UNIVERSIDADE DO VALE DO TAQUARI – UNIVATES PROGRAMA DE PÓS-GRADUAÇÃO *STRICTO SENSU* DOUTORADO EM AMBIENTE E DESENVOLVIMENTO

BIOECOLOGIA DE ÁCAROS EM FRUTÍFERAS NATIVAS DA REGIÃO NORDESTE DO PARÁ, AMAZÔNIA

Edna Antônia da Silva Brito

Lajeado/RS, dezembro de 2024

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Tese apresentada ao Programa de Pós-Graduação em Ambiente e Desenvolvimento, da Universidade do Vale do Taquari - Univates, como parte da exigência para obtenção do título de Doutora em Ambiente e Desenvolvimento, na linha de pesquisa Ecologia.

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A banca examinadora abaixo aprova a tese apresentada ao Programa de Pós-Graduação em Ambiente e Desenvolvimento, na linha de pesquisa Ecologia, para a obtenção do título de Doutora em Ambiente e Desenvolvimento.

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DEDICATÓRIA

Dedico esta tese aos meus filhos Maria Eduarda Brito, Arthur Antônio Brito, Eduardo Brito, Sophia Brito e ao meu esposo Rosevaldo Barros, que sempre me incentivaram e me apoioaram, sendo o motivo da minha felicidade.

AGRADECIMENTOS

A Deus, a força maior que me concedeu a graça de chegar até aqui, e que me deu coragem para superar todos os obstáculos.

Aos meus pais, Alfredo de Sousa Brito e Luzia da Silva Brito.

Ao Programa de Suporte à Pós-graduação de Instituições de Ensino Particulares, via Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (PROSUP/CAPES) e Univates, pela concessão da bolsa.

Ao professor Dr. Noeli Juarez Ferla, por aceitar o desafio de me orientar; por acreditar em minha capacidade, peça fundamental no desenvolvimento do trabalho.

À Dra. Aloyséia Cristina da Silva Noronha, que aceitou ser a coorientadora desta tese, colaborando da sua forma, no decorrer desse trabalho.

Ao meu querido esposo Rosevaldo Celestino Barros, por ser meu porto seguro, cuidando dos nossos filhos Maria Eduarda, Arthur Antônio, Eduardo Brito e Sophia Brito, para que fosse possível ir cursar e finalizar a tese.

Aos colegas do LABACARI da Univates, pela ajuda na identificação: Iury Castro, Naiara Nunes, Wesley, Tairis Costa, Adria Azevedo, Aline Pavan e Darliane Silva. E aos meus ex-alunos e alunos do IFPA Gizele, Laís, Raila e Felipe Martins. Expresso aqui, em nome deles, minha profunda gratidão a todas as pessoas que contribuíram direta ou indiretamente para a realização desta pesquisa.

Também gostaria de manifestar minha sincera gratidão às fazendas Bacuri, Coisas da roça, Arajivu e Jequiri pela valiosa colaboração e suporte durante a realização deste estudo. A infraestrutura disponibilizada, o ambiente acolhedor e o comprometimento da equipe foram fundamentais para o desenvolvimento desta pesquisa. Sem o apoio contínuo e a parceria destas instituições, a concretização deste trabalho não teria sido possível.

RESUMO

Este estudo teve como objetivo identificar a diversidade de espécies acarinas associadas a frutíferas nativas de ambientes naturais e agroecossistemas da região nordeste do Pará, com ênfase nos inimigos naturais associados às culturas de açaí, cacau, cupuaçu e bacuri. As coletas foram realizadas em quatro diferentes épocas do ano: período chuvoso (fevereiro/março); final do período chuvoso (maio/junho); início do período seco (agosto/setembro) e final do período seco (novembro/dezembro). Foram realizadas 20 amostras por planta, aleatoriamente, de cada cultura, onde foram coletadas cinco folhas da região mediana de cada planta, totalizando 100 folhas e 2 frutos por planta. As folhas foram coletadas com o auxílio de uma tesoura de poda e, quando necessário, com o auxílio de um podão com cabo telescópico. O material foi individualizado em sacos plásticos rotulados e armazenadas em caixas de isopor em baixas temperaturas com Gelox® para posterior encaminhamento ao laboratório. Foi realizada a triagem do material coletado sob microscópio estereoscópico (40x) com o auxílio de um pincel de ponta fina. Após a montagem, as lâminas foram mantidas em estufas a 50-60°C para a secagem do meio e clarificação dos espécimes por um período de sete dias, sendo em seguida vedadas. Para a análise estatística, foram realizadas coletas sistemáticas em períodos específicos ao longo de dois anos. Além da coleta de ácaros, foram registrados dados ambientais, como temperatura, umidade relativa, pressão atmosférica e precipitação. Foram realizados análises estatísticos através de esforço de amostragem e diversidade, índice de Shannon-Wiener, perfil de diversidade de Hill, escalonamento multidimensional não métrico (NMDS) para comunidade de ácaros e para a estrutura da comunidade de ácaros foram testadas por meio de análise de variância com permutações (n=99) (PERMANOVA) utilizando a função “adonis2” no pacote vegan no R. Também foram geradas curvas de rarefação para os valores de diversidade utilizando-se linguagem de programação estatística R, curvas de rarefação para estimativas de riquezas sua equitabilidade. Os resultados mostraram uma rica diversidade de espécies de ácaros nas frutíferas nativas, com destaque para aquelas associadas a condições específicas dos períodos seco e chuvoso em ambientes naturais e agroecossistemas. O estudo evidenciou que a presença de ácaros nas frutíferas nativas pode afetar tanto a produtividade quanto o desenvolvimento das plantas, sendo necessário um monitoramento constante para entender as variações sazonais e ambientais que influenciam a dinâmica dos ácaros fitófagos.

Palavras-chave: Ácaros predadores. Ácaros fitófagos. *Euterpe oleracea*. *Theobroma cacao*. *Theobroma grandiflorum*. *Platonia insignis*.

ABSTRACT

The study aimed to identify the diversity of mite species associated with natural native fruit trees and in agroecosystems in the northeastern region of Pará, with emphasis on natural enemies associated with crops. The collections were carried out at four different times of the year: rainy season (February/March); end of the rainy season (May/June); beginning of the dry season (August/September) and end of the dry season (November/December). Twenty samples were taken per plant, randomly from each crop, where five leaves were collected from the median region of each plant, totaling 100 leaves and 2 fruits per plant. The leaves were collected with the help of pruning shears, and when necessary, with the help of a pruning shear with a telescopic handle. The material was individually placed in labeled plastic bags and stored in Styrofoam boxes at low temperatures with Gelox® for later forwarding to the laboratory. The collected material was screened under a stereoscopic microscope (40x) using a fine-tipped brush. After assembly, the slides were kept in ovens at 50-60°C to dry the medium and clarify the specimens for a period of seven days, and were then sealed. For statistical analysis, systematic collections were carried out in specific periods over two years. In addition to collecting mites, environmental data were recorded, such as temperature, relative humidity, atmospheric pressure and precipitation. Statistical data were performed through sampling effort and diversity, Shannon-Wiener index, Hill diversity profile, non-metric multidimensional scaling (NMDS) for mite community and for the mite community structure were tested through analysis of variance with permutations (n=99) (PERMANOVA) using the "adonis2" function in the vegan package in R. Rarefaction curves were also generated for diversity values using the statistical programming language R, rarefaction curves for estimates of richness and its equitability. The results showed a rich diversity of mite species on native fruit trees, with emphasis on those associated with specific conditions during the dry and rainy seasons in natural environments and agroecosystems. The study showed that the presence of mites on native fruit trees can affect both productivity and plant development, requiring constant monitoring to understand the seasonal and environmental variations that influence the dynamics of phytophagous mites.

Keywords: Predatory mites. Phytophagous mites. *Euterpe oleracea. Theobroma cacao. Theobroma grandiflorum. Platonia insignis.*

SUMÁRIO

1 APRESENTAÇÃO

A tese intitulada "Bioecologia de Ácaros em Frutíferas Nativas da Região Nordeste do Pará" aborda um estudo sobre os ácaros que afetam as frutíferas nativas da região, com foco na diversidade de ácaros encontrados. O trabalho busca identificar as espécies de ácaros presentes nas culturas e os possíveis danos que podem causar às plantas.

A região Norte do Brasil possui uma grande diversidade de espécies de frutíferas nativas. Muitas dessas espécies, como o açaizeiro (*Euterpe oleracea* Mart. Arecaceae), bacurizeiro (*Platonia insignis* Mart. Clusiaceae), cacaueiro (*Theobroma cacao* L. Malvaceae) e cupuaçuzeiro (*Theobroma grandiflorum* (Willd. Ex Spreng.) Schum Malvaceae), são importantes para a renda dos agricultores locais, com uma demanda cada vez maior do mercado consumidor em outros estados do Brasil. Independentemente de serem de famílias e espécies de grande importância econômica, a expansão de áreas plantadas tanto em plantios solteiros ou em consórcios, também pode contribuir para o aumento gradativo das populações de pragas e doenças.

De forma geral, vários grupos de organismos causam sérios danos às plantas cultivadas, destacando-se ácaros e insetos. Os ácaros se apresentam como o segundo grupo mais diversificado dentro de artrópodes, depois dos insetos (KRANTZ; WALTER, 2009). Os ácaros que alcançam o status de praga mais importantes pertencem às famílias Eriophyidae, Tarsonemidae, Tenuipalpidae, Tetranychidae e Tuckerellidae (SCHRUFT, 1985; DUSO & LILLO, 1996, FLECHTMANN, 1979),

Os ácaros são organismos que ocorrem em todos os tipos de ecossistemas naturais e modificados. Estes organismos possuem uma grande diversidade de hábitos alimentares, podendo ser fitófagos, micófagos, saprófagos, coprófagos, necrófagos, parasitas e predadores (KRANTZ & WALTER, 2009). Estudos em áreas de vegetação natural podem contribuir para o melhor conhecimento da diversidade, bem como para a compreensão dos aspectos biológicos e evolutivos, levando à descoberta de inimigos naturais com características desejáveis em programas de manejo ecológico aplicado de pragas (FERES, 2008).

Diversas espécies têm se mostrado úteis ao controle biológico de ácaros fitófagos e pequenos insetos que são pragas agrícolas, sendo produzidos e utilizados comercialmente em diversos países, inclusive no Brasil (GERSON *et al.*, 2003 & HOY, 2011). A maior parte dos ácaros predadores dos ácaros-praga pertence à família Phytoseiidae, além de espécies das famílias Ascidae, Blattisociidae, Cunaxidae e Melicharidae (TAYLOR *et al*., 2012). Desta forma, o objetivo deste estudo foi identificar a diversidade de espécies de ácaros associadas às frutíferas nativas em ambientes naturais e agroecossistemas da região nordeste do Pará.

Estudos de levantamento faunístico podem resultar no registro de espécies promissoras como inimigas naturais de pragas, com potencial para serem utilizadas em programas de controle biológico aplicado (MENEZES *et al*., 2007 & MORAES & FLECHTMANN, 2008; BARBOSA *et al*., 2003), assim como indicar plantas hospedeiras que funcionem como reservatório dessas espécies e que podem ter importância em programas de controle biológico conservativo (LOFEGO *et al*., 2017).

Esta pesquisa está vinculada ao Programa de Pós-Graduação em Ambiente e Desenvolvimento - PPGAD, da Universidade do Vale do Taquari – Univates, na linha de pesquisa Ecologia, bem como tangencia as duas outras linhas do Programa, Tecnologia e Ambiente e Espaço e Problemas Socioambientais. Desta forma, o estudo desenvolvido dialoga diretamente com os objetivos do programa, que visa a avaliar a interação do homem com o ambiente, de forma ecocêntrica e interdisciplinar.

Além disso, a tese "Bioecologia de Ácaros em Frutíferas Nativas da Região Nordeste do Pará, Amazônia" pode ser relacionada de diversas maneiras aos Objetivos de Desenvolvimento Sustentável (ODS), metas estabelecidas pela Organização das Nações Unidas

(ONU) para serem alcançadas até 2030. Principalmente aos ODS que buscam a promoção da sustentabilidade ambiental, a conservação da biodiversidade e o apoio à agricultura sustentável.

Questões importantes relativas a aspectos teóricos aplicados à grande área das Ciências Ambientais listadas nessa pesquisa alcançam cinco dos 17 Objetivos de Desenvolvimento Sustentável da ONU:

ODS 2: Fome Zero e Agricultura Sustentável. O estudo dos ácaros em frutíferas nativas pode contribuir para a sustentabilidade da agricultura na região. Ao entender como essas pragas afetam as plantas, é possível desenvolver práticas de manejo que minimizem o impacto delas, favorecendo a produção de alimentos de forma mais sustentável e sem o uso excessivo de pesticidas, o que é fundamental para a segurança alimentar. Também traz como contribuição a identificação de formas de controle de pragas de maneira ecológica, contribuindo para uma agricultura mais eficiente e resiliente, especialmente em comunidades que dependem de frutíferas nativas para sua subsistência.

ODS 6: Água Potável e Saneamento. A agricultura sustentável nas frutíferas nativas também está vinculada ao uso responsável da água, o que é crucial para a manutenção da saúde das plantas e para o equilíbrio ecológico da região. Técnicas de manejo sustentável, como o controle biológico de pragas, podem ajudar a minimizar o impacto da agricultura no uso de água e na preservação dos recursos hídricos. Ao promover práticas agrícolas que respeitam o ciclo natural e minimizam o uso de produtos químicos, há um benefício indireto na preservação da qualidade da água nas regiões agrícolas.

ODS 12: Consumo e Produção Responsáveis, objetivo que visa a assegurar padrões sustentáveis de produção e consumo, promovendo a utilização eficiente de recursos naturais, reduzindo a geração de resíduos e minimizando os impactos ambientais negativos. A bioecologia de ácaros pode ajudar a otimizar o uso de recursos naturais na agricultura, promovendo práticas mais responsáveis no manejo de pragas. Isso pode incluir o uso de alternativas menos agressivas ao meio ambiente, como controle biológico ou manejo integrado de pragas (MIP). Assim, ao entender melhor os ecossistemas das frutíferas nativas, pode-se reduzir o uso de químicos e melhorar a gestão de recursos naturais, aumentando a eficiência do sistema agrícola.

ODS 13: Ação Contra a Mudança Global do Clima. Frutíferas nativas desempenham um papel crucial na preservação da biodiversidade local e na manutenção do equilíbrio ecológico, ajudando a mitigação de impactos climáticos. O manejo adequado das pragas, como ácaros, pode ajudar a manter a saúde das plantas e a garantir a resiliência dos ecossistemas agrícolas. O estudo pode contribuir para práticas agrícolas mais adaptadas às condições climáticas locais, tornando a produção mais resistente às mudanças climáticas, ao mesmo tempo em que preserva os recursos naturais.

O ODS 15 - “Vida Terrestre”, que tem como objetivo proteger, restaurar e promover o uso sustentável dos ecossistemas terrestres, gerenciar as florestas de forma sustentável, combater a desertificação, deter e reverter a degradação da terra, combater a caça e o tráfico ilegal de espécies, além de incentivar a conservação e o uso sustentável da biodiversidade de forma integrada com as comunidades locais. A pesquisa sobre os ácaros em frutíferas nativas também está intimamente ligada à conservação da biodiversidade, uma vez que muitos dos ácaros podem ter um papel ecológico importante, seja como parte da cadeia alimentar ou como reguladores naturais de outras espécies. Proteger frutíferas nativas e seus ecossistemas associados ajuda a preservar a flora e fauna local.

A tese aqui apresentada pode fornecer dados valiosos para estratégias de conservação e manejo sustentável das frutíferas nativas da região, que são essenciais para a preservação dos ecossistemas locais e da biodiversidade. Desse modo, as frutíferas nativas desempenham um papel significativo na promoção da saúde e no avanço dos Objetivos de Desenvolvimento Sustentável listados. Inserido na grande área das Ciências Ambientais, este trabalho apresenta uma visão interdisciplinar do uso dos recursos ambientais por sociedades tradicionais, com destaque à importância da valorização da cultura regional e aos aspectos socioeconômicos e ambientais envolvidos.

Além desta apresentação, a tese está organizada em cinco capítulos, cada um originando um artigo científico. Os referidos artigos foram submetidos a periódicos com qualis Capes 2017-2020 considerados superiores (A1-A4), sendo no mínimo dois aceitos ou publicados, conforme determinações do Programa de Pós-Graduação em Ambiente e Desenvolvimento – PPGAD.

- O primeiro artigo apresenta dados acerca dos danos causados por ácaro *Tuckerella ornata* em frutos do cacaueiro.
- O segundo artigo apresenta o levantamento da diversidade acarina associada a cultivos de açaizeiros nativos e cultivados, bem como sua distribuição nos períodos seco e chuvoso nos municípios de Bragança e Augusto Corrêa, no estado do Pará.
- O terceiro artigo descreve a amostragem para o conhecimento da diversidade de ácaros associados em áreas de cultivos de cacaueiros nos municípios de Bragança e Augusto Corrêa, bem como sua distribuição em períodos chuvosos e secos.
- O quarto artigo teve o objetivo conhecer a acarofauna associada a cultivos de cupuaçuzeiros em áreas cultivadas nos municípios de Bragança e Augusto Corrêa na

microrregião Bragantina, estado do Pará.

- O quinto artigo apresenta a fauna acarina, bem como sua ecologia na cultura de bacuri em áreas nativas nos municípios de Bragança e Augusto Corrêa, microrregião Bragantina, estado do Pará.

Assim, essa estruturação seguiu o que dispõe o Regimento do Programa de Pós-Graduação em Ambiente e Desenvolvimento – PPGAD (resolução 003/Consun/Univates, de Reitoria/Univates), de 12/01/2021, Seção II, do trabalho de conclusão, em seu Art. 32, inciso II, que apresenta o formato alternativo do trabalho de conclusão de curso do PPGAD, da Universidade do Vale do Taquari - Univates. Deste modo, o referido dispositivo determina:

a) título; b) resumo e abstract; c) apresentação; d) dois artigos aceitos ou publicados com fator de impacto (JCR igual ou superior a 0,5); e) discussões gerais, conclusões e referências.

2 CAPÍTULO 1. DAMAGE CAUSED BY *TUCKERELLA ORNATA* (ACARI: TUCKERELLIDAE) ON COCOA FRUITS (*THEOBROMA CACAO*) IN THE AMAZON REGION, STATE OF PARÁ, BRAZIL

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Artigo publicado na Revista: Systematic and Applied Acarology

Abstract

The study aimed to report peacock mites (Acari: Tuckerellidae) on cocoa fruits (*Theobroma cacao* L.; Malvaceae) in the northeast Bragantina region, state of Pará, Brazil. Two mite species were identified, *Tuckerella ornata*, with 149 specimens, 32.89% on leaves and 67.11% on fruits, and *Tuckerella knorri*, with only two specimens on leaves. It was found that green fruits with *T. ornata* significantly reduced the size and weight of seeds. More attacked fruits, with more severe damage, showed deformations and thick cracks. Significant damage was noted in the *Forastero* cocoa seeds, visible to the naked eye, with light brown spots and a fine crack on the epidermis.

keywords: Cocoa seeds, Tuckerellid mites, *Tuckerella knorri*, Peacock mites

Introduction

Brazil is the 7th largest producer of cocoa (*Theobroma cacao* L.; Malvaceae) in the world, and the state of Pará is the largest producer in the country, with 144,700 tons in an area of 149,700 hectares (IBGE, 2021). The cocoa fruit has economic importance for the Amazon region and generates income for family producers and cooperatives in the region. It is a commodity in demand in the international market to supply not only the food sector, mainly chocolate, but also the fertilizer, cosmetics, cleaning, and animal feed sector (Filgueira 2002; Chepote 2003).

In the Brazilian cocoa culture, mite families Eriophyidae, Tetranychidae, and Tuckerellidae have been reported. Only two species of phytophagous mites have been reported from cultivation in the state of Bahia: *Aceria reyesi* (Nuzacci) (Eriophyidae) and *Tetranychus mexicanus* (McGregor) (Tetranychidae) (Maia & Valverde 2017; De Carvalho *et al*. 2018). In the amazon region, *Tuckerella ornata* (Tucker) (Tuckerellidae) was cited in Belém do Pará (Flechtmann 1979). Eleven species of spider mites have already been associated with this plant worldwide (Migeon & Dorkeld, 2011– 2019).

Tuckerellidae, peacock mites, is a family with only 32 species, all belonging to the single genus *Tuckerella* (Krantz & Walter 2009; Khadem & Asadi 2017; Escobar-Garcia *et al*. 2022). They are ornamented mites with rows of four to seven pairs of long caudal arrows in the pygidial region, which can be white, webbed, oval, or circular, and easy to recognize. They are strictly phytophagous and can be seen with the naked eye due to their orange or reddish color (Meyer & Ueckermann 1997). The damages caused to the cocoa crop are deformations of the fruits and impairment of their initial development (Escobar-Garcia *et al*. 2021).

The objective of the work was to identify and report the tuckerellid mites and the damage caused to providing information to establish a method of control and correct management of these pests.

Materials and Methods

This research was carried out in cocoa plantations of the *Forastero* and *Trinitario* varieties in an agroforestry system in the Bragantine region, northeast of Pará. Two samplings were carried out from September 2021 to February 2022 in cocoa cultivation areas of two farms in the municipality of Bragança (1°10'18.6"S, 46°43'49.3"W 41 m altitude; 1°03 '59.8"S 46°44'40.0"W 16 m altitude) (Figure 1). The cocoa trees measured 1.5 to 3 meters in height and were between three and six years old (Figure 2A and B), of *Forastero* varieties, with yellow fruits, and *Trinitario*, with red fruits, grown in the same area. According to the Kopper classification system, the region was characterized by having a hot and humid equatorial climate of the Amw' type, with a rainy season between December and May and a dry season for the other months of the year (Da Silva *et al*. 2006).

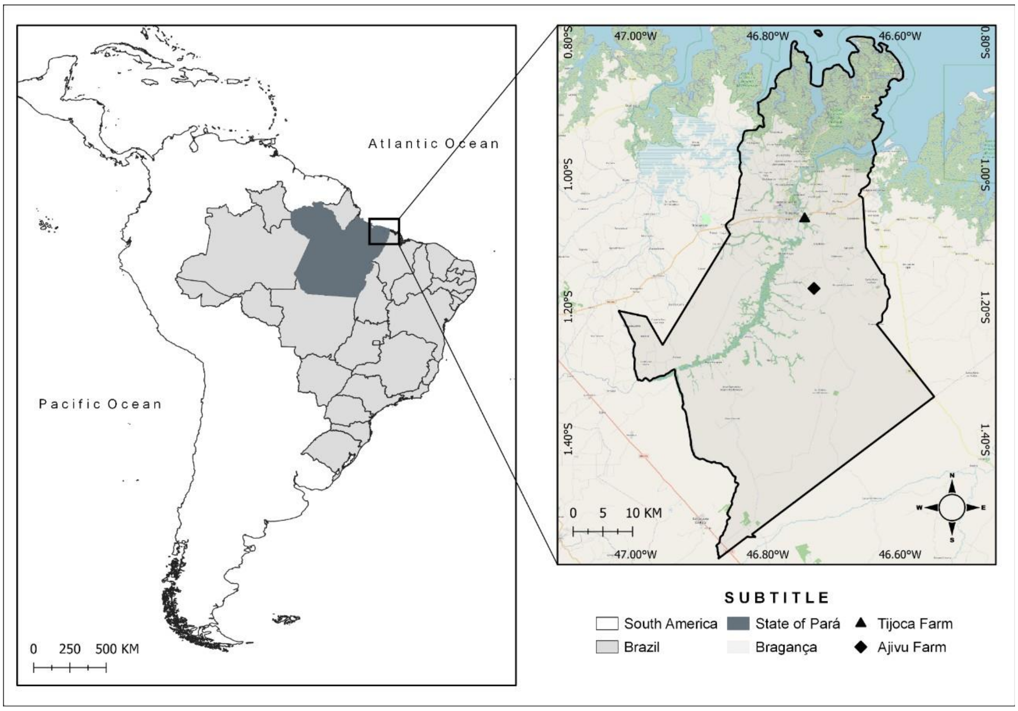


FIGURE 1. Location of cocoa production farms in the northeast region of the state of Pará, in the Amazon region.

Twenty cocoa plants were randomly sampled in the cultivation area, from which five leaves/ plants and twenty fruits/plants of the *Trinitario* and *Forastero* varieties were removed, with visible damage and no apparent damage. The leaves and fruits were packed in paper bags individually and adequately identified and transported to the Laboratory of Molecular Biology and Neuroecology of the Federal Institute of Education of Pará (IFPA) - Campus Bragança for sorting. The mites were collected and mounted on microscope slides with Hoyer's medium, taken to a drying oven at a temperature between 50–60ºC, and kept for 10 days. The identification was carried out at the Acarology Laboratory of the University of Vale do Taquari - Univates, using an Optical Microscope with phase contrast - Zeiss and dichotomous keys (McDaniel *et al*. 1975; Quirós-Gonzalez & Baker1984; Ochoa 1989; Meyer & Ueckermann 1997; Escobar-Garcia *et al*. 2021). Specimens were deposited in the reference collection of the

Laboratory of Acarology at Univates (ZAUMCN).

FIGURE 2. Three-year (**A**) and six-year-old (**B**) cocoa trees are evaluated.

Statistical analysis

All data were verified for the assumptions of the parametric analysis. Normality was examined using the Shapiro-Wilk test and homogeneity of variances using the Levene test. The effect of the presence of damage caused by mites on the weight and length of the fruit and on the weight of the seeds was investigated by applying the paired student t-test, as these data satisfied the assumptions of normality and homoscedasticity. On the other hand, the effect of damage on fruit diameter and the difference in the number of mites on leaves and fruits were tested using the paired Wilcoxon test, as these variables did not satisfy the assumptions for parametric analyses. Differences with error probability below 5% were considered significant.

To investigate which aspects of cocoa were most affected by mite infestation, we applied a Principal Component Analysis (PCA). Regression analyzes were also carried out in a Generalized Linear Model to verify the effect of the number of mites on the characteristics of fruits and seeds, considering only fruits with visible damage. The analyzes were performed using the programs RStudio 1.4.1106 (R Core Team 2018) and Past 4.09 (Hammer *et al*. 2001).

Results and Discussion

This work reports the presence of *Tuckerella ornata* and *Tuckerella knorri* Baker & Tuttle on fruits and leaves of cacao trees from plantations maintained in an agroforestry system in the Bragantina region, state of Pará. Until now, only *T. ornata* had been found in cocoa plant stems in Belém, Pará state (Flechtmann 1979). *Tuckerella ornata* was found in fruits that showed apparent damage. Higher populations of this species were found in fruits (67.11%) than in leaves (32.89%) (Figure 3). Furthermore, for the first time, *T. knorri* was found in low populations of cocoa (n=2). The presence of these mites on leaves suggests that they were moving to new feeding sites on the stems. These tuckerellid mites have already been reported for cocoa cultivation in Piura, Peru, outside the Amazon region (Escobar-Garcia *et al*. 2021). In that study, organic cocoa fruits were found with damage to the fruits and seeds infested with *T. knorri, T. ornata,* and *T. pavoniformis* (Ewing).

These data corroborate Escobar-Garcia *et al*. (2022) regarding *T. pavoniformis* found in *Mammea americana* L. (Calophyllaceae) in northwestern Peru. That study also noted that mite aggregations were more common, with higher population densities (average of 10.6 mites/cm²) on fruits than on branches (average of 3.4 mites/15 cm of branches), highlighting that this is the preferred feeding site for this species. Motile stages and *T. pavoniformis* eggs can easily be seen attached to the clefts found in the epicarp of the fruit. These tuckerellid mites appear to use these crevices to access feeding and oviposition sites and protect against predation and environmental factors.

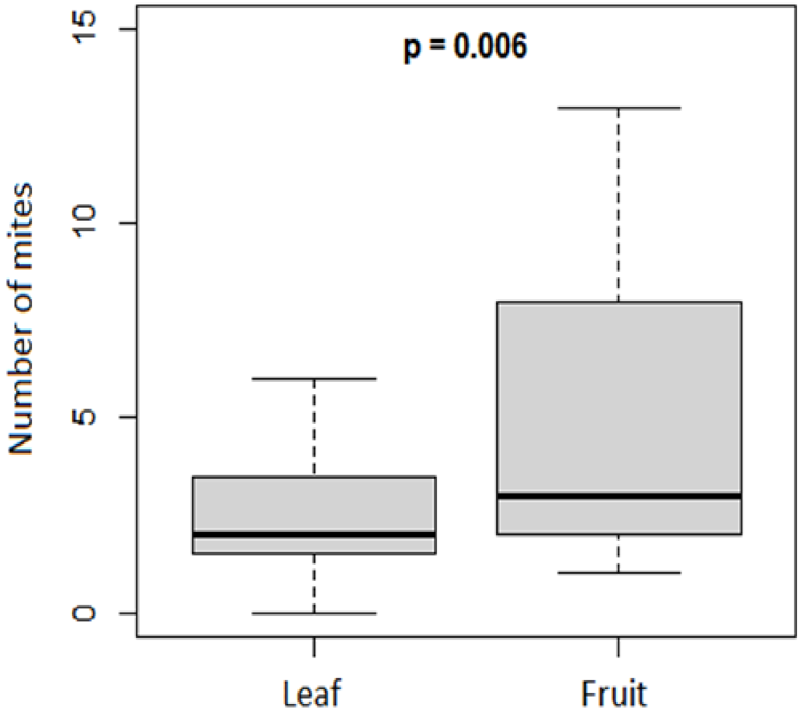
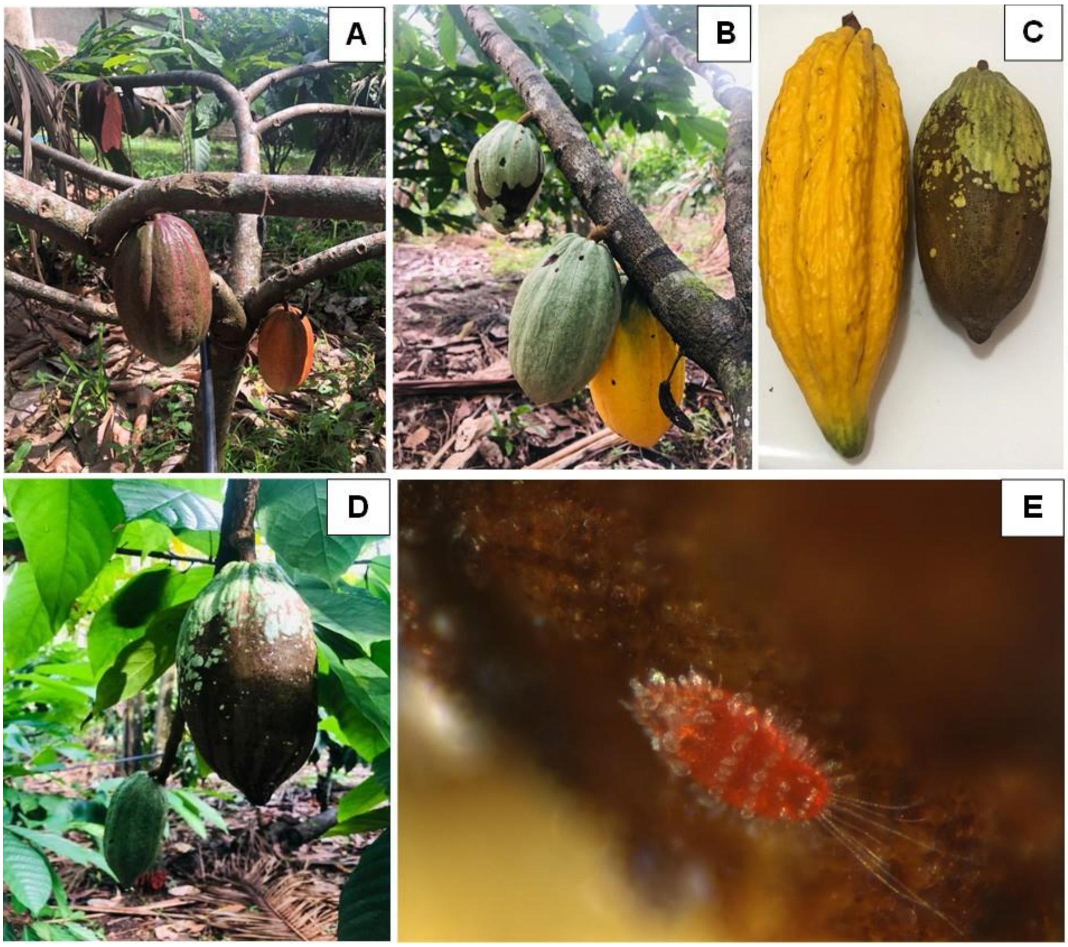


FIGURE 3. Mean population of *Tuckerella ornata* on leaves and fruits of forastero cacao (*p*=0.006).

