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ORIGINAL RESEARCH ARTICLE

Mite community response to different apple orchards

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Abstract

Brazil is one of the world's largest apple (*Malus domestica* Borkh: Rosaceae) producers. Throughout the production cycle, the crop is susceptible to infestations of phytophagous mites. The aim of this work was to understand the response of the mite community to cultivars, plant stratum and the management of apple orchards. The study was performed in conventional orchards (Fuji and Gala) and organic (Gala, Fuji and Eva). Monthly collections were carried out over one year. Forty plants were sampled per orchard, being three leaves per plant (apical, median and basal). The material was sorted and identified in the laboratory. A total of 7.193 mites were collected, with organic orchards having a higher average abundance (10.1±3.37) than conventional ones (7.39±1.82). The relative abundance of *Aculus schlechtendali* Nalepa (Eriophyidae) and *Panonychus ulmi* (Koch) (Tetranychidae) was higher in the conventional system. *Neoseiulus californicus* (McGregor) (Phytoseiidae) had higher relative abundance in the conventional system, while the organic had a higher richness of predatory mites. The cultivars influenced the mite community, with Eva having the highest mean abundance (17.7±9.13), followed by Gala (8.96±2.52) and Fuji (5.12±1.25). Regarding the stratum, the apical region had the highest mite abundance (13.3±4.82), followed by the median (6.99±1.86) and basal (5.38±1.30). Organic orchards kept the mite community in balance, conserving richness and diversity, with low populations of phytophagous and a constant and diverse presence of natural enemies.

Keywords *Aculus schlechtendali* · Fuji · Gala · *Malus domestica* · *Panonychus ulmi*

Introduction

Brazil is among the largest apple (*Malus domestica* Borkh: Rosaceae) producers in the world and the quality of the fruits in the country has been increasing every year (Kist et al. 2019, 2022). Brazilian apple production is mainly located in the higher regions of the Rio Grande do Sul, Santa Catarina and Paraná due to the favorable climate for the crop (Kist et al. 2019). Among the main apple cultivars produced in the world, Gala and Fuji are the most important (Iglesias et al. 2008; Fioravanço et al. 2010). New cultivars are emerging and pleasing the consumer's palate, as is the case of Eva (Fioravanço et al. 2010).

Conventional agriculture is widely used in several cultures because it is highly productive, but it has substantial negative externalities, including loss of biodiversity, soil erosion, environmental pollution, risk to human health and low agricultural yields (Gomiero et al. 2011; Campbell et al. 2017; Hulsmans et al. 2023). There is an urgent need to change the agricultural production system, aiming to achieve sustainable development (Raudonis et al. 2007; Walker et al. 2017; Zhu et al. 2018), and to ensure that the use of resources remains within planetary limits (Willer et al. 2021). As an alternative to conventional management, the organic agriculture system has been highlighted in several countries (Gomiero et al. 2011; Smith-Spangler et al. 2012; Caprio et al. 2015; Gomiero 2018; Hulsmans et al. 2023). Not spraying pesticides has been one of the main criteria used to differentiate organic from conventional agriculture (Sumberg and Giller 2022).

The indiscriminate use of pesticides in orchards can reduce populations of natural enemies and increase the population of phytophagous insects and mites (Lorenzato

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and Secchi 1993; Walker et al. 2017; Schmidt-Jeffris and Beers 2018). When these populations reach pest *status* in the crop, they cause environmental, economic and social impact (Brown and Hovmøller 2002; Anderson et al. 2004; Navia et al. 2011). In addition, the expansion of cultivation areas can help in the geographic distribution of agricultural pests (Wheeler and Hoebeke 2009).

Eriophyidae, Tarsonemidae and Tetranychidae are phytophagous mites found associated with the apple tree crop (Jeppson et al. 1975; Ferla and Moraes 1998; Silva et al. 2022; Rode et al. 2023, 2024a). Among these, *Panonychus ulmi* (Koch) (Tetranychidae), *Tetranychus urticae* Koch (Tetranychidae) and *Aculus schlechtendali* (Nalepa) (Eriophyidae) stand out as pest mites in the culture around the world (Nascimento et al. 2020; Kasap and Atlihan 2021; Nematollahi et al. 2021; Silva et al. 2022; Rode et al. 2023, 2024a). *Panonychus ulmi* stands out among the phytophagous mites with economic importance in the apple culture, for attacking the leaves, causing foliar tanning and reducing the photosynthetic capacity of the plant (Ferla and Botton 2008; Moraes and Flechtmann 2008). Probably, resistant individuals of *P. ulmi* and *T. urticae* might be selected by over use of pesticides (Mota-Sanchez and Wise 2023). *Aculus schlechtendali*, considered of economic importance for the apple tree in several countries, causes darkening of leaves, fruits and flowers (Duso et al. 2010; Nematollahi et al. 2021), affecting the physiological activity of the plant and the aesthetic quality of the fruits (Hoyt 1969; Easterbrook 1996; Walde et al. 1997; Spieser et al. 1998; Nematollahi et al. 2021). This species was previously considered of absent quarantine importance for Brazil, and is now present in the main producing regions of the country (Ferla et al. 2018; Nascimento et al. 2020; Corrêa et al. 2021; Silva et al. 2022; Rode et al. 2023, 2024a). The record of the presence of *A. schlechtendali* in southern Brazil serves as an alert for the apple production chain, as it is a species of quarantine importance present in Brazil (Ferla et al. 2018; Nascimento et al. 2020; Silva et al. 2022; Rode et al. 2023, 2024a).

