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ECOLOGY, BEHAVIOR AND BIONOMICS

Diversity of hemipterans in *Eucalyptus* spp. plantations in southeastern pará, Eastern Amazon, Brazil

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Abstract

Brazil has 10.2 million hectares of reforestation, which account for 81% of the timber produced in the country. The order Hemiptera contains the main phytophagous species. The study of population surveys allows the analysis of faunal composition, resource availability, as well as potential pests in future plantations, contributing to sustainable pest management. The objective of this study was to evaluate the diversity of insects of the order Hemiptera in *Eucalyptus* spp. plantations in southeastern Pará, Eastern Amazon. Yellow adhesive traps were used to collect entomofauna, with 12 collections in total, (6) during the dry season and (6) during the rainy season. A total of 28 traps were installed in areas with clones of *Eucalyptus urophylla*, *Eucalyptus grandis* and *Eucalyptus urograndis*, in three municipalities in Pará. The insects collected were analyzed through the faunal indices of abundance,constancy, dominance and frequency, and diversity of Shanon and Pielou. Principal component analysis (PCA) revealed the families that most influenced the different climatic seasons and in the different clones of *Eucalyptus* spp. A total of 18.320 individuals were collected, distributed in 24 families. The greatest abundance was observed in the dry season, influencing the seasonality of the families that presented the highest faunal indices. Cicadellidae presented high indices in the three clones, highlighting the clone *E. urograndis* with the greatest diversity of insects and richness of families, during the dry season, which demonstrates the strong preference of the families for the season and for this species, and indicates a great risk of becoming a potential pest in future commercial plantations, monitoring and preventive actions are recommended to mitigate the impact of these species.

Keywords Phytophagous species · Population surveys · Seasonality · Forest plantations · Hemiptera · Richness

Introduction

Brazil has 10.2 million hectares of reforested areas, which account for 81% of the wood produced in the country (IBA 2024; IBGE 2022). Of this total, 7.8 million hectares are allocated to eucalyptus cultivation, covering 76% of the entire planted area (IBA 2024). The main factor contributing to the rapid growth of this sector has been the establishment of new plantations in industrial projects, mainly in the pulp and paper segment (ABRAF 2013; IBA 2024).

The Brazilian forestry sector, comprised of the pulp, paper, charcoal, sawn timber, panels and particleboard industries, has been gaining prominence in the national economy. It is currently the world's largest exporter of pulp, with 24.3 million tons and earnings of US$ 7.9 billion (Silveira et al. 2001; IBA 2024). In addition, the value of Brazilian forestry production totaled R$ 27 billion, with a growth of 14.9% (IBGE 2022).

Eucalyptus is one of the main exotic species used for reforestation due to its rapid growth. In the 1980s, the government encouraged the planting of this species in the Amazon region (Ferreira and Silva 2004). Today, the state of Pará has been expanding its production area, with a total of

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175,125 thousand ha (IBA 2024) and shows great potential for the expansion of the forest-based sector, with the municipalities located in the southeast region of the state being the main producers of *Eucalyptus* spp. (Lunz and Azevedo 2016).

However, eucalyptus production is limited by the incidence of native pests, such as ants, termites, caterpillars and defoliating beetles, as well as by the emergence of new native and exotic pests that are introduced, such as psyllids, cicadas, microwasps and stink bugs (Gallo et al. 2002; Santos et al. 2008; Lunz and Azevedo 2016). Studies on insect diversity in *Eucalyptus* spp. plantations in the state of Pará have been carried out (Saliba et al. 2019a,b), but none have focused on the diversity of insects of the order Hemiptera.

The order Hemiptera has 10.700 described species and includes many primary phytophagous species, sap-sucking insects, that affect eucalyptus plantations in Brazil (Costa et al. 2014; Lemes and Zanuncio 2021a). Hemiptera have stylet-like mouthparts that can inject hydrolyzing or solidifying toxins capable of damaging leaf or stem tissues, causing tissue distortions or abnormalities in plant growth. In addition, they can transmit viruses or plant diseases to plants (Gallo et al. 2002; Gullan and Craston 2012).

Important species of exotic pest species of hemiptera frequently attack eucalyptus plantations, with emphasis on *Blastopsylla occidentalis* Taylor e *Glycaspis brimblecombei* Moore (Aphalaridae) e *Thaumastocoris peregrinus* Carpintero e Dellapé (Thaumastocoridae) (Lemes et al. 2021a, b, c). Other important ones are predatory bugs of the genus *Podisus spp.* Herrich-Schäffer, for example *P. nigrolimbatus* Spinola, *P. nigrispinus* Dallas e *P. connexivus* Bergroth, of the family Pentatomidae, predators of beetles and defoliating caterpillars of *Eucalyptus* spp. (Zanuncio et al. 2006, 2014; Nascimento et al. 2017; Ribeiro et al. 2021).

Insect diversity in commercial forest plantations is questioned due to the presence of few or only one exotic forest species, which are preferred by insect pests. According to Lemes and Zanuncio et al. (2021), extensive areas with *Eucalyptus* spp. monocultures can become attractive habitats for insect pests, such as the bronze bug. However, monocultures can also present an increase in insect diversity due to the availability of food, breeding sites and shelters for the occurrence of insects and pests (Lemes and Zanuncio et al. 2021b).

The study of population surveys using capture traps allows the analysis of faunal composition, resource availability, comparison of resource exploration methods and analysis of similarity of areas regarding the presence or absence of insects, as well as potential predictions for future plantations, contributing to sustainable management planning (Magurran 2004; Ferreira 2014; Garlet et al. 2016). Aiming at contributing to and advancing scientific population prospecting, this study aimed to evaluate the diversity of insects of the order Hemiptera and obtain information on the periods of greatest population incidence in *Eucalyptus* spp. plantations in southeastern Pará, Eastern Amazon.

Materials And Methods

Study Area

This study was conducted in 28 commercial plantation areas distributed in the municipalities of Paragominas (2° 59′ 51" S and 47° 21′ 13" W), Dom Eliseu (04º 17′ 48″ S and 47º 33′ 24″ W) and Ulianópolis (03º 45′ 32″ S and 47º 29′ 26″ W), where each area had on average approximately 500 ha, with *Eucalyptus urophylla*, *Eucalyptus grandis* and *Eucalyptus urograndis* (hybrid clone), aged between 1 and 6 years, in the Eastern Amazon, southeast of the state of Pará, Brazil.

