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Review Article

A decade of sampling reveals spittlebug population dynamics in different cultivation system

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ABSTRACT

There is a large proportion of degraded pastures in monoculture system, caused especially by the complex of spittlebugs (Hemiptera : Cercopidae), which are the main pest insects of pastures in Latin America. Hence, the aim of the research was to understand how the conversion from monoculture to silvipastoral systems impacts on the diversity of spittlebugs, and how the populations of these insects behave over the years in each of these systems. Insect sampling was carried out from January 2010 to December 2019. In each system (signalgrass monoculture or silvipastoral), the capture of adult spittlebugs was performed using entomological sweep nets, randomly throughout the area. We sampled 23,040 spittlebugs specimens over a period of 10 years. The spittlebug species collected were *Deois schach* (Fabricius) (45.3 %), *Notozulia entreriana* (Berg) (26.8 %), *Deois flavopicta* (Stål) (24.9 %); besides, *Mahanarva fimbriolata* (Stål) and *Mahanarva spectabilis* (Distant) that together represent 3 % of the total samples. The total abundance of specimens was significantly higher ($Z = -3.129$, $p = 0.0017$) in the monoculture compared to the silvipastoral system. The results of this study suggest that the silvipastoral system, in comparison to the monoculture system, could be capable of mitigating the damage caused by most species of spittlebugs by reducing the population and the pressure caused by these insects on the forages. However, special attention must be given to the species *D. schach*, which does not appear to have its population dynamics affected by changes in cultivation systems.

1. Introduction

In Brazil, there is a large proportion of degraded pastures (Cavalcanti et al., 2021), caused especially by the complex of spittlebugs belonging to the Cercopidae (Hemiptera) family, which are the main pest insects of pastures in Latin America (Schöbel and Carvalho, 2019). The increasingly widespread and intense occurrence of attacks of these pests in Brazilian pastures, containing native or cultivated forages, has been reflected in a relevant way in herd productivity; reaching a 74 % reduction in beef productivity and 31–43 % in forage production (Congio et al., 2020). These insects are also relevant pest for sugarcane. In the Neotropical region, considering sugarcane and pasture, these insects could cause damage of the order of 2.1 billion dollars (Thompson, 2004).

Inside the genus *Urochloa* (Hochst. ex A. Rich.) R. D. Webster (synonymous with *Brachiaria* [Hochst. ex A. Rich Stapf]), the *Urochloa*

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decumbens (Stapf.) stands out as one of the main species grown in Brazil. This species is capable of adapting to different soil and climate conditions and occupies thousands of hectares throughout Brazil (Ferreira et al., 2021). Extensive monoculture of this grass promotes susceptibility to pest attacks, notably spittlebugs (Valério and Koller, 1992). The insect nymphs of spittlebugs feeds on plant sap, causing weakening effects, while adults inject toxins that result in lesions, leading to subsequent yellowing and demise of the forage. These effects compromise the palatability and carrying capacity of the pasture, ultimately diminishing animal productivity (Valério and Nakano, 1987; Congio et al., 2020).

The adoption of silvipastoral systems is a sustainable alternative to extensive monoculture that involves the presence and use of trees, pasture, and animals in the same area. Since faunal diversity is closely related to the flora, it is possible that this system could increase the diversity of local entomofauna, helping to maintain the ecological equilibrium in the area (Stern et al., 1976; Paiva et al., 2020). Proving this hypothesis requires long-term studies. In this context, spittlebugs, which are abundant insects in most pasture ecosystems, can be used to evaluate the environmental impacts of a change from monoculture to a silvipastoral system.

Increased diversity in the community of primary producers can reduce the magnitude of the effects on primary consumers species (Jactel and Brockerhoff, 2007). It is possible that this statement also applies to the silvipastoral system, in which the association of trees, pastures establish different ecological niches that change the population dynamics of entomofauna (pests and natural enemies) (Auad et al., 2015; Paiva et al., 2020).

In Brazil, studies that evaluate the diversity of insects in pastures are scarce. Faunal surveys in silvipastoral and monoculture systems of *U. decumbens* have already been carried out for some groups such as Coleoptera (Auad and Carvalho, 2011; Giraldo et al., 2011), Hymenoptera (Auad et al., 2015), Diptera (Veríssimo et al., 2021) and general entomofauna (Paiva et al., 2020). This research provide evidence that the insect fauna changes upon conversion of the *B. decumbens* monoculture to a silvipastoral system, and encourage the implementation of silvipastures on a larger scale. However, the impact of the transition from a monoculture system to a more diverse silvipastoral system on spittlebug populations remains unknown. Knowledge of the population dynamics of the predominant species in each region, according to the type of cropping system used (monoculture or silvipastoral), seems to be of great importance for making decisions about the most effective time and type of management for this pest.

Considering that species diversity and abundance are influenced by cropping systems, spittlebug management programs must be adapted to the specific conditions of cropping. Hence, the aim of the research was carried out a long-term study to understand how the conversion from monoculture to silvipastoral systems impacts spittlebug diversity (abundance and species richness) and how the populations of these insects behave over the years in each of these systems. These information are essential to encourage the implementation of the silvipastoral system in regions with a history of spittlebugs problems.

2. Methods

2.1. Study area

This study was carried out at Embrapa Gado de Leite (Coronel Pacheco/MG, Brazil), at 21°33'22"S, 43°06'15"W and 410 m of altitude. The region has a rainy tropical climate, with an average annual rainfall of 1533 mm, a 19.5 ± 5 °C average annual temperature, rainy summers and dry winters, between June and September. According to the Köppen classification, the region's climate is Cwa (mesothermal), warm temperate climate with dry winter.

The soil in the experimental area is of the Red-Yellow Latosol type, with a clay texture and undulating relief in a mountainous area with a slope of approximately 30 %.