It was found that green fruits with *T. ornata* significantly reduced the size and weight of seeds. More attacked fruits with more severe damage showed deformations and thick cracks (Figure 4A– B). Significant damage was noted in the *Forastero* cocoa seeds, visible to the naked eye, with light brown spots and a fine crack in the epidermis (Figures 4A–D). Specimens remained wedged in depressions and cracks in the bark of branches or fruits of the host plant. Thus, these openings served as accommodation for these organisms, where they also continued to feed on epidermis cells, covering and damaging the fruit surface (Figure 4E). No mites were found on *Trinitario* cocoa fruits. The damage caused by tuckerellid mites in the cocoa culture has already been described by presenting deformations in the fruits and compromising the initial development of the same (Escobar-Garcia *et al*. 2021).

Tuckerella ornata infestation significantly reduced all measured traits (Table 1; Figure 5). Similar results found by Escobar-Garcia *et al*. (2021) show that tuckerellid mites feeding not only causes a significant reduction in the number of commercially important fruits per tree but also in the yield per fruit, i.e., the number of seeds. When comparing paired samples of fruits with damage and fruits without damage of the same phenological age, a significant difference was observed concerning length (cm), width (cm), weight (g), and the number of seeds ($p < 0.05$), with undamaged fruits showing higher values.

A report of *T. pavoniformis* found in *M. americana* in Peru showed that the analysis of the biometric characteristics recorded for infested ripe fruits revealed an average weight of 397.23 ± 20.79g, with individual weights ranging from 355.40 to 439g each. In most cases, the fruits of the trees sampled developed only one seed, with an average number of seeds of 1.52 ± 0.11, it was noted that the average percentage of pulp per fruit observed was 56.61 ± 1.74% (Escobar-Garcia *et al*. 2022).



FIGURES 4A-E. A. Trinitario variety cocoa fruit; B. Forastero variety cocoa fruit with deformation; C and D. Damage caused to fruits. E. *Tuckerella ornata* specimen.

TABLE 1. Effect of the presence and absence of damage caused by mite infestation on the weight, length, and diameter of cocoa fruits, the weight of their seeds, and the differences in the number of mites between leaves and fruits.

Variable	Statistic Test		g.l.	*p*-value
Fruit weight	Test T	T=-6.6356	19	< 0.001
Fruit length	Test T	T=-12.201	19	< 0.001
Fruit diameter	Wilcoxon	V=0	-	< 0.001
Seed weight	Test T	T=-3.9876	19	< 0.001

Mites on leaves *vs.* fruits	Wilcoxon V=2	-	0.007

Principal Component Analysis revealed that both fruit and seed weight were mostly affected by mite damage (Figure 6). Morphophysiological differences in cocoa fruits were also reported by Escobar-Garcia *et al*. (2021). In the study, significantly lower variables were observed in length, width, weight, and the number of seeds in fruits with damage compared to cocoa fruits without damage. Principal Component 1 (PC1), which accounted for 91% of the variation in the data, demonstrated that undamaged fruits and seeds had higher weights than those with damage, which separated the data into two groups along the gradient of axis 1. Significant differences were also found by Escobar-Garcia *et al.* (2021) regarding the width and weight of dry seeds affected by tuckerellid mites populations, noting higher values in seeds without damage to the fruit. From the results obtained from the quantitative variables for damaged and undamaged cocoa fruits, the authors conclude that there is an economic impact of approximately 10% on the final yield of dry cocoa seeds.

The results of the generalized linear models demonstrate that the increase in the populations of

T. ornata reduced the weight ($p < 0.001$), length ($p < 0.001$), and diameter of the fruits ($p < 0.001$), as well as the weight of seeds ($p < 0.001$; Figure 7).

According to the results obtained from the measured characteristics of the fruits with damage, 67.11% of *T. ornata* were found in fruits. Considering the seed weight, the diameter and length of fruits per plant, and the generalized linear models, it is concluded that the presence of these mites in cocoa trees causes an economic impact on the economy of the producing region.

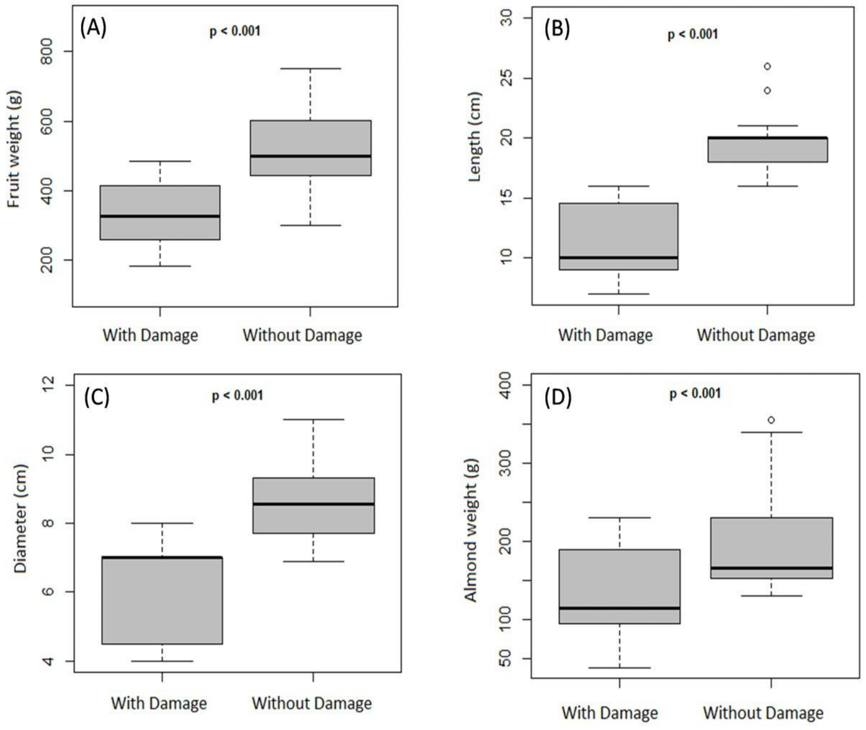


FIGURE 5. Effect of the presence or absence of *Tuckerella ornata* on the weight (A), length (B), and diameter (C) of cocoa fruits, and weight of seeds (D).

Diagnostic features of the pygidial region of females

Tuckerella ornata: has five pairs of elongated flagellated caudal setae equal in length (*h2, h3, h4, h5, h7, h8*), three pairs of short, wide oval setae (*h1, h3, h6*) on the opisthosoma, cuticle with regular reticulation and finely areolate, arrows *f1* and *f2* not equal in size and inserted in a transverse line (Figure 8a).

Tuckerella knorri: presents six pairs of elongated flagellate caudal setae equal in length (*h2, h3, h4, h5, h7, h8*), two pairs of short oval setae (*h1, h6*) on the opisthosoma, cuticle with irregular and finally areolate reticulation, arrows *f1* and *f2* equal in size and inserted in a transverse line (Figure 8b).

Final Considerations

This is the first work carried out with mites in the Northeast region of Pará and the first reporting damage caused on fruits by mites of the tuckerellid mites characterized by high populations, with damage caused by *T. ornata* in cocoa fruits. These damages are significant and worrying for the producers of this chain and the state's economy, as the state is the largest cocoa producer in the country. Thus, it is important to identify these pests for the correct phytosanitary management, avoiding greater impacts on the cocoa production chain in the Bragantine region and other regions of the state. It is suggested that new surveys be carried out in these other regions to recognize the associated species, as well as the losses in the production of this culture in the state.

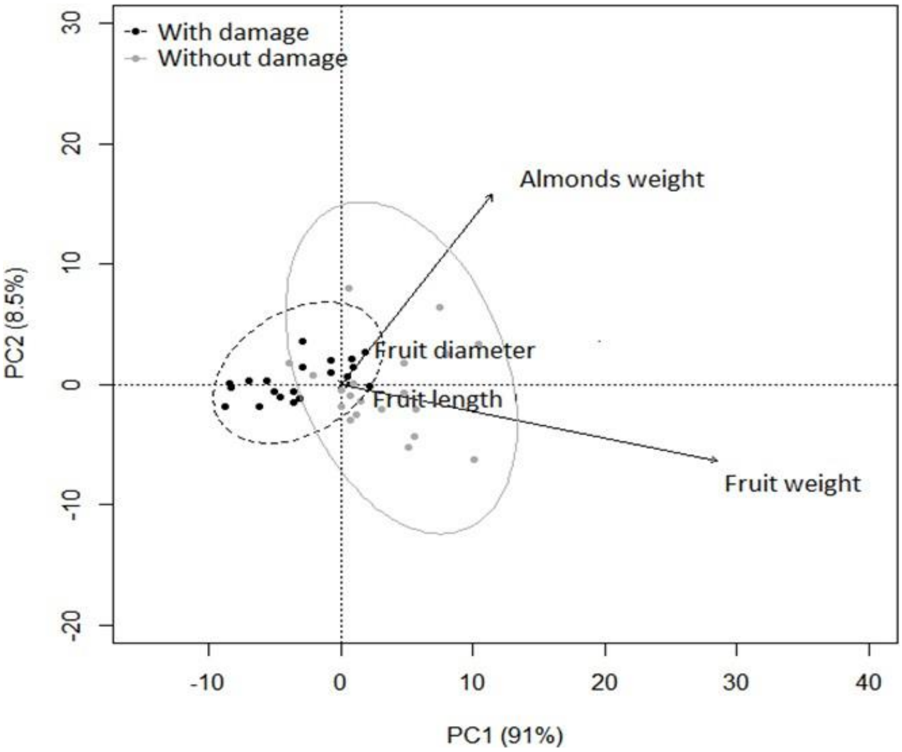


FIGURE 6. Principal Component Analysis for the effect of damage caused by *T. ornata* infestation on cocoa fruits and seeds characteristics.

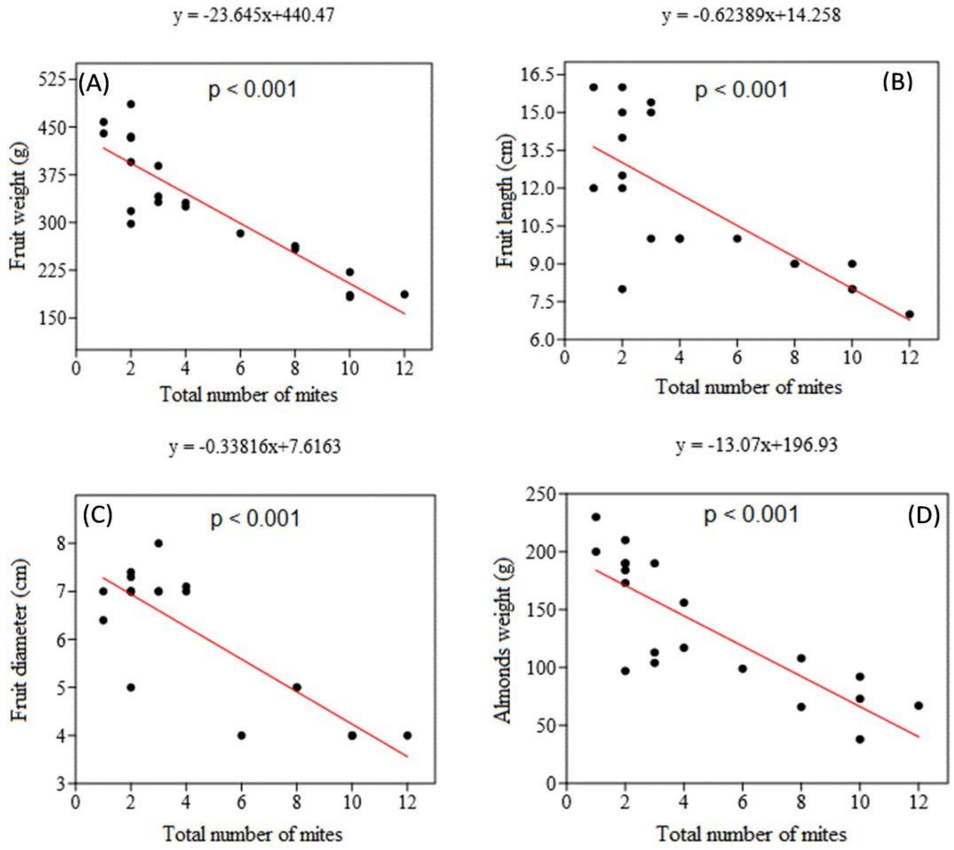


FIGURE 7. Generalized Linear Models demonstrating the effect of the total amount of *T. ornata* on the weight (A), length (B), and diameter (C) of cocoa fruits and the weight of the seeds (D).

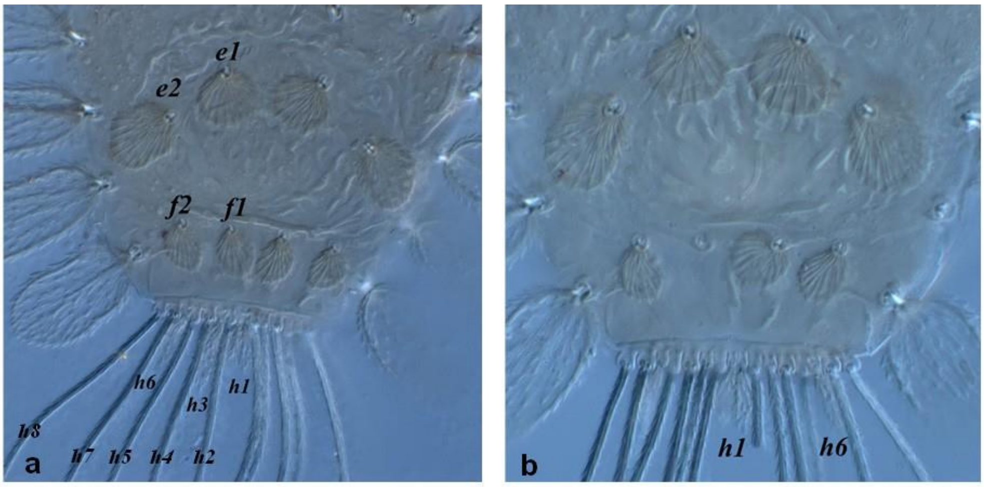


FIGURE 8. Pygidial region of females of *Tuckerella ornata* (**a**) and *Tuckerella knorri* (**b**).

Acknowledgements

We thank the Laboratory of Molecular Biology and Neuroecology - LBN, Campus Bragança, for sorting the materials. We appreciate the support of the Farm of Alto do Ajivu and Tijoca farm for providing the fields to carry out our research. We also thank the Laboratory of Acarology of Univates (Labacari) for supporting the identification of the species and image registrations.

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Submitted: 13 Aug. 2022; accepted by Rostislav Zemek: 17 Oct. 2022; published: 4 Jan. 2023

3 CAPÍTULO 2 – MITES ASSOCIATED WITH AÇAÍ PALM TREES (*EUTERPE OLERACEA*: ARECACEAE) IN NATIVE AND CULTIVATED AREAS OF THE STATE OF PARÁ (EASTERN AMAZON, BBRAZIL)

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Artigo publicado na Revista **Experimental and Applied Acarology** (2024) 93:229–252. ISSN 1572-9702 - DOI: https://doi.org/10.1007/s10493-024-00925-4 -qualis Capes A2, (2017-2020).

MITES ASSOCIATED WITH AÇAÍ PALM TREES (*EUTERPE OLERACEA*: ARECACEAE) IN NATIVE AND CULTIVATED AREAS OF THE STATE OF PARÁ (EASTERN AMAZON, BBRAZIL)

Abstract. The objective was to quantify and analyse the diversity of mites associated with native and cultivated açaí palms crops, as well as their distribution in the dry and rainy seasons in the municipalities of Bragança and Augusto Corrêa, state of Pará. Rarefaction curves were generated for diversity values using the statistical programming language R, rarefaction curves for estimates of richness and equitability and analysis of variance with permutations. A total of 2,069 mites from 28 families were sampled, being most representative Phytoseiidae (32.4%), Phytoptidae (13%), Cunaxidae (7.7%), Tetranychidae (5.6%) and Tydeidae (4.9%). Among predators, the most abundant species were *Amblyseius* sp. 1, *Armascirus amazoniensis* Wurlitzer & Silva, *Iphiseiodes zuluagai* Denmark & Muma, *Scutopalus tomentosus* Rocha, Skvarla & Ferla, and the phytophagous mites *Acaphyllisa* sp., *Davisella* sp., *Oligonychus* sp. and *Retracus johnstoni* Keifer. In the rainy season, more mites were sampled (n = 1,176) than in the dry season (n = 893). The greatest richness was observed in the dry period (73 species) and diversity was also greater in this period. In the municipality of Bragança there was greater richness (78 species) and the cultivated açaí trees had greater acarine abundance (74.7%) than the native ones. However, natives had slightly higher wealth (6%) than those cultivated. The diversity and richness of predatory mites show the potential of the Amazon biome to be used in applied biological control.

Key words: *Amblyseius*; *Scutopalus tomentosus;* *Acaphyllisa*; *Retracus johnstoni*; *Oligonychus*.

Introduction.

The açaí palm trees (*Euterpe oleracea* Mart.: Arecaceae), native to the Brazilian Amazon, has the state of Pará as the largest producer and consumer of the fruit. The gain in fruit production is related to the fact that açaí, previously aimed solely at local consumption, has reached new markets and has become a commodity and an important source of income and employment (Menezes et al., 2009). The fruit is consumed by all social classes, making it a product with high market potential, allowing added value, reducing market risks, making the activity competitive, generating employment and income in rural areas (Silva & Da Silva, 2006).

Several organisms reach pest status, causing damage to this palm tree, but there is little information about the presence of mites on this plant. Phytophagous mites with previously reported potential to cause damage to crops belong to the families Eriophyidae, Tarsonemidae and Tetranychidae (Schruft, 1985; Duso & Lillo, 1996). In Brazil, several phytophagous mite species have already been reported in *Euterpe edulis* Martius (Arecaceae): *Brevipalpus phoenicis* (Geijskes), *Brevipalpus* sp., *Tenuipalpus* sp. (Tenuipalpidae) e *Eutetranychus* sp., *Tetranychus* sp., *Oligonychus* sp. and *Schizotetranychus* sp. (Tetranychidae) (Arruda Filho & Moraes, 2002; Rodrigues et al., 2016).

With the increase in commercial crops in the state of Pará, research demands arise to ensure the safe and sustainable development of production (Oliveira et al., 2002). It is necessary, for example, to know the potential organisms that could reach pest status related to this palm tree, affecting survival or production (Santos et al., 2015). The occurrence of mite species in high populations can compromise the productivity of açaí groves, and it is important to identify arthropods that cause damage and injuries. In view of this, the need to know and identify the associated acarofauna, highlighting the phytophagous and predatory mites, is justified, aiming to create possibilities for alternative control of pest mites in that crop. This work aimed to understand the acarofauna associated with native açaí crops and cultivated in the dry and rainy seasons, as well as their distribution on the plant, in the municipalities of Bragança and Augusto Corrêa, state of Pará.

Materials and methods

Study location and sampling procedure

The study was carried Northeast of the state of Pará. The collections were carried out in commercial areas at Fazenda Alto Arajivu (coordinates 1º10'18.6"S, 46º43'49.3"W), at 41 m altitude and Sítio Jiquiri (1°03'59.8"S 46°44'40.0"W) 16 m above sea level, in areas of natural and commercial açaí cultivation in the Bragança (Bragantina microregion) and Augusto Corrêa, in the Sítio Coisas da Roça (1º03'58.91"S 46º66'23.30"W) and Fazenda Bacuri (1º04'11.10"S 46º66'33.82"W) (Figure 1). Collections took place in Augusto Corrêa, in the dry season, between August, October and December 2021, and in the rainy period, between January, April and June 2022, and in Bragança, the dry period corresponded to August and December and the rainy period, between January and June. The plants measured two to three meters in height, aged between three and eight years.

The region's climate is hot and humid equatorial (Amw'), according to the Köppen classification, characterized by a very 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 from 80-91%. The average temperature is 27.7 °C, which can vary from 20.4 to 32.8°C (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 a phase contrast microscope (Axio Scope. A1-Zeiss), and taxonomic keys. Species identification was carried out in the Acarology laboratory of the University of Vale do Taquari - Univates, using an OMAX 40x -2500x trinocular phase contrast microscope with an OMAX S35180U3-18Mp camera, and taxonomic keys (Baker and Tuttle 1994; Kazmierski 1998; Chant and McMurtry 2007; Mesa et al. 2009; Johann et al. 2013; Skvarla et al. 2014 and Wurlitzer et al. 2020 and others). Specimens proving the mite species collected in the study are deposited at 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) and used to explain the ordering generated in the analyses.

Statistical analysis

Data analysis. In order to explore and analyze in detail the variability and composition of these organisms in açaí plantations in two municipalities in the state of Pará/Brazil, during the months of mite collection.

Mite abundance by period, municipality and planting. This sample survey quantified and analyzed the diversity of mites in the two aforementioned municipalities (Augusto Corrêa vs. Bragança) during two different periods (dry vs. rainy), in addition to investigating this also in cultivated açaí plantations vs. native. As some species may not be determined because they are new species or genera or, even, due to the collection of immature individuals (which make taxonomic identification difficult), throughout this text, the organisms sampled will be treated as species or morphospecies. In this way, a pyramid graph was generated of the total number of mites within each family in order to enable an exploratory analysis of the distribution of these organisms between the two municipalities, the two periods and the two types of açaí planting. With this, it is possible to observe particularities and potential contributions of each taxonomic group to the mite community in this context.

Sampling effort and diversity. As part of the analysis in this study refers to the complexity and diversity of species/morphospecies, the sampling effort to collect the greatest taxonomic variability in these localities is important in order to become a representative analysis. Thus, rarefaction curves were generated for Chao1 diversity values with 99 permutations (Chao & Jost, 2015). This metric estimates the richness in a biological sample based on the number of rare and unique species present in the sample, considering species that were observed only once (singular species) and those that were observed twice (dual species), and so on. onwards, to make an estimate of total wealth. This makes this method more robust, especially when there may be many rare species in the sample that may not have been detected in the sample. Therefore, when Chao1 includes unique species in the estimate, it helps to correct biases caused by insufficient sampling (undersampling).

Therefore, the rarefaction curves for observed and extrapolated richness estimates were generated using the 'specpool' function of the vegan package (Oksanen et al. 2018) using the statistical programming language R (Ihaka & Gentleman, 1996; R Development Core Team 2022) for this and subsequent analyses. The calculation for these rarefaction curves and their respective dispersion measures (95% confidence interval) were based on the total abundance of specimens per species/morphospecies collected. They were generated using the `iNEXT´ function of the iNEXT package (Hsieh & Chao, 2016) in R.

Hill's diversity. Despite being able to analyze different diversity indices (e.g. Shannon-Winner, Simpsons, Margalef) in a particular and individual way, this approach may be biased towards what each of these indices considers in their respective formulas. In other words, each of them focuses on some premises that can give greater relevance to the presence of rare species, others that are more abundant, among other things. Hill's diversity profile is an interesting approach because it allows us to monitor, in a more dynamic way, how each of the mite communities (municipalities, periods, types of planting) behaves when different diversity indices attribute more weight to rare or dominant species (Hill, 1973).

In general, this analysis generates a scale along the x-axis of the graph based on the Renyi index with different orders of magnitude (Hill, 1973). This makes it possible to observe which communities are more diverse and on what scale of magnitude than the others and from what perspective (rarity of species/taxa vs. abundance of species/taxa). Thus, Hill's diversity profile is especially useful for verifying how the relative presence of more abundant species/taxa in comparison to less abundant ones contribute to altering the diversity of the organism community. Therefore, the scale on the x-axis focuses on different aspects of diversity and thus allows a more detailed analysis of the structure of the mite community based on simultaneous data on its richness, its evenness and its sensitivity to dominant species, with the values on the side left side of the graph more sensitive to rare species and the values on the right side are more sensitive to abundant or more common species (Tóthmérész, 1995). This analysis was carried out using the `renyi´ function (hill = TRUE) from the vegan package (Oksanen et al. 2018) in R.

Mite community structure. Species/morphospecies composition is an important factor in evaluating the diversity of organisms in a system or location. In this way, orders based on non-metric multidimensional scaling (NMDS) were generated for each attribute in question (period, municipality and planting) to evaluate the structure of mite communities in those locations. Before that, however, the abundance data was standardized using the `decostand' function (method = Hellinger) from the vegan package (Oksanen et al. 2018) in R. After that, this amount of standardized data was transformed into a dissimilarity matrix by the Bray-Curtis method using the vegan `vegdist´ function (Oksanen et al. 2018) in R. The arguments used to generate the NMDS were using the `metaMDS´ function (k = 3 dimensions) also from vegan (Oksanen et al. 2018) in R. The quality of the NMDS adjustment was evaluated using the resulting stress value, with values < 0.2 considered adequate.

To test whether the respective mite communities were statistically different from each other, we used an analysis of variance with permutations (n = 99) (PERMANOVA) using the `adonis2' function in the vegan package (Oksanen et al. 2018) in R. The permutations were stratified according to the collection campaigns (1st, 2nd, 3rd). Additionally, a multivariate homogeneity analysis of group dispersions was carried out using the vegan 'betadisper' function

(Oksanen et al. 2018) in R, which calculates the average distance of groups through their centroid, which helps to verify whether the results, significant or not, of PERMANOVA were not actually affected by data dispersion (greater variability within groups than between them).

The final ordering result generated by the NMDS can be affected by both the species/taxa present and ecological factors. Thus, to analyze which species/taxa were the most representative or determinant for the pattern generated by the NMDS ordination and which ecological factors (e.g. temperature, relative humidity, atmospheric pressure and precipitation) would be contributing significantly to those mite community structures, we we used the `envfit´ function from the vegan package (Oksanen et al. 2018). This function adjusts environmental vectors in the NMDS to assess how environmental variables can influence community structure. The interpretation of the results from this analysis involves the assessment 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.

Distribution in the plant. An experimental design was carried out to compare the abundance of mites in plant strata, in the basal, median, apical regions and in the fruit of cultivated vs. cultivated açaí palms. natives. As there were at least three collection campaigns (time factor) in the same sampling points, this demonstrates a repetition factor that can generate pseudo-repetitions or non-independence of the data, as it involves sampling organisms in exactly the same locations. To deal with data of this nature, we adjusted a Generalized Linear Mixed Model (GLMM) in order to evaluate which of the plant substrates would be significantly different from each other. Therefore, to obtain the best model that fits the data, two GLMMs were generated, one with a Poisson error distribution family and the other with negative binomial. These models were generated using the functions `glmer´ and `glmer.nb´, respectively from the lme4 package (Bates et al. 2015). Model selection was based on choosing the one with the lowest Akaike Information Criterion (AIC), using the `AICctab´ function from the bbmle package (Bolker & R Core Team, 2020).

The structure of these GLMMs was as follows: dependent variable – the number of mites observed; the independent variables – plant substrate (basal, median, apical, fruit) and the type of planting (cultivated vs. native), as well as the interaction between them (substrates * type of planting). The structure of the random effects of these models was nested (1/municipality/period). After that, paired comparisons were made between the different types of substrates and the types of açaí planting. For this, the 'emmeans' function was used, adjusting the p values using the False Discovery Rate (FDR) method, present in the emmeans package

(Lenth et. Al., 2018).

Results.

In total, 2,069 mites belonging to 28 families and 87 species/morphospecies were sampled (Table 1). The most representative families were Phytoseiidae (32.4%), Phytoptidae (13%), Cunaxidae (7.7%), Tetranychidae (5.6%) and Tydeidae (4.9%). According to our richness estimates, the quantity of mites sampled throughout this study was satisfactory, considering that the estimated richness was 96 ± 6 s.e.. Thus, the richness found in this work indicates that few species were no longer collected. Environmental variability (temperature and relative humidity) between municipalities and collection periods with the respective quantity of mites collected (Figure 2). The most abundant species were *Amblyseius* sp.1, *A. amazoniensis, Acaphyllisa* sp., *Davisella* sp., *I. zuluagai, R. johnstoni, S. tomentosus.*

Mite abundance and diversity. The data indicate that more mites were sampled in the rainy period (n = 1,176) than in the dry period (n = 893), or around 32% more mites in the rainiest and most humid period than in the hottest period (Figure 3A, Table 1). Despite a greater abundance of mites in the rainy season, greater richness was observed in the dry season with 73 species, while in the rainy season there were 65, that is, in the dry season 12.3% more species/morphospecies were sampled than in the rainy season. (Figure 3B). Due to the abundance of mites collected throughout this study in açaí crops, it was observed that both periods, the richness was similar between them and, possibly, there was a very efficient and satisfactory sampling of the diversity of mites in açaí crops (Figure 3B).

Regarding the Hill diversity profile, the dry period was more diverse, presenting higher values along the entire x axis for the Hill diversity order parameters (Figure 3C). However, the pattern of Hill's diversity profile was similar between both periods. This suggests that although the mite community in açaí crops is more diverse in the dry season, the rainy season was not far behind. This highlights similar dynamics between both mite communities, whether when less abundant (rare) species are more important for this estimate, when the scale moves to the left, that is, when more abundant taxa gain greater relevance moving towards the right. of the scale on the x-axis.