The natural vegetation of the areas near the plantations was classified as a Dense Ombrophilous Forest of upland (IBGE 2012; FAPESPA 2023). The soils were classified as Red Yellow Latosol, clayey texture, flat and gently undulating relief, dystrophic Yellow Latosol and petric Plinthosol, with a predominance of rugged relief (EMBRAPA 2013; FAPESPA 2023). The samples were collected in two periods (2015 and 2016), The climate in the study areas is of the Awi type, tropical rainy with a well-defined dry season, according to the Köppen classification. Average air temperatures ranged from 25 °C to 28 °C, characterizing high average temperatures during the years of study (Fig. 1), rainfall with annual rainfall regimes ranging from 2.250 mm to 2.500 mm, with an annual average of 1,802 mm for the region; the region has a rainy season from January to May and a dry season from July to November, with a relative humidity of 85% (Gonçalves et al. 2008; SIPAM 2009; FAPESPA 2023).

Insect Collection and Identification

Twenty-eight standardized yellow sticky traps (23 × 11 cm) with 2.0 × 2.0 cm grid lines on both sides (ISCA brand) were used for collection. Each trap was georeferenced (Serafim et al. 2011) and positioned between two trees, 1.60 m above the ground and 100 m from the edge of the plantation. Six collections were carried out each period/year during the years 2015 and 2016, totaling 12 annual collections. The method for capturing aerial insects associated with eucalyptus was the same used for detecting psyllids, bronze bugs and gall wasps, which recommends the use of yellow sticky capture traps placed between the trees in the plantation to sample these insect pests (Santana 2005; IPEF 2011; Barbosa et al. 2012). Each trap remained in the planting areas for one month, being collected and packaged in transparent plastic bags and sent to the Entomology Laboratory of Embrapa Amazônia Oriental, Belém, Pará. Trap sorting was performed based on the sampled area, and insect identification was performed at the family level using a stereoscopic magnifying glass and illustrated taxonomic keys (Fujihara 2016).

Faunal Analysis, Diversity Index and Guilds

The insects collected were analyzed using faunistic indices (dominance, frequency, abundance, constancy and diversity indices) to identify the predominant species in the traps. The ANAFAU software was used for the analyses (Moraes et al. 2003).

Dominance was defined as species with a frequency greater than 1/S, where S represents the species richness in the sampled area. The species were categorized as: Non-dominant (ND), Dominant (D) and Superdominant (SD).

The frequency (F) was calculated by adding the data from the monthly collections and then determining the percentage of individuals of each species in relation to the total number collected. The frequency distribution suggested by Silveira-Neto et al. (1976), was adopted: F = N/T × 100. Where, F = Frequency; N = Total number of individuals of each species captured; T = Total number of individuals captured. The confidence interval (CI) of the mean with 5% probability was determined, according to the classification: Very frequent (VF): number of individuals greater than the upper limit of the CI of 5%; Frequent (F): number of individuals within the CI of 5% and Uncommon (FF): number of individuals less than the lower limit of the CI of 5% (Fazolin 1991).

Abundance (A) was determined using the dispersion means suggested by Silveira Neto et al. (1976), through the standard deviation, standard error of the mean and confidence interval (CI), applying the "t" test at probability levels of 5% and 1%.The following abundance classes were established: Rare (r): number of individuals less than the lower limit of the CI at 1% probability; Dispersed (de): number of individuals located between the lower limits of the CI at 5% and 1% probability; Common (c): number of individuals located within the CI at 5% probability; Abundant (a): number of individuals located between the upper limits of the CI at 5% and 1% probability; and very abundant (va): number of individuals greater than the upper limit of the CI at 5% probability (Dajoz 1983).

Constancy (C) was calculated based on the percentage of occurrence of the species present in each sample of the survey (Silveira-Neto et al. 1976): $C = P/N \times 100$. Where: C = constancy; p = number of collections containing the species; N = total number of collections performed. The following classes were adopted: Constant species (W)—present in more than 50% of the collections; Accessory species (Y)—present in 25 to 50% of the collections and Accidental species (Z)—present in less than 25% of the collections (Dajoz 1983).

For the diversity indices, the Richness were calculated (*S*) obtained by the absolute number of species observed in the community by planting *Eucalyptus* spp., the Shannon diversity index (*H'*) which analyzes the diversity of insects collected in traps, being one of the most used, and estimates the specific diversity expressing the heterogeneity of insects in plantations (Magurran 1988). The higher the value of *H'*, the greater the diversity of the community studied, as obtained by the following relationship: $H' = -\sum pi.logpi$. Where: H' = Shannon diversity index, pi = ni/N; ni = number of sampled individuals of the i-th species. N = total number of sampled individuals.

O Pielou's evenness index (*J*), derived from Shannon's diversity index, measures the evenness of species distribution within the community. This index estimates evenness

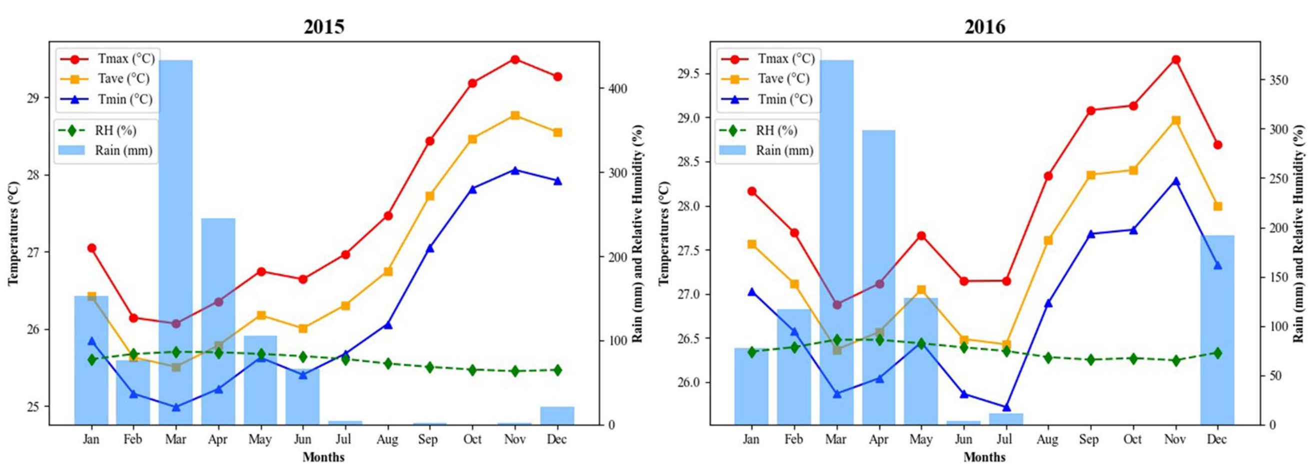

Fig. 1 Temperatures (°C), precipitation (mm) and relative humidity (%) in 2015 and 2016, southeastern Pará, Eastern Amazon. Source: INMET (2016)