Predatory mites are present in several apple producing Brazilian regions, with the most abundant Phytoseiidae, followed by Stigmaeidae (Lorenzato et al. 1986; Ferla and Moraes 1998; Klock et al. 2011; Johann and Ferla 2012; Silva et al. 2022; Rode et al. 2023, 2024a, b). Phytoseiidae can feed on phytophagous mites and have other alternative food sources, such as pollen, fungi, plant exudate and insects (McMurtry et al. 1970, 2013; McMurtry and Rodrigues 1987; Tixier 2018; Eini et al. 2023). *Neoseiulus californicus* (McGregor) (Phytoseiidae) is the most common species (Moraes et al. 2004; Silva et al. 2022) and has a high survival rate when exposed to agrochemicals used in pest management (Albayrak et al. 2022; Rode et al. 2024b). *Amblyseius chiapensis* DeLeon, *Euseius inouei* (Ehara and Moraes), *Euseius mesembrinus* (Dean), *Galendromus annectens* (De Leon), *Metaseiulus camelliae* (Chant and Yoshida-Shaul), *Metaseiulus eiko* (El-Banhawy), *Metaseiulus mexicanus* (Muma), *N. fallacis*, *Neoseiulus tunus* (De Leon), *P. macropilis*, *Proprioseiopsis cannaensis* (Muma), *Typhlodromalus marmoreus* El-Banhawy and *Typhlodromalus peregrinus* (Muma) are also species of Phytoseiidae found in Brazil (Lorenzato et al. 1986; Lorenzato and Secchi 1993; Ferla and Moraes 1998; Rode et al. 2024b).

The structure of the mite community in the different cultivars and stratum of the plant, and the effects of management on the mite fauna present in orchards in the main producing regions in Brazil is little known (Rode et al. 2023, 2024a, b). Understanding the ecological pattern of the mite community in the country's largest production region and the pattern of distribution and dispersion of mites in the plant strata, in the cultivars and at production sites is important, as these data allow for better implementation of future pest management actions in the Brazilian orchards (Rode et al. 2024b).

Therefore, the aim of this work was to understand the response of the mite community to cultivars, plant stratum and the management of apple orchards in Brazil.

Material and methods

Study area

The study was conducted in the 2020–21 in apple orchards located in the municipalities of Antônio Prado (28°22′44″S 49°56′12″W) and Muitos Capões (28°23′23″S 51°15′12″W), state of Rio Grande do Sul, and São Joaquim (28°53′23″S 51°23′06″W), state of Santa Catarina (Rode et al. 2023, 2024a, b).

Antônio Prado

In this locality, collections were performed in organic orchards that used the Eva, Fuji and Gala cultivars. The soil cover in all areas of this locality was preserved, with the presence of spontaneous plants, such as grasses and weeds, in association with the litter that was maintained in the area. There was no spraying of pesticides, nor insecticides/acaricides, nor herbicides in the areas of this locality. To control herbivores, only Bordeaux mixture, calcium sulphur, neem oil and Trap® wax attractant were used.

São Joaquim

In this locality, two conventional orchards were evaluated, one with the Fuji cultivar and the other with Gala. In both areas, the soil was kept covered by grasses and weeds, in association with litter. Pigs, sheep and chickens were kept grazing throughout the area, where they feed on spontaneous plants and aborted fruits. In these areas, whenever necessary, producers spray pesticides to control pests.

Muitos Capões

In this locality, collections were carried out in two conventional orchards one with the Fuji cultivar and the other with Gala. In both areas, the soil was kept unprotected, with the use of herbicides and weeding, and the spraying of chemical products to control pests is frequent.