The ordination of the mite community composition in relation to the period showed a satisfactory NMDS fit (stress = 0.10, non-metric fit [R2] = 0.98). PERMANOVA analysis indicated a significant difference in the structure of the mite community between the dry and rainy periods (F(1, 72) = 3.85, R2 = 0.05, P = 0.01. Figure 3D). Despite the statistical significance, the coefficient of determination (R2) was quite low, requiring caution when interpreting the proportion of variability explained by the NMDS. No statistical difference was observed in the homogeneity of dispersion between these groups (F (1,71) = 0.94, P = 0.32), indicating that the PERMANOVA result was not influenced by variability within the groups.

Out of a total of 87 acarine species, 11 of them played a significant role in the NMDS ordination (Table 2. Figure 3D), highlighting the importance of these species/morphospecies. Regarding the four ecological factors, it was observed that three of them had a significant contribution to this ordering (Figure 3D). Thus, temperature (R2 = 0.24, P = 0.001), relative humidity (R2 = 0.11, P = 0.015) and atmospheric pressure (R2 = 0.11, P = 0.008) were relevant in determining the community structure according to the NMDS.

Mite abundance and diversity. The data indicate that in Bragança there was greater abundance (n = 1,407), while Augusto Corrêa contributed a total of 662 individuals (Figure 4A). Bragança recorded more than twice the acarine abundance than Augusto Corrêa, making a percentage 112, 39% higher. Similarly, Bragança presented a greater richness, totaling 78 species, while Augusto Corrêa presented 48 species (Figure 4B). This represents a percentage difference of 62.5% more mite species in Bragança. The rarefaction curve shows that a slightly greater sampling effort in Bragança could collect some more species, not collected in this study, while the Augusto Corrêa rarefaction curve practically achieved a satisfactory sampling despite having collected fewer individuals and presenting lower richness. (Figure 4B).

Hill's diversity profile indicates antagonistic situations when rare species/morphospecies or abundant species/morphospecies are considered. For example, when rare species are more important for this estimate, Bragança presents greater diversity in the mite community, indicating that the greater number of individuals collected in this location may have contributed to increasing the structural complexity of the community, contributing species/morphospecies that would be difficult to collect. with a smaller number of individuals (Figure 4C). However, when observing the Shannon-Wiener index (exponential of entropy) represented by the number one, on the x axis, both municipalities present a very similar diversity to each other. From this point, towards the right of the graph, when more abundant species/taxa are more relevant, the acarine community of Augusto Corrêa becomes more diverse than that of Bragança. Therefore, unlike the diversity profile between periods (dry vs. rainy), where the difference in diversity was less pronounced, in the case of municipalities, the differences were marked to the point where the diversity of the mite community changed. Thus, when more abundant species/morphospecies have greater weight in the analysis of Hill's diversity profile, municipalities assume an opposite role than when rare species are considered.

The ordination of the mite community composition in relation to the municipality also presented a satisfactory fit in the NMDS (stress = 0.10, non-metric adjustment [R2] = 0.98). PERMANOVA analysis revealed significant differences in the structure of the mite community between Augusto Corrêa and Bragança (F(1, 72) = 3.86, R2 = 0.05, P = 0.01. Figure 4D). Again, the coefficient of determination (R2) was quite low, indicating that the variability explained by the NMDS in comparison with the analysis between periods must be analyzed with caution since other factors, not analyzed in this work, may help to explain the difference in mite community between the two municipalities. No statistically significant differences were found in dispersion homogeneity within groups (F (1,71) = 3.55, P = 0.053). Therefore, the results indicate that PERMANOVA was not affected by intra-group variability.

Analyzing the 87 species/morphospecies, we observed that 13 of them played a significant role in the ordination of the NMDS (Table 3. Figure 4D). When we consider ecological factors, again, temperature (R2 = 0.24, P = 0.001), relative humidity (R2 = 0.11, P = 0.009) and atmospheric pressure (R2 = 0.11, P = 0.009) showed significance for this analysis.

Abundance and diversity by cultivation. The results demonstrate that cultivated açaí palm trees had a greater number of mites (n = 1,316) than native ones (n = 753) (Figure 5A, Table 1). Therefore, the cultivated açaí trees analyzed in this study had a 74.7% higher percentage of mites than those of native ones. However, native plantations showed slightly greater richness (n = 70, or 6%) than those cultivated (n = 66). In the case of the rarefaction curve, the data indicate that, although there is a need for a relatively small sampling effort for native açaí plantations and a slightly larger one for cultivated ones, in relation to the abundance of mites to be collected (Figure 5B). It also suggests that wealth will not increase drastically, suggesting that the sampling effort for this work was sufficient.

Contrary to Hill's diversity profiles presented previously, this one related to the type of açaí planting (cultivated vs. native) suggests that the most discordant diversity parameter was species/morphospecies richness (parameter zero on the x-axis) (Figure 5C). Therefore, we can assume that both mite communities behave practically the same in both types of plantations, remembering, however, that in cultivated plantations the mite abundance was much greater (74.7%) than in native ones.

The ordination of the mite community composition in relation to the type of açaí cultivation presented a satisfactory fit in the NMDS (stress = 0.10, non-metric adjustment [R2]

= 0.98). PERMANOVA analysis revealed significant differences in mite community structure between cultivated and native plantings (F (1, 72) = 2.89, R2 = 0.03, P = 0.01. Figure 5D). Here, the coefficient of determination (R2) was slightly lower, indicating again that the variability explained by the NMDS, together with the analyzes between periods and municipalities, must be analyzed with caution as other factors, not analyzed in this work, can help to explain the difference in the mite community between the two types of açaí planting. Statistically significant differences were found in dispersion homogeneity within groups (F (1,71) = 4.15, P = 0.037) suggesting that PERMANOVA may have been affected more by variability within groups than between the two crop types of açaí.

Analyzing the 87 taxa, we observed that 14 of them played a significant role in the ordination of the NMDS (Table 4. Figure 5D). When we consider ecological factors, again, temperature (R2 = 0.28, P = 0.002), relative humidity (R2 = 0.11, P = 0.009) and atmospheric pressure (R2 = 0.11, P = 0.007) showed significance.

Distribution in the plant. There was a difference in the number of mites collected between the different types of açaí planting (Table 5. Figure 6). Furthermore, our data indicate that there is a significant difference in the number of mites collected on the different açaí substrates (Table 6. Figure 7). The observed difference was detected between the basal substrates of cultivated açaí palms (higher quantity) and the apical substrate and native fruit (lower quantity). There was also a difference between the median substrate of cultivated açaí trees (larger quantity) with the same apical substrate and the fruit of native açaí trees (smaller quantity) and, finally, the median substrate (more mites) with the fruit of native açaí trees (less mites) (Figure 7). However, there was no significant interaction between the types of plantations (Table 6).

Discussion.

This is the first study carried out in the Bragantina microregion of Northeast Pará, reporting the fauna and diversity of mites in açaí palm trees in native and cultivated areas, in two municipalities in the state of Pará. To date, little is known about the distribution, dynamics and effects of predatory and phytophagous mites in cultivated açaí crops and in natural environments. It is known that the quality and production of açaí can be impacted by the presence of phytophagous mites.

The majority of species and specimens collected belonged to the families Phytoseiidae, Phytoptidae, Cunaxidae, Tetranychidae and Tydeidae. Phytoseiid mites present variations in lifestyle, with specialization in the use of food sources, and mites of the genera *Amblyseius* and T*yphlodromus* are commonly reported as predators of tetranychid mites (McMurtry & Croft, 1997). Species of both genera were identified in the present study. *Amblyseius* sp. 1 was the most abundant species in natural systems and in the rainy season, followed by *Amblyseius* sp. 3 and sp. 2. These mites are predominant in the North region, where environmental factors such as temperature and relative humidity interfere with the structure of the mite community, as their occurrence was greater during the period of greater precipitation. In previous studies carried out on *Elaeis guineensis* Jacq. (Arecaceae), in the state of Amazonas, during the rainy season, mites of the genus *Amblyseius* were reported in greater abundance during the period (Cruz et al., 2019). These results also confirm those found in coconut trees on the coast of Bahia (Lawson-Balagbo et al., 2008). The genus *Amblyseius* houses a great diversity of species that are natural enemies of several organisms (Amaral, 2017). The cunaxid mites *S. tomentosus* and *A. amazoniensis* were also common. In areas with cultivated systems and during the dry period, *Amblyseius* sp. 2, *Amblyseius* sp.3 and *I. zuluagai* were the most abundant species. The latter species has also been reported in Bahia in *Cocos nucifera* L., *E. oleracea* and *E. guineensis* (Arecaceae) (Souza et al., 2015).

Among the phytophagous mites, mites from the families Phytoptidae, Tetranychidae, Tenuipalpidae and Eriophyidae stood out. Thus, as in other studies, phytophagous mites were found in a group of Arecaceae plants in Brazil, the most diverse of which have been representatives of the superfamily Eriophyoidea (Flechtmann 1994, 1998; Flechtmann & Santana, 1997; Santana & Flechtmann, 1998; Santana et al., 1994; Gondim Jr. 2000; Rodrigues et al., 2016). Tetranychidae are strictly phytophagous and have great potential to reduce the production of economically important crops, mainly due to their high reproductive potential (Rodrigues et al., 2016).

Among the phytophagous mites identified in açaí palm trees, the following stood out: *T. ornata*, *B. yothersi*, *Brevipalpus* sp.1, *Brevipalpus* sp.2, *Ceratarsonemus* sp., *Tarsonemus* sp.2, *Xenotarsonemus* sp.1, *Xenotarsonemus* sp.2 and *Xenotarsonemus* sp.3. Specimens of *T. ornata* were lodged in the cracks of açaí fruits. The Tenuipalpidae were in the fruit stalk and continued to be present in many fallen fruits. Mites from the families Bdellidae, Eupodidae, Phytoseiidae, Stigmaeidae and Tydeidae were also collected from the fruits.

The greatest richness was observed in the dry period with 73 species, while in the rainy period it was 65 species. In relation to the types of açaí cultivation, the highest number of mites was found in the basal part of the leaflets in cultivated açaí, while in native açaí groves the highest average number of mites found was in the middle part of the leaflets. As for diversity, the dry period was more diverse compared to the rainy period. The greatest abundance of Phytoseiidae mites was found in the dry period. Thus, as in a similar survey in the state of Pará reported by De Alfaia et al. (2023), which shows a positive association between Phytoseiidae and temperature, as higher temperatures increase the prevalence of these mites.

The municipality of Bragança presented greater richness, with 62.5% more species than Augusto Corrêa. Cultivated açaí palm trees also had a greater abundance, 74.7% greater than in native ones. However, native açaí trees presented a greater species/taxa richness (6%) than those cultivated. In this way, biological control can occur naturally in this type of system because it is more diverse, as already reported in some studies (e.g. McMurtry & Croft, 1997; Easterbrook et al. 2001; Wright & Chambers, 1994), where the predatory mites, as they have high potential as biological control agents, can be used as part of an integrated pest management program (IPM). Knowing the diversity of mites in açaí palm trees, especially in natural environments and in planted areas, is fundamental for integrated pest management and could contribute to supporting future research into the control of organisms with the potential to cause damage to this crop. Therefore, it is essential to know and prevent outbreaks of these organisms that can cause damage and protect the crop from possible damage.

Acknowledgements

To the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support and to the Federal Institute of Education, Science and Technology of Pará - IFPA for logistical support.

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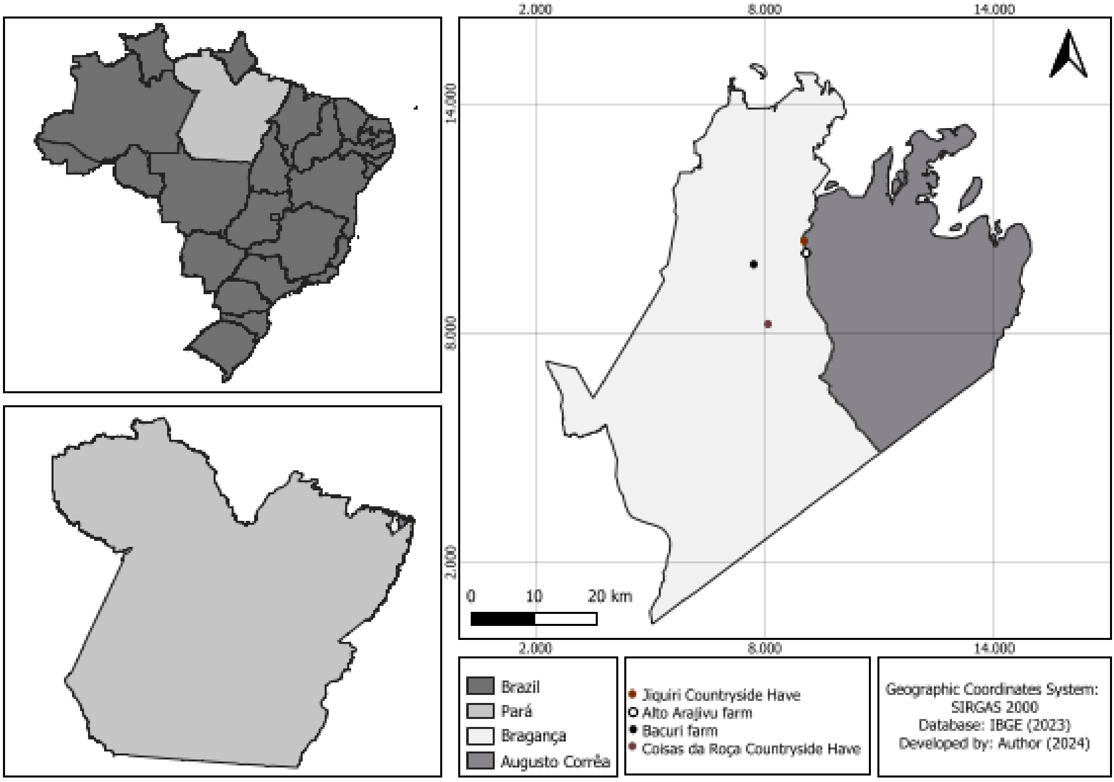

FIGURE 1: Location of açaí tree crops evaluated in the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará, Pará, Brazil.

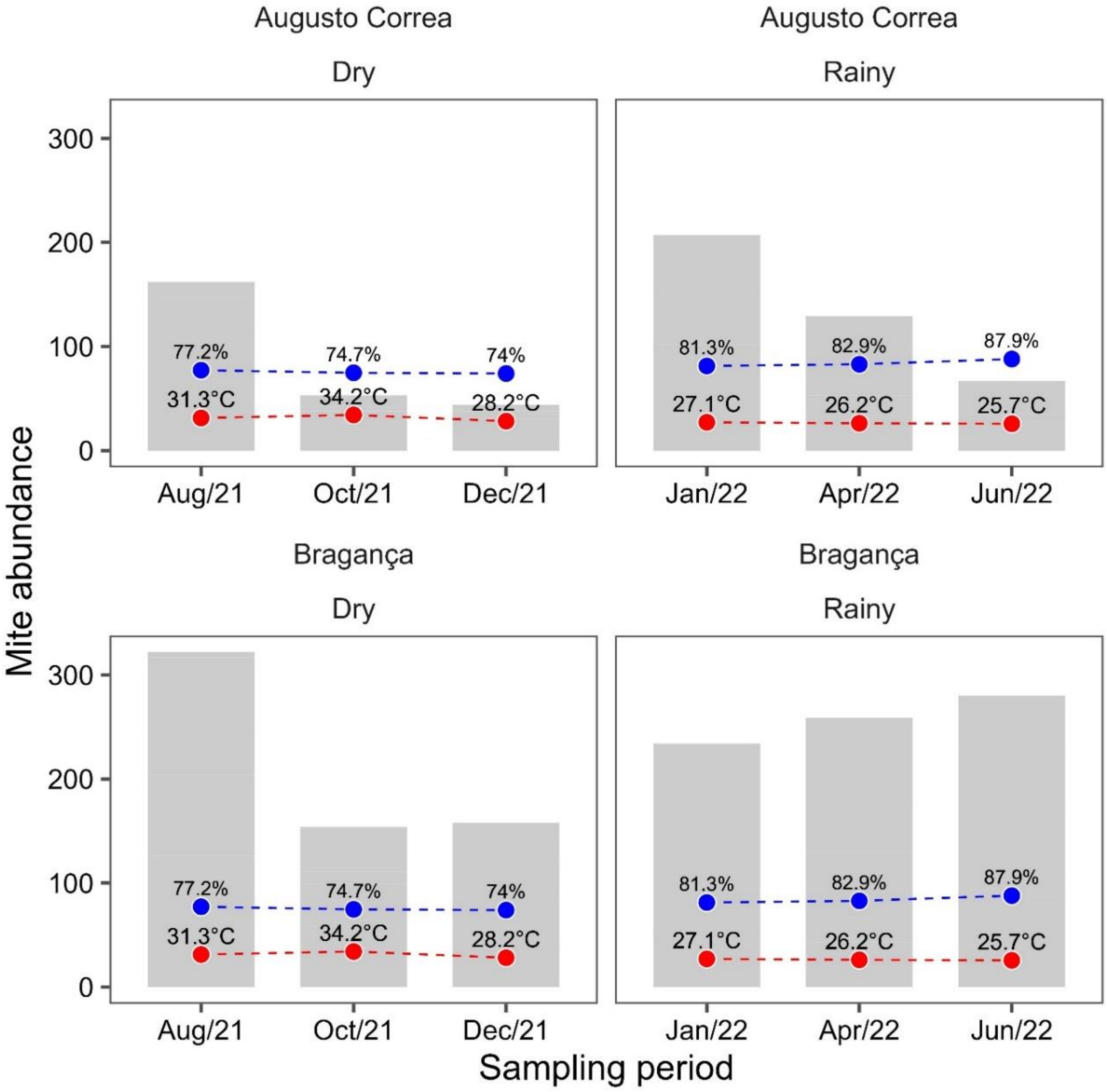

FIGURE 2. Total amount of mites collected per period by municipality.

Table 1. Acarofauna collected in the Açaí culture during the Dry and Rainy periods, in the municipalities of Augusto Corrêa and Bragança, state of Pará, Brazil. (N - total number of mites sampled).

		Augusto Corrêa				**Bragança**				**N**	**%**
	Species/morphospecies	Dry		Rainy		Dry		Rainy			
Families (N)		Cultivated	Native	Cultivated	Native	Cultivated	Native	Cultivated	Native		-
Acaridae (88)	Immature	0	0	0	0	0	0	1	1	**2**	0.1
	Rechiacarus sp.	59	0	0	0	2	0	22	0	**83**	4.0
	Tyrophagus putrescentiae	0	0	0	0	0	3	0	0	**3**	0.1
Ameroseiidae (1)	*Ameroseius* sp.	0	0	1	0	0	0	0	0	**1**	0.0
Ascidae (18)	*Asca* sp.1	0	0	0	0	1	1	0	1	**3**	0.14
	Asca sp.3	0	0	0	0	1	0	0	8	**9**	0.4
	Immature	0	0	0	0	0	3	2	1	**6**	0.3
Bdellidae (33)	*Bdella ueckermanni*	1	0	16	0	8	0	0	0	**25**	1.2
	Hexabdella sp. 2	0	0	0	0	5	2	0	0	**7**	0.3
	Trachymolgus sp.	0	0	0	0	0	1	0	0	**1**	0.0
Caligonellidae (5)	*Neognatus* sp.	0	0	2	0	3	0	0	0	**5**	0.2
Cheyletidae (20)	*Cheletomimus* (*H.*) *bakeri*	0	0	2	0	0	0	0	2	**4**	0.2
	Cheletomimus (*H.*) *darwin*	0	7	0	0	0	4	0	1	**12**	0.6
	Cheletomimus (*H.*) *duosetosus*	0	0	0	0	0	1	0	2	**3**	0.1
	Cheletomimus (*H.*) *wellsi*	0	0	0	0	1	0	0	0	**1**	0.0
Cunaxidae (159)	*Armascirus amazoniensis*	3	1	0	0	2	2	26	28	**62**	3.0
	Cunaxatricha n. sp.	0	0	0	0	3	2	0	0	**5**	0.2
	Neobonzia sp.	0	0	0	0	2	2	0	0	**4**	0.2
	Neocunaxoides ovatus	0	0	0	0	2	2	6	10	**20**	1.0
	Scutopalus tomentosus	0	0	0	0	10	9	32	17	**68**	3.3
Diptilomiopidae (62)	*Davisella* sp.	0	0	14	0	0	0	35	13	**62**	3.0
Eriophyidae (81)	*Acaphyllisa* sp.	0	0	42	0	2	0	10	27	**81**	3.9
Erythraeidae (1)	Immature	0	0	0	0	0	0	0	1	**1**	0.0
Eupalopsellidae (5)	*Eupalopsellus* sp.	0	0	1	0	1	1	1	1	**5**	0.2
Eupodidae (27)	*N. genus*	0	0	0	0	9	1	8	9	**27**	1.3
Glycyphagidae (16)	*Lepidoglyphus* sp.	0	0	5	0	0	3	2	6	**16**	0.8
Iolinidae (67)	*Paraproneinatus* sp.	15	0	2	0	6	5	2	1	**31**	1.5

	Pseudopronematus sp.	0	7	3	0	0	0	22	4	**36**	1.7
Laelapidae (5)	*Pseudoparasitus* sp.	0	0	0	0	0	0	1	1	**2**	0.1
	Immature	0	0	0	0	2	0	0	1	**3**	0.1
Ologamasidae (5)	Ologamasidae | Immature	0	0	0	0	2	0	0	3	**5**	0.2
Oribatida (99)	Oribatida	7	4	1	0	81	0	2	4	**99**	4.8
Parholaspididae (1)	Immature	0	0	0	0	0	0	1	0	**1**	0.0
Phytoptidae (268)	*Retracus johnstoni*	0	0	150	0	3	3	82	30	**268**	13.0
Phytoseiidae (677)	*Amazoniaseius imparisetosus*	0	0	0	0	0	2	0	3	**5**	0.2
	Amblydromalus sp.	0	0	0	0	0	0	0	1	**1**	0.0
	Amblydromalus itacoatiarensis	24	2	0	0	7	0	3	15	**51**	2.5
	Amblyseius n. sp.1	0	6	0	0	9	18	15	99	**147**	7.1
	Amblyseius n. sp.2	11	4	9	0	22	15	7	8	**76**	3.7
	Amblyseius n. sp.3	0	14	0	0	30	58	0	34	**136**	6.6
	Amblyseius n. sp.6	0	0	0	0	1	12	0	9	**22**	1.1
	Amblyseius largoensis	0	0	11	0	0	1	0	0	**12**	0.6
	Amblyseius tamatavensis	0	0	0	0	1	0	0	0	**1**	0.0
	Euseius alatus	0	1	0	0	0	0	0	0	**1**	0.0
	Euseius inouei	1	0	0	0	0	2	1	0	**4**	0.2
	Iphiseiodes quadripilis	0	0	0	0	0	2	0	0	**2**	0.1
	Iphiseiodes zuluagai	1	5	1	0	42	8	0	0	**57**	2.8
	Leonseius regularis	0	1	0	0	0	13	1	0	**15**	0.7
	Metaseiulus (*M.*) *ferlai*	0	0	0	0	0	1	0	0	**1**	0.0
	n. genus sp.1	0	0	0	0	0	1	0	2	**3**	0.1
	Paraphytoseius orientalis	0	0	0	0	0	1	0	0	**1**	0.0
	Phytoscutus sexpilis	1	0	0	0	0	0	0	0	**1**	0.0
	Proprioseiopsis neotropicus	0	2	0	0	0	0	1	2	**5**	0.2
	Typhlodromips n. sp.	0	0	0	0	0	1	0	2	**3**	0.1
	Typhlodromips mangleae	21	1	0	0	8	0	0	6	**36**	1.7
	Typhlodromus (*T*) n. sp.	0	0	0	0	8	1	0	0	**9**	0.4
	Immature	0	0	0	0	19	17	19	33	**88**	4.3
Stigmaeidae (17)	*Agistemus brasiliensis*	1	0	4	0	1	0	0	1	**7**	0.3
	Agistemus n. sp.1	0	1	0	0	0	4	0	0	**5**	0.2
	Zetzellia quasagistemas	0	0	0	0	0	1	0	0	**1**	0.0
	Immature	0	0	1	0	0	0	2	1	**4**	0.2

Tarsonemidae (15)	*Ceratarsonemus* sp.	0	0	0	0	0	1	0	3	**4**	0.2
	Tarsonemus sp.2	1	0	0	0	0	0	0	0	**1**	0.0
	Xenotarsonemus sp.1	0	0	0	0	0	0	0	1	**1**	0.0
	Xenotarsonemus sp.2	0	0	0	0	0	0	0	3	**3**	0.1
	Xenotarsonemus sp.3	0	0	3	0	0	0	0	3	**6**	0.3
Tenuipalpidae (90)	*Brevipalpus yothersi*	0	0	37	0	0	0	0	0	**37**	1.8
	Brevipalpus sp.1	2	1	12	0	0	0	0	0	**15**	0.7
	Tenuipalpus sp.1	0	3	0	0	0	7	0	0	**10**	0.5
	Immature	0	0	26	0	0	2	0	0	**28**	1.4
Tetranychidae (115)	*Oligonychus* sp.	3	1	0	0	54	9	0	15	**82**	4.0
	Tetranychus urticae	12	0	0	0	2	0	0	1	**15**	0.7
	Tetranychus aff. *palmarum*	5	1	0	0	11	0	1	0	**18**	0.9
Triophtydeidae (42)	*Triophtydeus lebruni*	10	0	2	0	0	0	2	17	**31**	1.5
	Triophtydeus sp.	5	0	0	0	1	0	1	0	**7**	0.3
	Triophtydeidae | Immature	2	0	2	0	0	0	0	0	**4**	0.2
Tuckerellidae (47)	*Tuckerella ornata*	0	0	18	0	15	0	0	14	**47**	2.3
Tydeidae (101)	*Brachytydeus formosa*	1	0	38	0	0	1	0	1	**41**	2.0
	Pretydeus sp.1	0	1	0	0	0	1	0	2	**4**	0.2
	Pretydeus sp.2	0	0	0	0	0	0	0	2	**2**	0.1
	Pseudolorryia sp.1	1	0	0	0	0	1	0	14	**16**	0.8
	Pseudolorryia sp.2	0	0	0	0	10	0	0	0	**10**	0.5
	Tydeus sp.1	5	0	0	0	1	0	0	1	**7**	0.3
	Tydeus sp.2	0	0	0	0	7	0	0	0	**7**	0.3
	Immature	0	0	0	0	14	0	0	0	**14**	0.7
Winterschmidtiidae (4)	*Oulenziella* sp.	3	0	0	0	0	0	0	0	**3**	0.1
	Immature	1	0	0	0	0	0	0	0	**1**	0.0

	Augusto Corrêa				**Bragança**			
	Dry		Rainy		Dry		Rainy	
	Cultivated	Native	Cultivated	Native	Cultivated	Native	Cultivated	Native
Diversity								
Richness	25	19	25	0	40	42	28	50
Abundance	196	63	403	0	409	225	308	465
Dominance	0.14	0.10	0.18	0.00	0.09	0.10	0.12	0.08

Shannon-Wiener	2.47	2.55	2.27	0.00	2.93	2.95	2.52	3.10	
Uniformity	0.47	0.68	0.39	0.00	0.47	0.46	0.44	0.44	
Equitability	0.77	0.87	0.71	0.00	0.79	0.79	0.76	0.79	-

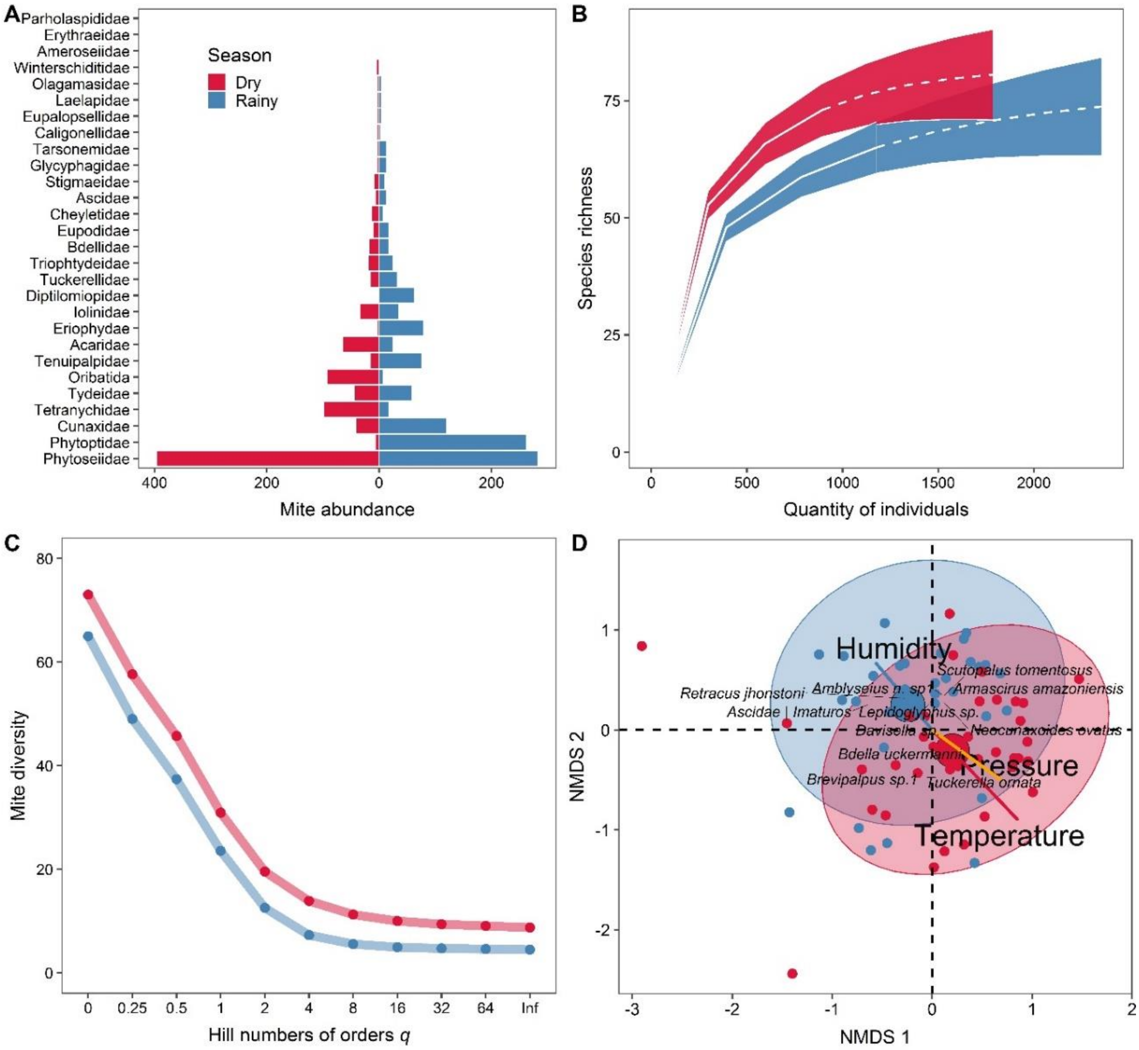

FIGURE 3. Comparative analysis of the mite community in the dry and rainy seasons: abundance, richness, diversity and community structure in the açaí palm. (A) Total number of mites sampled between the dry and rainy seasons. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute amount 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 by solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes the lato sensu diversity, 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. abundant species. 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 equitability; common species have more

weight). (D) Nonmetric multidimensional scaling (NMDS) plot differentiating the composition of the mite community. Larger points indicate group centroids and smaller points represent sampling sites. The environmental variables `temperature´ and `humidity´ contributed significantly to the pattern of this ordination. Note: the colors are according to the sampling period (red for `dry´ and blue for `rainy´).

