophagus putrescentiae* (HI)	0	0	0	0	0	1	0	1	**2**	0.2
Ascidae (16)	*Asca* sp.1 (P)	0	0	0	0	5	0	0	0	**5**	0.4
	Asca sp.2 (P)	2	0	0	0	1	0	0	0	**3**	0.3
	Ascidae | Immature (P)	2	0	2	0	2	0	2	0	**8**	0.7
Bdellidae (9)	*Bdella ueckermanni* (P)	1	0	0	0	0	0	0	0	**1**	0.1
	Bdella sp.1 (P)	0	0	0	0	1	0	3	0	**4**	0.3
	Hexabdella n. sp. (P)	0	0	0	0	3	0	1	0	**4**	0.3
Blattisociidae (6)	*Lasioseius* sp.1 (P)	0	0	0	0	4	0	1	0	**5**	0.4
	Lasioseius sp.2 (P)	0	0	0	0	1	0	0	0	**1**	0.1
Caligonellidae (1)	*Neognatus* sp. (P)	0	0	0	0	0	0	1	0	**1**	0.1
Cheyletidae (2)	Cheyletidae Immature (P)	0	0	0	0	1	0	1	0	**2**	0.2
Cunaxidae (76)	*Armascirus amazoniensis* (P)	6	2	6	1	9	1	4	8	**37**	3.1
	Armascirus n. sp. (P)	1	0	0	0	1	0	0	0	**2**	0.2
	Cunaxatricha n. sp. (P)	0	0	0	0	3	1	0	0	**4**	0.4
	Cunaxoides sp. (P)	2	0	1	0	2	0	5	0	**10**	0.8
	Neocunaxoides ovatus (P)	0	0	0	0	1	0	0	0	**1**	0.1
	Scutopalus tomentosus (P)	1	0	10	0	4	0	7	0	**22**	1.9
Eupodidae (39)	Eupodidae n. gen. (P)	5	1	12	0	15	2	3	0	**39**	3.3
Glycyphagidae (17)	*Glycyphagus* sp.	0	0	13	0	2	0	0	0	**15**	1.3
	Lepidoglyphus sp.	0	0	2	0	0	0	0	0	**2**	0.2
Iolinidae (134)	*Homeoponematus* sp. (P)	0	0	0	0	4	0	1	0	**5**	0.4
	Parapronematus sp. (P)	116	0	3	0	4	0	1	0	**124**	10.5
	Pronematulus sp. (P)	0	0	0	0	3	0	0	0	**3**	0.3
	Pseudopronematus sp. (P)	1	0	0	0	0	0	1	0	**2**	0.2
Laelapidae (2)	Laelapidae | Immature (P)	0	0	1	0	0	0	1	0	**2**	0.2
Oribatida (72)	Oribatida	12	0	5	0	54	0	1	0	**72**	6.1
Phytoseiidae (370)	*Amblyseius* n. sp. 1 (P)	8	0	56	0	18	0	60	0	**142**	12.1
	Amblyseius n. sp. 2 (P)	8	0	0	0	18	0	0	0	**26**	2.2
	Amblyseius n. sp. 3 (P)	11	12	0	0	18	5	0	0	**46**	3.9
	Amblyseius n. sp. 4 (P)	0	0	0	0	0	0	1	0	**1**	0.1
	Amblyseius n. sp. 5 (P)	1	0	0	0	0	0	0	0	**1**	0.1
	Amblyseius itacoatiarensis (P)	3	0	0	0	0	0	0	0	**3**	0.3
	Amblyseius tamatavensis (P)	13	0	0	0	0	0	0	0	**13**	1.1
	Amblydromalus n. sp. (P)	0	0	0	0	2	0	0	0	**2**	0.2
	Euseius inouei (P)	1	0	0	0	0	0	0	0	**1**	0.1
	Iphiseiodes zuluagai (P)	15	0	0	0	5	0	2	0	**22**	1.9
	Leonseius regularis (P)	2	0	0	0	1	0	1	0	**4**	0.3

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TABLE 1. (Continued)