Collection and sorting

In the orchards, the evaluated trees were identified with ribbons. In each orchard, 40 plants were sampled, selected from the fifth row, counting from the edge. Collections were carried out monthly from September 2020 to August 2021. For sampling, three leaves of a median branch of each plant in the apical, median and basal regions of the branch were detached, totaling 120 leaves/orchard/month. In the senescence period, branches were collected from the central part of the plant and three buds from the apical, median and basal regions were sorted, totaling 120 buds/orchard/month. The material was packed individually, in previously identified transparent plastic bags, kept at low temperature and taken to the Laboratory of Acarology (Labacari) of the University of Vale do Taquari—Univates, Lajeado, RS. Screening was performed under a Leica S6E stereoscopic microscope, with the aid of a fine brush. The mites were mounted on microscope slides in Hoyer's medium (Jeppson et al. 1975).

Mite identification

Mites were identified using Zeiss Axio Scope A1 phase contrast optical microscope and specific bibliography (Baker and Tuttle 1994; Chant and McMurtry 1994, 2007; Amrine and Stasny 1994; Amrine et al. 2003; Fan and Zhang 2005; Johann et al. 2013; Skvarla et al. 2014; Silva et al. 2016). Specimens representing each of the species found in the study were labeled, stored in slide holder boxes, stored in a climate-controlled room and deposited in the Mite Reference Collection of the Natural Sciences Museum of the University of Vale do Taquari—Univates (Sisgen: A8302CB).

Data analysis

Mean mites/culture system/apple cultivar/plant stratum

Data were quantified by extracting the mean and standard error of the number of mites observed in each: i – cultivation system (organic or conventional), ii – apple cultivar (Eva, Fuji, Gala) and iii – plant stratum (apical, median, basal). The standard error was performed using the dplyr package (Ihaka and Gentleman 1996; Wickham et al. 2020; R Core Team 2021).

Combined comparison between crops/cultivars/plant stratum

To evaluate the pair-by-pair significance of the different cropping systems, apple cultivars and plant stratum, jointly, a Generalized Linear Model with Poisson distribution family and interaction between these three variables (crops * cultivars * stratum) in R. The model parameters were extracted with the 'ANOVA' function of the car package (Fox and Weisberg 2019) in R. This procedure was implemented using ANOVA type II adhering to the principle of marginality, testing each term after all others. Furthermore, the statistical test for the GLM was calculated by the likelihood ratio (LR) method. Afterward, a pairwise comparison was made between each one of the variables combined above, such as Conventional Fuji Apical *vs.* Conventional Eva Apical. This comparison was made by the 'emmeans' function of the package of the same name (Lenth 2019). The significance between pairs of variables was extracted by the 'pwpm' function of the last package.

Multivariate analysis of mite diversity

The abundance of mites was standardized according to the Hellinger method by the *vegan* package (Oksanen et al. 2018) for R. Through an exploratory analysis, the diversity of mites was verified, according to the specie and its respective quantity, grouping according to the cropping system by the orchard in question and the plant stratum where these arthropods were collected. Thus, a heat map with hierarchical groupings was generated using the mite database. The heat map was built using the Complex Heatmap package (Gu et al. 2016). The matrix was generated using the Euclidean distance method, and the chosen hierarchical grouping method was based on Unweighted Pair-Group Method using Arithmetic Averages (UPGMA) of the dissimilarity measures.

The composition of the mite community by cropping system, by apple cultivar or by plant stratum was analyzed with a non-metric multidimensional scaling (NMDS) using the abundance matrix with standardized Euclidean distance with the Hellinger method. The NMDS was generated with the *vegan* package (Oksanen et al. 2018) for R. The stress value (<0.2) resulting from the NMDS was used to assess the quality of sorting.

Differences in mite community structure between the cited groups were tested with permutation analysis of variance (PERMANOVA) using the *vegan* 'adonis 2' function (Oksanen et al. 2018) and, where appropriate, pairwise comparisons were made between each group based on 1.999 permutations, Pillai test method and P-values adjusted by the 'fdr' method through the 'pairwise.perm.

anova' function of the 'RVAideMemoire' package (Hervé et al. 2018) in R.

Each mite species was individually plotted on the general NMDS according to their *scores* and represented by means of *scatter plots* proportional to their abundance and contour lines. This graphic representation is generated according to the *vegan* (Oksanen et al. 2018). Each mite species was plotted, showing relative abundance according to cropping system, cultivar and plant stratum. The most important mite taxa were identified, contributing to the dissimilarity between groups was analyzing using the *vegan* (Oksanen et al. 2018).