For the establishment of the monoculture, the soil preparation protocol and the application of correctives and fertilizers were similar to those adopted in the silvipastoral system since the areas were contiguous and shared the same slope and type of soil. Since the establishment of the pasture in 1997, the pasture areas had not received any additional fertilizer or corrective applications until 2010. From January 2010 to December 2019 the experiment was conducted. Between 2011 and 2014, the pastures received 64 kg N ha–1 urea, 16 kg P ha–1 ($P2O5$), and 64 kg K ha–1 ($K2O$) annually, divided into two applications during the summer. From 2014 to 2019, there were no fertilizer applications. Both systems maintained control over weeds and leaf-cutting throughout the entire experiment duration. Leaf-cutting ants were controlled by the application of granulated baits (sulfluramid 0.3 % active ingredient) at a dosage of 10 g per square meter of ant hill. Weeds were controlled by the herbicide application of 2,4-dichlorophenoxyacetic acid at 1.0 L ha–1 (670 g active ingredient ha–1). The application of the herbicide was done with a manual costal sprayer, with a capacity for 20 L. It is important to note that the signalgrass were grazed during the experiments.

The experiment was carried out in two areas of 4 ha each. One was a *U. decumbens* monocultural pasture. The second area was a silvipastoral system, installed in November 1997, composed of 30 m wide strips of *U. decumbens* alternated with 10 m wide strips of the trees *Acacia mangium* Willd and *Eucalyptus grandis* W. Hill ex Maiden planted in a 3 m× 3 m spacing, from 13 to 22 years of age throughout the insect sampling.

2.2. Sampling and insect identification

Insect sampling was carried out over ten years period, from January 2010 to December 2019. Sampling was performed at intervals of 15–21 days, always in the morning (from 9 to 11 a.m.). In each of these systems, adult spittlebugs were randomly captured using entomological sweep nets. Permanent 160 m linear transects were established for sweep net trap spittlebug adults at each site. Sweep net transects were walked slowly and one sweep was taken every two meters for a total of 80 sweeps/ transect with six sweep net transects randomly established at each site. The vegetative portions of plants (*U. decumbens*) along each transect were swept. The samples were transported to the Entomology Laboratory (Embrapa Gado de Leite) and the spittlebugs were separated and stored in vials with 70 % alcohol for identification. In the first two years, the specimens were sent to taxonomists for identification. In subsequent years, the specimens sampled were compared with vouchers of the species collected which have been deposited in the entomological collection of Embrapa Gado de Leite.

2.3. Statistical analyses

Abundance was determined by the average number of individuals for each species of spittlebug collected per month. The data did not meet the assumptions of normality for residue and homogeneity of variance (Shapiro-Wilk test and Bartlett test, $p < 0.01$). We used a generalized linear mixed model (GLMM) to assess if there was a significant difference in abundance (response variable) of each of the spittlebug species in relation to the silvipastoral and monoculture systems as a fixed factor and sampling years as a random factor using the "lme4" package (Bates et al., 2017). The GLMM selection was previously performed to choose the best model to fit count data using the "hnp" package (Moral et al., 2017).

Spearman's correlation was calculated to measure the degree of association between the average number of specimens in each study system, collected during the total and years-long sampling period and the meteorological variables (monthly average of temperature, relative humidity, and precipitation total). The climate variables were obtained from the Centro de Previsão de Tempo e Estudos Climáticos of the Instituto Nacional de Pesquisa Espaciais (INPE) which is 1 km from the experimental area.

The nonparametric analyses used for quantitative discrete variables (i.e., the number of adult insects collected per system) did not require data normality or linearity.

To examine changes in the composition of Cercopidae species in both systems (monoculture and silvipastoral) for each of the sampling years and to compare species composition between the two systems over the 10 years of sampling, we used Non-Metric Multidimensional Scaling (NMDS) and Permutational Multivariate Analysis of Variance (PERMANOVA) to test for differences between the systems. The "vegan" (Oksanen et al., 2023), "ggplot2" (Wickham, 2016), and "dplyr" (Wickham et al., 2023) packages were used.

Circular analysis was used to test whether there was a temporal variation in the abundance of spittlebug species in each of the monoculture and silvipastoral systems (Agostinelli and Lund, 2013). The occurrence of population peaks was determined with the Oriana program (Kovach, 2011). The concentration (r) was calculated, using rates ranging from 0 (maximum dispersion of data) to 1 (maximum concentration of data in the same direction). The Rayleigh Uniformity Test (Mendoza, 1994) was used to analyze the uniform distribution of abundance throughout the year.

The constancy rate (C) was calculated using the Bodenheimer method, following Silveira Neto et al. (1976), where $C = p \times 100/N$, in which (p) is the number of collections containing the species under analysis and (N) is the total number of collections. Species were classified as constant (occurring in more than 50 % of collections), accessory (occurring in 25–50 % of collections) or accidental (occurring in less than 25 % of collections).

To evaluate the preference of each of the spittlebug species for the silvipastoral and monoculture systems, we used the Indicator Value (IndVal) analysis (Dufrene and Legendre, 1997), using the "indicspecies" R package (Caceres et al., 2016).

Based in Stiernet and Lumaret (1993) the distribution and prevalence of spittlebug species over the months of the year were analyzed. Thus, species gathering > 10 % of spatial or temporal assemblages (number of specimens) were called 'core species' and composed 'core groups'.

Comparisons of abundance, species composition, correlation analysis and the IndVal estimate were performed with R version 4.0.3 (Team, 2020).

3. Results

During the 10 years of collections, 23,040 specimens of spittlebugs were sampled. The spittlebug species (Cercopidae) collected were *Deois schach* (Fabricius) (45.3 %), *Notozulia entreriana* (Berg) (26.8 %), *Deois flavopicta* (Stål) (24.9 %); besides, *Mahanarva fimbriolata* (Stål) and *M. spectabilis* (Distant) that together represent 3 % of the total samples (Table 1).