Families (N)	Genre and species	Augusto Corrêa				Bragança				Total	%
		Dry		Rainy		Dry		Rainy			
		Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit		
	Paraamblyseius multicirculares (P)	2	0	0	0	0	0	0	0	**2**	0.2
	Phytoseiidae | Males (P)	10	0	0	0	10	0	1	0	**21**	1.8
	Phytoseiidae | Immature (P)	15	0	10	0	20	0	4	0	**49**	4.2
	Proprioseiopsis neotropicus (P)	9	0	8	0	3	0	0	0	**20**	1.7
	Typhlodromalus aripo (P)	0	0	0	0	2	0	0	0	**2**	0.2
	Typhlodromips mangleae (P)	2	0	1	0	0	0	1	0	**4**	0.3
	Typhlodromips n. sp. (P)	0	0	0	0	5	0	0	0	**5**	0.4
	Typhlodromus (*Typhlodromus*) n. sp. (P)	0	0	1	0	5	0	0	0	**6**	0.5
Stigmaeidae (21)	*Agistemus* n. sp. 1 (P)	2	0	0	0	2	0	6	0	**10**	0.8
	Agistemus n. sp. 2 (P)	1	0	0	0	1	0	0	0	**2**	0.2
	Agistemus brasiliensis (P)	3	0	0	0	3	0	1	0	**7**	0.6
	Zetzellia aff. *quasagistemas* (P)	1	0	0	0	1	0	0	0	**2**	0.2
Tarsonemidae (13)	*Tarsonemus* sp.1 (F)	1	0	0	0	12	0	0	0	**13**	1.1
Tenuipalpidae (20)	*Brevipalpus yothersi* (F)	9	0	0	0	5	0	0	0	**14**	1.2
	Tenuipalpus bacuri (F)	3	0	0	0	3	0	0	0	**6**	0.5
Tetranychidae (199)	*Oligonychus* sp. (F)	10	0	19	0	100	0	35	0	**164**	13.9
	Tetranychus urticae (F)	25	0	8	0	2	0	0	0	**35**	3.0
Triophtydeidae (3)	*Triophtydeus* sp.1 (HI)	2	0	0	0	1	0	0	0	**3**	0.3
Tuckerellidae (152)	*Tuckerella knorri* (F)	0	0	0	0	2	0	0	0	**2**	0.2
	Tuckerella ornata (F)	0	0	0	0	27	55	1	68	**150**	12.8
Tydeidae (21)	*Brachytydeus* sp.1 (HI)	0	0	0	0	1	0	0	0	**1**	0.1
	Brachytydeus sp.2 (HI)	5	0	4	0	2	0	0	0	**11**	0.9
	Paralorryia sp.1 (HI)	1	0	0	0	1	0	0	0	**2**	0.2
	Paralorryia sp.2 (HI)	0	0	0	0	3	0	0	0	**3**	0.3
	Pretydeus n. sp. (HI)	0	0	0	0	4	0	0	0	**4**	0.3
Winterschmidtiidae (3)	*Czenspinskia* sp. (HI)	0	0	0	0	2	0	0	0	**2**	0.2
	Neocalvolia sp. (HI)	0	0	0	0	1	0	0	0	**1**	0.1
	Total	**312**	**15**	**163**	**1**	**400**	**65**	**146**	**76**	**1.178**	

The ordination of the mite community composition in relation to the period showed satisfactory NMDS adjustment (stress = 0.10, non-metric adjustment [R2] = 0.98). PERMANOVA analysis indicated significant differences in mite community structure between the dry and rainy periods (F(1, 34) = 5.96), R2 = 0.14, P = 0.01, Figure 3D). However, it is important to note that, despite the statistical significance; the coefficient of determination (R2) was low, requiring caution in interpreting the proportion of variability explained by the NMDS. No statistical difference was observed in the homogeneity of dispersion between these groups (F(1,34) = 2.87, P = 0.11), indicating that the PERMANOVA result was not influenced by the variability between the groups. Of 67 mite taxa, 24 of them played a significant role in the NMDS ordination (Table 2; figure 3D), highlighting the importance of these species, with some of them not yet being taxonomically described. Furthermore, when considering ecological factors, it was observed that both temperature ($R2 = 0.41$, $P = 0.001$) and relative humidity ($R2 = 0.68$, $P = 0.001$) had a significant contribution to this ordering, indicating its relevance in determining the structure of the community.