Results

The results presented here are complementary to those of Rode et al. (2023, 2024a, b). A total of 7.193 mites were collected, and organic orchards had a higher mean abundance (10.1±3.37) than conventional orchards (7.39±1.82) (Fig. 1A). Regarding the cultivar, it was observed that Eva had the highest mean abundance (17.7±9.13), followed by Gala (8.96±2.52) and Fuji (5.12±1.25). Finally, the apical stratum of the plant had the highest mite abundance (13.3±4.82), followed by the median (6.99±1.86) and basal

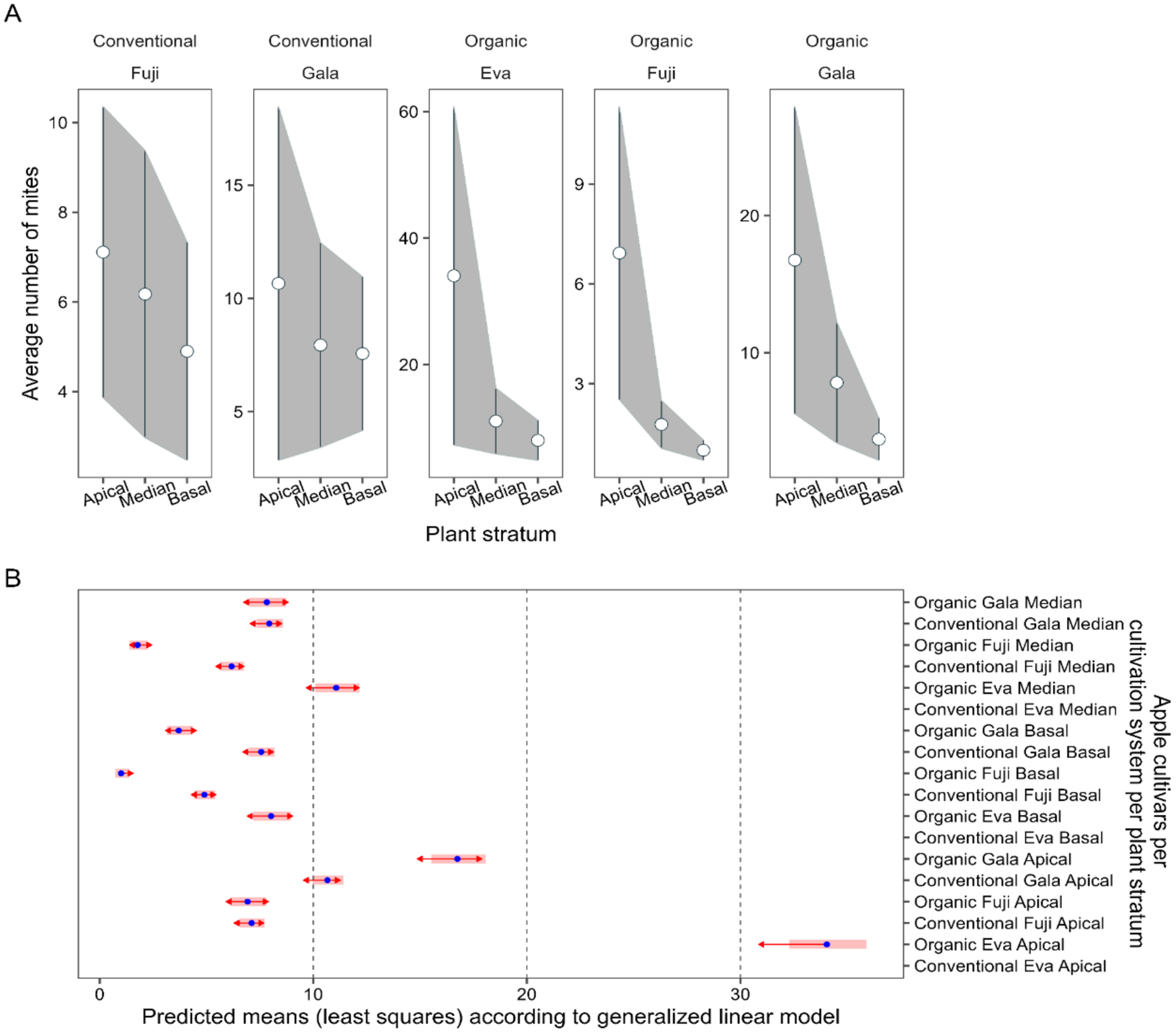


Fig. 1 **A** Mean quantity (points) and standard error (vertical bars) of mites in different cropping systems per apple cultivar per plant layer. The scale on the y-axis was adjusted according to the values of each variable. The grayish shadow connecting the vertical bars has been added to make the data easier to interpret and visualize. **B** Paired comparison of the average amount of mites depending on the cultivation system (organic, conventional) and its respective cultivar (Eva, Fuji, Gala) according to one of the three stratum analyzed (apical, median, basal)