A total of 7564 spittlebugs were collected in the silvipastoral system and, 15,476 specimens were sampled in the monoculture

Table 1
Abundance, Generalized Linear Mixed Model (GLMM) statistics, constancy index for spittlebugs (Hemiptera: Cercopidae) species collected with sweep net between January 2010 and December 2019, from monoculture and silvipastoral systems in Coronel Pacheco, Brazil.

	Abundance			GLM		Constancy[3]	
Species	SP[1]	M[2]	Total	z	*p-value*[2]	SP	MP
Deois flavopicta	1093	4642	5735	−3.475	0.0005***	Y	Y
Deois schach	5383	5061	10,444	−0.610	0.5420[NS]	X	X
Mahanarva fimbriolata	69	540	609	−3.067	< 0.0022***	Z	Z
Maharnarva spectabilis	62	22	84	2.339	0.0193***	Z	Z
Notozulia entreriana	957	5211	6168	−5.752	< 0.0001***	Y	X
Total	7564	15,476	23,040	−3.403	0.0007***		

[1]SP= Silvipastoral and [2]M = Monoculture; [2]***significant at 0.01 and [NS] not significant; [3] Constancy index: X-constant; Y-accessory and Z- accidental.

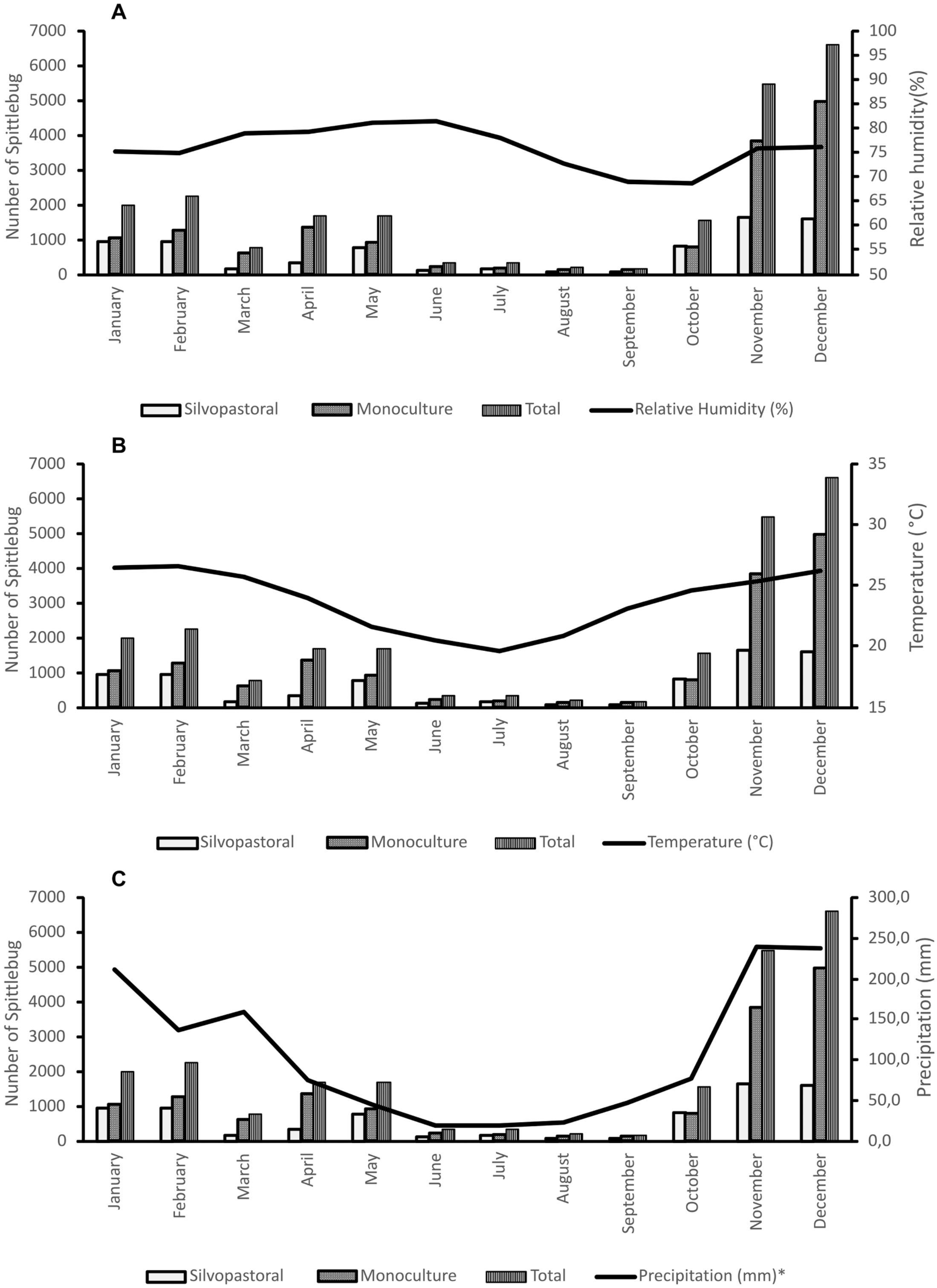

Fig. 1. Species of spittlebugs (Hemiptera: Cercopidae) collected with sweep net and the accumulated mean relative humidity (A) temperature (B) and precipitation (C) between January 2010 and December 2019 from monoculture, silvopastoral or monoculture + Silvopastoral systems in Coronel Pacheco, Brazil.

system. All five spittlebug species occurred in both cropping systems (Table 1). The total abundance of specimens was significantly higher (Z = -3.129, $p = 0.0017$) in the monoculture compared to the silvipastoral system. Regarding the species, it was observed that *D. flavopicta, N. entreriana,* and *M. fimbriolata* were more abundant in the monoculture system; *M. spectabilis* was more abundant in the silvipastoral system, whereas *D. schach* did not differ statistically between the two systems (Table 1).