from the abundance of individuals among species in the evaluated community, referring to how individuals are distributed among species (Magurran 2004). Its value ranges from 0 (minimum evenness) to 1 (maximum evenness), where the higher the value of J, the greater the evenness of the community studied among existing species and can be obtained by the equation (Pielou 1966; Gomide et al. 2006): $J' = H'/H'_{max}$. Where, H' = Shannon diversity index; $H'max$ = Maximum diversity index. The diversity of a community is maximum if S = N or if the N/S ratio is approximately constant. It is determined by the following equation: $H'max = ln(S)$, where, S = total number of species sampled; ln = Naperian logarithm.Guilds were defined based on criteria such as taxonomy, trophic preference, nesting habits and behavior.

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Statistical Analysis

The data were subjected to Principal Component Analysis (PCA) to identify the insect families with the greatest influence on the first principal component, based on their factor loadings. The families with the highest factor loadings were those that contributed the most to the variability explained by this component, highlighting their influence on the different climatic seasons and on the *Eucalyptus* spp. clones. This approach allowed a better understanding of the relationship between insect families and specific environmental conditions. All analyses were performed using the statistical software R (version 4.3.3, R Core Team 2024).

Results

Qualitative and Quantitative Analysis

A total of 18.320 individuals were collected, distributed in 24 families (Table 1). Of this total, 11.835 (*64.6%*) were found in the rainy season and 6.485 individuals (*35.4%*) in the dry season, representing the largest number of insects collected for the two years of collection. The families Cicadellidae (*70.9%*), Aphididae (*5.47%*), Thaumastocoridae (*5.2%*), Aphalaridae (*4.79%*), Psyllidae (*4.06%*), Membracidae (*3.58%*) and Cercopidae (*2.91%*) presented the largest number of individuals present in both periods and in years of collection (Tabela 1).

When evaluating the different clones individually, the hybrid clone *E. urograndis* presented the highest number of insects collected, 11.459 (*62.55%*), distributed in 23 families. The clone *E. urophylla* presented 4.776 (*26.07%*) individuals, distributed in 21 families, while *E. grandis* presented the lowest number of insects, 2.085 (*11.38%*), distributed in 16 families (Table 1). It is worth mentioning that the family Cicadellidae presented the highest number of insects collected in all clones evaluated throughout the two years of the study.

The Cicadellidae family showed high levels of dominance, abundance, frequency and constancy, being found in more than *50%* (W) of the collections in the plantations for all three *Eucalyptus* spp. clones studied (Table 1). It was classified as superdominant, superabundant, superfrequent and constant.

The families Aphalaridae, Aphididae, Membracidae and Psyllidae presented significant indices and were classified as dominant, very abundant, very frequent and constant for the clones *E. urophylla* and *E. urograndis,* while in *E. urograndis* these indices were different (Table 1). For *E. grandis*, only the families Aphididae, Cercopidae and Thaumastocoridae presented the same indices of dominance, abundance, frequency and constancy.

The families Largidae, Pyrrhocoridae, Scutelleridae and Tingidae were dominant and presented variations in different levels of abundance, frequency and constancy for the three clones. However, the family Largidae presented lower rates only in *E. grandis* (Table 1). In relation to the other families collected, they did not obtain significant rates for dominance, abundance, frequency and constancy in the different clones of *Eucalyptus* spp.

For the Shannon diversity index (*H'*) and evenness index (*J'*), the *Eucalyptus* spp. clones did not show differences, presenting significantly similar values. The *E. urograndis* clone stands out for presenting the greatest diversity of insects, with the greatest richness of families, having 23 of the 24 families found (Table 2).

The difference between the upper and lower limits of the confidence interval is small (0.002) and the same for all three clones evaluated, suggesting that the faunal indices calculated for the *Eucalyptus* spp. species are accurate and reliable. These results may suggest that the community is well represented in the data and that the families related to these indices are occupying dominant or frequent roles in these plantations, with little variation in their (Table 2).

The families with the highest abundance in each clone were identified and the pattern of occurrence throughout the study years and climatic periods was evaluated. A predominance of insects collected in the dry period was observed, with the family Cicadellidae being particularly dominant in both study years. Notably, the number of Cicadellidae insects increased considerably during the dry period in all clones and study years (Fig. 2), with a total abundance of 12.989 individuals, 8.939 (*68.82%*) in the dry period and 4.050 (*31.18%*) in the rainy period. In 2015, the abundance of Cicadellidae increased by *40.79%* in *E. urophylla* (Fig. 2a), *51.46%* in *E. urograndis* (Fig. 2b) and *40.8%* in *E. grandis* (Fig. 2c) compared to the rainy period. A similar pattern was observed in 2016, with

Table 1 Dominance (D), Abundance (A), Frequency (F), Constancy (C) and percentage of insects collected from the order Hemiptera, in the years 2015 and 2016 in plantations of *E. urophylla*, *E. urograndis* and *E. grandis* in southeastern Pará, Eastern Amazon, Brazil