Table 1 Mean amount of mites/culture system/cultivar/stratum

Cultivation system	**Cultivar**	**Stratum**	Mean±SE	Order/ infestation*
Organic	Eva	Apical	34.00±26.8	1º
Organic	Gala	Apical	16.80±11.2	2º
Organic	Eva	Median	11.10±5.19	3º
Conventional	Gala	Apical	10.70±7.82	4º
Organic	Eva	Basal	8.02±3.16	5º
Conventional	Gala	Median	7.94±4.52	6º
Organic	Gala	Median	7.82±4.4	7º
Conventional	Gala	Basal	7.56±3.4	8º
Conventional	Fuji	Apical	7.11±3.25	9º
Organic	Fuji	Apical	6.92±4.4	10º
Conventional	Fuji	Median	6.18±3.2	11º
Conventional	Fuji	Basal	4.90±2.43	12º
Organic	Gala	Basal	3.70±1.54	13º
Organic	Fuji	Median	1.78±0.71	14º
Organic	Fuji	Basal	1.00±0.30	15º

*Positioning from the highest level of infestation to the lowest level

(5.38±1.30) (Fig. 1B). When comparing the three variables in a combined way (culture system + cultivar + stratum) it was observed that in the apical stratum of Eva there is a higher mean abundance of mites (34±26.8) (Table 1; Fig. 1A), followed by the apical stratum of Organic Gala, with less than half the population (16.8±11.2). On the other hand, organic Fuji showed lower average abundance in the basal (1.0±0.3) and median (1.78±0.71) stratum.

In general, all variables and interactions analised were significantly different between them and each other as shown in Table 2.

Table 2 General parameters of the generalized linear model comparing the number of mites between organic and conventional cultivation systems, between Eva, Fuji, Gala cultivars, between apical, median, basal stratum and between them

	Degrees freedom	**X^2**	***p*-value**
Cultivation system	1	26.13	< 0.001
Cultivar	2	1332.81	< 0.001
Stratum	2	1102.39	< 0.001
Cultivation system *vs.* cultivar	1	115.86	< 0.001
Cultivation system *vs.* stratum	2	251.73	< 0.001
Cultivar *vs.* stratum	4	16.06	0.002
Cultivation system *vs.* cultivar *vs.* stratum	2	21.31	< 0.001

The relative abundance of phytophagous mites *A. schlechtendali* and *P. ulmi* was higher in the conventional system, while *Polyphagotarsonemus latus* (Banks) (Tarsonemidae) was more abundant in the organic system (Fig. S1). The panel suggests that *Neoseiulus californicus* had greater relative abundance in the conventional system, while the other predators, especially *Agistemus brasiliensis* Matioli, Ueckermann and Oliveira (Stigmaeidae), *Agistemus riograndensis* Johann and Ferla (Stigmaeidae), *Euseius inouei* Ehara and Moraes and *E. mesembrinus* (Dean) (Phytoseiidae), were abundant in the organic system. Among the generalists, the highest relative abundance was of *Tydeus californicus* Banks (Tydeidae) and *Fungitarsonemus* sp. (Tarsonemidae), in the organic system and *Tarsonemus merus* (Lin and Zhang) (Tarsonemidae), in the conventional system. The other mite species were present in low populations, showing no preference for the production system.

The relative abundance of phytophagous mites *A. schlechtendali* and *P. latus* was higher in plants of the Gala cultivar, while *P. ulmi* was more abundant in the Fuji cultivar (Fig. S2). Regarding predatory mites, *A. brasiliensis* and *A. riograndensis* showed higher relative abundance in cultivar Eva. *Neoseiulus californicus* was more abundant in the Fuji and Gala cultivars, as well as the generalist *T. merus*. *Tydeus californicus* had higher relative abundance in cultivar Eva. Other mite species were present in low populations, showing no preference for the apple cultivar.

The relative abundance of phytophagous mites *A. schlechtendali* and *P. latus* was higher in the apical stratum, while for *P. ulmi*, it was higher in the middle stratum of the plant (Fig. S3). *Neoseiulus californicus* and *A. brasiliensis* showed greater relative abundance in the basal stratum, whereas *A. riograndensis* in the median. Among the generalists, the highest relative abundance was for *T. californicus* and *T. merus* in the basal stratum and *Tarsonemus waitei* Banks (Tarsonemidae) in the apical stratum of apple trees. The other mite species were present in low populations, showing no preference for the production system.