Deois schach and *D. flavopicta* were classified as constant and accessory species in both cropping systems, respectively. *N. entreriana* was classified as an accessory in the silvipastoral system and constant in the monoculture system. For those of the genus *Mahanarva*, the occurrence was accidental regardless of the cultivation system used (Table 1).

We observed a positive and significant correlation between the number of spittlebugs collected each month and the temperature and precipitation in the silvipastoral (Temperature: S = 86.9, $p = 0.012$; Precipitation: S = 58, $p = 0.003$) and monoculture (Temperature: S = 108. 12, $p = 0.031$; Precipitation: S = 74, $p = 0.008$) systems; as well as with the total monthly number of spittlebugs in the two systems (Temperature: S = 87.911, $p = 0.013$; Precipitation: S = 64, $p = 0.005$). No correlation was detected with relative humidity (Fig. 1). Rainfall was also the predominant factor in the population fluctuation of spittlebugs in the analysis of monthly

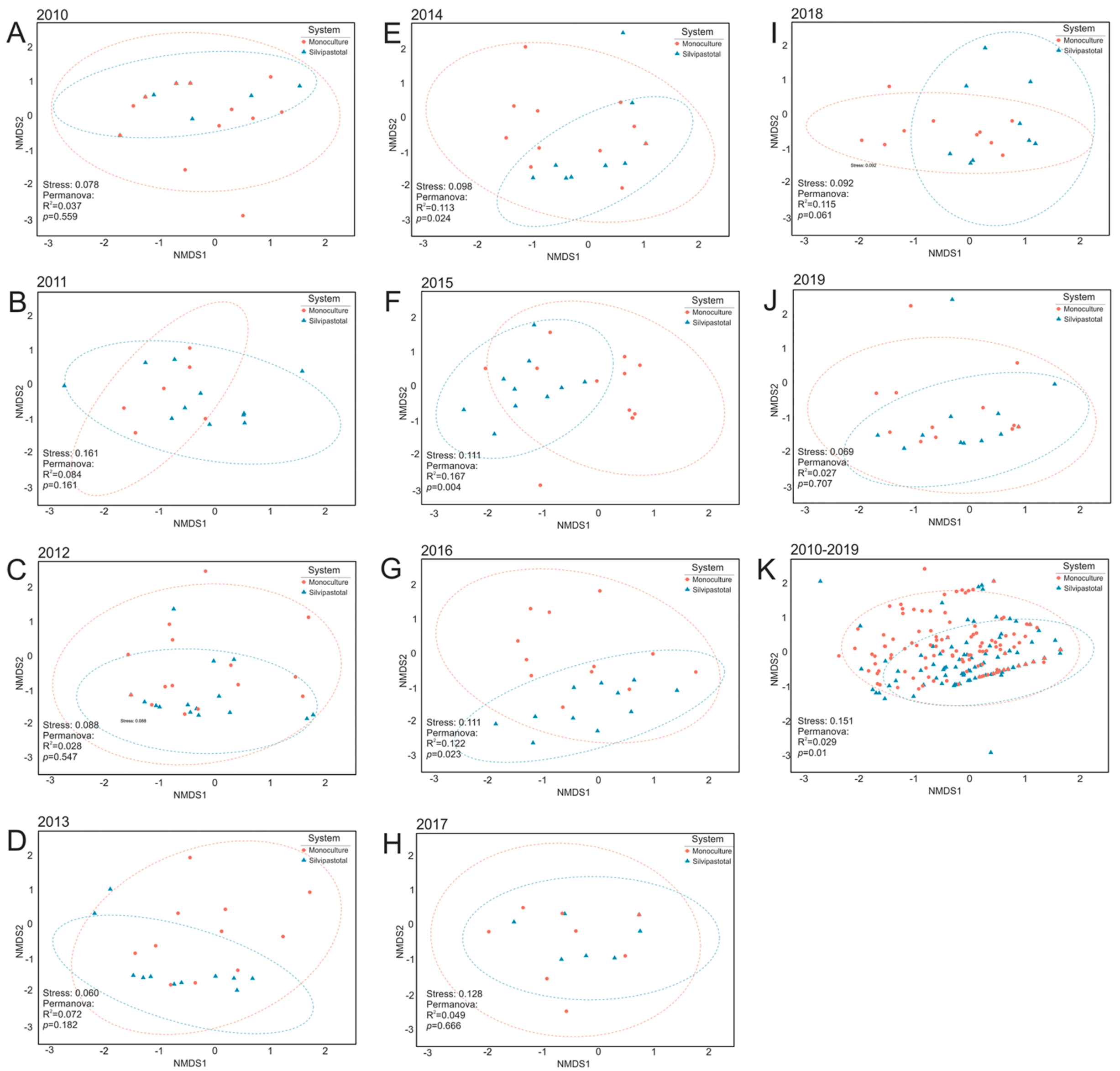

Fig. 2. Non-metric multidimensional scaling (NMDS) ordination based on the species composition of spittlebugs (Hemiptera: Cercopidae) collected with sweep nets from silvipastoral and monoculture (2) systems in Coronel Pacheco, Brazil. A-J: correspond to the analyses conducted by year between 2010 and 2019; K – corresponds to the joint analysis of all data collected throughout the sampling period (2010–2019).The figure was created using R software (Version 4.4.2) (https://www.r-project.org/), RStudio software (Version 2024.09.1 Build 394) (https://posit.co/download/rstudio-desktop/) and CorelDRAW 2018 software (Version 20.1.0.708) (https://www.coreldraw.com/en/pages/coreldraw-2018/).

sampling for each year (see Supplementary Figures S1, S2, and S3).