Families	Clones															TIC[6]	%
	E. urophylla					*E. urograndis*					*E. grandis*						
	NI[1]	D[2]	A[3]	F[4]	C[5]	NI	D	A	F	C	NI	D	A	F	C		
Alydidae	8	D	r	FF	Z	0	-	-	-	-	0	-	-	-	-	8	0.04
Aphalaridae	404	D	va	VF	W	463	D	va	VF	W	11	D	d	FF	Y	878	4.79
Aphididae	376	D	va	VF	W	532	D	va	VF	W	94	D	va	VF	W	1.002	5.47
Berytidae	2	ND	r	FF	Z	7	D	r	FF	Y	0	-	-	-	-	9	0.05
Cercopidae	158	D	a	VF	W	218	D	a	VF	W	157	D	va	VF	W	533	2.91
Cicadellidae	2.945	SD	sa	SF	W	8.571	SD	sa	SF	W	1.473	SD	sa	SF	W	12.989	70.9
Cicadidae	3	ND	r	FF	Z	2	ND	r	FF	Z	0	-	-	-	-	5	0.03
Coreidae	0	-	-	-	-	1	ND	r	FF	Z	0	-	-	-	-	1	0.01
Delphacidae	4	ND	r	FF	Z	11	D	r	FF	Z	3	ND	r	FF	Z	18	0.10
Dictyopharidae	2	ND	r	FF	Z	5	ND	r	FF	Y	5	-	-	-	-	12	0.07
Flatidae	0	-	-	-	-	1	ND	r	FF	Z	0	-	-	-	-	1	0.01
Fulgoridae	0	-	-	-	-	7	D	r	FF	Z	0	-	-	-	-	7	0.04
Gerridae	5	ND	r	FF	Z	4	ND	r	FF	Y	0	-	-	-	-	9	0.05
Largidae	29	D	d	FF	W	61	D	c	F	W	41	ND	r	FF	Z	117	0.72
Lygaeidae	5	ND	r	FF	Z	6	D	r	FF	Z	4	-	-	-	-	15	0.08
Membracidae	234	D	va	VF	W	309	D	va	VF	W	112	D	c	F	W	655	3.58
Miridae	3	ND	r	FF	Z	13	D	r	FF	Z	1	ND	r	FF	Z	17	0.09
Pentatomidae	4	ND	r	FF	Z	6	D	r	FF	Y	2	ND	r	FF	Z	12	0.07
Psyllidae	353	D	va	VF	W	337	D	va	VF	W	53	D	c	F	W	743	4.06
Pyrrhocoridae	35	D	c	F	W	53	D	c	F	W	22	D	c	F	W	110	0.60
Reduviidae	2	ND	r	FF	Z	3	ND	r	FF	Z	0	-	-	-	-	5	0.03
Scutelleridae	20	D	d	FF	W	113	D	c	F	W	13	D	d	FF	Y	146	0.80
Thaumastocoridae	160	D	a	VF	W	716	D	va	VF	W	76	D	va	VF	Y	952	5.2
Tingidae	24	D	d	FF	W	20	D	d	FF	W	18	D	c	F	Y	62	0.34
TIC	4.776	-	-	-	-	11.459	-	-	-	-	2.085	-	-	-	-	18.320	100
NFC[7]	21	-	-	-	-	23	-	-	-	-	16	-	-	-	-	-	-
%CI[8]	26.07	-	-	-	-	62.56	-	-	-	-	11.38	-	-	-	-	-	100

[1]*NI* Number of insects collected per family in each clone, [2]*D* dominant, *ND* non dominant, *SD* Super dominant, [3]*sa* super abundant, *va* very abundant, *a* abundant, *c* common, *de* dispersed, *r* rare, [4]*SF* Super frequent, *VF* Very frequent, *F* frequent, *FF* somewhat frequent, [5]*W* Constant species, *Y* Accessory species, *Z* Accidental species, [6]*TIC* total number of insects collected, [7]*NFC* Number of families collected, [8]*%CI* percentage of insects collected per clone (confidence interval)

increases of *37.64%* in *E. urophylla* (Fig. 2d), *26.14%* in *E. urograndis* (Fig. 2e), and *3.59%* in *E. grandis* (Fig. 2f).

The Aphalaridae family presented the highest number of insects collected during 2015 for the three clones and in 2016 this pattern was maintained only in *E. urophylla*. In *E. urograndis* and *E. grandis*, this family presented the highest abundance of insects in the rainy season, with an increase of *48.96%* and *33.34%* respectively, in relation to the dry season (Fig. 2e, 2f).

The Aphididae family presented a similar behavior, with the highest number of insects collected during the rainy season in 2015 for the *E. urophylla* clone, with an increase of *56.57%*, and in 2016 for the *E. urograndis* and *E. grandis* clones, with increases of *37.29%* and *74.19%* respectively (Fig. 2a, e, f). For Cercopidae, the occurrence pattern varied for the two years of study in the evaluated clones (Fig. 2), while the Membracidae family maintained a similar collection pattern in both years of study, with the highest number of individuals collected in the dry season (Fig. 2).

The Psyllidae family presented the highest number of insects collected in the dry season during 2015 for the three clones evaluated, with an increase ranging from *74%* to *94.33%*. However, in 2016, the opposite behavior was observed, with the highest number of insects collected in the rainy season for the three clones, with an increase ranging from *8.75%* to *23.47%* (Fig. 2d, e, f).

Guilds

The guilds were formed for the families with greater abundance, being separated into two suborders within the order Hemiptera, Sternorrhyncha and Auchenorrhyncha, and by size: large and small. In Sternorrhyncha, the guild of small insects was classified, including the families Aphalaridae, Psyllidae and Aphididae (Table 3). And for the suborder Auchenorrhyncha, large insects belonging to the families Cicadellidae and Membracidae, such as the guild of sucking leafhoppers (Table 4).

Principal Component Analysis (PCA)

Principal component analysis for the climate seasons was performed by analyzing the database of families collected in the study, explained *79.6%* of the existing variability and revealed two principal components, which explain that the first principal component (PC1) is responsible for *50.7%* of the multidimensional variation of the entire data set evaluated, while the second component (PC2) is responsible for *28.9%* (Fig. 3a). The variance was mainly influenced by the families Miridae, Delphacidae, Scutelleridae, Cicadellidae, Membracidae, Pyrrhocoridae and Lygaeidae, all with positive eigenvalues and which contributed significantly to the dry season, distinguishing it from the rainy season. In other words, the occurrence of one may be associated with the emergence of another with similar biological behavior, favored by the dry season.

Among the clones studied, *E. urograndis* presented the greatest family similarity, with the greatest positive contributions from the families collected during the dry season, indicating a relationship between these insects and plantations of this species in southeastern Pará (Fig. 3b).