TABLE 2. Species/taxa of mites with significant contribution to the NMDS ordination based on community structure in the Dry and Rainy periods (Figure 2D).

Espécies	**p-value**
Ascidae | Imaturos	0.01
Bdella uekermanni	0.01
Armascirus amazoniensis	0.01
Neocunaxoides ovatus	0.03
Scutopalus tomentosus	0.03
Davisella sp.	0.03
Lepidoglyphus sp.	0.04
Retracus johnstoni	0.01
Amblyseius n. sp1	0.04
Brevipalpus sp.1	0.02
Tuckerella ornata	0.02

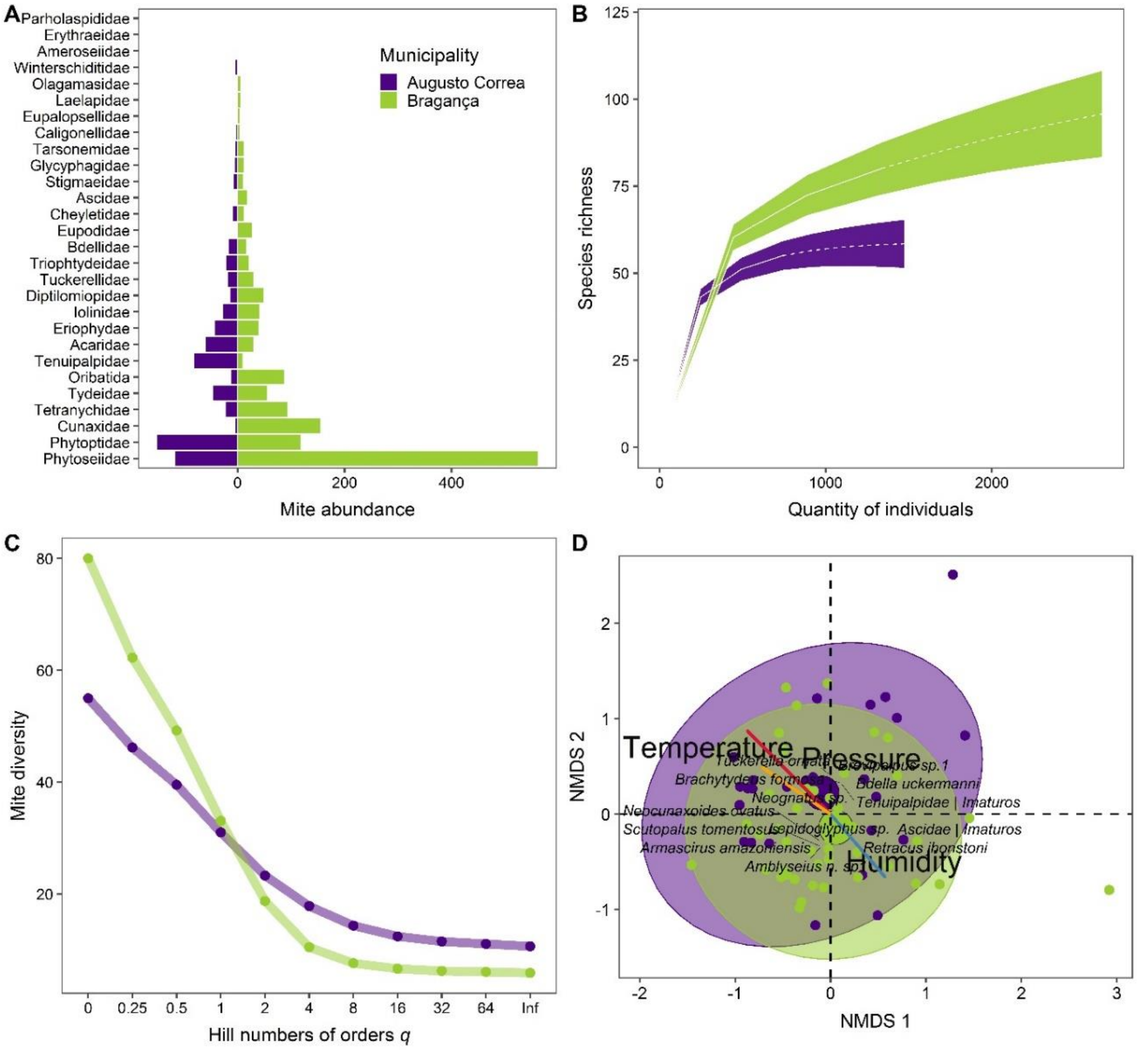

FIGURE 4. Comparative analysis of the mite community in the municipalities of Augusto Correa and Bragança, Pará, Brazil: abundance, richness, diversity, and structure. (A) Total number of mites sampled between the municipalities of Augusto Correa vs. Bragança, Pará, Brazil. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute amount collected per period. The left side of the pyramid represents the municipality of Augusto Correa and the right side represents the municipality of Bragança. (B) Species rarefaction curves with 95% confidence intervals. Observed values of species richness are shown by solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes the lato sensu diversity, 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. abundant species. 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, species

abundance has more weight (greater equability; common species have more weight). (D) Nonmetric multidimensional scaling (NMDS) plot differentiating the composition of the mite community. Larger points indicate group centroids and smaller points represent sampling sites. The environmental variables `temperature´ and `humidity´ contributed significantly to the pattern of this ordination. Note: the colors are in accordance with the sampling period, being purple for `Augusto Correa´ and green for `Bragança´).

TABLE 3. Species/taxa of mites with significant contribution to the NMDS ordination based on community structure in Augusto Corrêa and Bragança (Figure 4D).

Espécies	**p-value**
Ascidae | Imaturos	0.01
Bdella uekermanni	0.02
Neognatus sp.	0.04
Armascirus amazoniensis	0.03
Neocunaxoides ovatus	0.03
Scutopalus tomentosus	0.02
Lepidoglyphus sp.	0.03
Retracus johnstoni	0.02
Amblyseius n. sp1	0.03
Brevipalpus sp.1	0.01
Tenuipalpidae | Imaturos	0.02
Tuckerella ornata	0.02
Brachytydeus formosa	0.03

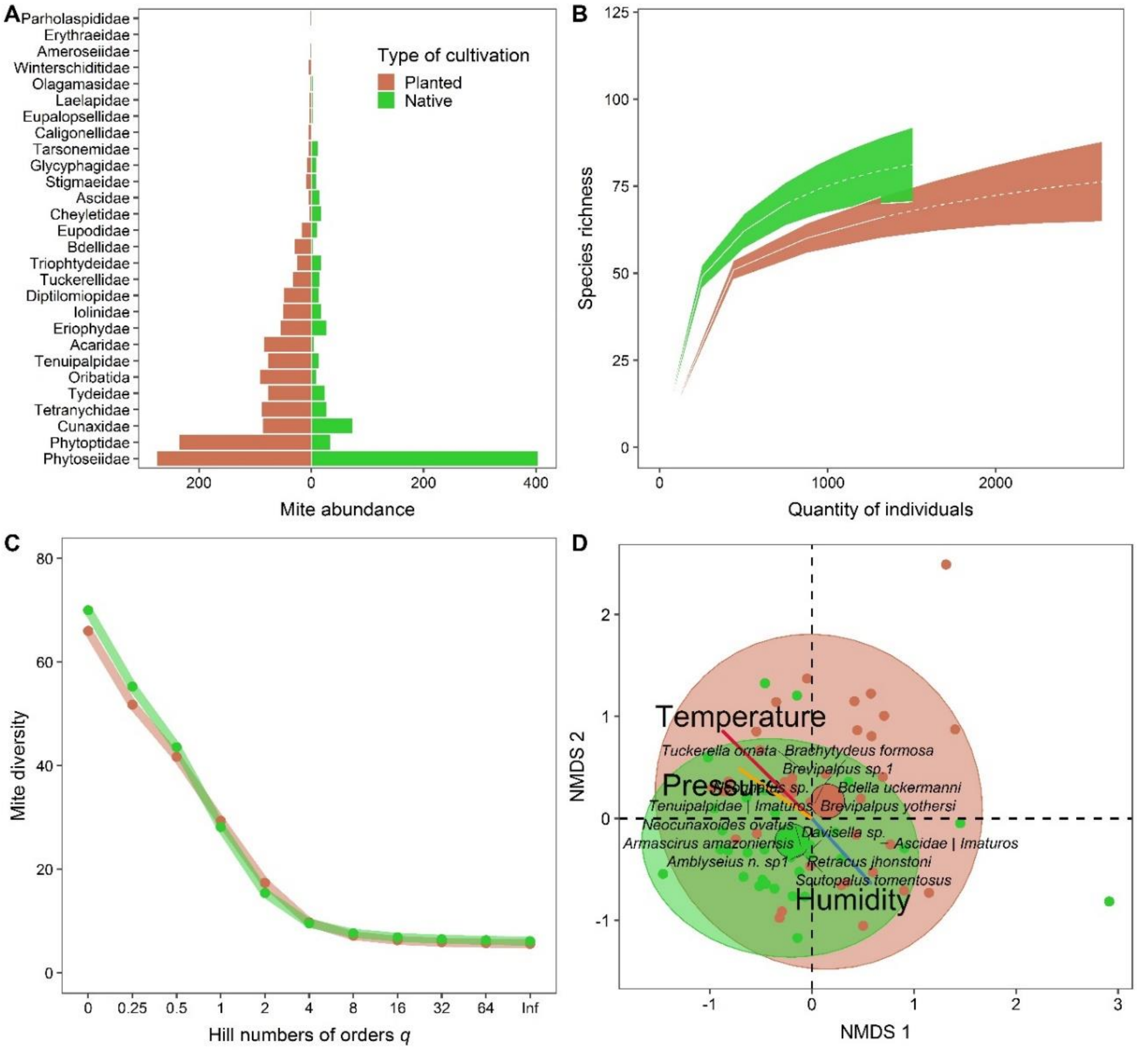

FIGURE 5. Comparative analysis of the mite community in cultivated and native açaí plantations, Pará, Brazil: abundance, richness, diversity, and structure. (A) Total number of mites sampled between crop types. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute amount collected by crop type. The left side of the pyramid represents cultivated plantations and the right side represents native plantations. (B) Species rarefaction curves with 95% confidence intervals. Observed values of species richness are shown by solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes the lato sensu diversity, 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. abundant species. 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 equitability; common species have more

weight). (D) Nonmetric multidimensional scaling (NMDS) plot differentiating the composition of the mite community. Larger points indicate group centroids and smaller points represent sampling sites. The environmental variables `temperature´ and `humidity´ contributed significantly to the pattern of this ordination. Note: the colors are in accordance with the sampling period (light brown for `cultivated açaí´ and green for `native açaí´).

TABLE 4. Species/taxa of mites with significant contribution to the NMDS ordination based on community structure in Augusto Corrêa and Bragança (Figure 5D).

Espécies	p-value
Ascidae | Imaturos	0.01
Bdella uekermanni	0.01
Neognatus sp.	0.02
Armascirus amazoniensis	0.01
Neocunaxoides ovatus	0.02
Scutopalus tomentosus	0.01
Davisella sp.	0.02
Retracus johnstoni	0.02
Amblyseius n. sp1	0.01
Brevipalpus yothersi	0.03
Brevipalpus sp.1	0.03
Tenuipalpidae | Imaturos	0.04
Tuckerella ornata	0.01
Brachytydeus formosa	0.04

TABLE 5. Results of the generalized linear mixed model (negative binomial) comparing the number of mites found on açaí trees.

Tipo de plantio	Substrato	Média	Desvio-padrão
Cultivado	Basal	40	14
Nativo	Basal	27	18
Cultivado	Mediana	37	20
Nativo	Mediana	34	25
Cultivado	Apical	26	19
Nativo	Apical	17	19

Cultivado	Fruto	23	19
Nativo	Fruto	13	13

TABLE 6. Results of the generalized linear mixed model (negative binomial) comparing the number of mites found in açaí trees.

Efeitos fixos	**X^2**	**G.L.**	**p-valor**
Tipo de plantio	4.72	1	0.029*
Substrato	17.3	3	< 0.001***
Substrato: Tipo de plantio	1.03	3	0.791

Efeitos aleatórios	**Variância**	**D.P.**
Município	0.000	0.000
Período	0.271	0.521

Seleção de modelos	**AICc^1**	**dAICc^2**	**G.L^3**	**Peso^4**
GLMM negativa binomial (modelo escolhido)	633.4.	0.0	11	1
GLMM Poisson	1102.2	468.8	10	< 0.001

G.L.: Graus de liberdade; p-valor: Probabilidade de encontrar valores de z ao acaso. ^{1} – Estimativa do AIC; ^{2} – Diferenças entre os AICs; ^{3} – Graus de liberdade; ^{4} - Peso dos AICs

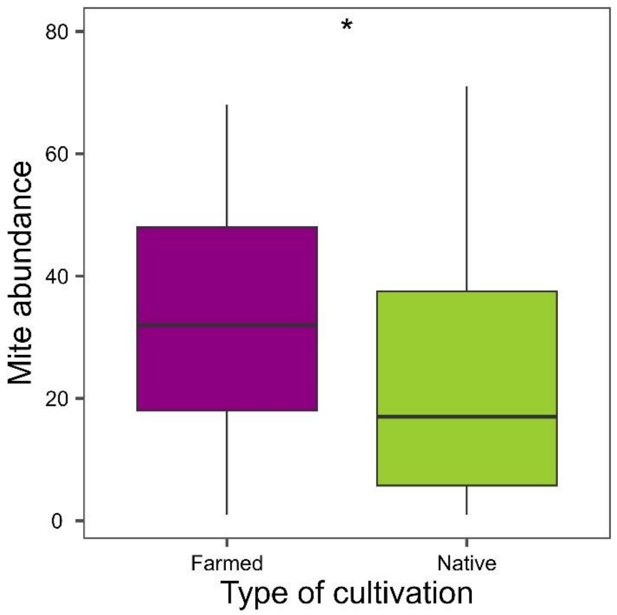

FIGURE 6. Comparison of the number of mites collected on cultivated and native açaí plants. Notes: asterisk indicates significant difference (< 0.05).

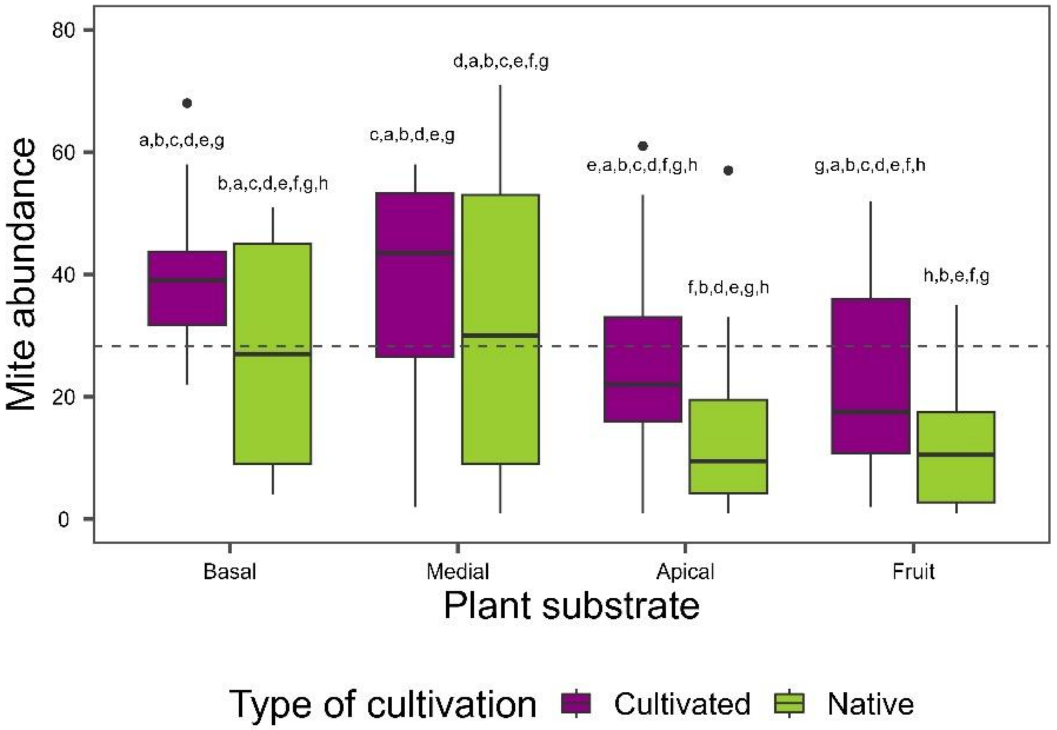

FIGURE 7. Comparative analysis of the quantity of mites collected according to the plant substrate of cultivated and native açaí plants. Notes: dashed line indicates the general mean of mites; the letters above the boxplots indicate significant difference when they are different between them and non-significant difference when they are the same between them (repeated).

4 CAPÍTULO 3 - BIOECOLOGY OF MITES ASSOCIATED WITH COCOA TREES (*THEOBROMA CACAO*: MALVACEAE) IN THE BRAGANTINA MICROREGION OF THE STATE OF PARÁ, EASTERN AMAZON, BRAZIL

Artigo aceito para publicação: 06/11/2024

Revista: Systematic and Applied Acarology

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, Brasil, 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.nov 1 (12.1%) and *Parapronematus* sp. (10.5%). Among the predatory mites, the phytoseiid mites were more abundant and prevalent, with *Amblyseius* sp. nov 1 and family Cunaxidae *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 Brazilian, 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* (Nuzzaci) (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 study aimed 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 municipality 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 municipality Augusto Corrêa, state of Pará, Brazil (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.

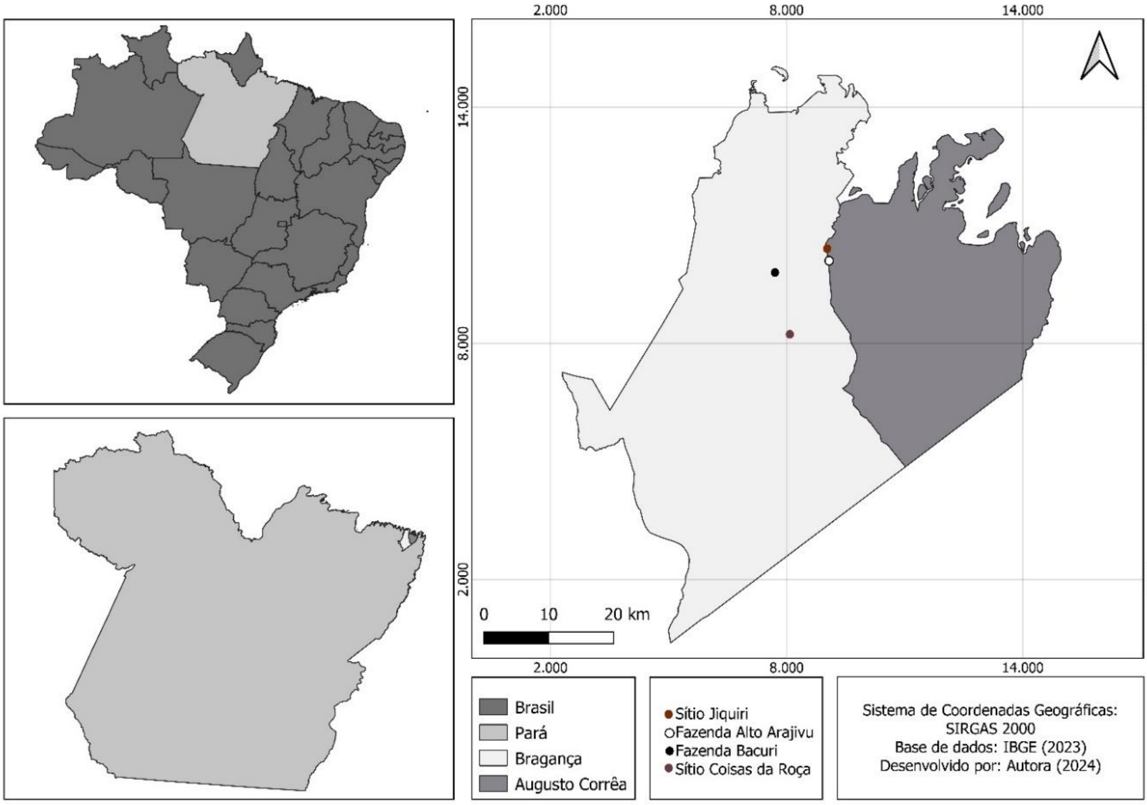

Figure 1: Location of cocoa crops assessed in the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará, Pará, Brazil.

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 a phase 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 & 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).

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 values after 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 takes into account 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 of diversity, 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 ordering was 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 the average 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. unknown feed behaviour tradução mites were rare with low abundant. The most abundant species were *Oligonychus* sp. (13.9%), *T. ornata* (12.2%), *Amblyseius* sp. nov 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.

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 G - Generalist.

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* (G)	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
Blattisocidae (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)	*Homopronematus* 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
	Pronematus 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.6 (P)	0	0	0	0	0	0	1	0	**1**	0.1
	Amblyseius n. sp.7 (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
	Paraamblyseius multicircularis (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 (G)	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 (G)	2	0	0	0	1	0	0	0	**3**	0.3
Tuckerellidae (152)	*Tuckerella knorri* (G)	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 (G)	0	0	0	0	1	0	0	0	**1**	0.1
	Brachytydeus sp.2 (G)	5	0	4	0	2	0	0	0	**11**	0.9
	Paralorryia sp.1 (G)	1	0	0	0	1	0	0	0	**2**	0.2
	Paralorryia sp.2 (G)	0	0	0	0	3	0	0	0	**3**	0.3
	Pretydeus n. sp. (G)	0	0	0	0	4	0	0	0	**4**	0.3

Winterschmidtiidae (3)	*Czenspinskia* sp. (G)	0	0	0	0	2	0	0	0	**2**	0.2
	Neocalvolia sp. (G)	0	0	0	0	1	0	0	0	**1**	0.1
	Total	312	15	163	1	400	65	146	76	1.178	
		Augusto Corrêa				**Bragança**					
		Dry		Rainy		Dry		Rainy			
		Leaf	Fruit	Leaf	Fruit	Leaf	Fruit	Leaf	Fruit		
	Richness	37	3	19	1	51	6	26	3		
	Abundance	312	15	163	1	400	65	146	76		
	Dominance	0.16	0.66	0.16	1.00	0.10	0.72	0.23	0.79		
	Shannon-Wiener	2.64	0.63	2.31	0.00	2.99	0.64	2.09	0.41		
	Uniformity	0.38	0.62	0.53	1.00	0.39	0.32	0.31	0.50		
	Equitability	0.73	0.57	0.78	0.00	0.76	0.36	0.64	0.37		

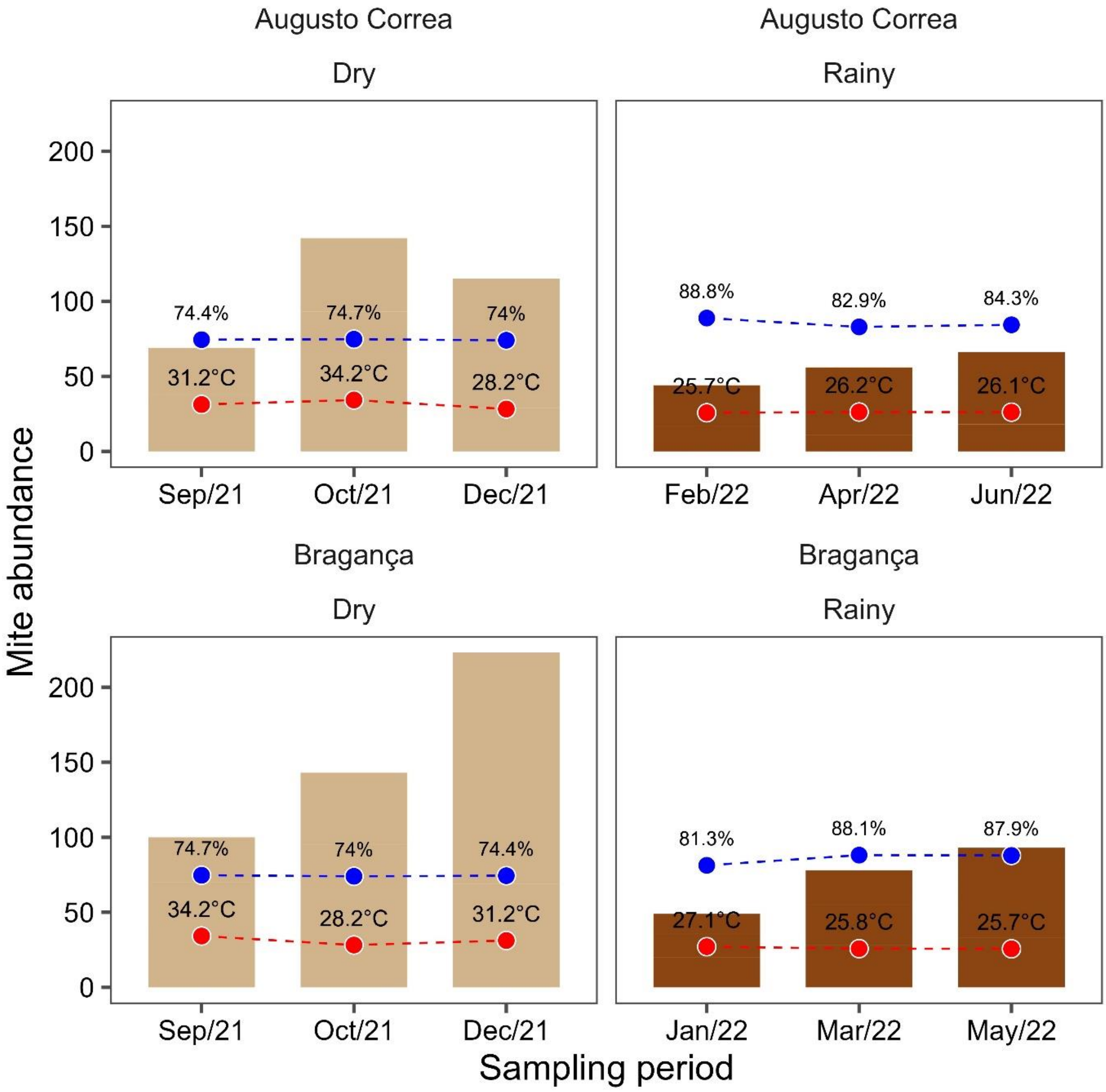

Figure 2. Mite abundance, temperature (°C) and relative air humidity (%) observed in cocoa cultivation in the dry and rainy periods in the municipalities of Bragança and Augusto Corrêa, state of Pará, Brazil.

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%).

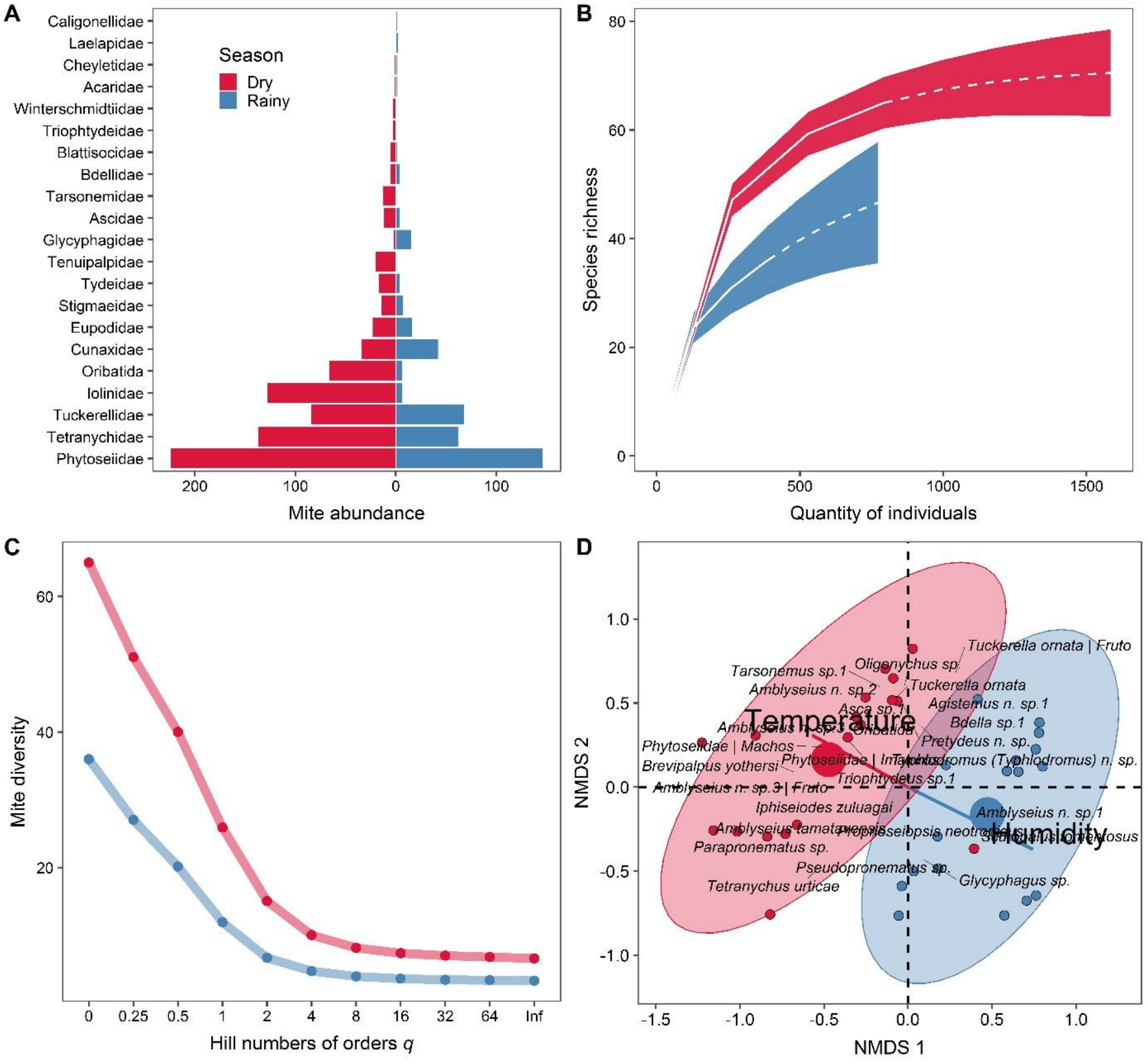

Figure 3. Comparative analysis of the mite community on cocoa trees in the dry (red color) and rainy (blue) periods: abundance, richness, diversity and community structure. (A) Total number of mites/family sampled between the dry and rainy periods. The y-axis shows the mite families, while the x-axis 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	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
Phytoseiidae | Immature	0.03

Pseudopronematus sp.	0.03

* Non-metric multidimensional scaling.