We observed that the species composition between the silvipastoral and monoculture systems differed in some years (2014: PERMANOVA – $p = 0.024$; 2015: PERMANOVA – $p = 0.004$; and 2016: PERMANOVA – $p = 0.023$) (Fig. 2E-G). Differences between the two systems were also observed when considering the entire sampling period (PERMANOVA – $p = 0.029$) (Fig. 2K).

Regarding seasonality, the species *D. flavopicta*, *M. fimbriolata,* and *M. spectabilis*, showed a grouped distribution in the rainy season (October to March) in both systems and also when the total of each species collected in both systems was considered (Table 2, Fig. 3, Fig. 4). *Notuzilia entreriana* presented a clustered distribution only in the silvipastoral system ($r = 0.875$; Z = 682.7 and $p < 0.0001$), whereas *D. schach* presented a random distribution in both systems and when the total number of specimens collected in both systems was considered (Table 2, Fig. 3, Fig. 4). Regarding the total abundance of spittlebugs, it was observed that in the silvipastoral system ($r = 0.480$; Z = 1630.2 and $p < 0.0001$) the distribution was random and in the monoculture system ($r = 0.560$; Z = 4994, 5 and $p < 0.0001$) and for the general total of spittlebugs ($r = 0.535$; Z = 6593.8 and $p < 0.0001$) the distribution was clustered (Table 2, Fig. 3, Fig. 4).

Notozulia entreriana (stat=0.731; $p < 0.0001$) and *M. fimbriolata* (stat=0.445; $p = 0.006$) were significantly and strictly related to monoculture area by indicator value (IndVal) analysis. We identified four core species, distributed in two core groups formed by four (monoculture) and two (silvipastoral) species. *Deois schach* was the most prevalent species, appearing every month in both systems and being the prevailing species for 7 months in the monoculture area and for 10 months in the silvipastoral area (Table 3).

4. Discussion

Long-term studies are important to evaluate the behavior of organisms because it minimizes the bias that can occur in short-term studies, especially when the latter coincide with atypical climatic events, which can lead to wrong conclusions.

In the silvipastoral system, although the diversity was the same in the present research (5 species), the abundance of spittlebugs (Cercopidae) in this system is observed to be half compared to the signalgrass monoculture system. A strong relationship is also emphasized between the temporal abundance of this insect-pest and temperature, which, in general, is concentrated in the rainy season.

Spittlebugs (Cercopidae) occur from the southern United States to northern Argentina (Paladini et al., 2018). In Brazil, the predominant species are from the genera *Mahanarva, Deois* and *Notozulia* (Hernández et al., 2021). The three genera were present in the samples of both monoculture and the silvipastoral experimental areas, with a predominance of *D schach* (46 %). This species was also predominant represented 84 and 95 % of the species sampled, in the studies carried by Auad et al. (2009a,2010) out in Coronel Pacheo, MG, Brazil.

According to Alvarenga et al. (2017), the performance of adults of *M. spectabilis* and *D. schach* is better on *Urochloa ruziziensis*. *Mahanarva spectabilis* was a major problem when it fed on *Pennisetum purpureum*, but on *Cynodon dactylon* and *Panicum maximum*, none of the spittlebugs developed properly, indicating that these plants are less suitable for them. Additionally, according to Silva et al. (2017) Molasses grass, Tanzania, Makueni, and Jaragu plants are less suitable food sources for *M. spectabilis* nymphs and adults. In Brazil, spittlebug species (Hemiptera:Cercopidae) are associated not only with the host plant, but also with the region of Brazil. In several studies carried out in Brazil over the last 5 decades, *Deois incompleta* (Walker 1851) and *N. entreriana* were recorded in all

Table 2
Measurements of the concentration (*r*), Rayleigh Test, distribution and season of the year with the greatest total abundance of spittlebugs (Hemiptera: Cercopidae) species collected with sweep net between Janurary 2010 and December 2019, from monoculture and silvipastoral systems in Coronel Pacheco, Brazil.

Species	*r*	Rayleigh Test (Z)	p-value	Distribution	Season
	Silvipastoral				
Deois flavopicta	0.899	945.4	< 0.0001	Clustered	Rainy
Deois schach	0.362	640.0	< 0.0001	Random	-
Mahanarva fimbriolata	0.766	41.1	< 0.0001	Clustered	Rainy
Maharnarva spectabilis	0.557	19.5	< 0.0001	Clustered	Rainy
Notozulia entreriana	0.875	682.7	< 0.0001	Clustered	Rainy
Total	0.480	1630.2	< 0.0001	Random	-
	Monoculture				
Deois flavopicta	0.867	3988.9	< 0.0001	Clustered	Rainy
Deois schach	0.396	762.7	< 0.0001	Random	-
Mahanarva fimbriolata	0.825	388.7	< 0.0001	Clustered	Rainy
Maharnarva spectabilis	0.665	32	0.0008	Clustered	Rainy/Dry
Notozulia entreriana	0.393	799.4	< 0.0001	Random	-
Total	0.560	4994.5	< 0.0001	Clustered	Rainy
	Total (Silvipastoral+Monoculture)				
Deois flavopicta	0.872	4927.8	< 0.0001	Clustered	Rainy
Deois schach	0.374	1362.0	< 0.0001	Random	-
Mahanarva fimbriolata	0.817	427.5	< 0.0001	Clustered	Rainy
Maharnarva spectabilis	0.594	29.7	< 0.0001	Clustered	Rainy
Notozulia enteriana	0.436	12059.9	< 0.0001	Random	-
Total	0.535	6593.8	< 0.0001	Clustered	Rainy