Among conventional crops, there was a similarity between orchards of different cultivars and the plant stratum analyzed. However, in general, they could be grouped according to the area of study. The heat map shows that six species of mites were more representative throughout the study (*A. schlechtendali*, *N. californicus*, *P. ulmi*, *P. latus*, *T. merus* and *A. riograndensis*) (Fig. 2). The initial exploratory analysis, through the generation of a heat map with hierarchical clustering, recognized four large groups, suggesting that the diversity of mites in organic crops is more similar to each other than in conventional crops.

The ranking generated by NMDS had a stress value of 0.09, suggesting an excellent fit of the model. Regarding the structuring of the mite community according to the cultivation system, there were different types of composition, therefore, of grouping. When analyzing the mite community according to the cultivation system, it is possible to verify a significantly different structure in the diversity of mites that make up organic vs. conventional cultures (PERMANOVA, F(1,20) = 9.94, P-value < 0.001), both groups

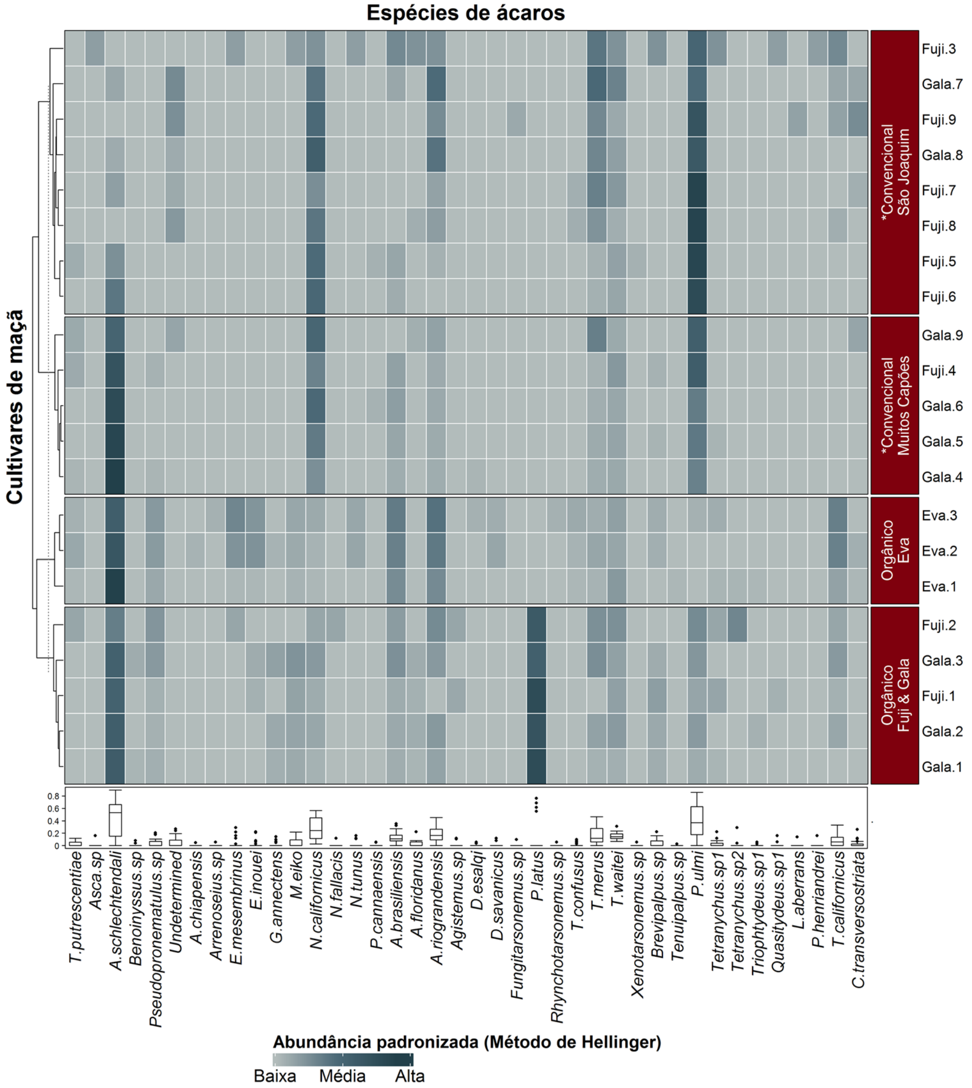


Fig. 2 Grouped heat map based on the standardized amount (Hellinger's method) of mites in two cropping systems (organic [O], conventional [C]), three apple cultivars (Eva [E], Fuji [F], Gala [G]) and three plant stratum (apical [A], middle [M], basal [B]). The numbers after the acronyms indicate the sampling location (1 for Muitos Capões and 2 for São Joaquim). Hierarchical cluster analysis was generated with Euclidean distance matrix and UPGMA clustering medium. The cophenetic correlation coefficient was 0.83, on a scale of 0–1. The asterisks within the red quadrants demonstrate that the grouping in question is predominantly conventional and from the locality indicated within them

having homogeneous variances between them (Permutest, F(1,19) = 2.69, P-value = 0.12) (Fig. 3A).