Table 2 Faunistic indices for clones of *Eucalyptus* spp. in southeastern Pará, Eastern Amazon, Brazil

Faunistic indices	*E. urophylla*	*E. urograndis*	*E. grandis*
Shannon index (H')	2,03	2,08	2,10
Richness index (S)	2,52	2,64	2,18
Evenness index (J')	0,68	0,68	0,77
CI	2,031–2,033	2,085–2,087	2,098–2,10

**CI* Confidence Interval ($p = 0.05\%$)

Discussion

Qualitative and Quantitative Analysis

This study investigated the diversity and abundance of insects of the order Hemiptera in *Eucalyptus* spp. plantations located in southeastern Pará, Eastern Amazon. The results indicated a greater abundance of insects during the dry season, particularly among the families Cicadellidae, Aphalaridae, Psyllidae, Aphididae and Thaumastocoridae,

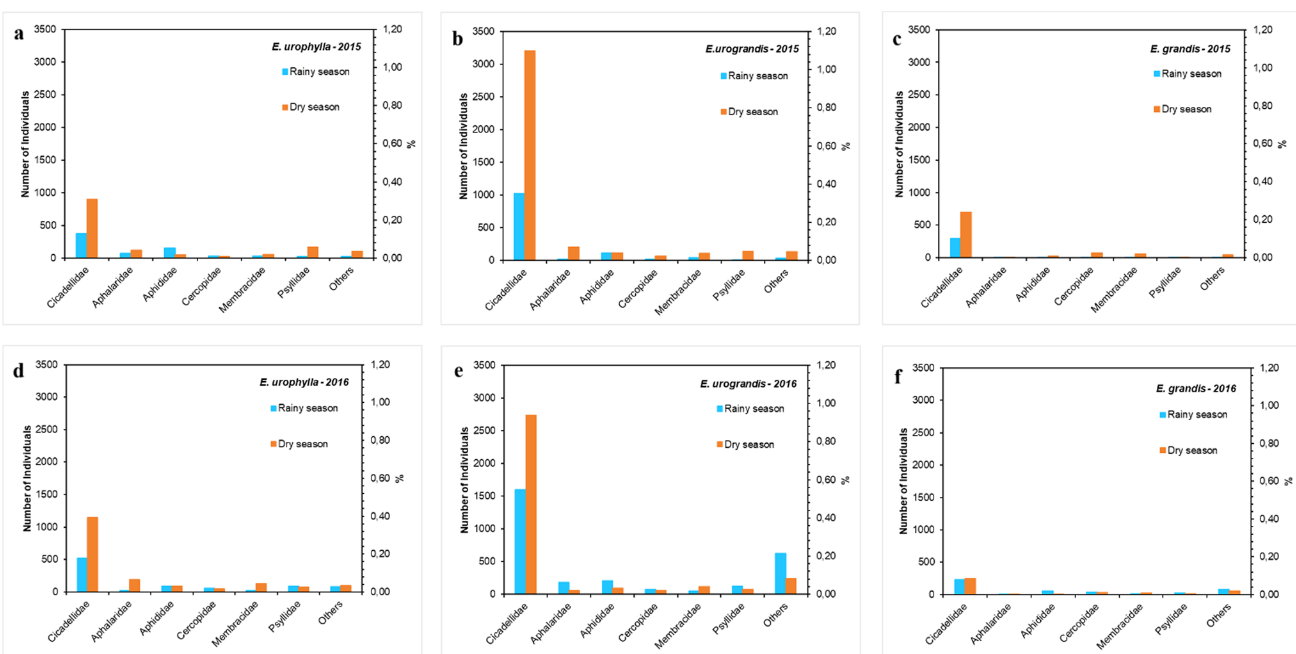

Fig. 2 Number of individuals and percentage of families collected during the dry and rainy seasons in 2015 and 2016 in commercial areas of *Eucalyptus* spp. in southeastern Pará, Eastern Amazon, Brazil, (**a**) 2015 – clone *E. urophylla,* (**b**) 2015 – clone *E. urograndis*, (**c**) 2015 – clone *E. grandis*, (**d**). 2016 – clone *E. urophylla*, (**e**). 2016 – clone *E. urograndis* and (**f**). 2016 – clone *E. grandis*

Table 3 Relationship of families of the suborder Sternorrhyncha by guild in different clones of *Eucalyptus* spp. in southeastern Pará, Eastern Amazon, Brazil

Suborder	Superfamily	Family	Guild	Description of Guilds
Sternorrhyncha	Psylloidea Psylloidea	Aphalaridae Psyllidae	Small insects	Small species, ranging from 1 mm to about 10 mm in length Phytophagous insects, with a feeding habit: sucking and excreting honeydew, favoring the occurrence of sooty mold Plant pests of economic interest: they cause damage to plants, with significant losses in production Found on abaxial part of the leaves in large populations
	Aphidoidea	Aphididae		Small species, ranging from 1 mm to about 10 mm in length Phytophagous, polyphagous insects, with feeding habits: sucking and excreting honeydew, favoring the occurrence of sooty mold The population is numerous and is found on leaves, branches, stems, roots and rarely on leaves and flowers Pests of plants of economic interest: they cause damage to plants, with significant losses in production

Source: Gallo et al. (2002); Costa et al. (2014); Wolff et al. (2024)

which exhibited the highest faunal indices for the three clones of *Eucalyptos* spp. Other families such as Miridae, Delphacidae, Scutelleridae, Cicadellidae, Membracidae, Pyrrhocoridae and Lygaeidae stood out as similar in occurrence during the dry season to the clone *E. urograndis*.

Previous faunal surveys in *Eucalyptus* spp. plantations by Dorval et al. (2010) and Garlet et al. (2016) similarly identified Hemiptera as the most abundant order. Nsabimana (2013) reported high family diversity within the order Hemiptera in *Eucalyptus* spp. plantations in southern Rwanda, Africa, emphasizing the ability of the order to exploit multiple nutritional resources in forest ecosystems. Mendel and Prosatov (2019) highlighted that the order Hemiptera is seen more frequently in *Eucalyptus* spp. plantations, corroborating the results found in the present study for the three clones evaluated. According to Penteado et al. (2014), noted that sap-sucking insects due to their feeding behavior and interactions with other organisms, are prevalent in forest plantations. These insects can exploit available resources, potentially causing both direct and indirect damage to crops. The relative abundance of families such as Aphalaridae (878 individuals), Aphididae (1,002), Cercopidae (533), Cicadellidae (12,989), Psyllidae (743), Thaumastocoridae (952), and Membracidae (655) across both climatic seasons reflects the significant number of individuals collected from *Eucalyptus* spp. clones over the two-year period.