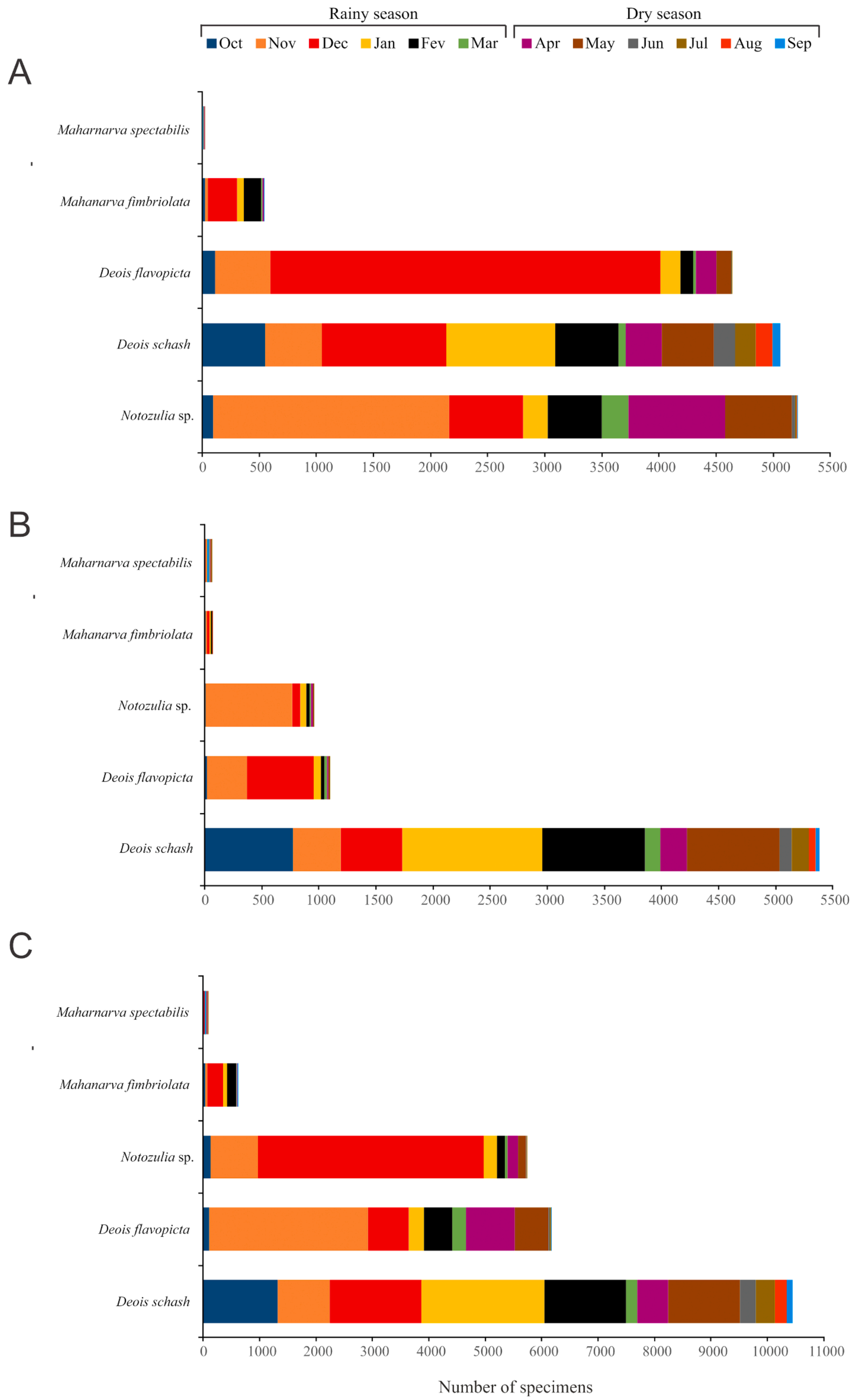

Fig. 3. Species of spittlebugs (Hemiptera: Cercopidae) collected with sweep net between January 2010 and December 2019 from monoculture (A) and silvipastoral (B) and monoculture + Silvipastoral (C) systems in Coronel Pacheco, Brazil. The figure was created using Excel software (Version 2108) (https://www.microsoft.com/pt-br/) and CorelDRAW 2018 software (Version 20.1.0.708) (https://www.coreldraw.com/en/pages/coreldraw-2018/).