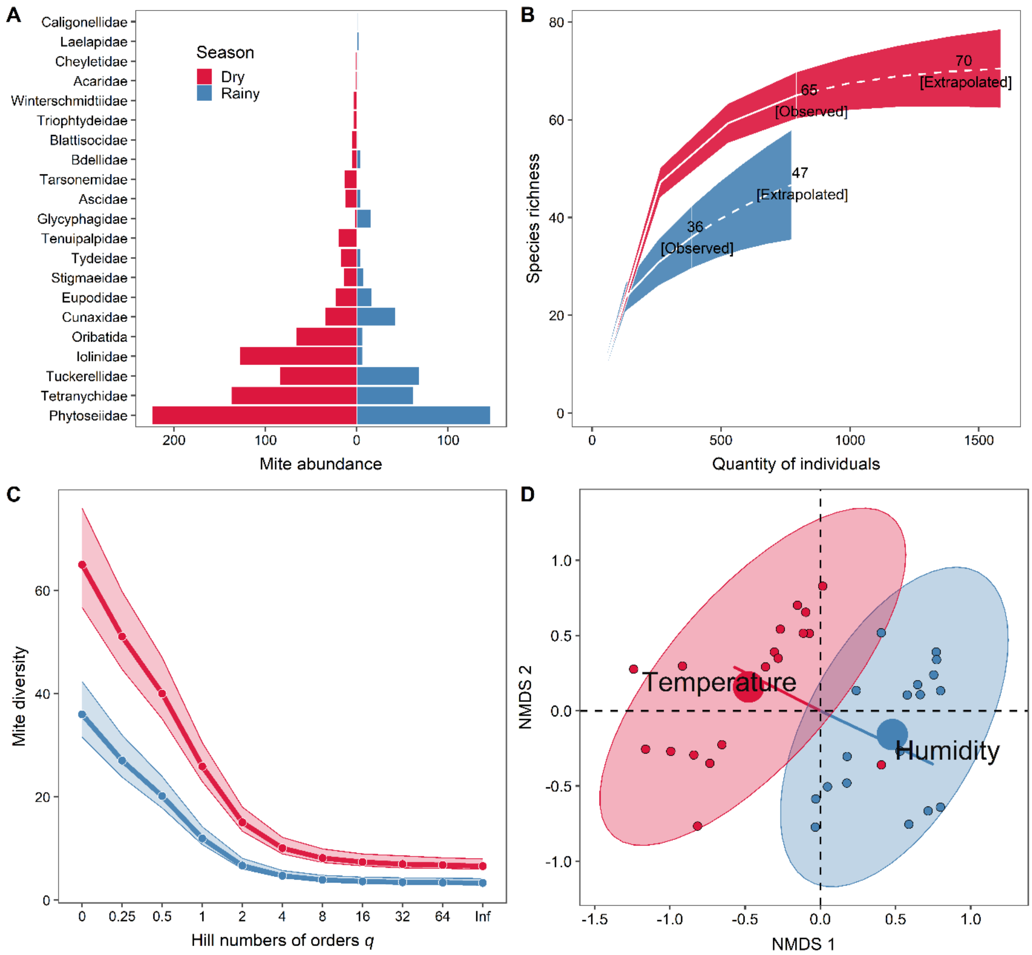

FIGURE 3. Comparative analysis of the mite community on cocoa trees in the dry (red color) and rainy (blue) periods: abundance, richness, diversity and community structure. (A) Total number of mites/family sampled between the dry and rainy periods. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute quantity collected per period. The left side of the pyramid represents the dry season, and the right side represents the rainy season. (B) Species rarefaction curves with 95% confidence intervals. Observed species richness values are shown as solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes diversity *lato sensu*, while the x-axis shows the gradual change in this diversity for both mite communities. Some diversity indices on the x-axis can be inferred: 0 = species richness; 1 = Shannon-Wiener index (entropy exponential); 2 = Simpson index; and inf = Berger-Parker index. This continuum of values on the x-axis reflects the contributions of rare vs. rare species. abundant. Thus, the left side of the x-axis indicates that the diversity found is more sensitive to rare species, while on the right side of the x-axis, the abundance of species has more weight (greater equability; common species have more weight). (D) Non-metric multidimensional scaling (NMDS) plot differentiating mite community composition. Larger dots indicate group centroids and smaller dots represent sampling sites. The environmental variables 'temperature' and 'humidity' contributed significantly to the pattern of this ordering.