Table 3. Mite species in cocoa trees with significant contribution to the ordination by NMDS* based on community structure in the municipalities of Augusto Corrêa and Bragança, state of Pará.

Species	**p-value**
Amblyseius n. sp.1	0.01
Amblyseius n. sp.2	0.01
Amblyseius n. sp.3	0.01
Amblyseius n. sp.3 | Fruit	0.01
Amblyseius tamatavensis	0.01
Asca sp.1	0.01
Brevipalpus yothersi	0.01
Glycyphagus sp.	0.01
Iphiseiodes zuluagai	0.01
Oligonychus sp.	0.01
Parapronematus sp.	0.01
Phytoseiidae | Male	0.01
Pretydeus n. sp.	0.01
Proprioseiopsis neotropicus	0.01
Pseudopronematus sp.	0.01
Scutopalus tomentosus	0.01
Tarsonemus sp.1	0.01
Tetranychus urticae	0.01
Tuckerella ornata	0.01
Tuckerella ornata |Fruit	0.01
Triophtydeus sp.1	0.02
Bdella sp.1	0.03
Brachytydeus sp.2	0.03
Oribatida	0.03
Typhlodromus (*Typhlodromus*) n. sp.	0.03
Agistemus n. sp.1	0.04
Lasioseius sp.1	0.04

Phytoseiidae | Immature	0.04

* Non-metric multidimensional scaling.

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 axis for 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.

Table 4. Comparative analysis of mite biodiversity in the municipality of Augusto Corrêa, 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 5. 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)

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.

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 Rich Coast (OCHOA & OCONNOR, 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* sp.nov 1 showed greater abundance during the rainy season in the both municipalities evaluated. Species of this genus are predominant mites in the North region (LAWSON-BALAGBO *et al*., 2008; PEÑA *et al*., 2009; GONDIM JR. *et al*., 2012; CRUZ *et al*., 2019 e 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* 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.

Acknowledgements.

To the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support and to the Federal Institute of Education, Science and Technology of Pará - IFPA for logistical support.

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5 CAPÍTULO 4 - MITE DIVERSITY OF CUPUAÇU TREES (*THEOBROMA GRANDIFLORUM*: MALVACEAE) IN THE STATE OF PARÁ, AMAZON, BRAZIL

Artigo aceito em 05/12/2024

Revista Internacional de Acarologia

DOI:10.1080/01647954.2024.2441883

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ABSTRACT. The study aimed to understand the mite fauna associated with cupuaçu tree crops in areas in the municipalities of Bragança and Augusto Corrêa in the Bragantina microregion, state of Pará, Brazil. The influence of mites on cupuaçu production and quality is a topic of growing interest, motivated by the economic and environmental importance of this crop in the state of Pará. In order to investigate the variability and composition of these organisms in cupuaçu plantations in two different locations, systematic collections were carried out at specific periods over two years. In addition to mite collection, environmental data such as temperature, relative humidity, atmospheric pressure and precipitation were recorded. Statistical data were obtained through sampling effort and diversity, Hill diversity profile and nonmetric multidimensional scaling (NMDS) for mite communities. A total of 868 mites belonging to 53 species were sampled. Seventeen families/suborders of mites were identified, the five most abundant being: Eriophyidae (44.7%), Phytoseiidae (21.1%), Cunaxidae (9%), Oribatida (5.5%) and Tenuipalpidae (3.5%). The data indicate a greater quantity of mites sampled during the rainy season compared to the dry season, representing approximately 90% more mites in the rainy and wetter season than in the hottest season in both sampled municipalities. Greater richness was observed during the dry period, with 38 taxa identified. Bragança contributed a total of 551 individuals, while Augusto Corrêa recorded 317 mites. For the Shannon-Wiener index, the municipalities exhibited similar diversity. Therefore, we highlight the importance of these results for understanding the mite community associated with cupuassu trees.

Keywords: *Armascirus amazoniensis; Eriomacrotergum flechtmanni; Gymnaceria cupuaçu.*

INTRODUCTION. The cupuaçu plants, *Theobroma grandiflorum* (Willd. Ex Spreng.) K. Schum. (Malvaceae), is a fruit species of great importance to the Amazon region due to its value both as fresh and industrialized fruit (FALCÃO & LLERAS, 1983). Native to the Amazon region, this species is still being domesticated for large-scale cultivation (CAVALCANTE, 2010). In Brazil, its production is concentrated in the North region, in the states of Acre, Pará and Rondônia (FRAIFE FILHO et al., 2009). Cupuaçu tree planting in the state of Pará is mostly combined with other crops, making it more profitable for rural producers, especially for family farming, indigenous people and small producers (GUIMARÃES & DURIGAN, 2018). As it is an ombrophilous species, cupuaçu orchards adapt well to single crops, in temporary or permanent consortiums in different arrangements, resulting in greater efficiency in soil use, increasing the economics generated by shaded or intercropped crops. These characteristics allow this crop to be used as one of the main components of agroforestry systems in the North region (GASPAROTTO et al., 1997; CARVALHO et al., 1999).

Studies on the mite fauna associated with cupuaçu cultivation in the state of Pará are limited. However, there are already studies evaluating plant species from other botanical families in the North region, such as Arecaceae (NAVIA & FLECHTMANN, 2005; REIS *et al.*, 2012; 2014, CRUZ *et al*., 2015; 2019, DE ALFAIA *et al*., 2023; FERREIRA *et al*., 2023), Euphorbiaceae (FERES, 2001), Malpighiaceae (NORONHA *et al*., 2020), Malvaceae (FLECHTMANN, 1979; OLIVEIRA *et al*., 2012; OLIVEIRA & NAVIA, 2013; SOUSA *et al*., 2018; BRITO *et al*., 2023).

To date, few studies have been carried out evaluating the mite fauna associated with cupuaçu cultivation. There are reports of eriophyids described in plant species of the genus *Theobroma: Aceria reyesi* (Nuzacci) and *Floracarus theobromae* Keifer (*Theobroma cacao* L.: Malvaceae), *Gymnaceria cupuassu* Oliveira, Rodrigues & Flechtmann, in cupuaçuzeiro in the state of Bahia and *Eriomacrotergum flechtmanni* Rodrigues, Návia & Oliveira on cupuaçu leaves in the state of Amazonas (RODRIGUES et al., 2016), *Agistemus amazonicus* Paktinat-Saeij, Bacheri & Noronha in cupuaçu in Pará state (PAKTINAT-SAEIJ *et al*., 2016), *Aceria reyesi* (Nuzzaci), the cocoa bud mite, 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 Committee of the Cocoa Crop Plan - CEPLAC, in the municipality of Ouro Preto do Oeste, where the occurrence of Eriophyoidea mites associated with cocoa crops for the production of hybrid seeds was observed and, above all, in the ESTEX-OP germplasm bank, where severe damage was observed in the form of shortening of internodes and death of terminal branches (TREVISAN *et al*., 2012). Among the families of predatory mites that have potential in the biological control of pests in plants are: Anystidae, Ascidae, Bdellidae, Cheyletidae, Cunaxidae, Laelapidae, Macrochelidae, Phytoseiidae, Rhodacaridae and Stigmaeidae (MORAES, 2002 &

CARRILLO *et al*., 2015).

In order to understand the diversity of mite species in cupuaçu crops in the state of Pará, predatory and phytophages mites associated with cupuaçu were identified, expanding knowledge of local diversity and enabling future management actions in the cupuaçu. Thus, this study aimed to understand the mite diversity associated with cupuaçu crops in cultivated areas in the municipalities of Bragança and Augusto Corrêa, in the Bragantina microregion, state of Pará.

MATERIALS AND METHODS

Study area. The study was carried out in two cupuaçu cultivation areas in the Bragantina microregion, northeastern Pará state. The collections were carried out in 2021 to 2022, covering the months of September, October and December (2021) for the dry period, and February, April and June (2022) for the rainy season, totaling six collections in the municipalities of Bragança and Augusto Corrêa. The climate of the region is hot and humid equatorial (Amw’, according to the Köppen classification), characterized by a very rainy season, between January and May, and a dry season, from July to December. The average annual rainfall is 2,500 mm. The relative humidity varies between 80 and 91%. The average temperature is 27.7 °C, but can vary from 20.4 to 32.8 °C (MARTORANO et al., 1993).

Sampling methods. The plants measured two to 10 meters tall and were four to ten years old. Three collections of leaves were carried out in cultivated areas at Fazenda Alto Arajivu (coordinates 1º10'18.6"S, 46º43'49.3"W), at an altitude of 41m, and at Sítio Jiquiri (1°03'59.8 "S 46°44' 40.0"W), 16m above sea level, in the municipality of Bragança, and Sítio loja da roça and Fazenda Bacuri (missing coordinates), in the municipality of Augusto Corrêa (Figure 1). Twenty plants were sampled by automatic drawing, and five leaves were collected from each plant. The samples were placed in paper bags and sent for screening to the biology laboratory of the Federal Institute of Education of Pará, in Bragança. After screening, the mites were mounted on slides in Hoyer's medium and placed in an oven for 10 days at 50-60°C. Species identification was performed in the Acarology Laboratory of the Universidade do Vale do Taquari – Univates, using a trinocular phase contrast microscope OMAX 40x − 2500x with an OMAX S35180U3-18Mp camera, and taxonomic keys of the mites under study. Specimens confirming the mite species collected in the study are deposited at the Museum of Natural Sciences (ZAUMCN) at UNIVATES, Lajeado–RS.

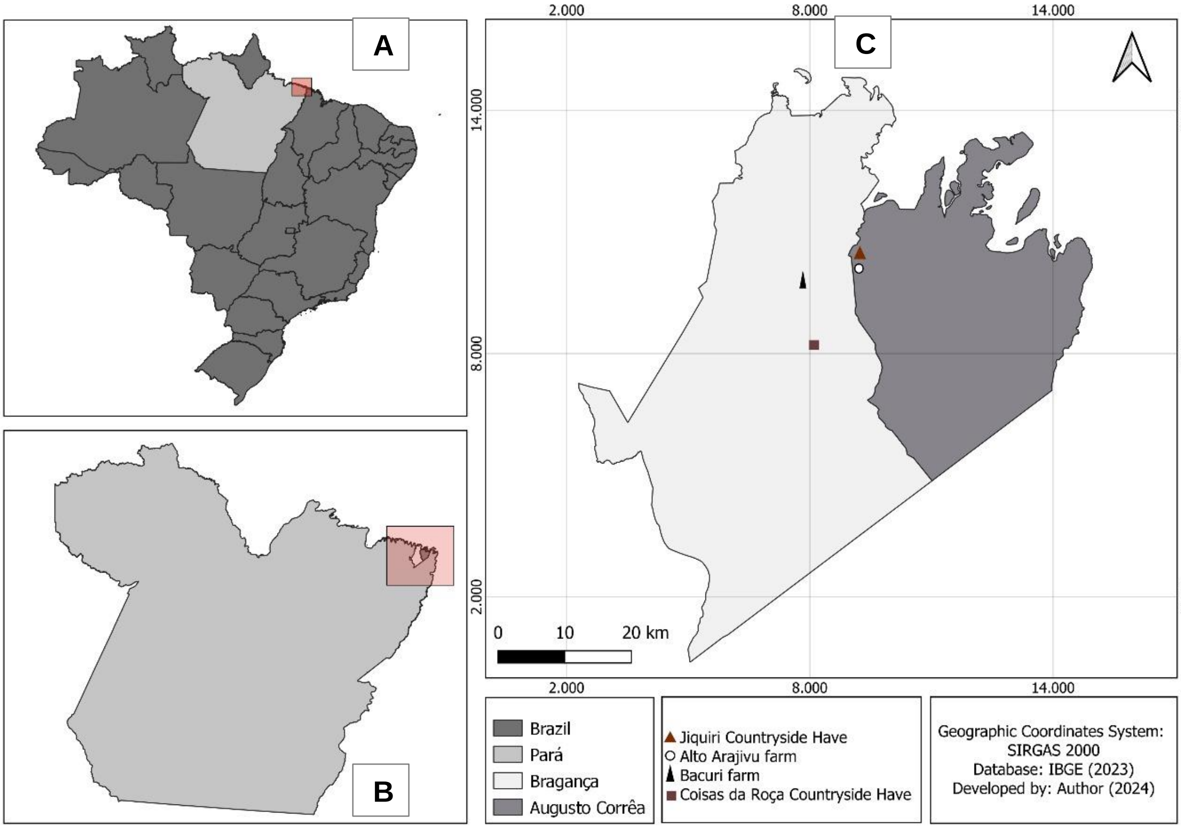

Figure 1: Location of *Theobroma grandiflorum* crops assessed in the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará, Pará, Brazil. A (Brazil), B (Pará), C (Region of the study sites).

Climate Data Collection. In order to investigate the variability and composition of mites in cupuaçu plantations in two different locations, systematic collections were carried out at specific periods over the course of two years. In addition to collecting mites, environmental data such as temperature, relative humidity, atmospheric pressure and precipitation were recorded. These data were obtained from the National Institute of Meteorology in order to analyze their possible influence on the diversity of mites in cupuaçu plantations. The aim is to provide fundamental information for farmers' decision-making and for the sustainability of this important crop in the Amazon region.

Mite abundance by period, municipality and type of planting. Considering the possibility that some species could not be identified during the period of this research, either due to the discovery of new species or genera, or the collection of immature individuals that make taxonomic identification difficult, it was decided to treat the sampled organisms as species or taxa, whenever possible. Thus, the analysis of mite diversity began with the preparation of a pyramid-shaped graph, which represents the total number of mites collected by taxonomic family. This allows an exploratory analysis of the distribution of these organisms between the two municipalities and the two seasonal periods, providing an overview of what was sampled in the cupuaçu plantations.

Statistical Analyses - To ensure a representative analysis of the complexity and taxonomic diversity of the species collected in the studied locations, a major sampling effort was made to capture the greatest possible taxonomic variability. As part of this analysis, rarefaction curves were generated for the Chao1 diversity values with 99 permutations, following the methodology proposed by Chao & Jost (2015). The Chao1 metric is an estimate of species richness in a biological sample, based on the number of rare and unique species present in the sample, taking into account species observed only once (singular species) and those observed twice (double species), and so on. This approach allows for a more accurate estimate of total species richness, especially when there is a significant presence of rare species that may not have been detected in the sample. By including unique species in the estimate, the Chao1 method helps to correct possible biases caused by insufficient sampling or under sampling. Thus, rarefaction curves using the Chao1 index make it possible to analyze the taxonomic diversity present in the collected samples, allowing for a more robust interpretation of the results obtained in this study.

Rarefaction curves for observed and extrapolated richness estimates were generated using the `specpool' function of the vegan package (OKSANEN *et al*., 2018), employing the statistical programming language R (IHAKA & GENTLEMAN, 1996; R Development Core Team, 2022) for this and subsequent analyses. The calculation of these rarefaction curves and their dispersion measures (95% confidence intervals) were based on the total abundance of specimens per species or taxon collected.

The implementation of rarefaction curves and the generation of confidence intervals were performed using the `iNEXT´ function of the iNEXT package (HSIEH *et al*., 2016) in the R environment. This approach provides a detailed visualization of the species diversity present in the collected samples, allowing an accurate assessment of the observed richness and a reliable estimate of the extrapolated richness, together with its associated confidence intervals.

Hill's Diversity Profile - When analyzing different diversity indices, such as Simpson, Shannon-Wiener and Margalef, individually, there is a risk of bias due to the different assumptions and weightings present in the formulas of these indices. Each of them emphasizes certain characteristics of the community, such as the presence of rare species versus more abundant species, among other factors. An interesting approach to circumvent this general limitation presented by many individual indices is the Hill diversity profile, proposed by Hill (1973). This method allows a more dynamic analysis of diversity, as it allows observing how different mite communities (in different municipalities, periods) behave when different diversity indices attribute more weight to rare or dominant species. Essentially, the Hill diversity profile provides a more comprehensive and flexible view of diversity, allowing a more complete understanding of community structure and how it varies in response to different factors. This is especially relevant in the present study, which seeks a more holistic understanding of mite diversity in cupuaçu plantations in different contexts. In general, the analysis of the Hill diversity profile generates a scale along the x-axis of the graph, based on the Renyi index with different orders of magnitude (HILL, 1973). This approach allows us to observe which communities are more diverse and at what scale of magnitude in relation to others, taking into account the perspective of rarity versus abundance of the species present. The Hill diversity profile is especially useful for investigating how the relative presence of more abundant species compared to less abundant ones contributes to altering the diversity of the community of organisms. The scale on the x-axis focuses on different aspects of diversity, allowing a more detailed analysis of the structure of the mite community based on simultaneous data on its richness, evenness and sensitivity to dominant species. Therefore, values on the x-axis further to the left of the graph are more sensitive to rare species, while values further to the right are more sensitive to abundant or common species (TÓTHMÉRÉSZ, 1995). This analysis was performed using the `renyi´ function (with the parameter hill = TRUE) of the vegan package (OKSANEN *et al*., 2018) in the R environment.

Mite community structure - Nonmetric multidimensional scaling (NMDS)-based ordinations were performed to assess the structure of mite communities in the studied locations, considering different attributes, such as seasonal periods and municipalities. Before applying NMDS, abundance data were standardized using the ‘decostand’ function of the vegan package (OKSANEN *et al.,* 2018) in the R environment, using the Hellinger standardization method. Subsequently, these standardized data were transformed into a dissimilarity matrix by the Bray-Curtis method, using the ‘vegdist’ function of the vegan package (OKSANEN *et al*., 2018). The NMDS was then performed using the `metaMDS´ function of the vegan package, with the three-dimensional configuration (k = 3), aiming to adequately represent the structure of the mite communities. The quality of the NMDS fit was assessed by the resulting stress value, with values lower than 0.2 being considered adequate, indicating a good representation of the data. To assess whether the mite communities in different contexts were statistically different from each other, a permutation analysis of variance (PERMANOVA) was performed using the \`adonis2´ function of the vegan package, with 99 permutations. The permutations were stratified according to the collection campaigns. In addition, a multivariate homogeneity analysis of group dispersions was conducted using the \`betadisper´ function of the vegan package. This analysis allows verifying whether the PERMANOVA results were influenced by the dispersion of the data, assessing whether there is greater variability within the groups than between them.

To investigate which species are most representative or determinant for the pattern generated by NMDS and which ecological factors, such as temperature, relative humidity, atmospheric pressure and precipitation, contribute significantly to the structures of mite communities, the \`envfit´ function of the vegan package (OKSANEN *et al*., 2018) was used. This function fits environmental vectors in the NMDS space to assess how environmental variables can influence community structure.

RESULTS

A total of 868 mites were sampled during the study period (Table 1). Seventeen families/suborders were identified, with the most abundant being Eriophyidae (50.9%), Phytoseiidae (21.1%), Cunaxidae (9%), Oribatida (5.5%) and Tenuipalpidae (3.5%). A total of 53 species/morphospecies were recorded. The greatest richness was presented by Phytoseiidae, with 17 species, followed by Tydeidae, with five and Cunaxidae, with four. The other families presented lower richness. Among the predators were more abundant and common *Armascirus amazoniensis* and *Scutopalus tomentosus* (Cunaxidae), *Amblyseius* spp.1,2 and 3 (Phytoseiidae) and *Agistemus* sp.1 (Stigmaeidae); among the phytophagous *Eriomacrotergum flechtmanni* and *Gymnaceria cupuassu* (Eriophyidae) and *Brevipalpus yothersi* (Tenuipalpidae).

Table 1. Mitefauna associated with cupuaçu cultivation in the dry or rainy season, in the municipalities of Augusto Corrêa and Bragança, state of Pará, Brazil. n= wealth/family; N= abundance and % = relative percentage of species/morphospecies. P - Predator; F - Phytophagous and G - Generalist.

Families (n)	**Species/morphospecies**	**Augusto Corrêa**		**Bragança**		N	%
		Dry	**Rainy**	**Dry**	**Rainy**		
Acaridae (1)	*Caloglyphus* sp. (G)	10	0	0	0	**10**	1.2
	Unidentified Immature (G)	2	0	0	0	**2**	0.2
Ascidae (2)	*Asca* sp.1 (P)	0	0	0	2	**2**	0.2
	Asca sp.3 (P)	0	0	2	0	**2**	0.2
	Unidentified Immature (P)	0	0	0	1	**1**	0.1
Bdellidae (1)	*Hexabdella* n. sp. (P)	0	0	1	0	**1**	0.1
Canestrinidae (1)	*Hypopes* sp.1 (P)	0	0	1	0	**1**	0.1
Cheyletidae (1)	*Cheletomimus* (*Hemicheyletia*) *darwinia* (P)	0	0	1	0	**1**	0.1
Cunaxidae (4)	*Armascirus amazoniensis* (P)	8	6	30	0	**44**	5.1
	Cunaxatricha n. sp. (P)	0	0	0	5	**5**	0.6
	Cunaxoides sp. (P)	0	0	0	2	**2**	0.2
	Scutopalus tomentosus (P)	0	15	3	9	**27**	3.1
Eriophyidae (2)	*Eriomacrotergum flechtmanni* (F)	0	152	7	229	**388**	44.7
	Gymnaceria cupuassu (F)	31	0	23	0	**54**	6.2
Eupodidae (1)	N. gen. (P)	0	2	5	5	**12**	1.4
Glycyphagidae (1)	*Lepidoglyphus* sp.	0	1	1	0	**2**	0.2
Iolinidae (2)	*Parapronematus* sp. (P)	1	1	1	0	**3**	0.3
	Pseudopronematus sp. (P)	0	0	2	1	**3**	0.3
Oribatida (1)	Unidentified Oribatida	1	1	45	1	**48**	5.5
Phytoseiidae (17)	*Amblyseius* n. sp.1 (P)	2	0	4	39	**45**	5.2
	Amblyseius n. sp.2 (P)	15	0	8	0	**23**	2.6
	Amblyseius n. sp.3 (P)	0	36	2	6	**44**	5.1
	Amblyseius n. sp.4 (P)	0	1	4	0	**5**	0.6
	Amblyseius chiapensis (P)	0	0	1	0	**1**	0.1
	Galendromimus aveolaris (P)	0	0	0	1	**1**	0.1
	Iphiseiodes kamahorae (P)	0	1	0	4	**5**	0.6
	Iphiseiodes quadripilis (P)	0	0	2	0	**2**	0.2
	Iphiseiodes zuluagai (P)	4	0	1	0	**5**	0.6

	Leonseius regularis (P)	0	2	4	5	**11**	1.3
	Paraamblyseius multicircularis (P)	0	0	0	2	**2**	0.2
	Paraphytoseius orientalis (P)	1	0	6	0	**7**	0.8
	Phytoseius (*Phytoseius*) *averrhoae* (P)	0	0	12	0	**12**	1.4
	Proprioseiopsis neotropicus (P)	0	0	3	1	**4**	0.5
	Typhlodromalus aripo (P)	0	0	1	0	**1**	0.1
	Typhlodromips mangleae (P)	1	0	0	0	**1**	0.1
	Typhlodromips n. sp. (P)	0	0	1	0	**1**	0.1
	Unidentified Immature (P)	1	3	4	5	**13**	1.5
Stigmaeidae (3)	*Agistemus* n. sp.1 (P)	0	3	9	8	**20**	2.3
	Agistemus n. sp.2 (P)	0	1	1	0	**2**	0.2
	Agistemus brasiliensis (P)	0	0	1	0	**1**	0.1
	Unidentified Immature (P)	0	0	3	0	**3**	0.3
Tarsonemidae (3)	*Fungitarsonemus* sp. (F)	0	2	0	0	**2**	0.2
	Neotarsonemoides sp. (F)	0	0	1	0	**1**	0.1
	Tarsonemus sp.2 (F)	0	0	1	0	**1**	0.1
Tenuipalpidae (2)	*Brevipalpus yothersi* (F)	0	0	28	0	**28**	3.2
	Tenuipalpus n. sp.1 (F)	0	1	1	0	**2**	0.2
	Unidentified Immature (F)	1	0	0	0	**1**	0.1
Tydeidae (5)	*Brachytydeus* n. sp. 1 (G)	0	0	0	1	**1**	0.1
	Brachytydeus formosa (G)	0	1	0	3	**4**	0.5
	Pretydeus n. sp. (G)	0	7	0	0	**7**	0.8
	Pretydeus n. sp.2 (G)	0	0	0	1	**1**	0.1
	Pretydeus n. sp.3 (G)	0	2	0	0	**2**	0.2
Winterschmidtiidae (1)	*Neocalvolia* sp. (G)	1	0	0	0	**1**	0.1

	Augusto Corrêa		**Bragança**	
	Dry	Rainy	Dry	Rainy
Diversity				
Richness	14	19	35	21
Abundance	79	238	220	331
Dominance	0.22	0.43	0.09	0.49
Shannon-Wiener	1.90	1.39	2.78	1.33
Uniformity	0.47	0.21	0.46	0.18
Evenness	0.72	0.47	0.78	0.43

Richness estimates indicate that the abundance of mites sampled was satisfactory for the study, although there is potential for greater sampling, given that 46 mite taxa were identified, while the estimated richness was 58 ± 8 s.e.. Regarding environmental variability, including temperature and relative humidity, between the different municipalities and collection periods, together with the corresponding amount of mites collected (Figure 2).

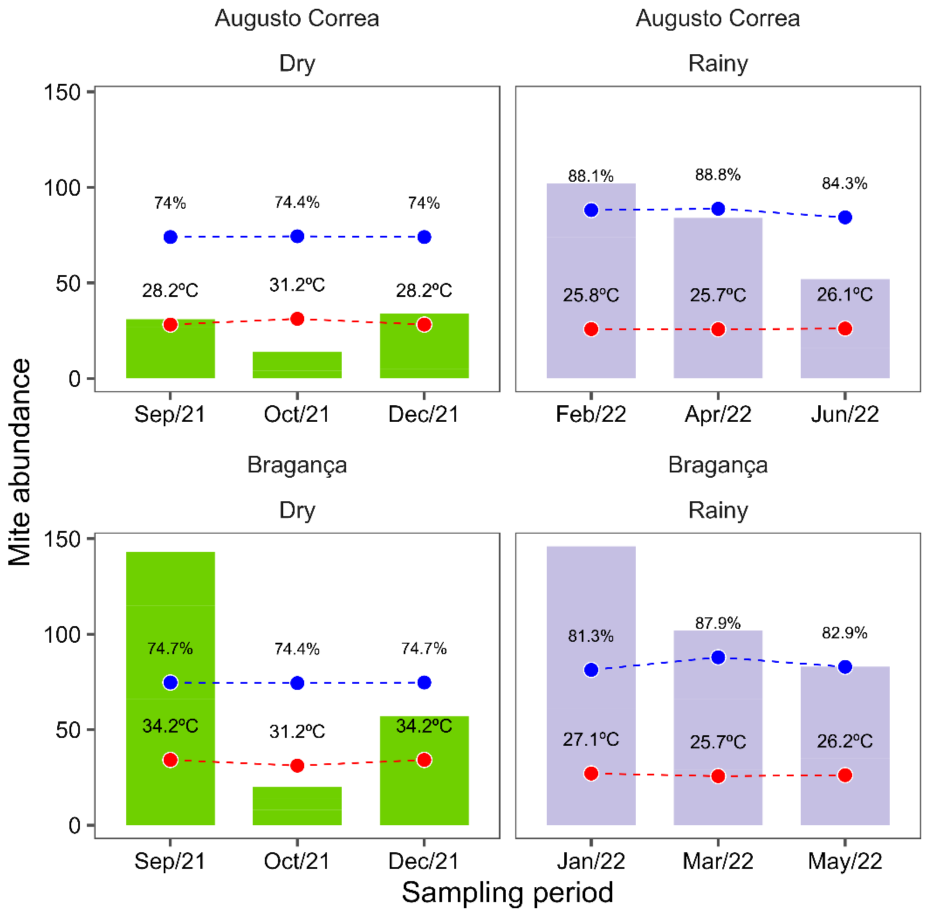

Figure 2. Mite abundance in cupuaçu in the dry and rainy seasons of the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará, Pará, Brazil.

Quantity and diversity of mites by period - The data indicate a greater number of mites sampled during the rainy period (n = 569) compared to the dry period (n = 299), representing approximately 90% more mites in the rainy period than in the hottest period (Figure 3A, Table 1). Despite the greater abundance of mites during the rainy season, greater richness was observed during the dry season, with 38 species identified, compared to the 25 observed in the rainy season. Approximately 52% more species were sampled during the dry season compared to the rainy season (Figure 3B). Regarding the Hill diversity profile, we observed that the dry period exhibited greater diversity, with higher values along the entire x-axis for the Hill diversity order parameters (Figure 3C). However, a very similar pattern of curves was observed in the Hill diversity profile between both periods.

The ordination of mite community composition in relation to periods revealed an excellent fit of the NMDS, evidenced by the low stress (0.04) and a high non-metric fit (R2 = 0.99), indicating that the NMDS effectively captured the underlying structure of mite communities in the different periods. When performing the PERMANOVA analysis, a significant difference in the mite community structure was found between the dry and rainy periods (F (1, 34) = 13.9, R2 = 0.29, P = 0.01. Figure 3D). The statistical significance of this result suggests that the distribution patterns of mites varied consistently between the dry and rainy periods.