When the same mite community was evaluated from the perspective of different apple cultivars, a significant difference was observed between them (PERMANOVA, F(1,18) = 3.51, P-value = 0.003) (Fig. 3B). However, the difference only occurred between Eva and the other two cultivars Fuji and Gala (Pairwise comparison, P-value < 0.02), and the greater overlap of species between Fuji and Gala makes the mite diversity of both more similar to each other (Pairwise comparison, P-value < 0.08). However, in ordering the three apple cultivars, it was found that the pairs Eva–Fuji and Eva–Gala did not show homogeneity between their variances (Permutest, F(1,18) = 3.72, P-value = 0.04; Pairwise comparison, P-value < 0.045). This may have been generated by the lower amount of sampling in Eva, which may have contributed to reducing a greater representation of mite taxa in this cultivar and, thus, decreasing the ability of the model to accurately distinguish how different it was from the other two apple varieties. Finally, all plant stratum showed a great sharing/overlapping of mite species (PERMANOVA, F(2,18) = 0.51, P-value = 0.85) whose variances were equally homogeneous among themselves (Permutest, F(1,18) = 2.27, P-value = 0.76) (Fig. 3C).

The mite species were evaluated individually according to the proportion of individuals sampled by each of the three conditions, cropping systems, apple tree cultivars and stratum within the plant (Fig. 4).

The highest proportion of *N. californicus* and *P. ulmi* composed the conventional community of the Fuji and Gala cultivars. *Agistemus brasiliensis* and *A. riograndensis* were composing in greater proportion the communities of Eva and Gala in organic cultivation. Similarly, *A. schlechtendali* was composing in larger proportions the Eva community in the organic system. As shown in Fig. 2, there was no considerable difference between plant stratum.

The dissimilarity analysis performed for both cropping systems and apple cultivars indicates that between nine and 10 mite species were responsible for discriminating the pairs

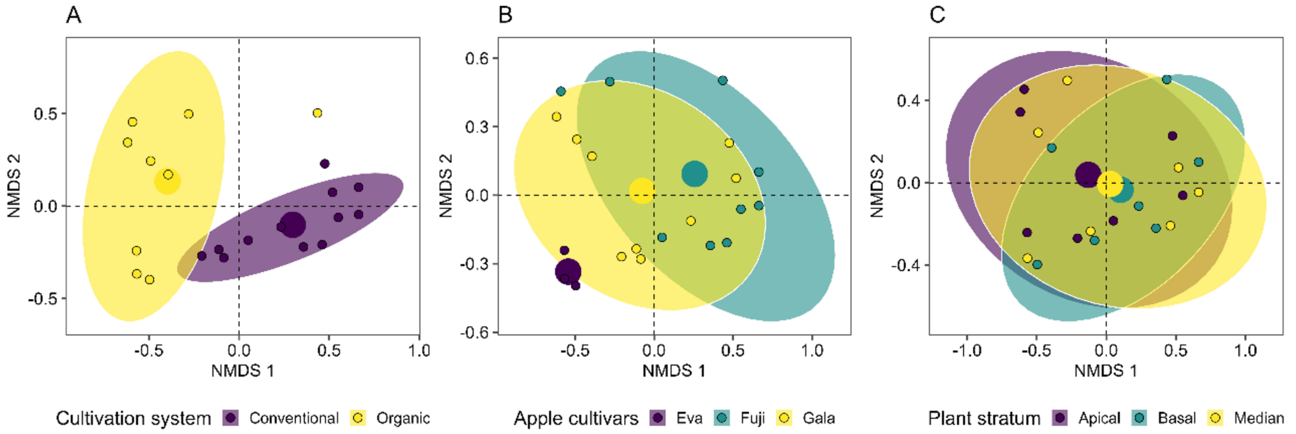


Fig. 3 Non-metric multidimensional scaling (NMDS, stress = 0.09, two dimensions) showing mite community composition in three different contexts: **A** two cropping systems (organic, conventional), **B** three apple cultivars (Eva, Fuji, Gala), **C** three plant stratum (apical, median, basal). Shaded ellipses surround each group at a 95% confidence level