TABLE 2. Mite species in cocoa with significant contribution to the ordination by NMDS* based on community structure in the dry and rainy periods.

Species	p-value
Amblyseius **n. sp.** 1	0.01
Amblyseius **n. sp.** 2	0.01
Amblyseius **n. sp.** 3 | Fruit	0.01
Amblyseius tamatavensis	0.01
Brevipalpus yothersi	0.01
Iphiseiodes zuluagai	0.01
Oligonychus sp.	0.01
Oribatida	0.01
Parapronematus sp.	0.01
Phytoseiidae | Male	0.01
Pretydeus **n. sp.**	0.01
Scutopalus tomentosus	0.01
Tarsonemus sp.1	0.01
Tetranychus urticae	0.01
Tuckerella ornata | Leaves	0.01
Tuckerella ornata | Fruit	0.01
Agistemus **n. sp.**1	0.02
Asca sp.1	0.02
Bdella sp.1	0.02
Proprioseiopsis neotropicus	0.02
Triophtydeus sp.1	0.02
Pseudopronematus sp.	0.03

TABLE 3. Comparative analysis of mite biodiversity in the municipality of Augusto Correa, Pará, Brazil: dry season versus rainy season.

Diversity	**Augusto Corrêa**			
	Dry		Rainy	
	Leaf	Fruit	Leaf	Fruit
Richness	37 (IC95%:40–52)	3 (IC95%:7–13)	19 (IC95%:31–43)	1 (IC95%:1–1)
Abundance	312	15	163	1
Dominance	0.16 (IC95%:0.06–0.08)	0.66 (IC95%:0.08–0.20)	0.16 (IC95%:0.05–0.09)	1.00 (IC95%:1.00–1.00)
Shannon-Wiener	2.64 (IC95%:2.96–3.24)	0.63 (IC95%:1.76–2.52)	2.31 (IC95%:2.83–3.21)	0.00 (IC95%:0.00–0.00)
Uniformity	0.38 (IC95%:0.43–0.53)	0.62 (IC95%:0.76–0.95)	0.53 (IC95%:0.49–0.63)	1.00 (IC95%:1.00–1.00)
Equitability	0.73 (IC95%:0.78–0.83)	0.57 (IC95%:0.86–0.98)	0.78 (IC95%:0.80–0.87)	0.00 (IC95%:0.00–0.00)

TABLE 4. Comparative analysis of mite biodiversity in the municipality of Bragança, Pará, Brazil: dry season versus rainy season.

Diversity	Bragança			
	Dry		Rainy	
	Leaf	Fruit	Leaf	Fruit
Richness	51 (IC95%:44–55)	6 (IC95%:19–29)	26 (IC95%:30–41)	3 (IC95%:21–32)
Abundance	400	65	146	76
Dominance	0.10 (IC95%:0.06–0.08)	0.72 (IC95%:0.05–0.11)	0.23 (IC95%:0.05–0.09)	0.79 (IC95%:0.05–0.10)
Shannon-Wiener	2.99 (IC95%:3.00–3.24)	0.64 (IC95%:2.53–3.05)	2.09 (IC95%:2.79–3.19)	0.41 (IC95%:2.58–3.12)
Uniformity	0.39 (IC95%:0.41–0.51)	0.32 (IC95%:0.60–0.78)	0.31 (IC95%:0.50–0.65)	0.50 (IC95%:0.49–0.58)
Equitability	0.76 (IC95%:0.77–0.82)	0.36 (IC95%:0.83–0.92)	0.64 (IC95%:0.80–0.87)	0.37 (IC95%:0.82–0.91)

Discussion

This is the first study carried out in the Northern region of Brazil reporting the fauna and diversity pattern of mites in cocoa crops, in the state of Pará. Mites were sampled and the most abundant families were Phytoseiidae, Tetranychidae, Tuckerellidae, Iolinidae and Cunaxidae, in addition to those unidentified taxa from the Oribatida. In another similar study with the cupuaçu crop (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum, Malvaceae), Silva *et al*. (2009) carried out a faunal survey of mites and the most common families were Phytoseiidae, Tenuipalpidae, Cheyletidae, Cunaxidae, Tarsonemidae, Tetranychidae and Tydeidae, in addition to those of the suborders Oribatida and Acaridida.