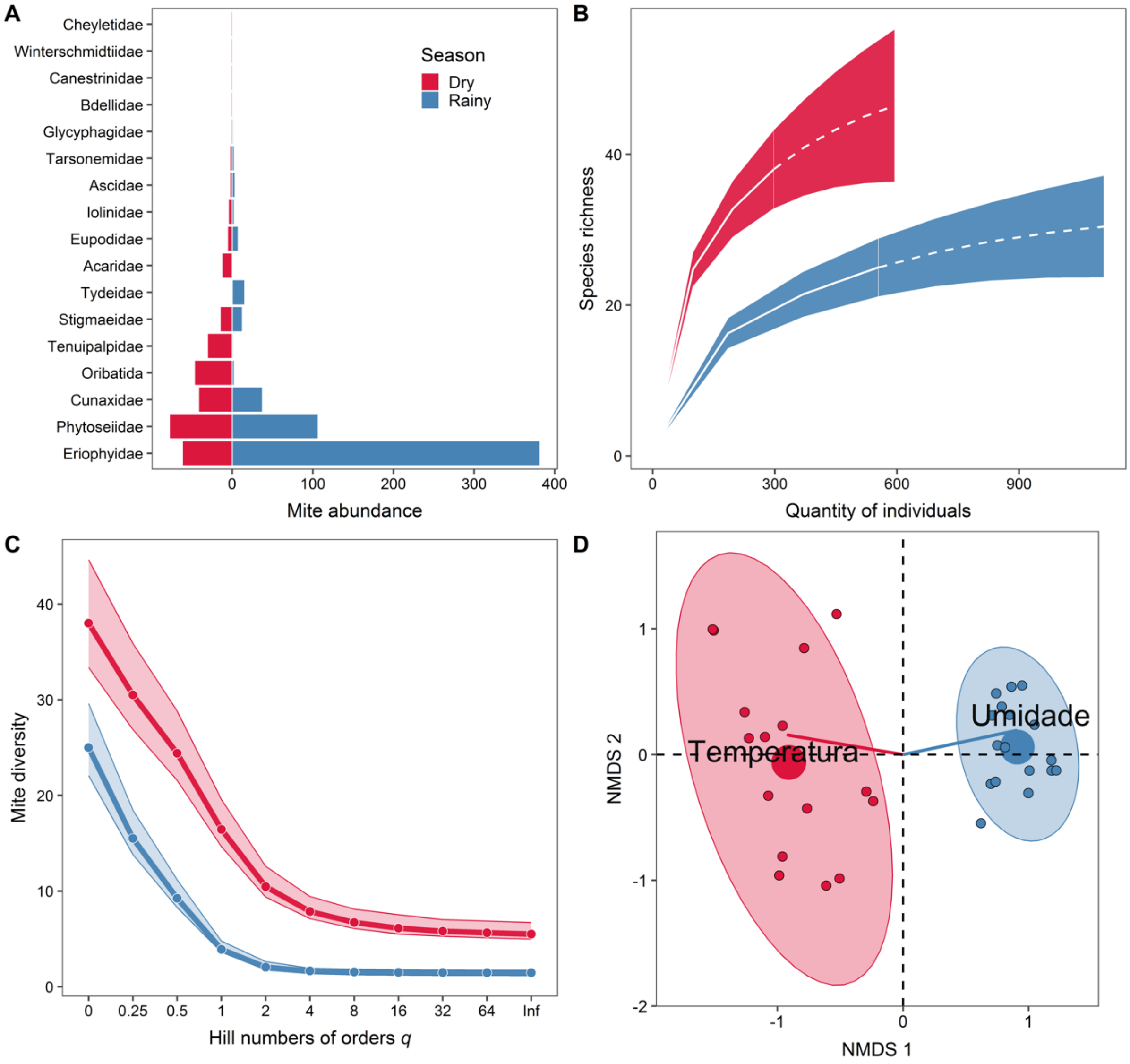

Figure 3. Comparative analysis of the mite communityem cupuaçu in the dry and rainy periods: abundance, richness, diversity and community structure. (A) Total number of mites sampled dry and rainy periods. The y-axis shows the mite families, while the x-axis shows the abundance

of mites organized according to the absolute number collected per seasons. 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 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. 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. For the 4 parts of the figure, red refers to the red for `dry´ and blue refers to the seasons `rainy.

Furthermore, a statistically significant difference in the homogeneity of dispersion was observed between the period groups (F (1, 34) = 62, P = 0.001), indicating that the variability in the distribution of mites within the groups was considerable. This may suggest that the heterogeneity in the distribution of mites may have somehow influenced the PERMANOVA result, particularly during the warm period, where mite dispersion appeared to be more heterogeneous (Figure 3D).

Of the 53 species identified, 11 demonstrated a significant contribution to the NMDS ordination (Table 2), highlighting the relevance of these species or taxa in the structure of mite communities. Regarding the ecological factors considered, it was observed that two of them exerted a considerable influence on this ordination (Figure 3D). Temperature (R2 = 0.86, P = 0.001) and relative humidity (R2 = 0.84, P = 0.015) stood out as the main determinants in modeling the mite community structure, according to the NMDS suggesting a strong correlation between temperature, relative humidity, and the composition of mite communities. On the other hand, atmospheric pressure (R2 = 0.17, P = 0.067) and precipitation (R2 = 0.23, P = 0.053) demonstrated a relatively smaller contribution to the NMDS ordination, although they may still have a less pronounced, but still relevant, impact on this process.

Table 2. Mite species/morphospecies in cupuaçu with significant contribution to the NMDS ordination based on community structure in the Dry and Rainy periods (Figure 2D).

Species	**p-value**
Amblyseius n. sp.1	0.01
Amblyseius n. sp.2	0.01
Amblyseius n. sp.3	0.01
Armascirus amazoniensis	0.01
Brevipalpus yothersi	0.01

Caloglyphus sp.	0.01
Eriomacrotergum flechtmanni	0.01
Unidentified Oribatida	0.01
Phytoseius (*Phytoseius*) *averrhoae*	0.01
Scutopalus tomentosus	0.03
Iphiseiodes zuluagai	0.04

Abundance and richness of mites by municipality - The data reveal a discrepancy in the amount of mites sampled between the municipalities of Bragança and Augusto Corrêa. Bragança contributed a total of 551 individuals, while Augusto Corrêa recorded 317 mites (Figure 4A, Table 1). Therefore, Bragança presented a significantly higher amount of mites compared to Augusto Corrêa, representing a 73% higher proportion of mites. Similarly, Bragança exhibited a higher richness of mites, with a total of 41 species identified, while Augusto Corrêa presented only 27 species (Figure 4B). This difference in taxonomic diversity represents a percentage discrepancy of 75% more mite species in Bragança compared to Augusto Corrêa.

Hill's diversity profile demonstrates something contrasting about the importance of rare and abundant species or taxa within mite communities. When considering the relevance of rare species, we observe that the municipality of Bragança exhibited greater diversity in the mite community, as evidenced by the left side of the graph (Figure 4C). This trend suggests that the greater number of individuals collected in this location may have contributed to increasing the structural complexity of the community, allowing the presence of species or taxa that would be less likely to be captured in a sample with a smaller number of individuals.

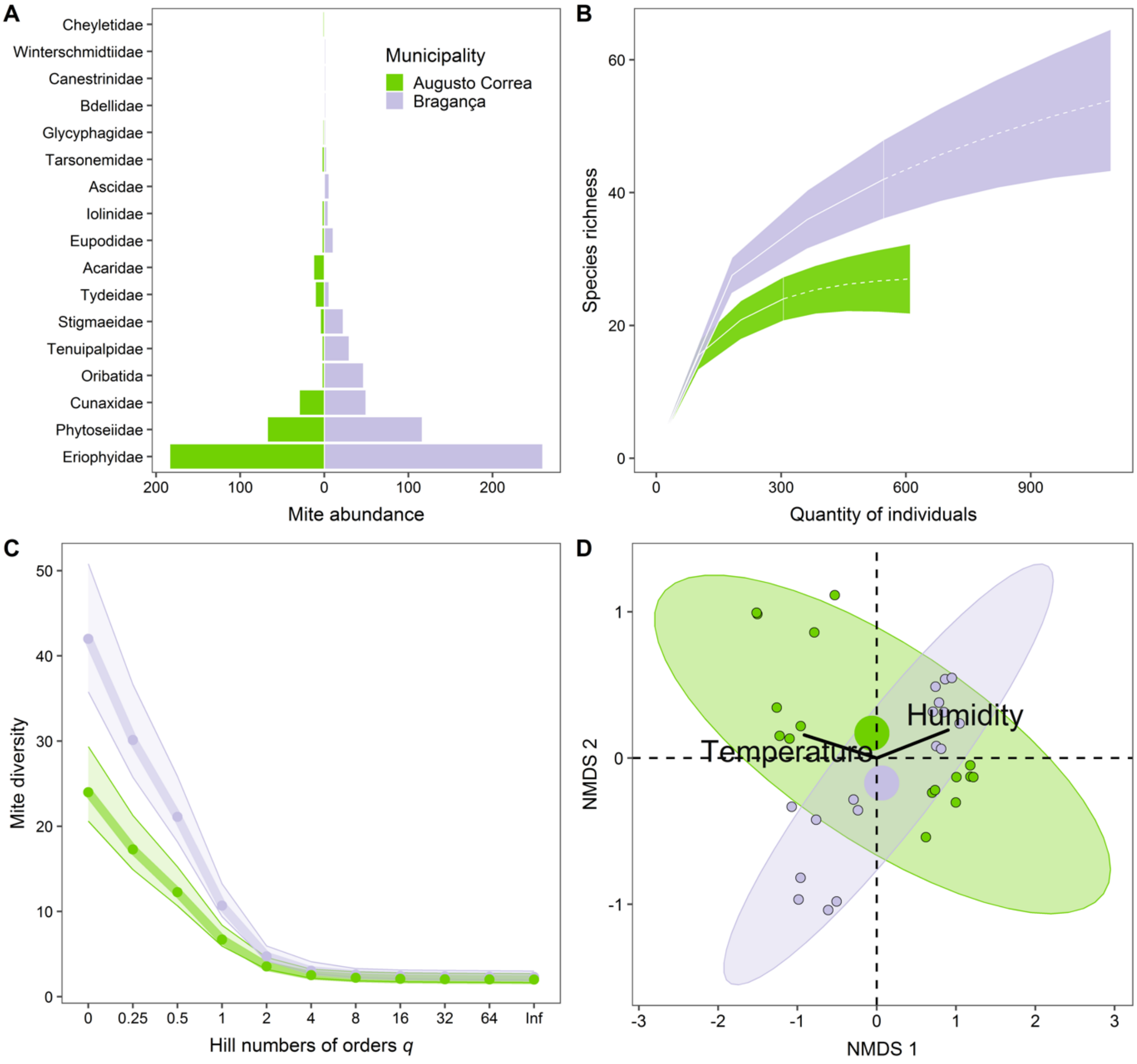

Figure 4. Comparative analysis of the mite community in cupuaçu in the municipalities of Augusto Corrêa and Bragança, Pará, Brazil: abundance, richness, diversity and structure. (A) Total number of mites sampled among the municipalities of Augusto Corrêa vs. Bragança, Pará, Brazil. The left side of the pyramid represents the municipality of Augusto Corrêa and the right side represents the municipality of Bragança. (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. For the 4 parts of the figure, purple refers to Augusto Corrêa and green refers to Bragança.

On the other hand, when considering the Shannon-Wiener index (represented by the number one on the x-axis), both municipalities exhibit a diversity quite similar to each other. From this point on, towards the right of the graph, where the most abundant species or taxa are more relevant, the diversity in the mite community in both municipalities becomes practically identical (Figure 4C). This pattern suggests that, when focusing on the contribution of the most abundant species or taxa, the structure of the mite communities in Bragança and Augusto Corrêa is quite similar, regardless of the differences observed in the abundance and total richness of mites between the two locations.

The ordination of the mite community composition in relation to the municipality presented a highly satisfactory fit in the NMDS, as evidenced by the low stress values (0.04) and high nonmetric fit (R2 = 0.99) (Figure 4D). The PERMANOVA analysis revealed significant differences in the mite community structure between Augusto Corrêa and Bragança (F (1, 34) = 3.01, R2 = 0.08, P = 0.03. Figure 4D). This is because other factors not analyzed in this study may have influenced the difference in the mite community between the two municipalities. No statistically significant differences were found in the homogeneity of dispersion within the groups (F (1, 34) = 1.98, P = 0.18). Therefore, the results indicate that PERMANOVA was not influenced by intragroup variability.

Table 3. Mite species/morphospecies in cupuaçu with significant contribution to the NMDS ordination based on community structure in Augusto Corrêa and Bragança (Figure 3D).

Species	**p-value**
Amblyseius n. sp.1	0.01
Amblyseius n. sp.2	0.01
Amblyseius n. sp.3	0.01
Armascirus amazoniensis	0.01
Brevipalpus yothersi	0.01
Caloglyphus sp.	0.01
Eriomacrotergum flechtmanni	0.01
Unidentified Oribatida	0.01
Phytoseius (*Phytoseius*) *averrhoae*	0.01
Scutopalus tomentosus	0.01
Iphiseiodes zuluagai	0.02

Despite the 53 taxa identified in this work, we noticed that the same 11 taxa that were observed for the periods (dry; rainy) were also identified as playing a significant role in the NMDS ordination (Table 3; Figure 4D), however, presenting even more significant p values. Therefore, our results highlight the consistency of these taxa as important contributors to the mite community structure in both periods and municipalities studied. Finally, the analysis indicated that temperature (R2 = 0.86, P = 0.001) and relative humidity (R2 = 0.84, P = 0.015) are the main determinants in shaping the mite community structure. On the other hand, atmospheric pressure (R2 = 0.17, P = 0.067) and precipitation (R2 = 0.23, P = 0.053) demonstrated a relatively smaller contribution to the NMDS ordination.

DISCUSSION

This is the first study carried out in the northern region of Brazil reporting the mite fauna, its diversity, as well as the distribution in the dry and rainy seasons in cupuaçu crops in the state of Pará. A total of 868 mites were sampled and the most abundant and common families were Eriophyidae, Phytoseiidae, Cunaxidae, Tenuipalpidae and the suborder Oribatida. In another similar study carried out with the cupuaçu crop in the state of Maranhão, the most common families were Cheyletidae, Cunaxidae, Phytoseiidae, Tarsonemidae, Tenuipalpidae, Tetranychidae and Tydeidae and the suborders Acaridida and Oribatida, confirming the mite diversity in the crop (SILVA et al., 2009).

Among the most abundant phytophagous mites, Eriophyidae and Tenuipalpidae stood out. *Eriomacrotergum flechtmanni* was found in greater abundance in the municipalities of Bragança and Augusto Corrêa, during the rainy season, while *G. cupuassu* was found in both municipalities, during the dry season. The presence of phytophagous mites in cupuaçu cultivation is a concern due to the potential impact on the production and quality of this crop. The main families of phytophagous mites already reported in previous studies of the genus *Theobroma* were Eriophyidae, Tenuipalpidae, Tetranychidae and Tuckerellidae. Six species of eriophyid mites have been reported associated with *Theobroma* spp., however, only *A. reyesi* was known to cause serious damage and its importance as a cocoa pest in some countries in Central and South America (CARVALHO et al., 2018).

The analysis of the rarefaction curve reveals that while the rarefaction curve for Bragança suggests that an additional sampling effort could result in the collection of more taxa, apparently not captured during collections in cupuaçu plantations, the rarefaction curve for Augusto Corrêa demonstrates that the sampling carried out was relatively satisfactory, despite the smaller number of individuals collected and the lower richness observed. Regarding the richness of mites found, the dry season in both municipalities had 38 species and only 25 during the rainy season.

However, it is important to note that, although the dry season already presented greater richness, suggests that there is still potential for the discovery of more taxa if there is an increase in the collection effort. On the other hand, for the rainy season, there seems to be a lower diversity of mites that could be aggregated with the same sampling effort. These results are corroborated by studies carried out in the North region that show a substantial positive association between Phytoseiidae and temperature, where higher temperatures increase the prevalence of these mites (DE ALFAIA et al., 2023). This result suggests a comparable dynamic between the two mite communities, where less abundant (rare) taxa play a more significant role as the scale shifts to the left, while more abundant taxa gain relevance as the scale shifts to the right along the x-axis.

Among the predatory mites, generalist species of Phytoseiidae were the most abundant and prevalent, namely, species of the genera *Amblyseius*, *P. averrhoae* and *L. regularis*, followed by Cunaxidae and Stigmaeidae. Thus, as in the study on predatory mites associated with cupuaçu trees in the state of Bahia in agroforestry systems, Nuvoloni et al. (2022) observed that the cupuaçu tree can act as a reservoir for predatory mites. A determining factor for the presence of generalist predatory mites may be the consumption of alternative food that allows the maintenance of predators in environments where preferred prey are not present (McMURTRY et al., 2013).

Amblyseius sp. 1 was more abundant during the rainy season in Bragança, while *Amblyseius* sp. 3 was abundant in Augusto Corrêa, also during the rainy season. Species of this genus are predominant in the North region, demonstrating the influence of environmental factors, such as high temperature and relative humidity, on the structure of the mite community, with greater occurrence during the period of greatest rainfall. In studies carried out with *Elaeis guineensis* Jacq. (Arecaceae), in the state of Amazonas, during the rainy season, mites of the genus *Amblyseius* were also reported in greater abundance during the period (CRUZ et al., 2019). This genus contains a great diversity of species, which are natural enemies of several organisms (AMARAL, 2017). In other studies, other authors confirmed that phytoseiid mites were the most diverse among predatory mites in other ecosystems (McMURTRY et al., 2013). Thus, this work corroborates and confirms phytoseiid mites as the most diverse and abundant group in the world, information already reported by other authors (TIXIER et al., 2008).

Understanding the diversity of mites in cupuaçu crops within the Amazon biome is crucial for integrated pest management, as it allows for the identification and prediction of periods when phytophagous mites, such as Eriophyidae and Tenuipalpidae, may reach high population levels, as demonstrated by their abundance. This makes it easier to establish integrated pest management strategies. In addition, understanding the diversity, abundance and population richness of natural enemies in cupuaçu is essential for the development of natural biological control methods. Thus as the genus Phytoseiidae appears to be the most diverse and abundant genus of Phytoseiidae associated with cupuaçu, it is important to invest in studies that seek to test the predation potential of species of this genus on pests associated with cupuaçu.

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ACKNOWLEDGEMENTS. Thanks are to the entire team at the Acarology Laboratory at Univates – Labacari, Brazil. We are grateful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

(CAPES) for financial support, Prosuc/CAPES for the scholarship of the first author. Thanks are the National Council for Scientific and Technological Development (CNPq) for the research grant (PQ 1D 310146/2023-2) of Dr. Noeli Juarez Ferla.

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6 CAPÍTULO 5. MITE DIVERSITY ON BACURI CULTURE (*PLATONIA INSIGNIS:* CLUSIACEAE) FROM NATIVE AREAS OF THE STATE OF PARÁ, AMAZON, BRAZIL

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Enviado para revista International Journal of tropical Insects (JTIS)

Abstract. The aim of this study was to quantify and analyze the diversity of mites associated with Bacuri culture (*Platonia insignis* Mart.; Clusiaceae) in native areas, as well as their distribution in the dry and rainy periods in the municipalities of Bragança and Augusto Corrêa, Bragantina microregion, state of Pará, Brazil. Rarefaction curves were generated for diversity values using the statistical programming language R, rarefaction curves for richness estimates, their equitability and analysis of variance with permutations. A total of 493 mites from 21 families were sampled, with the most representative being Eriophyidae (25.5%), Phytoseiidae (21.3%), Tenuipalpidae (13.3%), Tuckerellidae (11.4%) and Tydeidae (6.4%). Among the most abundant mites, Gen. n. (Eriophyidae), *Amblyseius* spp., *Tenuipalpus bacuri* Flechtmann & Noronha, *Tuckerella ornata* (Tucker) and *Tydeus* sp. stood out. Despite the greater abundance of mites in the rainy season, greater richness was observed in the dry season, with 44 species identified, compared to the 27 species in the rainy season. Approximately 62% more species were sampled in the dry season. The number of phytophagous mites found in bacurizeros is worrying due to the potential impact on the production of this crop. These mites cause direct or indirect damage to host plants.

Keywords: *Amblyseius*; *Retracrus johnstoni; Tenuipalpus bacuri*; *Tuckerella ornata; Tydeus* sp.

Introduction. The Bragantina microregion, located in the Northeastern mesoregion of Pará, Brazil, stands out as a notable example of how intensive land use can lead to a complete modification of the original landscape and ecological conditions (DENICH, 1986; DENICH; KANASHIRO, 1995). This microregion has a history of land use that goes back more than a century, where the natural vegetation has been modified by intense human activity, currently facing major problems due to disorderly occupation, generating discussions about the speed of occupation of space, the use of available natural resources and degradation due to the misuse of these resources (ALMEIDA; VIEIRA, 2008). In this region, fragments of secondary forests also stand out, with a predominance of plants popularly known as Bacuri (*Platonia insignis* Mart.; Clusiaceae), due to their high capacity for natural regeneration. Under natural conditions, the species reproduces sexually (seeds) and asexually (root shoots). In areas of primary vegetation, it is common to find young plants originating from seeds and very rarely from root shoots (CARVALHO, 2007; De CARVALHO, 2018). It is a fruit tree, native to the Amazon, monotypic for the genus *Platonia*. The state of Pará is considered the center of diversity, with emphasis on populations located in the mesoregion of Northeast Pará and Marajó Island, belonging to the native fruits of economic interest to the region (CARVALHO; NASCIMENTO, 2017). Its fruits are used for juices, jellies, ice cream, sweets, cakes, etc... (HOMMA et al., 2009).

Despite the economic relevance of Bacuri, studies on the mite fauna associated with this crop in Pará are limited. Some studies mention mites from the families Phytoseiidae and Tenuipalpidae, including the phytophagous mite Tenuipalpus bacuri Flechtmann & Noronha, identified in clones in the municipalities of Tomé-Açu and Belém, with special attention to the presence of the mite on the surfaces of the leaves (FLECHTMANN; NORONHA, 2013; NORONHA et al., 2015). However, there are still few studies focused on the diversity of mites associated with Bacuri, which highlights the importance of research that addresses this issue.

Given the abundance of Bacuri plants in secondary forests and the economic importance of this fruit tree in the Pará market, many family farmers were encouraged to manage them. Therefore, the municipalities of Bragança and Augusto Corrêa/PA, located in the Bragantina microregion, were selected for the present study, as the region is one of the oldest in the state of Pará with a predominance of secondary forests, with native Bacuri plants as the predominant species in many areas. Therefore, the aim of this study was to quantify and analyze the diversity of mites associated with bacuri culture in native areas, as well as their distribution in the dry and rainy periods in the municipalities of Bragança and Augusto Corrêa, Bragantina microregion, state of Pará.

Materials and methods

Collection Site. The study was carried out in native Bacuri crops in the Bragantina microregion, northeastern Pará, Brazil between September 2021 and December 2022. Collections took place at the following locations: Alto Arajivu Farm (1º10'18.6"S, 46º43'49.3"W; 41 m altitude), Sítio

Jiquiri (1°03'59.8"S, 46°44'40.0"W; 16 m), Coisas da Roça Farm (1º03'58.91"S, 46º66'23.30"W) and Bacuri Farm (1º04'11.10"S, 46º66'33.82"W), in Bragança and Augusto Corrêa. The region has a tropical monsoon climate (Köppen Am), with an average temperature of 27°C and relative humidity between 84% and 91% (GOVERNMENT OF THE STATE OF PARÁ, 2022).

Sampling. In each municipality, 20 plants per area were sampled, randomly selected by means of a random draw. For each plant, five leaves (from the median regions), five flowers and five green fruits were collected. The samples were placed in separate paper bags to avoid cross-contamination and sent to the Biology laboratory of the Federal Institute of Education of Pará for screening.

Processing and Identification. In the laboratory, the mites were mounted on slides using Hoyer's medium, and the slides were placed in an oven at 50-60°C for 10 days, aiming to dry the medium and distend the specimens. Species identification was performed in the Acarology Laboratory of the University of Vale do Taquari – Univates, using an OMAX trinocular microscope (40x-2500x) with an OMAX S35180U3-18Mp camera and taxonomic keys (insert the keys that were used) and 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 & 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.

Data Analysis. In addition to capturing mites, environmental data such as temperature, relative humidity, atmospheric pressure, and precipitation were recorded, obtained from the National Institute of Meteorology (INMET, 2024). These data were used to investigate the possible influence of these factors on the diversity of mites in Bacuri plants. The objective is to provide information that can guide farmers' decisions, promoting the sustainability of this crop.

Abundance of Mites. The analysis of mite diversity began with the creation of pyramid-shaped graphs representing the total number of mites collected per family. This approach allowed an exploratory analysis of the distribution of mites between the two municipalities and the two seasonal periods, providing an overview of the sampling in the Bacuri plantations.

Sampling Effort and Diversity. To ensure a comprehensive analysis of taxonomic diversity, a sampling effort was made to capture the greatest possible variety of species. Rarefaction curves were generated to estimate diversity using the Chao1 index, with 99 permutations, according to the methodology of Chao & Jost (2015). The Chao1 index estimates species richness, considering both rare species and those with greater abundance, offering a more accurate estimate of total diversity, especially in cases of undersampling. Rarefaction curves and their confidence intervals (95%) were calculated based on the total number of specimens collected per species, using the specpool function of the vegan package (OKSANEN et al., 2018) in the R environment. The confidence intervals were generated using the iNEXT function of the iNEXT package (HSIEH et al., 2016), allowing a robust assessment of the observed and extrapolated richness of the samples.

Hill Diversity Profile. To avoid the bias associated with the isolated use of diversity indices, such as Simpson, Shannon-Wiener and Margalef, the Hill diversity profile (Hill, 1973) was used. This index allows us to observe how the diversity of mite communities varies as a function of the weight attributed to rare or dominant species. The Hill diversity plot was generated using the renyi function (with the hill parameter = TRUE) from the vegan package (OKSANEN et al., 2018) in R. The values on the x-axis of the plot indicate different aspects of diversity, with the left part sensitive to rare species and the right part to more abundant species (TÓTHMÉRÉSZ, 1995). This analysis was conducted using the `renyi´ function (with the parameter hill = TRUE) of the vegan package (OKSANEN *et al*., 2018) in the R environment.

Mite community structure**.** To analyze the structure of mite communities in the studied locations, ordinations based on non-metric multidimensional scaling (NMDS) were performed, considering different attributes, i.e. periods and municipalities. Before applying NMDS, abundance data were standardized using the `decostand´ function of the vegan package (OKSANEN *et al*., 2018) in the R environment, employing the Hellinger standardization method. Then, these standardized data were transformed into a dissimilarity matrix by the Bray-Curtis method, using the `vegdist´ function of the vegan package. The Hellinger method is ideal for species abundance data, balancing the importance of common and rare species, while the Bray-Curtis dissimilarity matrix calculates the difference between samples considering both the presence and abundance of species.

The NMDS was performed using the `metaMDS´ function of the vegan package, configured for three dimensions (k = 3), seeking to adequately represent the structure of the mite communities. The quality of the NMDS fit was assessed by the resulting stress value, with values lower than 0.2 considered adequate, indicating a good representation of the data. To evaluate the statistical difference between the mite communities in different contexts, a permutation analysis of variance (PERMANOVA) was conducted using the `adonis2´ function of the vegan package, with 99 permutations stratified according to the collection campaigns. In addition, a multivariate homogeneity analysis of group dispersions was performed using the `betadisper´ function of the vegan package, to verify whether the dispersion of the data influenced the PERMANOVA results, evaluating the variability within and between groups. To investigate which species or species are most representative for the pattern generated by NMDS and which ecological factors, such as temperature, relative humidity, atmospheric pressure and precipitation, contribute significantly to the structures of mite communities, the `envfit´ function of the vegan package was used. This function fits environmental vectors in the NMDS space to evaluate how environmental variables influence community structure, interpreting the direction and magnitude of significant environmental vectors in relation to the dispersion of samples in the ordination space. In short, environmental vectors indicate how environmental variables are associated with the distribution of samples in the NMDS.

Results. During the study period, a total of 493 mites were sampled, belonging to 21 mite families, in addition to those of the suborder Oribatida (Table 1). The most abundant families were Eriophyidae (25.5%), Phytoseiidae (21.3%), Tenuipalpidae (13.3%), Tuckerellidae (11.4%) and Tydeidae (6.4%). Fifty-one species were identified, including determined species, genera and new species/genera of mites, as well as immature. The richness estimate suggests that the abundance of mites sampled was satisfactory for the study, although there is potential for a more comprehensive sampling, since 51 species were identified, while the estimated richness was 70 ± 12 s.e.. Environmental variability, including temperature and relative humidity, between different municipalities and collection periods, together with the corresponding amount of mites collected (Figure 2).

Abundance and diversity. The data indicate a slightly higher abundance of the mitefauna sampled in the rainy season (n = 277) compared to the dry season (n = 216), representing approximately 28% more mites in the rainy and humid season than in the dry and hot season (Figure 3A, Table 1). Despite the greater abundance in the rainy season, greater richness was observed in the dry season, with 44 species, compared to the 27 observed in the rainy season. In other words, approximately 62% more species were sampled in the dry season compared to the rainy season (Figure 3B). However, it is important to highlight that, although the dry season has already presented greater richness, there is still potential for the discovery of more species if there is an increase in the collection effort. On the other hand, for the rainy season, there seems to be less diversity to be aggregated with the same increase in sampling effort. It was observed that the dry period exhibited greater diversity, with higher values along the entire x-axis for the Hill diversity order parameters (Figure 3C). However, a very similar pattern of curves was observed in the Hill diversity profile between both periods. This result suggests a comparable dynamic between the two communities, where the less abundant (rare) species play a more significant role when the scale shifts to the left, while the more abundant species gain relevance as the scale shifts to the right of the axis.

The ordination of community composition in relation to the period revealed a satisfactory fit of the NMDS, evidenced by the low stress (0.06) and high nonmetric fit (R2 = 0.99), indicating that the NMDS effectively captured the underlying structure of the mite communities in the different periods. When performing the PERMANOVA analysis, a significant difference in the structure of the mite community was observed between the dry and rainy periods (F (1, 28) = 4,48, R2 = 0,13, P = 0,01. Figure 3D). The statistical significance of this result suggests that mite distribution patterns vary consistently between dry and rainy periods. Furthermore, no statistically significant difference in dispersion homogeneity was observed between period groups (F(1,28) = 3,24, P = 0,08), suggesting that heterogeneity in mite distribution did not influence the PERMANOVA result (Figure 3D). Among the 51 species, four were shown to contribute significantly to the NMDS ordination (Table 2), highlighting the relevance of these species or species in the structure of the communities. Regarding the ecological factors considered, three exerted considerable influence on this ordination (Figure 3D). Relative humidity (R2 = 0,72, P = 0,001), precipitation (R2 = 0,62, P = 0.001) and temperature (R2 = 0,56, P = 0.001) stood out as the main determinants in the modeling of the structure of the mite communities, according to the NMDS, suggesting a strong association between the variations in these variables and the composition of the communities. On the other hand, atmospheric pressure (R2 = 0,17, P = 0,078) demonstrated a low, non-significant contribution to the NMDS ordination, although it may still have a less pronounced impact on this process.

Abundance and diversity by municipality. The data show a slightly higher number of mites in Augusto Corrêa, with 283 individuals, while Bragança recorded 210 mites (Figure 4A, Table 1). Augusto Corrêa had a higher abundance of mites compared to Bragança, in a proportion 34% higher. Similarly, Augusto Corrêa still exhibited greater richness, with 38 species, while Bragança had 34 species (Figure 4B). This difference in taxonomic diversity represents a percentage discrepancy of 11% more than in Bragança, in relation to Augusto Corrêa.