The clones studied presented the Cicadellidae family with the highest index of collected individuals, classified as an indicator species according to the faunal indices. It is important to highlight that the indicator families of the set of insects collected in each clone were those families that obtained greater prominence in the faunal indices in relation to the others (Silveira-Neto et al. 1995). Gonzaga et al. (2021) found the Cicadellidae family with high indices of dominance, abundance, frequency and constancy in *E. urograndis* clones, corroborating the present study; however, no records of cicadellids causing damage to *Eucalyptus* spp. plantations in Brazil were found.

Table 4 Relationship of families of the suborder Auchenorrhyncha by guild in different clones of *Eucalyptus* spp. in southeastern Pará, Eastern Amazon, Brazil

Suborder	Infraorder	Family	Guild	Description of Guilds
Auchenorrhyncha	Cicadelloidea	Cicadellidae	Large insects	Length ranges between 2 to 30 mm among the specimens collected Known as leafhoppers or leafhoppers Phytophagous, polyphagous insects that feed on phloem sap. They are found on leaves or branches Vectors of phytopathogens and cause damage to plants
	Membracoidea	Membracidae		The length varies between 2 and 12 mm in length among the specimens collected Phytophagous, polyphagous insects that feed on phloem sap. They are found on leaves or branches Vectors of phytopathogens and cause damage to plants

Source: Gallo et al. (2002); Costa et al. (2014); Takiya et al. (2024)

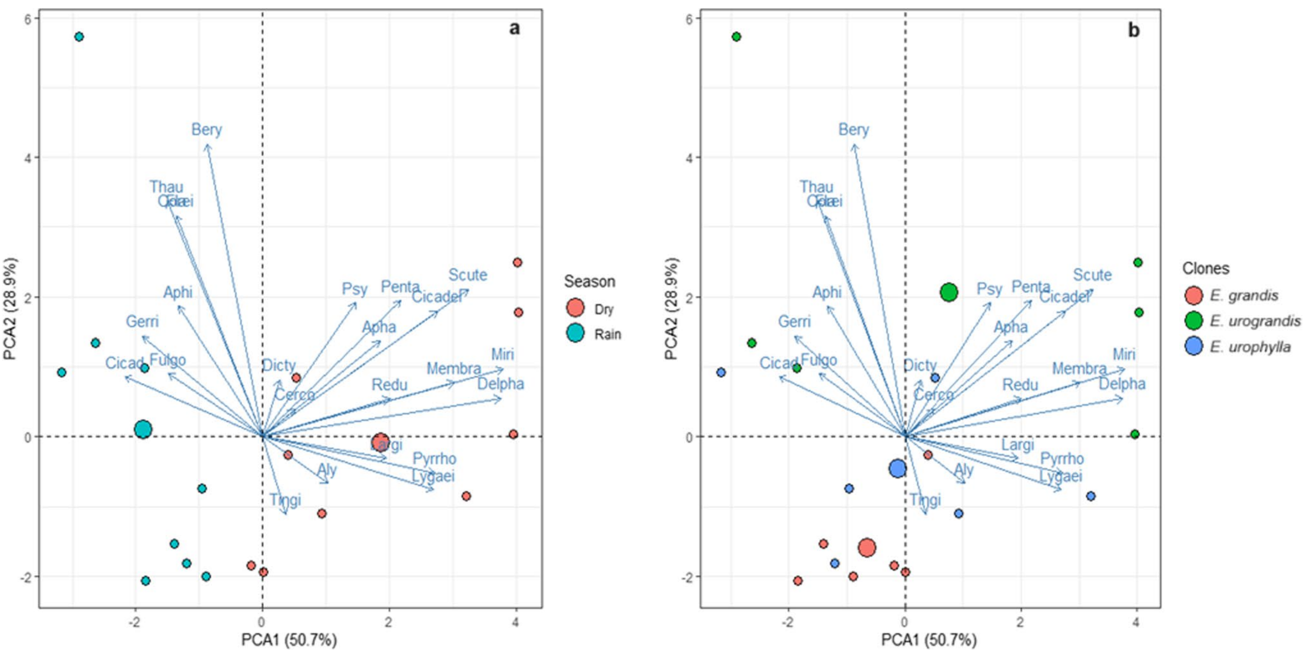

Fig. 3 PCA for analysis of similarity between insect families of the order Hemiptera. **a** PCA of insect families collected in the different climatic seasons, dry (orange circle) and rainy (blue circle) and (**b**) PCA of insect families collected, in the dry season, according to each clone of *Eucalyptus* spp., being *E. grandis* (orange circle), *E. urograndis* (green circle) and *E. urophylla* (blue circle), in southeastern Pará, Eastern Amazon, Brazil

The families Aphalaridae, Aphididae, Psyllidae and Thaumastocoridae are known to have important insect pests for *Eucalyptus* spp. crops (Lunz and Azevedo 2016). The main exotic pests described for eucalyptus in Brazil, with high dispersion, are the shell psyllid, the bronze bug and the gall wasp, belonging to the families Aphalaridae, Thaumastocoridae and Eulophidae (Hymenoptera), respectively (Wilcken 2003; Wilcken 2010; Soliman 2014; Saliba et al. 2019a, b).

The clones *E. urophylla* and *E. urograndis* presented a greater number of collected insects belonging to the Aphalaridae family, which includes the pest psyllids, *B. occidentalis* Taylor and *G. brimblecombei* Moore (Aphalaridae). These have specificity with their hosts, mainly with the species of the genus *Eucalyptus* spp., *E. urophylla*, *E. camaldulensis*, *E. urograndis* and the genus *Corymbia* for *B. occidentalis* (Burckhardt et al. 2014; Penteado et al. 2014; Queiroz et al. 2018; Saliba et al. 2019a; Barreto et al. 2020; Dal Pogetto et al. 2024). Saliba et al. (2019a) described these species in *Eucalyptus* spp. plantations in the state of Pará and Camargo et al. (2014), in a similar study, highlighted an increase in the population of *G. brimblecombei* in months of little or no precipitation, corroborating this study.

The Thaumastocoridae family presented the largest number of insects collected in *E. urograndis*. It is important to highlight the specificity of the insect pest *T. peregrinus* Carpintero & Dellapé, with clones of *E. urophylla* and *E. grandis*, these being important hosts for the development and reproduction of this pest (Soliman 2012; Lemes et al. 2021a, b, c). This species was described in the state of Pará in surveys of eucalyptus plantations, with a peak population of the species in the dry season (Saliba et al. 2019b), corroborating the present study. *T. peregrinus* causes direct damage to trees, such as changes in canopy color (bronze appearance) and defoliation, which can lead to plant death (Lunz and Azevedo 2016).