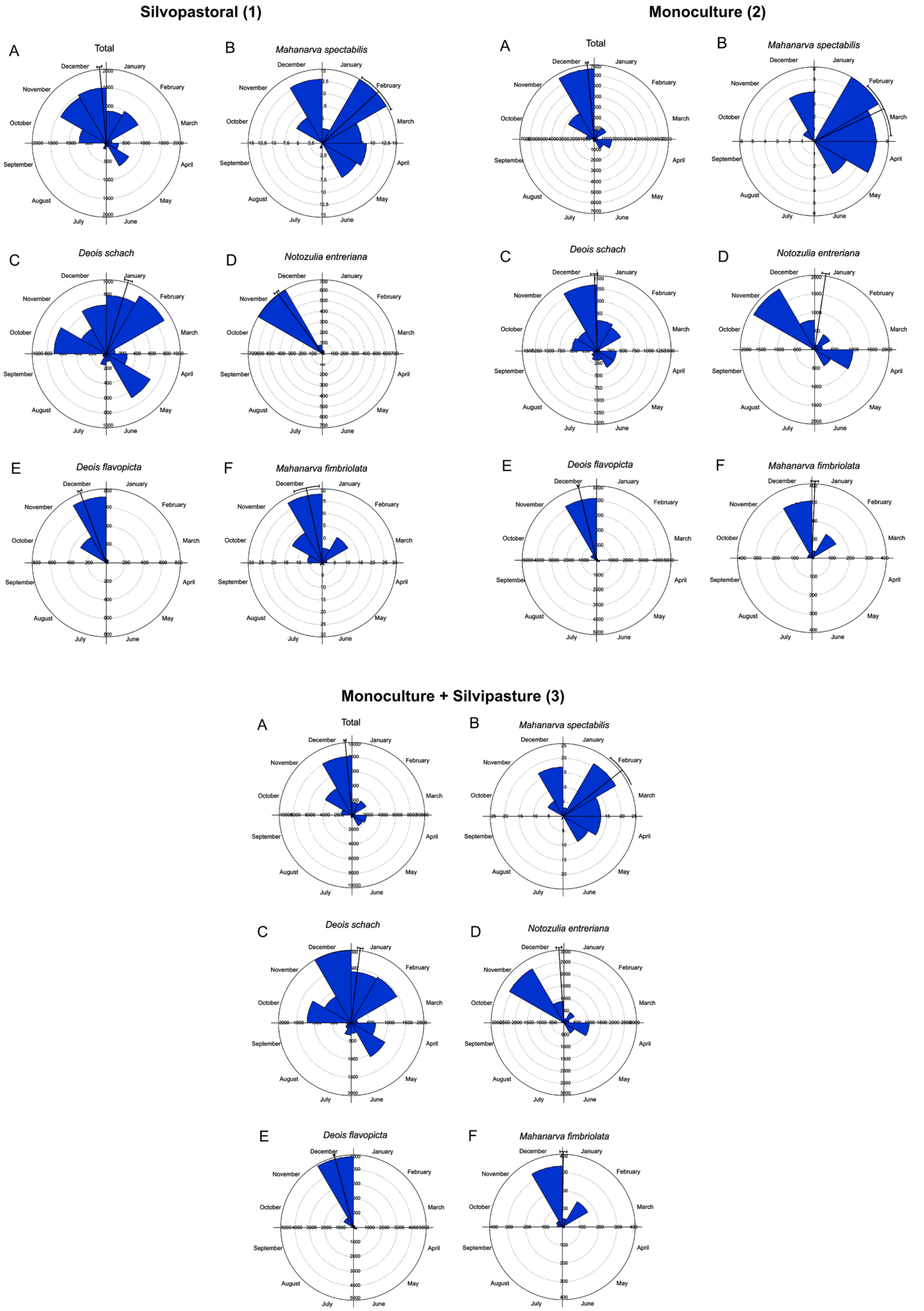

Fig. 4. Circular analysis for the abundance of species and total of spittlebugs (Hemiptera: Cercopidae) collected with sweep net between January 2010 and December 2019 from silvipastoral (1); monoculture (2) and monoculture + Silvipastoral (3) systems in Coronel Pacheco, Brazil. The figure was created using Oriana software (Version 4) (https://www.kovcomp.co.uk/oriana/) and CorelDRAW 2018 software (Version 20.1.0.708) (https://www.coreldraw.com/en/pages/coreldraw-2018/).

Table 3
Composition of seasonal core groups of spittlebugs (Hemiptera: Cercopidae) species in monoculture and silvipastoral systems in Coronel Pacheco, Brazil.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Monoculture											
Deois flavopicta	12.5	-	-	13.2	10.8	-	-	-	-	14.5	15.8	63.1
Deois schach	67.8	42.9	18.7	23.4	38.7	83.4	91.1	96.7	94.3	69.9	16.1	20.2
Mahanarva fimbriolata		11.6	-	-	-	-	-	-	-	-	-	-
Mahrnarva spectabilis	-	-	-	-	-	-	-	-	-	-	-	-
Notozulia entreriana	15.3	36.6	68.1	62.6	50.1	12.1	-	-	-	12.3	67.3	12.0
	Silvipastoral											
Deois flavopicta	-	-	10.4	-	-	-	-	-	-	-	22.6	47.6
Deois schach	90.5	91.2	76.3	86.3	97.0	98.1	96.2	98.3	100.0	95.9	27.2	43.9
Mahanarva fimbriolata	-	-	-	-	-	-	-	-	-	-	-	-
Mahrnarva spectabilis	-	-	-	-	-	-	-	-	-	-	-	-
Notozulia entreriana	-	-	-	-	-	-	-	-	-	-	48.9	-

The values correspond to relative abundances (>10 %) of core species.
(-) Correspond to relative abundaces (<10 %).

regions of Brazil (North, South, Center-West, Southeast and Northeast). *Deois flavopicta* and *M. fimbriolata* were not reported in the South and Northeast regions. *Deois schach* was sampled in the Center-West, Southeast and Northeast regions, and in these last two regions *Aeneolamia selecta* (Walker 1858) was recorded (Guagliumi, 1969; Souza, 1976; Santos and Correia, 1979; Sa, 1981; Ramiro et al., 1984; Melo et al., 1984; Hewitt, 1986; Oliveira and Alves, 1988; Lyra Netto et al., 1989; Fazolin et al., 1997; Bernardo et al., 2003; Boas, 2005; Castro et al., 2007; Auad et al., 2009a; Lohmann et al., 2011). The most abundant genera of spittlebugs observed in the present study (Table 1) coincide with those reported in other studies carried out in the Brazil in recent decades, with a predominance of the *D. schach* species in the Southeast region (Auad et al., 2009a, 2009b), the same region where the current research was conducted.

Studies have shown that climatic factors have a greater influence on the diversity of spittlebugs than the forage species used (Auad et al., 2009b). We observed that the abundance of spittlebug species was twice as high in the monoculture system compared to the silvipastoral system. A great abundance of spittlebugs in monoculture system compared to with a silvipastoral system had already been recorded in a previous study in the same region (Paiva et al., 2020). It is possible that the microclimatic changes that occurred due to the presence of trees in pasture areas are unfavorable in the development of spittlebug populations.