The pattern of the curves for both municipalities was similar and indicated that an additional sampling effort could result in the collection of more species, apparently not captured during the collections in the Bacuri crops (Figure 4B). This was also reflected in the pattern of the Hill diversity profile curves, which showed a similar pattern between the municipalities. Thus, when considering the relevance of rare species, we observed that in Augusto Corrêa there was greater diversity (Figure 4C). This trend suggests that the greater abundance collected in this location may have contributed to increasing the structural complexity of the community, allowing the presence of species that would be less likely to be captured in a sample with a smaller number of individuals. However, when considering the Shannon-Wiener index, both municipalities exhibit similar diversity between them. From this point on, towards the right of the figure, where the most abundant species are more relevant, the diversity of the two municipalities becomes identical (Figure 4C). This pattern suggests that, when the study focuses on the contribution of the most abundant species, the structure of the mite communities in Bragança and Augusto Corrêa is similar, regardless of the differences in abundance and total richness between the locations.

The ordering of the composition of the communities in relation to the municipality showed the same pattern for the periods (Figure 4D). In the PERMANOVA analysis for the municipalities, there was a significant difference in the structure of the communities between Augusto Corrêa and Bragança (F(1, 28) = 2,53, R2 = 0,08, P = 0,01. Figure 4D). However, it is important to highlight that the coefficient of determination (R2) was low, suggesting that the variability explained by NMDS compared to the analysis between the municipalities should be interpreted with caution. This is because other factors not analyzed in this study may have influenced the difference in the communities between the two municipalities. Statistically significant differences were found in the homogeneity of dispersion within the groups (F(1, 28) = 5,20, P = 0,02). Therefore, the results indicate that PERMANOVA may have been influenced by intragroup variability. Despite the 51 species identified, we observed again that four species played a significant role in the NMDS ordination (Table 3; Figure 4D), with a difference for the periods of only one species (*Amblyseius* sp.2 by *Amblyseius* sp.3). Therefore, our results highlight the consistency of these species as contributors to the structure of the mite community in both periods and municipalities studied. Finally, the analysis of the environmental variables had the same values as the analysis carried out for the different periods, since it is based on the same data matrix used for both factors (dry vs. rainy; Augusto Corrêa vs. Bragança).

Discussion. This is the first study carried out in bacuri culture, in which the mitefauna and its diversity in municipalities of the state of Pará are reported. A total of 493 mites were sampled, the families with the greatest abundance were Eriophyidae, Phytoseiidae, Tenuipalpidae, Tuckerellidae and Tydeidae. Among the families of phytophagous mites, Eriophyidae, Tuckerellidae and Tenuipalpidae presented the greatest abundance.

The phytophagous mites of *Gen. n.* and *T. bacuri* were found in greater abundance in the municipalities of Bragança and Augusto Corrêa, during the rainy season, and *T. ornata* was found in both municipalities during the dry season. The presence of phytophagous mites in bacuri cultivation is a concern due to the potential impact on the production of this crop. These phytophagous mites cause direct or indirect damage to host plants. Noronha *et al.* (2015) reported damage to the abaxial surface of leaves caused by *T. bacuri*, where it presented reddish-brown coloration along the secondary veins, directed from the edge to the central part of the leaf blade.

The main phytophagous mite species already reported in Clusiaceae plant species were *Tetranychus* sp., Tenuipalpidae and Tuckerellidae. Sacramento *et al.* (2007) reported *Tetranychus* sp. causing damage to mangosteen fruits (*Garcinia mangostana* L.: Clusiaceae), with spots and discoloration of the fruit and producing damage with a rusty appearance, making harvesting and classification of the fruits according to the ripening stage difficult. *Tuckerella pavoniformis* (Ewing) (Tuckerellidae) was observed in *Mammea americana* L. fruits (Guttiferae) in northwestern Peru (ESCOBAR-GARCIA *et al.*, 2022). Among the predatory mites, the most abundant and prevalent were from the Phytoseiidae family and, as they are important for biological control, many species of these predators were found in the collected samples, such as the mites Amblyseius sp. 3 and L. regularis, followed by the Tydeidae and Iolinidae families. Regarding the richness of mites found, the dry period in both municipalities presented 44 and the rainy period only 27, that is, in the dry period 62% more species of mites were sampled than in the rainy period, this shows that the temperature variable had an influence on the mite community in this studied crop. These results are also corroborated by studies carried out in the state of Pará with plants of the Arecaceae family as shown in the studies of De Alfaia et al., (2023).

Amblyseius n. sp. 3 was more abundant in the dry season in both municipalities sampled, and *Amblyseius* sp. 2 was found only in the municipality of Bragança during the rainy season. Species of this genus are predominant in the northern region, influenced by environmental factors (temperature and relative humidity) in the structure of the mite community. The greatest abundance was observed during the period of greatest rainfall. Other studies carried out on Arecaceae plants in the northern region also observed a high frequency of species of this genus (CRUZ et al. 2019; LAWSON-BALAGBO et al., 2008; PEÑA et al., 2009; GONDIM JR. et al., 2012 e DE ALFAIA et al., 2023).

Knowledge of the diversity of mites in bacuri culture in the Amazon biome in the state of Pará is fundamental for integrated pest management, making it possible to contain and predict the periods during which phytophagous mite specimens may reach high population levels, as shown by the abundance of mites from the families Eriophyidae, Tenuipalpidae and Tuckerellidae found.

Acknowledgements. To the Coordination for the Improvement of Higher Education Personnel (CAPES) for the financial support.

The authors declare that they have no conflict of interest.

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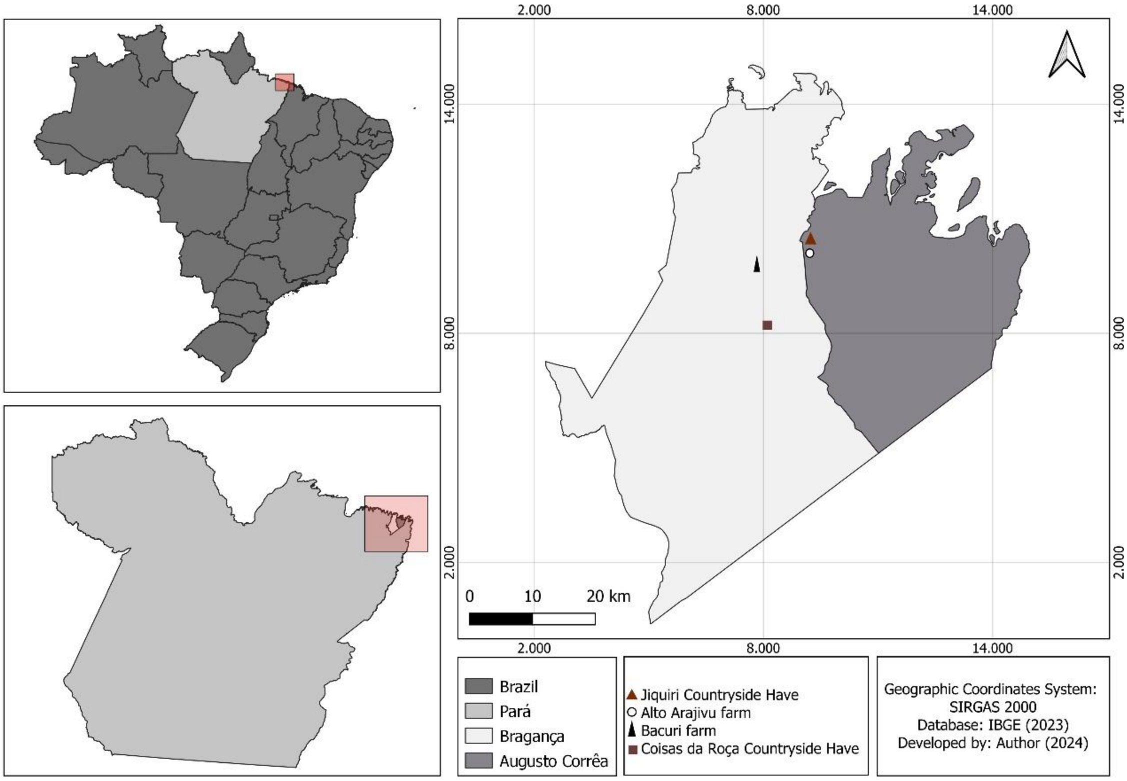

Figure 1: Location of bacuri crops assessed in the municipalities of Bragança and Augusto Corrêa, in the Northeast of Pará, Pará, Brazil.

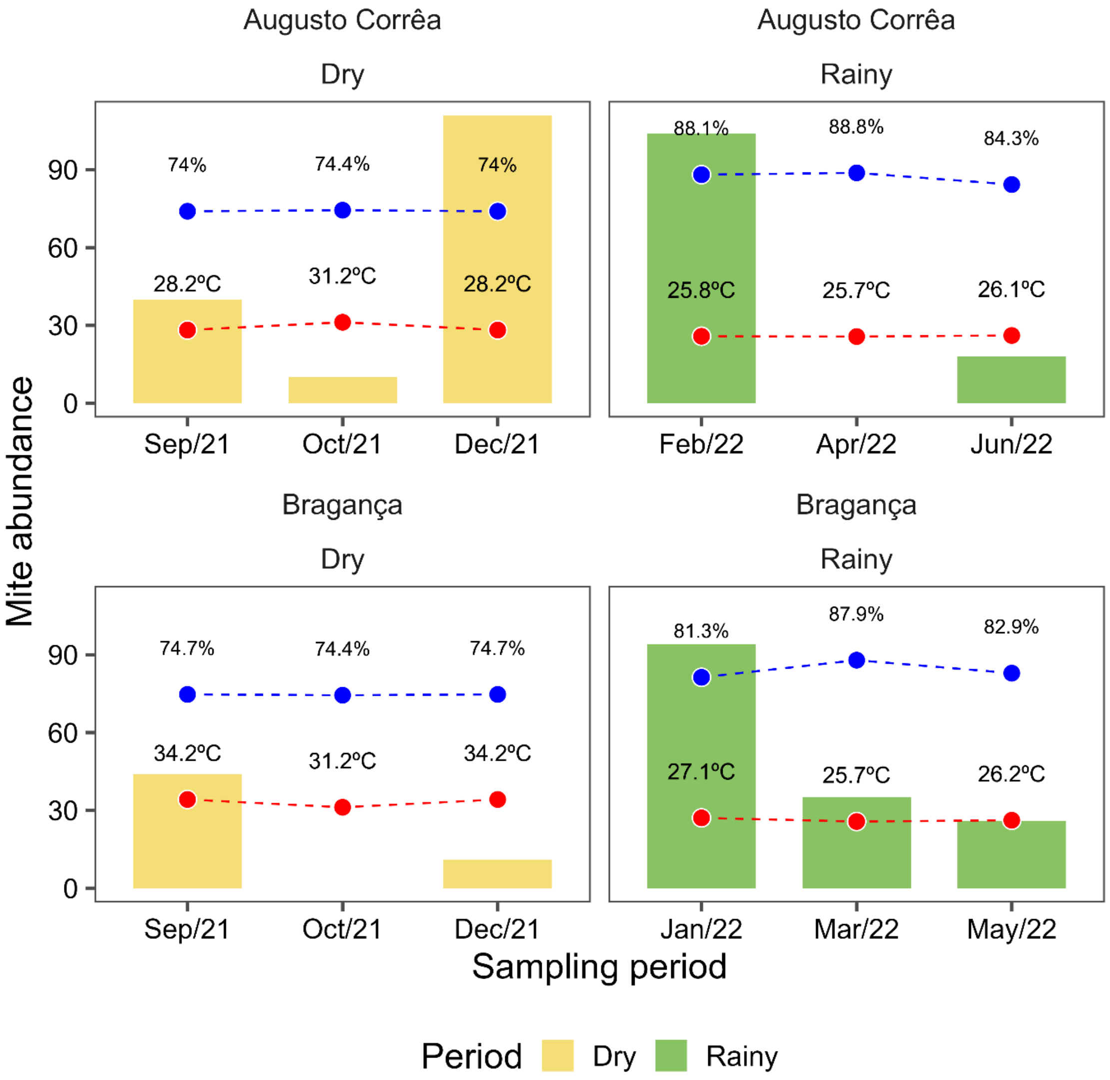

Figure 2. Total quantity of mites em bacuri collected per period in the municipalities of Bragança and Augusto Corrêa., Nordeste do Pará, Brasil.

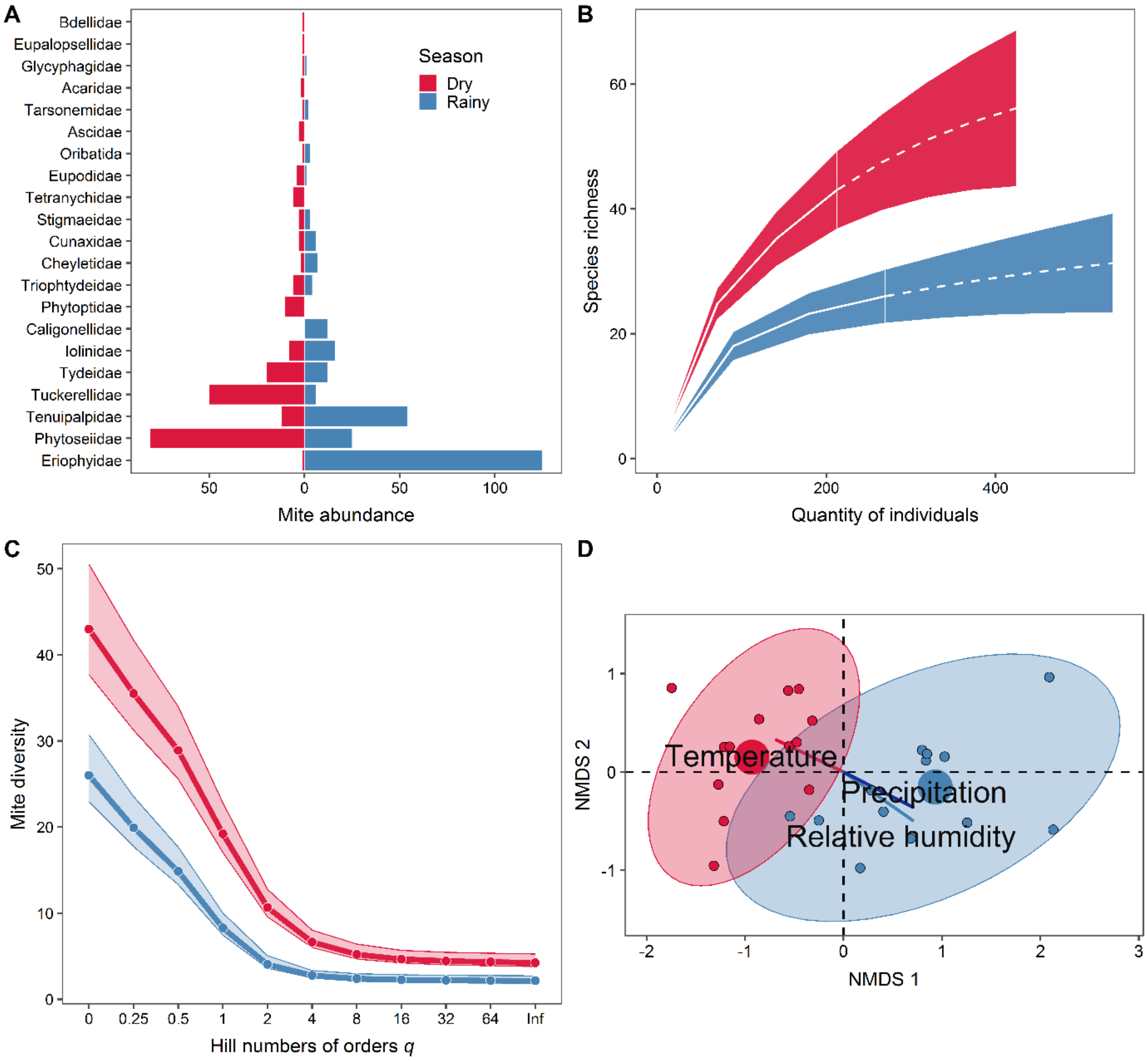

Figure 3. Comparative analysis of the mite community em bacuri in the dry and rainy periods: abundance, richness, diversity and community structure. (A) Total number of mites sampled between the dry and rainy seasons. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute amount 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 by solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes the lato sensu diversity, 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. 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 equitability; common species have more weight). (D) Nonmetric multidimensional scaling (NMDS) graph differentiating the composition of the mite community. Larger points indicate group centroids and smaller points represent sampling sites. The environmental variables `temperature´ and `humidity´ contributed significantly to the pattern of this ordination. Note: the colors are according to the sampling period, with red for `dry´ and blue for `rainy´).

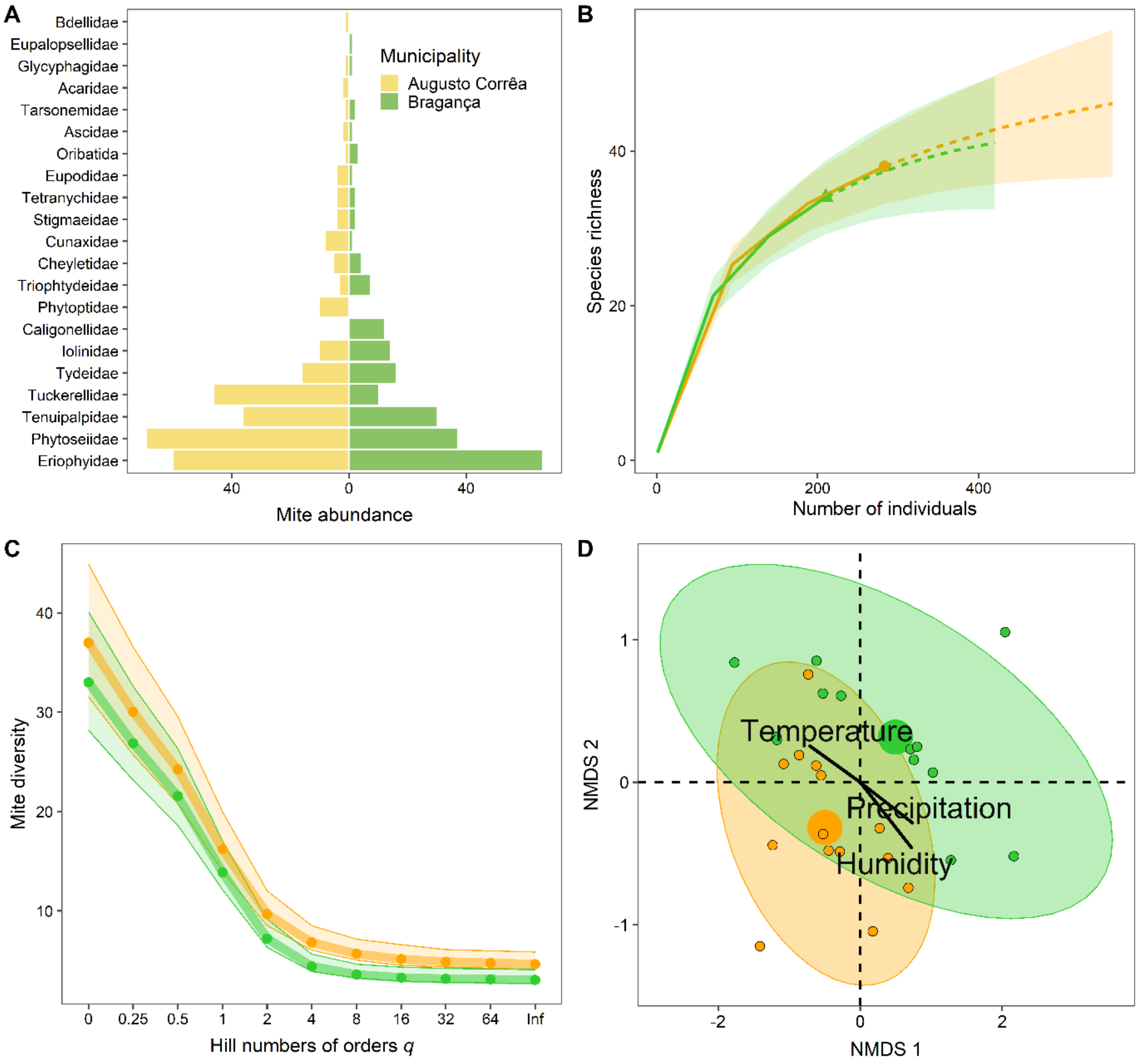

Figure 4. Comparative analysis of the mite community em Bacuri in the municipalities of Augusto Corrêa and Bragança, Pará, Brazil: abundance, richness, diversity and structure. (A) Total number of mites sampled between the municipalities of Augusto Corrêa vs. Bragança, Pará, Brazil. The y-axis shows the mite families, while the x-axis shows the abundance of mites organized according to the absolute amount collected per period. The left side of the pyramid represents the municipality of Augusto Corrêa and the right side represents the municipality of Bragança. (B) Species rarefaction curves with 95% confidence intervals. Observed values of species richness are shown by solid lines, while dashed lines indicate extrapolation. (C) Hill diversity profile. The y-axis denotes the lato sensu diversity, 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. abundant species. 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 equitability; common species have more weight). (D) Nonmetric multidimensional scaling (NMDS) plot differentiating the composition of the mite community. Larger points indicate group centroids and smaller points represent sampling sites. The environmental variables `temperature´ and `humidity´ contributed significantly to the pattern of this ordination. Note: the colors are according to the sampling period (yellow for `Augusto Corrêa´ and green for `Bragança´).

Table 1. Mite fauna associated with bacuri culture in municipalities of Augusto Corrêa and Bragança, in dry and rainy seasons, in the state of Pará, Brazil.

Families	**Species**	**Augusto Corrêa**		**Bragança**		**N**	**%**
		Dry	Rainy	Dry	Rainy		

Acaridae	*Tyrophagus putrescentiae*	2	0	0	0	**2**	0.4
Ascidae	*Asca* sp.1	1	0	1	0	**2**	0.4
	Asca sp.2	1	0	0	0	**1**	0.2
Bdellidae	*Hexabdella* n. sp. 2	0	0	1	0	**1**	0.2
Caligonellidae	*Neognatus* sp.	0	0	0	12	**12**	2.4
Cheyletidae	*Cheletomimus* (*H.*) *bakeri*	0	3	0	0	**3**	0.6
	Cheletomimus (*Cheletomimus*) *duosetosus*	0	0	0	4	**4**	0.8
	Cheletomimus (*Hemicheyletia*) *darwinia*	2	0	0	0	**2**	0.4
Cunaxidae	*Cunaxatricha* n. sp.	1	6	0	0	**7**	1.4
	Cunaxoides sp.	1	0	0	0	**1**	0.2
	Neoscirula n. sp.	0	0	1	0	**1**	0.2
Eriophyidae	*N. gen.*	0	60	1	65	**126**	25.6
Eupalopsellidae	*Eupalopsellus* sp.	1	0	0	0	**1**	0.2
Eupodidae	*Eupodidae* gen. nov	3	1	1	0	**5**	1.0
Glycyphagidae	*Lepidoglyphus* sp.	1	0	0	1	**2**	0.4
Iolinidae	*Parapronematus* sp.	1	4	6	8	**19**	3.9
	Pseudopronematus sp.	1	4	0	0	**5**	1.0
Oribatida	Oribatida	0	1	1	2	**4**	0.8
Phytoptidae	*Retracrus johnstoni*	10	0	0	0	**10**	2.0
Phytoseiidae	*Amblyseius* n. sp.2	0	0	0	14	**14**	2.8
	Amblyseius n. sp.3	15	0	12	0	**27**	5.5
	Amblyseius n. sp.4	0	1	0	0	**1**	0.2
	Amblydromalus n. sp.	1	0	0	0	**1**	0.2
	Arrenoseius n. sp.	6	0	0	0	**6**	1.2
	Euseius alatus	0	0	1	0	**1**	0.2
	Iphiseiodes zuluagai	5	1	0	0	**6**	1.2
	Leonseius regularis	12	3	1	0	**16**	3.2
	Metaseiulus (*Metaseiulus*) n. sp.1	5	0	2	0	**7**	1.4
	Metaseiulus (*M.*) *ferlai*	1	1	0	3	**5**	1.0
	Proprioseiopsis neotropicus	1	0	0	0	**1**	0.2
	Typhlodromalus aripo	2	0	0	0	**2**	0.4
	Typhlodromus (*Typhlodromus*) n. sp.	2	0	0	0	**2**	0.4
	Immature	11	2	4	0	**17**	3.4
Stigmaeidae	*Agistemus* n. sp.1	0	0	1	0	**1**	0.2
	Agistemus brasiliensis	1	0	0	0	**1**	0.2
	Zetzellia aff. *quasagistemas*	1	2	0	1	**4**	0.8
Tarsonemidae	*Tarsonemus* sp.2	1	0	0	2	**3**	0.6
Tenuipalpidae	*Brevipalpus* sp.1	0	0	0	1	**1**	0.2
	Brevipalpus sp. 2	0	0	0	1	**1**	0.2
	Tenuipalpus bacuri	11	24	0	12	**47**	9.5
	Immature	1	0	0	16	**17**	3.4
Tetranychidae	*Tetranychus urticae*	4	0	2	0	**6**	1.2
Triophtydeidae	*Triophtydeus* sp.1	2	1	0	2	**5**	1.0
	Triophtydeus sp.2	0	0	2	0	**2**	0.4
	Immature	0	0	2	1	**3**	0.6
Tuckerellidae	*Tuckerella ornata*	40	6	10	0	**56**	11.4
Tydeidae	*Brachytydeus* n. sp. 1	0	0	3	0	**3**	0.6
	Brachytydeus sp. 2	1	2	0	2	**5**	1.0
	Pretydeus n. sp.	9	0	1	0	**10**	2.0
	Pseudolorryia sp.	0	0	2	0	**2**	0.4
	Tydeus sp.	4	0	0	8	**12**	2.4

	Augusto Corrêa		**Bragança**	
	Dry	Rainy	Dry	Rainy
Diversity				
Richness	34	17	20	18
Abundance	161	122	55	155
Dominance	0.09	0.29	0.11	0.21

Shannon-Wiener	2.83	1.81	2.56	2.07
Uniformity	0.50	0.35	0.64	0.44
Equitability	0.80	0.63	0.85	0.71

Note: N: total number of mites sampled for the corresponding taxon; %: relative percentage of species.

Table 2. Mite species em bacuri with significant contribution to NMDS ordination based on community structure in the Dry and Rainy periods (Figure 2D).

Species	**p-value**
Amblyseius n. sp.2	0.01
Neognatus sp.	0.01
Amblyseius n. sp.3	0.02
Leonseius regularis	0.02

Table 3. Mite species em bacuri with significant contribution to NMDS ordination based on community structure in Augusto Corrêa and Bragança (Figure 3D).

Species	**p-value**
Amblyseius n. sp.2	0.01
Amblyseius n. sp.3	0.01
Neognatus sp.	0.01
Leonseius regularis	0.03

7 DISCUSSÃO GERAL

O levantamento identificou espécies-chave que podem ser tanto benéficas quanto prejudiciais nas culturas do açaí, bacuri, cacau e cupuaçu na região Nordeste do Pará, Amazônia. A diversidade e a abundância de ácaros encontrados nas quatro culturas analisadas revelam que os ácaros são componentes importantes dos ecossistemas agrícolas e naturais da região, influenciando diretamente a saúde das plantas e a qualidade das produções.

O estudo revelou uma grande diversidade de ácaros, tanto fitófagos quanto predadores, presentes nas plantas das culturas avaliadas. A presença de ácaros fitófagos pertencente às famílias Eriophyidae, Phytoptidae, Tarsonemidae, Tenuipalpidae, Tetranychidae e Tuckerellidae destaca a necessidade de monitoramento constante, visto que esses ácaros podem causar danos significativos às folhas e frutos, afetando a produtividade. Por outro lado, os ácaros predadores desempenham papel crucial no controle natural das populações de pragas, o que sugere que práticas de manejo agroecológico, como a preservação de *habitats* para esses ácaros benéficos, podem ser eficazes para manter o equilíbrio ecológico nas plantações. Assim como mostrado em outros estudos, os ácaros fitófagos são encontrados em grupos de plantas de Arecaceae no Brasil, sendo mais diversos aqueles da superfamília Eriophyoidea (FLECHTMANN 1994, 1998, FLECHTMANN & SANTANA 1997, SANTANA & FLECHTMANN 1998; SANTANA *et al* 1994; GONDIM Jr. *et al*. 2000).

A região Nordeste do Pará apresenta características climáticas que influenciam diretamente a dinâmica das populações de ácaros. A umidade relativa e as temperaturas elevadas podem favorecer a proliferação de ácaros fitófagos, especialmente em períodos de seca, quando as plantas ficam mais suscetíveis a estresses ambientais. Além disso, os períodos de chuva intensa podem alterar as populações de ácaros, tanto pela remoção física das pragas quanto pelo aumento na abundância de predadores naturais. Estudo realizado com a cultura do coqueiro (*Cocos nucifera*) no estado do Pará por De Alfaia *et al*. (2023) mostra uma associação positiva entre Phytoseiidae e a temperatura, onde temperaturas mais elevadas aumentam a prevalência destes ácaros.

O impacto dos ácaros nas culturas de cacau, açaí, cupuaçu e bacuri é multifacetado. No caso do cacau, por exemplo, a infestação de ácaros pode comprometer a quantidade das sementes, como mostrado no primeiro artigo desta tese, além de reduzir a vigorosidade das plantas. No açaí e no cupuaçu, embora os danos causados por ácaros fitófagos ainda sejam pouco estudados, há evidências de que a interação com esses organismos pode afetar o desenvolvimento da planta e a qualidade dos frutos como mostra De Alfaia *et al.* (2023) a quantidade de ácaros em frutos de coqueiros (*Cocus nucifera* L.) com ácaros fitófagos *Acéria guerreironis* Keifer.

O levantamento realizado é uma base importante para o futuro desenvolvimento de estratégias de manejo e conservação das culturas na região. No entanto, é fundamental que pesquisas adicionais sejam feitas para entender melhor as interações entre os ácaros e as diferentes famílias de frutíferas nativas, além dos impactos de diferentes práticas agrícolas na dinâmica dessas populações. A variabilidade entre os microclimas dentro da região e a diversidade genética das espécies de plantas cultivadas também devem ser consideradas para um manejo mais preciso e adaptado às condições locais.

O levantamento de ácaros nas frutíferas nativas da região Nordeste do Pará trouxe importantes contribuições para o entendimento das dinâmicas ecológicas locais. O estudo não apenas ampliou o conhecimento sobre as populações de ácaros, mas também destacou a importância de adotar práticas de manejo integrado de pragas para promover a sustentabilidade das culturas. Investimento contínuo em pesquisa e o aprimoramento das técnicas de manejo são fundamentais para a promoção de uma agricultura mais sustentável e adaptada à realidade da região.