Among the most abundant families of phytophagous mites, Tetranychidae and Tuckerellidae stood out. These phytophagous mites cause direct or indirect damage to host plants. This causes concern for the cocoa farming chain, as the mites feeding on the plant tissues of leaves and fruits cause this damage. Fungivorous species belonging to the Tarsonemidae have been reported on cocoa trees in Brazil and Costa Rica (Ochoa & O'Connor 1998; Rezende *et al*. 2015). Six species of eriophyid mites were reported associated with *Theobroma* spp., however, only *A. reyesi* was reported causing damage to cocoa in some Central and South American countries (Carvalho *et al*. 2018).

The highest diversity index of mites found in cocoa crops was in the leaves, both in the dry and rainy seasons. However, it is worth noting that in the dry period there was greater abundance and diversity, compared to the rainy period. *Tuckerella ornata* and *Oligonychus* sp. were more abundant in Bragança, with *Oligonychus* sp. was more present in the leaves, while *T. ornata* abundant in the fruits. *Tetranychus urticae* appears, however, in low populations. *Tetranychus urticae* found in greater abundance in the municipality of Augusto Corrêa in the dry period,thus, favored by the low rainfall (Pascual & Ferragut 2003). *Tuckerella ornata* was found only in the municipality of Bragança, with greater abundance in cocoa fruits, especially in the rainy season.

Among the most abundant and prevalent predatory mites, and with the potential to be studied and tested for applied biological control, are phytoseiid species from the genera *Amblyseius*, *Iphiseiodes, Proprioseiopsis, Typhlodromalus*, followed by those from the families Iolinidae and Cunaxidae. Thus, as in the study on mites associated with *Byrsonima crassifolia* (L.) (Malpighiaceae) in the eastern Amazon, there was a greater abundance of predators for Phytoseiidae

(Noronha *et al*. 2020). A determining factor to explain this phenomenon may be the consumption of alternative food from generalist species of this family, which allows the maintenance of predators in environments where preferred prey is absent or scarce (McMurtry *et al*. 2013). *Amblyseius* **n. sp.** 1 showed greater abundance during the rainy season in the both municipalities evaluated. Species of this genus are predominant mites in the North region, as already reported (Lawson-Balagbo *et al*. 2008; Peña *et al*. 2009; Gondim Jr. *et al*. 2012; Cruz *et al*. 2019; De Alfaia *et al*. 2023), possibly defined by environmental factors such as temperature and relative humidity that interfere in the structure of the mite community. Cruz *et al.* (2019), in studies carried out on *Elaeis guineensis* Jacq. (Arecaceae), in the state of Amazonas, during the rainy season, mites of the genus *Amblyseius* sp. were also reported in greater abundance. This genus encompasses a great diversity of species, which are natural enemies of several organisms (Amaral 2017). Several studies have confirmed that phytoseiid mites are the most diverse among predatory mites in ecosystems (McMurtry *et al*. 2013). Tixier *et al*. (2008) states that this group is the most diverse and abundant in the world.

The richness in the dry period, in the two municipalities, was 65 and for the rainy period, only 36, that is, in the dry period 80.5% more species of mites were sampled than in the rainy period. These results are reinforced by studies carried out in the North region, which show a substantial positive association between Phytoseiidae and temperature. Therefore, higher temperatures increase the prevalence of these mites (De Alfaia *et al*. 2023).

Knowledge of the diversity of mites in cocoa crops in the Amazon biome in the state of Pará is fundamental for integrated pest management, making it possible to contain and predict periods during which specimens of phytophagous mites may reach high population levels, as shown in abundance of Tetranychidae and Tuckerellidae found. This makes it easier to establish integrated pest management strategies in cocoa crops. Furthermore, understanding the diversity, abundance and population richness of natural enemies in cocoa is essential for the development of natural biological control methods. Species of the genus *Amblyseius* have the potential to be used in applied biological control programs for phytophagous mites.

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