The families Largidae, Pyrrhocoridae and Tingidae were present in the three eucalyptus clones evaluated and belong to a group of generalist predatory insects that feed on the hemolymph of adult insects and larvae (Mora-Estrada et al. 2017) and are considered effective biological pest control agents (Abreu et al. 2015). The occurrence of these families in the eucalyptus plantations evaluated may be associated with the feeding habits of these insects, acting as indicators of a possible occurrence of insect pests in the plantations. It is necessary to emphasize the need for studies on the diversity of insects belonging to this suborder in forest crops. The families described above, including the Scutelleridae family, which presented the largest number of insects collected in the *E. urograndis* clone, comprise species belonging to the suborder Heteroptera, encompassing bugs with broad feeding habits, classified as phytophagous, predatory or hematophagous (Gallo et al. 2002; Gullan and Craston 2012; Panizzi and Grazia 2015).

Root (1973) describes that specialist herbivores tend to remain in less diverse habitats, with high concentrations of host species that provide the resources necessary for their maintenance. Thus, monocultures of *Eucalyptus* spp. that have only one host species may present a greater abundance of insect species, corroborating the present study, where homogeneous plantations of *E. urograndis*, *E. urophylla* and *E. grandis* presented high diversity of families. Plantations with *Eucalyptus* spp. species covering vast areas and long cultivation periods may favor the abundance and diversity of arthropods (Murdoch et al. 1972; Zanuncio et al. 1989). For Gullan and Craston (2012), the quality of the available food has a dominant influence on the abundance of insects and the damage they cause; according to the authors, the quality of the food of hybrid clones is higher than that of the parental plants and has greater nutritional value.

The order Hemiptera includes herbivorous and phytophagous insects, including agricultural and forestry pests, with the ability to inject toxins into plants or transmit viruses, which can harm plant growth in the short or long term (Gullan and Cranston 2012). This group of insects can cause diseases causing damage ranging from direct to indirect to plants (Gullan and Cranston 2012; Grazia et al. 2024). Direct damage includes growth abnormalities and induction of galls or retardation in plant development (Gullan and Craston 2012). While indirect damage involves the release of sugary feces (honeydew), produced by scale insects, aphids and psyllid nymphs, which serve as food for the fungus *Capnodium elaeophilum* Motagne, causing sooty mold that covers leaves or fruits, providing photosynthesis and plant development (Huerta et al. 2010; Gullan and Craston 2012; Spodek et al. 2015; Queiroz et al. 2021). The reflection of insect forecasts is expected to be a constant threat to the productivity of *Eucalyptus* spp. monocultures, causing often irreversible economic damage to the plantation (Barbosa et al. 2014).

The low expressivity of individuals collected from other families may be related to the occurrence of a substitution in the faunal composition, where some groups prefer homogeneous areas and others prefer more heterogeneous areas (Ferreira and Marques 1998), and there may not be a significant difference in the abundance of these insect families. According to Silveira-Neto et al. (1995), many rare species compared to a small number of abundant species are acceptable in a monoculture. Species with this distribution pattern can perform specific functions, and in situations of environmental change, they easily adapt to the new environment, maintaining community life, which is the great advantage of diversity (Silveira-Neto et al. 1976).

Forest plantations, consisting of a single species in large areas and cultivated for long periods, can result in a reduction in local biodiversity mainly due to the loss of habitats and greater incidence of sunlight between fragments, characterizing them as simplified or less complex ecosystems (Thomazini and Thomazini 2000; Costa and Araldi 2014). Meanwhile, in areas of native forests, there is an ecological formation with different specific niches in the different plant stratifications, causing significant changes in the dynamics of animal populations, as they present a greater diversity of flora and fauna (Viana et al. 1992; Costa and Araldi 2014).

For family diversity and richness, the clone *E. urograndis* presented the highest values, which may be related to the greater number of indicator families found in this clone, mainly in relation to the abundance of insects collected from the Cicadellidae family, which contributed with the largest number of individuals collected. The Shannon index (*H'*) indicates that this clone is susceptible to the occurrence of these families. A similar study carried out by Purspasari et al. (2021) presented Shannon indices with values ranging from 1.71 to 2.38 in clones of *E. alba* and *E. urophylla*, and Garlet et al. (2016) with values ranging from 2.3 to 2.33 in the survey of species diversity in *E. dunnii*, *E. grandis* and *E. grandis* x *E. urophylla* (hybrid clone), corroborating the present study. Magurran (2011) highlighted that the highest values for the diversity index H' can be influenced by the increase in species richness and the uniformity of the values of the collected samples.

The richness (*S*) of the families was similar for the three clones, with more expressive values for the clone *E. urograndis*. The richness index in studies of insect diversity in population surveys reflects the biological richness of the environment, which is favorable to the development of natural communities of individuals. The increasing increase in insects is due to the adaptation to these crops, resulting from the abundance of food and the decrease in the diversity of natural enemies (Cantarelli and Costa 2014).

For the equitability index (*J'*), the clones *E. urophylla* e *E. urograndis* (*0,68*) presented values similar to the clone *E. grandis* (*0,77*), indicating that these plantations present uniformity in the distribution of families. Balanced environments promote the greatest number of species, as well as biological interactions between the individuals that inhabit such ecosystems. This uniformity can be explained by the possible absence of predators or competing individuals in these forest monoculture environments (Saliba et al. 2021).

Other factors such as temperature and humidity contribute to the distribution of species, impacting the development, behavior, and feeding of the present insect populations. During the collection periods, the temperature ranged from 26ºC to 28ºC, and humidity from 80 to 85% (Fig. 1). According to Rodrigues (2004), temperature can directly influence the increase in insect populations and their development; the optimal temperature range varies between 15 and 38ºC, with 25ºC being the optimal temperature, while humidity ranges from 40 to 80%. The seasonality of insects, subject to climate variations, is important for Neotropical systems, since the availability of resources for herbivorous insects is a determining factor for the distribution of these individuals (Araújo 2013). For Silva et al. (2011), temperature, relative humidity and precipitation are climatic variables with a strong influence on the seasonal pattern of tropical insects.