8 CONSIDERAÇÕES FINAIS

O levantamento realizado sobre os ácaros em frutíferas nativas da região Nordeste do Pará proporcionou uma visão detalhada da diversidade e das dinâmicas populacionais desses organismos, além de contribuir para o entendimento dos impactos que eles podem causar nas culturas locais. Os resultados mostraram uma rica diversidade de espécies de ácaros nas frutíferas nativas, com destaque para aquelas associadas a condições específicas do período seco e chuvoso e a práticas agrícolas. As espécies encontradas possuíam diferentes comportamentos ecológicos, o que implica em abordagens diferenciadas para o manejo de suas populações.

O estudo evidenciou que a presença de ácaros nas frutíferas nativas pode afetar tanto a produtividade quanto a saúde das plantas, sendo necessário um monitoramento constante para entender as variações sazonais e ambientais que influenciam a dinâmica dos ácaros fitófagos.

O controle sustentável de ácaros em frutíferas nativas pode contribuir para a conservação dos ecossistemas locais e para a promoção de sistemas agrícolas mais resilientes. Isso se alinha com os Objetivos de Desenvolvimento Sustentável (ODS), da Organização das Nações Unidas (ONU), especialmente no que tange à agricultura sustentável (ODS 2) e à conservação da biodiversidade (ODS 15). Assim, esta pesquisa contribui para o entendimento da bioecologia dos ácaros em frutíferas nativas e abre caminhos para o desenvolvimento de estratégias de manejo mais eficientes e sustentáveis, alinhadas aos desafios ambientais e sociais da região Nordeste do Pará.

No final deste trabalho sobre a bioecologia de ácaros em frutíferas nativas da região Nordeste do Pará, a pesquisa não só trouxe contribuições com conhecimento científico e com possíveis inovações práticas para o manejo de pragas e a preservação ambiental, mas também fortalece a pesquisa na região Amazônica e potencializa o desenvolvimento profissional do pesquisador. O impacto dessa pesquisa pode ser sentido tanto no meio acadêmico quanto na sociedade, refletindo-se em políticas públicas, práticas agrícolas mais sustentáveis e benefícios econômicos para as comunidades locais.

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APÊNDICE

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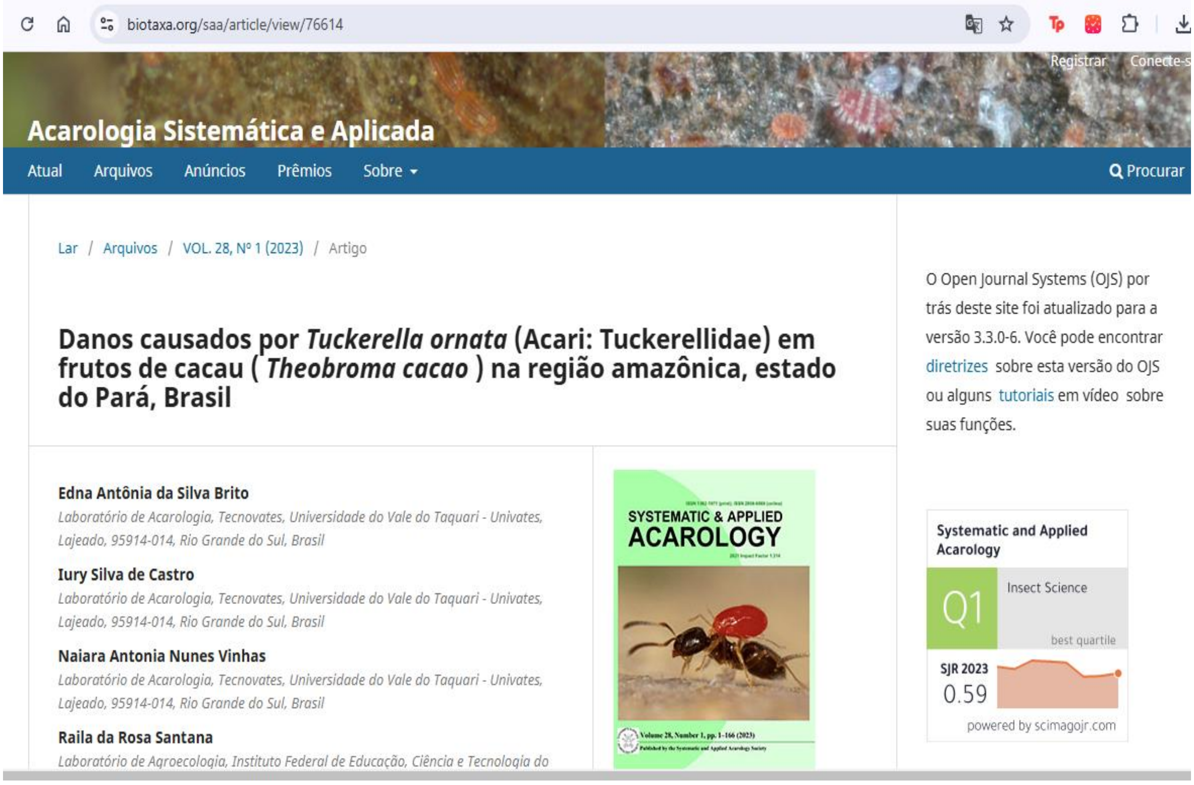
Artigo publicado pela Revista Systematic & Applied Acarology– (CAPES A3)

DOI: https://doi.org/10.11158/saa.28.1.2



Danos causados por *Tuckerella ornata* (Acari: Tuckerellidae) em frutos de cacau (*Theobroma cacao*) na região amazônica, estado do Pará, Brasil

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Systematic & Applied Acarology 28(1): 11–19 (2023)
https://doi.org/10.11158/saa.28.1.2

ISSN 1362-1971 (print)
ISSN 2056-6069 (online)

Article

Damage caused by *Tuckerella ornata* (Acari: Tuckerellidae) on cocoa fruits (*Theobroma cacao*) in the Amazon region, state of Pará, Brazil

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Abstract

The study aimed to report peacock mites (Acari: Tuckerellidae) on cocoa fruits (*Theobroma cacao* L.; Malvaceae) in the northeast Bragantina region, state of Pará, Brazil. Two mite species were identified, *Tuckerella ornata*, with 149 specimens, 32.89% on leaves and 67.11% on fruits, and *Tuckerella knorri*, with only two specimens on leaves. It was found that green fruits with *T. ornata* significantly reduced the size and weight of seeds. More attacked fruits, with more severe damage, showed deformations and thick cracks. Significant damage was noted in the *Forastero* cocoa seeds, visible to the naked eye, with light brown spots and a fine crack on the epidermis.

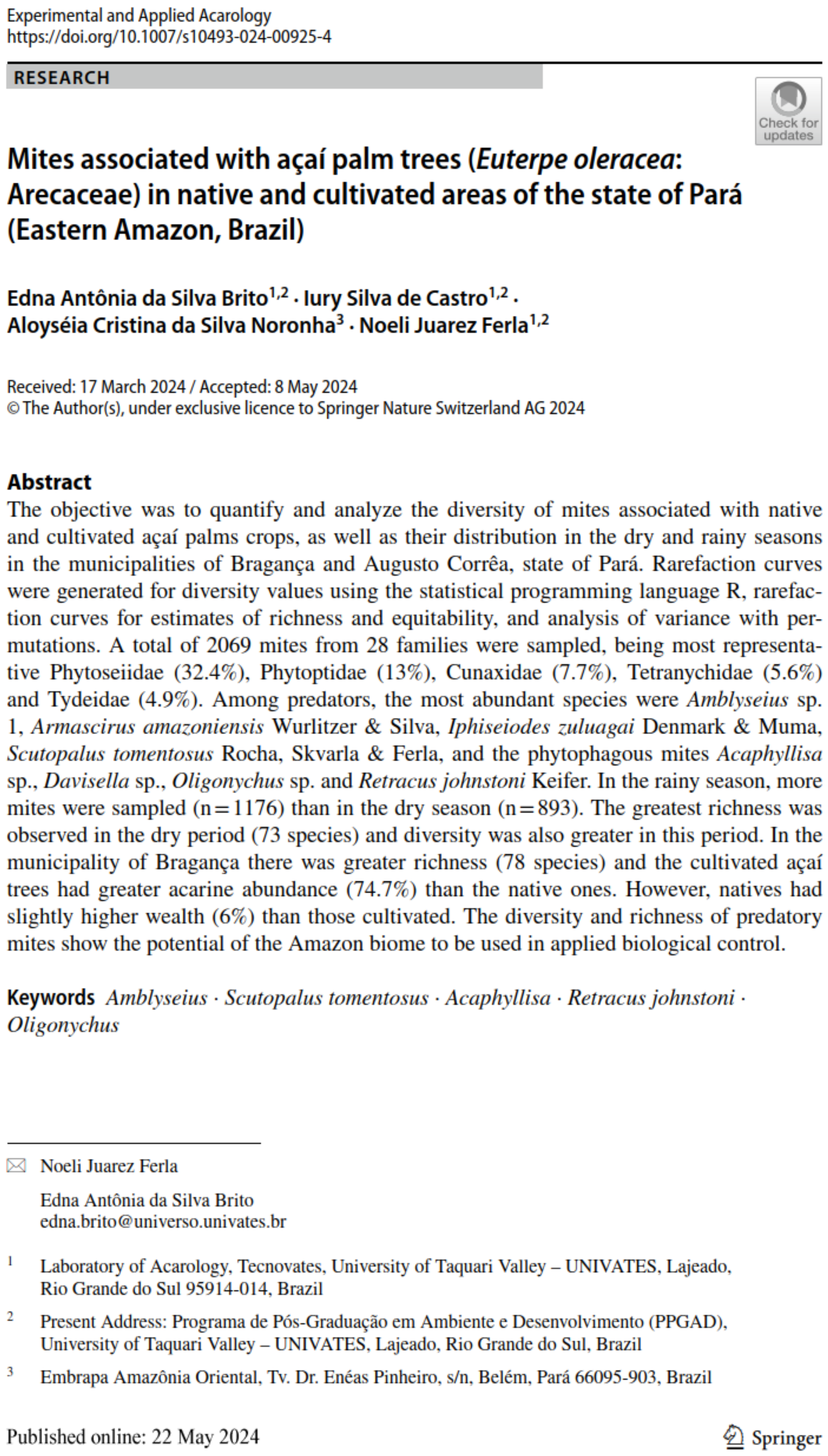
keywords: Cocoa seeds, Tuckerellid mites, *Tuckerella knorri*, Peacock mites

Introduction

Brazil is the 7th largest producer of cocoa (*Theobroma cacao* L.; Malvaceae) in the world, and the state of Pará is the largest producer in the country, with 144,700 tons in an area of 149,700 hectares (IBGE, 2021). The cocoa fruit has economic importance for the Amazon region and generates income for family producers and cooperatives in the region. It is a commodity in demand in the international market to supply not only the food sector, mainly chocolate, but also the fertilizer, cosmetics, cleaning, and animal feed sector (Filgueira 2002; Chepote 2003).

In the Brazilian cocoa culture, mite families Eriophyidae, Tetranychidae, and Tuckerellidae have been reported. Only two species of phytophagous mites have been reported from cultivation in the state of Bahia: *Aceria reyesi* (Nuzacci) (Eriophyidae) and *Tetranychus mexicanus* (McGregor) (Tetranychidae) (Maia & Valverde 2017; De Carvalho *et al.* 2018). In the amazon region, *Tuckerella ornata* (Tucker) (Tuckerellidae) was cited in Belém do Pará (Flechtmann 1979b). Eleven species of spider mites have already been associated with this plant worldwide (Migeon & Dorkeld, 2011–2019).

Tuckerellidae, peacock mites, is a family with only 32 species, all belonging to the single genus *Tuckerella* (Krantz & Walter 2009; Khadem & Asadi 2017; Escobar-Garcia *et al.* 2022). They are ornamented mites with rows of four to seven pairs of long caudal arrows in the pygidial region, Artigo publicado pela **Revista Experimentaal and Applied Acarology** – (CAPES A2)



Experimental and Applied Acarology
https://doi.org/10.1007/s10493-024-00925-4

RESEARCH

Mites associated with açaí palm trees (*Euterpe oleracea*: Arecaceae) in native and cultivated areas of the state of Pará (Eastern Amazon, Brazil)

Edna Antônia da Silva Brito[1,2] · Iury Silva de Castro[1,2] · Aloyséia Cristina da Silva Noronha[3] · Noeli Juarez Ferla[1,2]

Received: 17 March 2024 / Accepted: 8 May 2024

Abstract

The objective was to quantify and analyze the diversity of mites associated with native and cultivated açaí palms crops, as well as their distribution in the dry and rainy seasons in the municipalities of Bragança and Augusto Corrêa, state of Pará. Rarefaction curves were generated for diversity values using the statistical programming language R, rarefaction curves for estimates of richness and equitability, and analysis of variance with permutations. A total of 2069 mites from 28 families were sampled, being most representative Phytoseiidae (32.4%), Phytoptidae (13%), Cunaxidae (7.7%), Tetranychidae (5.6%) and Tydeidae (4.9%). Among predators, the most abundant species were *Amblyseius* sp. 1, *Armascirus amazoniensis* Wurlitzer & Silva, *Iphiseiodes zuluagai* Denmark & Muma, *Scutopalus tomentosus* Rocha, Skvarla & Ferla, and the phytophagous mites *Acaphyllisa* sp., *Davisella* sp., *Oligonychus* sp. and *Retracus johnstoni* Keifer. In the rainy season, more mites were sampled (n = 1176) than in the dry season (n = 893). The greatest richness was observed in the dry period (73 species) and diversity was also greater in this period. In the municipality of Bragança there was greater richness (78 species) and the cultivated açaí trees had greater acarine abundance (74.7%) than the native ones. However, natives had slightly higher wealth (6%) than those cultivated. The diversity and richness of predatory mites show the potential of the Amazon biome to be used in applied biological control.

Keywords *Amblyseius* · *Scutopalus tomentosus* · *Acaphyllisa* · *Retracus johnstoni* · *Oligonychus*

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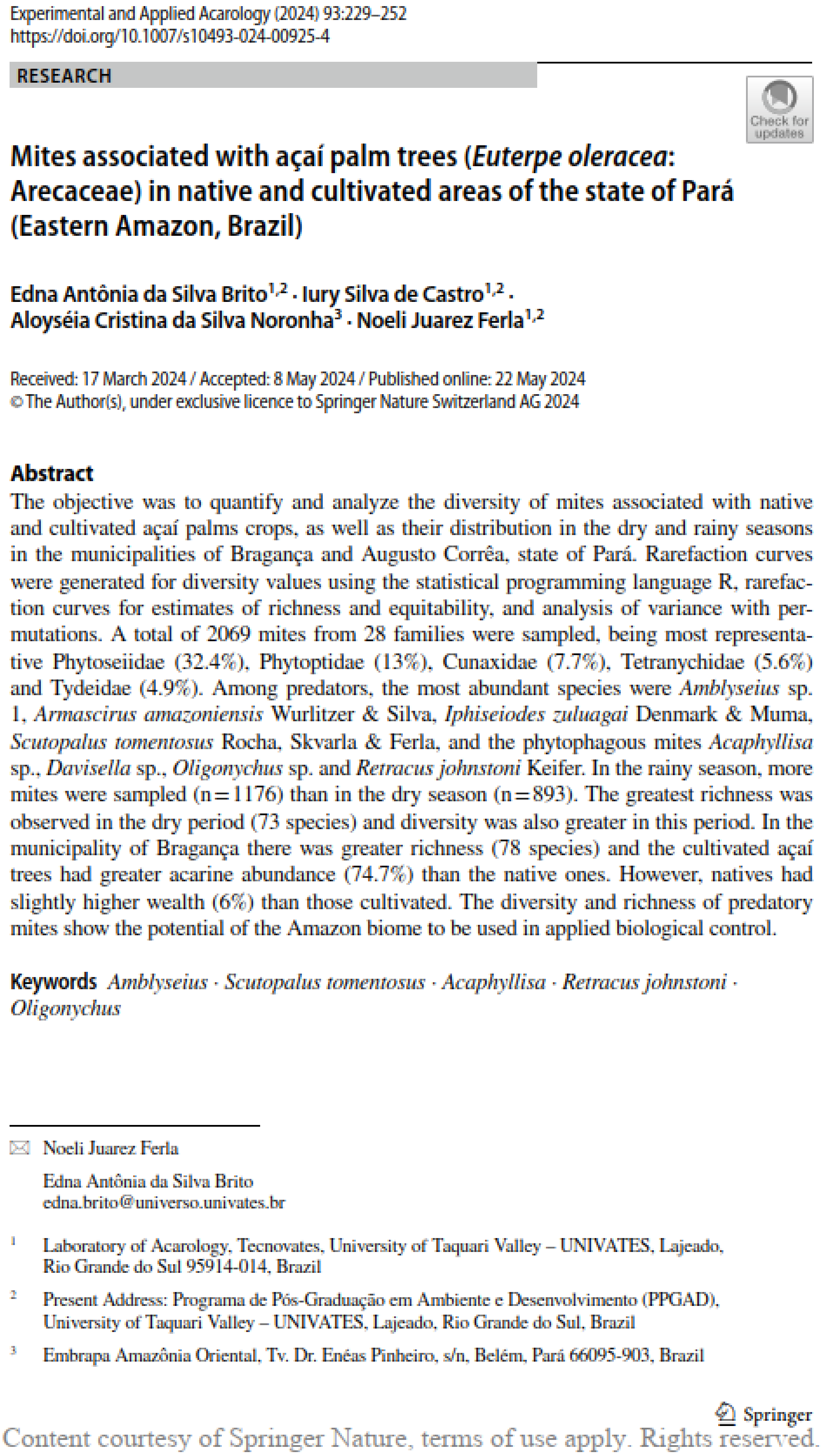

Experimental and Applied Acarology (2024) 93:229–252
https://doi.org/10.1007/s10493-024-00925-4

RESEARCH

Mites associated with açaí palm trees (*Euterpe oleracea*: Arecaceae) in native and cultivated areas of the state of Pará (Eastern Amazon, Brazil)

Edna Antônia da Silva Brito[1,2] · **Iury Silva de Castro**[1,2] ·
Aloyséia Cristina da Silva Noronha[3] · **Noeli Juarez Ferla**[1,2]

Received: 17 March 2024 / Accepted: 8 May 2024 / Published online: 22 May 2024

Abstract

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Artigo aceito pela Revista **Acarologia Sistemática e Aplicada** – (CAPES A3)

International Journal of Acarology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/taca20

Mite diversity of cupuaçu trees (*Theobroma grandiflorum*: Malvaceae) in the state of Pará, Amazon, Brazil

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To cite this article: Edna Antônia da Silva Brito, Lury Silva de Castro, Naiara Antônia Nunes Vinhas, Aloyséia Cristina da Silva Noronha & Noeli Juarez Ferla (26 Dec 2024): Mite diversity of cupuaçu trees (*Theobroma grandiflorum*: Malvaceae) in the state of Pará, Amazon, Brazil, International Journal of Acarology, DOI: 10.1080/01647954.2024.2441883

To link to this article: https://doi.org/10.1080/01647954.2024.2441883

INTERNATIONAL JOURNAL OF ACAROLOGY
https://doi.org/10.1080/01647954.2024.2441880

Mite diversity of cupuaçu trees (*Theobroma grandiflorum*: Malvaceae) in the state of Pará, Amazon, Brazil

Edna Antônia da Silva Brito[a], Lury Silva de Castro[a], Naiara Antônia Nunes Vinhas[a], Aloyséia Cristina da Silva Noronha[b] and Noeli Juarez Ferla[a]

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ABSTRACT

The aim of this study was to identify the mite fauna associated with cupuaçu plantations in Bragança and Augusto Corrêa, Pará, Brazil. In order to investigate the variability and composition of these organisms in cupuaçu plantations in two different locations, systematic collections were carried out at specific times throughout two periods. In addition to mite collection, environmental data such as temperature, relative humidity, atmospheric pressure and precipitation were recorded. Statistical data were obtained through sampling effort and diversity, Hill's diversity profile and nonmetric multidimensional scaling (NMDS). A total of 868 mites belonging to 53 species were sampled. Seventeen families/suborders of mites were identified, the five most abundant being: Eriophyidae (44.7%), Phytoseiidae (21.1%), Cunaxidae (9%), Oribatida (5.5%) and Tenuipalpidae (3.5%). The data indicated a greater number of mites sampled during the rainy season compared to the dry season, representing approximately 90% more mites in the rainy season. Greater richness was observed during the dry season, with 38 taxa identified. Bragança contributed a total of 551 individuals, while Augusto Corrêa recorded 317 mites. For the Shannon- Wiener index, the municipalities presented similar diversity. Therefore, we highlight the importance of these results for understanding the mite community associated with cupuaçu trees.

ARTICLE HISTORY
Received 1 July 2024
Accepted 5 December 2024

KEYWORDS
Eriomacrotergum flechtmanni; *Gynaecoecia cupuassu*; *Agistemus amazonicus*; cupuaçu

Introduction

The cupuaçu plant, *Theobroma grandiflorum* (Willd. Ex Spreng.) K. Schum. (Malvaceae), is a fruit species of great importance to the Amazon region due to its value both as fresh and industrialized fruit (Falcão and Lleras 1983). Native to the Amazon region, this species is still being domesticated for large-scale cultivation. (Cavalcante 2010). In Brazil, its production is concentrated in the North region, in the states of Acre, Pará and Rondônia (Fraife Filho et al. 2009). Cupuaçu tree planting in the state of Pará is mostly combined with other crops, making it more profitable for rural producers, especially for family farming, indigenous people and small producers . As it is an ombrophilous species, cupuaçu orchards adapt well to single crops, in temporary or permanent consortiums in different arrangements, resulting in greater efficiency in soil use, increasing the economics generated by shaded or intercropped crops. These characteristics allow this crop to be used as one of the main components of agroforestry systems in the North region (Gasparotto et al. 1997; Carvalho et al. 1999).

Studies on the mite fauna associated with cupuaçu cultivation in the state of Pará are limited. However, there are already studies evaluating plant species from other botanical families in the North region, such as Arecaceae (Navia and Flechtmann 2005; Reis et al. 2012, 2014; Cruz et al. 2015, 2019; De Alfaia et al. 2023; Ferreira et al. 2023), Euphorbiaceae (Feres 2001), Malpighiaceae (Noronha et al. 2020), Malvaceae (Flechtmann 1979; Oliveira et al. 2012; Oliveira and Navia 2013; Sousa et al. 2018; Escobar-Garcia et al. 2021; Brito et al. 2023).

To date, few studies have been carried out evaluating the mite fauna associated with cupuaçu cultivation. There are reports of eriophyids described in plant species of the genus *Theobroma*: *Aceria reyesi* (Nuzzaci) and *Floracarus theobromae* Keifer (*Theobroma cacao* L.: Malvaceae), *Gynaecoecia cupuassu* Oliveira, Rodrigues & Flechtmann, in cupuaçuzeiro in the state of Bahia and *Eriomacrotergum flechtmanni* Rodrigues, Návia & Oliveira on cupuaçu leaves in the state of Amazonas (Rodrigues et al. 2016), *Agistemus amazonicus* Paktinat-Saeij, Bagheri & Noronha in cupuaçu in Pará state. *Aceria reyesi*, the cocoa bud mite, considered an emerging agricultural pest in the states of Bahia and Rondônia (Oliveira and Navia 2013). The first report of *A. reyesi*, in Rondônia, was made at the Ouro Preto Experimental Station (ESTEX-OP), of the Executive Committee of the Cocoa Crop Plan – CEPLAC, in the municipality of Ouro Preto do Oeste, where the occurrence of Eriophyoidea mites associated with cocoa crops for the production of hybrid seeds was observed and, above all, in the ESTEX-OP germplasm bank, where severe damage was observed in the form of shortening of internodes and death of terminal branches (Trevisan et al. 2012). Among the families of predatory mites that have potential in the biological control of pests in plants are: Anystidae, Ascidae, Bdellidae, Cheyletidae, Cunaxidae, Laelapidae, Macrochelidae, Phytoseiidae, Rhodacaridae and Stigmaeidae (de 2002; Carrillo et al. 2015).

In order to understand the diversity of mite species in cupuaçu crops in the state of Pará, predatory and phytophagous mites associated with cupuaçu were identified, expanding knowledge of local diversity and enabling future management actions in the cupuaçu. Thus, this study aimed to understand the mite diversity associated with cupuaçu crops in cultivated areas in the municipalities of Bragança and Augusto Corrêa, in the Bragantina microregion, state of Pará.

Materials and methods

Study area

The study was carried out in two cupuaçu cultivation areas in the Bragantina microregion, northeastern Pará state. The collections were carried out in 2021 to 2022, covering the months of September, October and December (2021) for the dry period,

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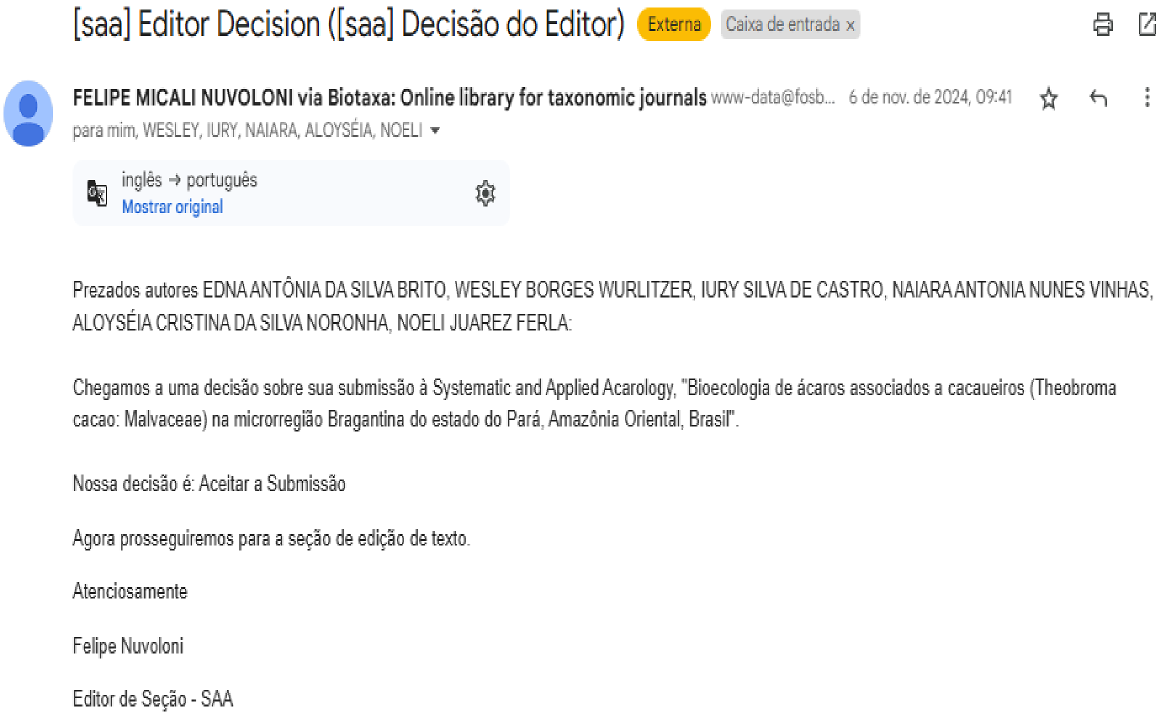

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Chegamos a uma decisão sobre sua submissão à Systematic and Applied Acarology, "Bioecologia de ácaros associados a cacaueiros (Theobroma cacao: Malvaceae) na microrregião Bragantina do estado do Pará, Amazônia Oriental, Brasil".

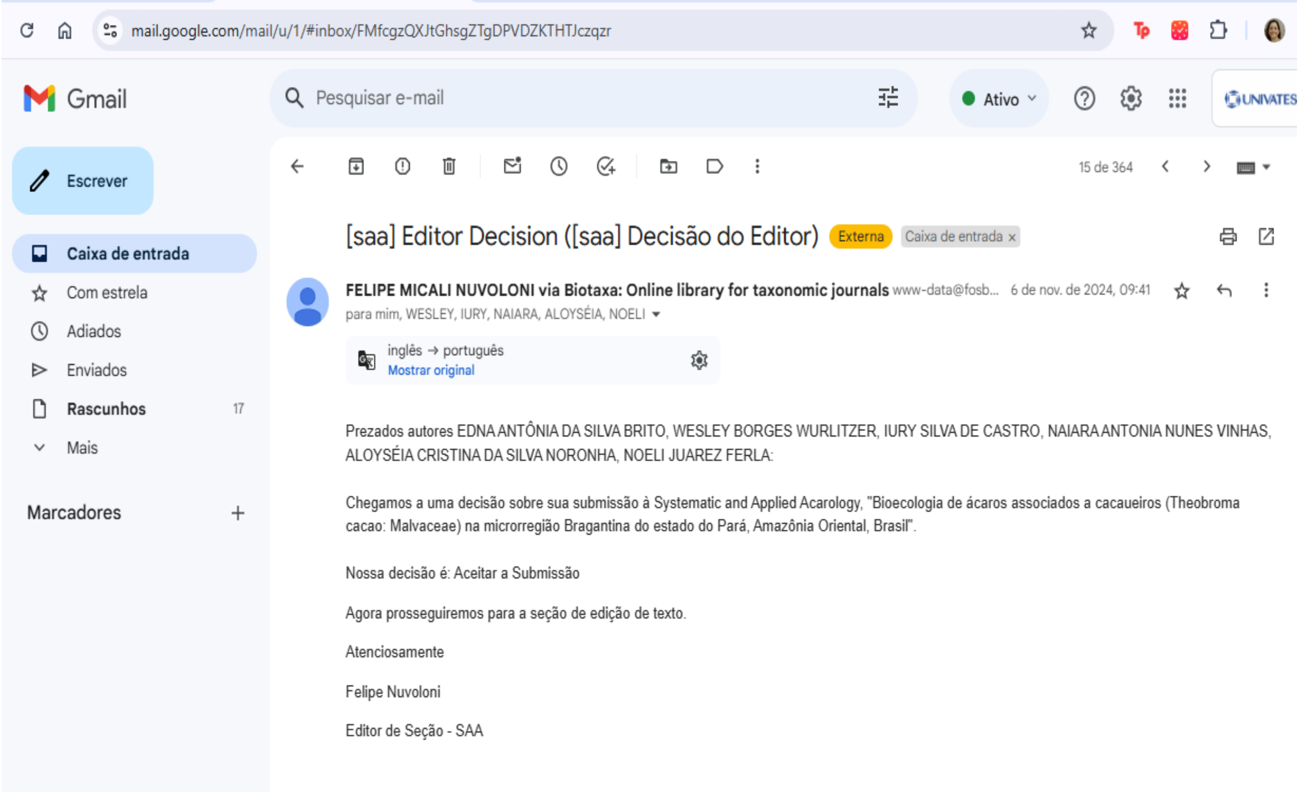
Nossa decisão é: Aceitar a Submissão

Agora prosseguiremos para a seção de edição de texto.

Atenciosamente

Felipe Nuvoloni

Editor de Seção - SAA



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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.

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