In fact, it has been demonstrated that the association of trees, pastures and livestock promotes changes in the microclimate that interfere with the entomofauna, due to the establishment of different niches (Stern et al., 1976). Furthermore, pastures managed in silvipastoral environments have a greater number of natural enemies than those managed in monoculture (Auad et al., 2015; Paiva et al., 2020). A study comparing the population densities of spittlebugs between native fields and areas cultivated with *U. ruziziensis* recorded 105 times greater infestation in the latter case (Pires et al., 2000). In this context, silvipastoral approaches could deliver benefits for invertebrate conservation and ecosystem services if integrated into landscapes. When individual invertebrate orders were compared Kinneen et al. (2024) found Hemiptera were more abundant in traditional pastures, while Lepidoptera and Coleoptera were found in greater abundance in forest edge habitats.

Regarding the physiology of forage plants, the shading caused by the presence of trees, in the silvipastoral system, allows an increase in crude protein levels and a reduction in fiber levels (Paciullo et al., 2007), also promoting the formation of larger plants and photosynthetic rate. These factors may favor the migration of the insect from adjacent conventional pastures to silvipastoral areas. However, this fact does not guarantee the maintenance of the insect in these areas, due to the environmental resistance (vegetation, natural enemies) provided by this system. The presence of bushes and trees also seems to make the insect's movement more difficult, leading them to prefer to move back to open areas with homogeneous and low vegetation, which facilitates the insect's dispersal due to the lower structural complexity of the community and plant distribution pattern (Sujii et al., 2000).

In Brazil, studies that evaluate the diversity of insects in pastures are scarce. Some studies compared the insect fauna between the silvipastoral system and *U. decumbens* monoculture for some groups such as Coleoptera (Auad and Carvalho, 2011; Giraldo et al., 2011) Hymenoptera (Auad et al., 2015), Diptera (Syrphidae and Asilidae) (Veríssimo et al., 2021) and for general entomofauna (Paiva et al., 2020). These studies demonstrated that, in general, higher biodiversity and low abundance of entomofauna was recorded in the silvipastoral system. Additionally, the results of the species composition analyses indicated that, overall, the species composition between the two systems is different, with this difference varying over the years. Our results suggest that the conversion from monoculture to the silvipastoral system generates a negative impact on spittlebug populations, which is currently the main biotic problem in pastures in Brazil.

The abundance of spittlebugs in pastures correlated significantly with temperature and precipitation in the period between samplings, regardless of the cultivation system used. In fact, there was an increase in temperature and precipitation in the transition months between the dry and rainy periods (September/October), which appeared to shape the distribution pattern and seasonality of most spittlebug species.

Abiotic factors are fundamental in shaping population dynamics, influencing fluctuations, and determining spittlebug activity patterns throughout the year. Typically, the peak hatching period and lowest nymphal mortality occur during the rainy season (Sujii et al., 2002), with the number of generations varying based on the abiotic conditions. During the dry months of the year, the insect resists unfavorable environmental conditions in the form of diapause eggs laid during the rainy season, in different proportions and with programming for different diapause durations (Sujii et al., 1995). In general, the massive appearance of the first generation occurs with the synchronization of diapausing eggs that were deposited in the last generation before the dry season. However, although studies on spittlebugs suggest that the seasonality of these insects always occurs in a clustered distribution during the rainy season (Castro et al., 2005; Valério, 2009), we observed here that the seasonality of pasture spittlebugs varied depending on the species and management system adopted.

In fact, it is observed that the highest abundance of adults in both systems occurred after the start of the rainy season, which was also reported for other species of the Cercopidae as *Zulia carbonaria* (Lallemand 1924) and *Aeneolamia reducta* (Lallemand 1924) in pasture in Colombia (Peck, 2002; Castro et al., 2005) and *Aeneolamia contigua* (Walker 1851) in sugarcane in Mexico (Olán-Hernández et al., 2016). However, when each species of spittlebug is analyzed separately, it is possible to verify species with an aggregate distribution such as *D. flavopicta, M. fimbriolata* and *M. spectabilis* and species with a random distribution such as *D. schach*. These results suggest that *D. schach*, the most abundant species throughout the study period, appears to have greater biological plasticity, which gives it an adaptive advantage, allowing this species to present high adult populations, practically throughout the year, even in months with low rainfall, such as between June and September, when other species of spittlebugs are practically not detected. Furthermore, *D. schach* is the only species that showed practically equal adult populations in the two cultivation systems studied, reinforcing its adaptive capacity. On the other hand, through indicator value (IndVal), the species *N. entreriana* and *M. fimbriolata* are considered closely associated with the monoculture system.

Regarding cultivation systems, a random distribution of spittlebugs in the silvipastoral system is observed, likely due to the high abundance of *D. schach* in this system, since the other species presented a grouped distribution.

Analysis of the rate of constancy showed that species *D. schach* and *D. flavopicta*, respectively, remained constant and accessory in both cultivation environments. *Notozulia entreriana* was an accessory in the silvipastoral system and constant in the monoculture system. In other words, *Deois flavopicta* in both systems and *N. entreriana* in silvipastoral remained in an intermediate stage of adaptation. On the other hand, *Deois schach* in both systems and *N. entreriana* in the monoculture system showed adaptation based on the systems.

Historically, *U. decumbens* monoculture system allowed spittlebug species to develop and reach high population densities, requiring control chemical measures, which are not always effective, especially because of the extensive dimension of the pasture areas (Buitrago et al., 2022). The results of this long-term study suggest that the silvipastoral system, in comparison to the monoculture system, could be capable of mitigating the damage caused by most species of spittlebugs by reducing the population and the pressure caused by these insects on the forages. However, special attention must be given to the species *D. schach*, which was the predominant specie in both cultivation systems.

Ethics statement

Not applicable: This manuscript does not include human or animal research.

Author contributions

A.M.A. conceived and designed the study; A.M.A. and T.T.R. Investigation; A.M.A. and C.M.O. analysed the data; A.M.A., C.M.O. and T.T.R. interpreted the data; A.M.A. wrote the first draf; A.M.A., C.M.O. and T.T.R. substantially revised subsequent drafs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03534.

Data availability

No data was used for the research described in the article.

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