In the dry season, which coincides with the period of higher temperatures and lower rainfall, a greater abundance of collected insects was recorded. Penteado et al. (2014) relates this fact to the lower rainfall regime and, consequently, greater availability of food and the dispersion capacity of the species, favoring their introduction and establishment. It should be noted that periods of intense rainfall can have a direct negative effect on small insects and, to a greater extent, on larger insects, reducing the population levels of these individuals (Costa et al. 2014), corroborating the present study.

The Cicadellidae family presented the highest number of insects collected during the dry season, which may be associated with their ability to regulate body temperature, favoring their bioecology and better development, and may present two or more generations per year (Silveira-Neto et al. 1976; Takiya et al. 2024). This fact is relevant, as these conditions favor the rapid development of heliothermic insects, capable of regulating their body temperature based on the incidence of sunlight for better development (Silveira-Neto et al. 1976).

Therefore, it is possible that the high temperature in *Eucalyptus* spp. plantations influenced the greater abundance of these insects in the dry season, suggesting frequent sampling of this family, as they can become pests within the plantations. Costa et al. (2022) highlighted that populations of insects that live in native areas, close to plantations, can reach pest status and cause direct damage to *Eucalyptus* spp. crops. Similarly, other insect families such as Psyllidae, Aphalaridae and Aphididae also play an important role as pests in large crops, including forestry crops, such as eucalyptus plantations. Takia et al. (2024) describes more than one hundred species belonging to this family as pests that cause direct or indirect damage to host plants. Psyllids and aphalarids are efficient colonizers, have great dispersal capacity and show specificity with host plants (Queiroz et al. 2013; Grazia et al. 2024).

Guilds

Triplehorn and Johnson (2013) explain that conventional ecological theory postulates that each species occupies a unique niche, with a specific lifestyle, habitat and diet. Insect communities exhibit grouped insect species that have largely overlapping niches, generating competition, but environmental instability prevents one competitor from being eliminated by another. This results in the formation of numerous guilds, where groups of insects utilize the same food source in different ways. The order Hemiptera plays an important role in maintaining ecological balance and trophic relationships (Marques et al. 2014); the relationship between an insect species and other organisms, based on food or other vital resources, defines the ecological role or niche (Triplehorn and Johnson 2013). Ferreira (2014) describes that the structure of ecological communities includes complex relationships between symbiotic organisms, such as the interaction between hosts and parasitoids, competitors, predators and prey.

The families Aphalaridae, Psyllidae and Aphididae, belonging to the suborder Sternorrhyncha, were classified as small insects. These families include the main exotic pests for *Eucalyptus* spp. crops. They are families of great economic importance in forest plantations, as they cause direct and indirect damage to monocultures, such as the occurrence of *C. elaeophilum*, a fungus that causes soot that covers the leaves, preventing photosynthesis in plants due to the excretion of large amounts of honeydew (Santana 2005; Santana 2008; Wilcken 2010; Cantarelli and Costa 2014; Costa et al. 2014; Wolff et al. 2024).

Garlet (2012) reports that the introduction of exotic insect pests causes significant economic losses due to the damage caused to forests, such as excessive sap removal and destruction of cells or tissues through biting and sucking activities. The families Cicadellidae and Membracidae, belonging to the suborder Auchenorrhyncha, comprise the guild of large insects, phytophagous leafhoppers capable of causing deformations or lesions in the attacked plants, such as loss of growth capacity, yellowing or necrosis in the leaves, and can be agents of transmission of phytopathogens and inoculate toxic substances into the plants (Gullan and Cranston 2012; Costa et al. 2014; Takyia et al. 2024).

Principal Component Analysis (PCA)

Principal component analysis allowed us to observe qualitative patterns without loss of information from the sampled data, based on the differences and similarities represented by two components (dimensions) (Santo 2012; Sabharwal and Anjum 2016). Insect families that correspond to the greatest variation in the first component are strongly associated with their occurrence in the dry season, corroborating the greater number of insects collected during this season. Saliba et al. (2021) reported that dry conditions associated with climate change influence the population increase of insect species in forest environments. Environmental variations and changes in resource availability influence the distribution, abundance, and richness of hemipteran insects (Andrewy and Hughes 2005) and, according to Rodrigues (2004), temperature directly interferes with the development of insect populations.

It is important to highlight that these families are responsible for most of the observed dispersion, presenting positive influences, indicating that much of the variability of the data can be explained by their occurrence during the dry season in *E. urograndis* plantations in southeastern Pará. According to Ramsfield et al. (2016), trees become more susceptible to forest insects during dry periods, as the reduction in water availability compromises the defenses and vigor of the plants. *Eucalyptus* spp. plantations provide refuge for some animal species, emerging as a new habitat due to the availability of resources such as shelter, nectar, nesting or reproduction (Lopes et al. 2007).

Oliveira (2018) highlights the use of planted forests as access routes to other fragments by fauna, acting as ecological corridors and refuges for different species. Free-living insects, being more generalist, tend to have their distributions more conditioned by the periods of the year most conducive to their occurrence (Araújo 2013). Begon et al. (2006) described that temporal variations in conditions and resources can influence species richness. The dry season and the occurrence of pest species are important factors that affect the establishment and productivity of eucalyptus plantations worldwide (Saadaoui et al. 2017).

Conclusion

In view of the above, the aerial entomofauna of the order Hemiptera associated with the species *E. urophylla, E. grandis* and *E. urograndis*, in the southeast of the state of Pará, Eastern Amazon, is strongly influenced by seasonality, with greater abundance and diversity of individuals during the dry season. The family Cicadellidae stands out for these characteristics in the dispersion pattern presented in the years of study and in the high rates in the three clones trained. The families Aphalaridae, Aphididae, Membracidae and Psyllidae stood out in the clones *E. urophylla* and *E. urograndis*.

In particular, the clone *E. urograndis* was the most diverse in the number of insects and presented a greater richness of families, highlighting the greater attractiveness for the occurrence of the families studied. A strong association between the families Miridae, Delphacidae, Scutelleridae, Cicadellidae, Membracidae, Pyrrhocoridae and Lygaeidae for this clone suggests that when one of these families is present, others are likely to emerge during the dry season. The preference for *E. urograndis* highlights the potential risk of these families becoming plausible in plantations of this clone, and constant monitoring is recommended to prevent possible outbreaks and preventive actions to mitigate the impact of these species. The clone *E. urograndis* can be considered a preferred host for many families of the order Hemiptera.

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Data Availability Data supporting the findings of this study are available upon request from the author.

Declarations

Competing Interests The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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