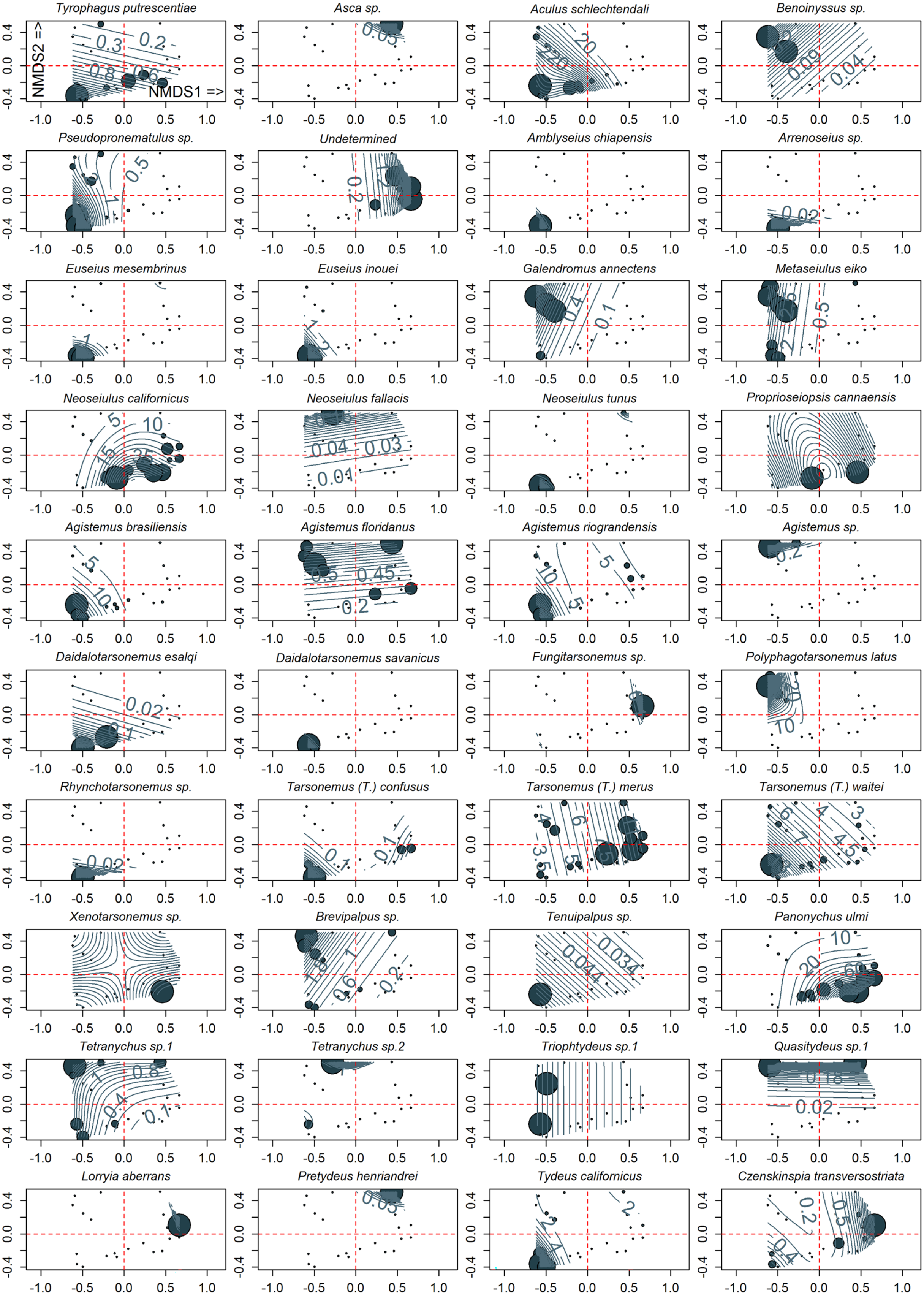
of groups, sometimes having a greater abundance for one of them, sometimes for the other (Table 3). When comparing the most important species present in the communities of organic and conventional crops, it appears that *P. ulmi* was present in greater abundance in conventional orchards, and when comparing the cultivars to each other, *P. ulmi* presented greater abundance in Fuji and Gala when compared to Eva, and in Fuji when compared to Gala. However, *A. schlechtendali* was found to be more abundant in organic orchards. Regarding the cultivars, Eva was more abundant than Fuji, Gala was more abundant than Eva and Gala were more abundant than Fuji. *Neoseiulus californicus* was present with greater abundance in conventional orchards, and when comparing cultivars, the species was more abundant in Fuji and Gala than Eva, and in Gala than Fuji.

Discussion

In this study, we observed that organic orchards harbor communities with greater abundance of mites, with emphasis on the apical leaves of Eva, where *A. schlechtendali* showed high populations. *Aculus schlechtendali*, *N. californicus*, *P. ulmi*, *P. latus*, *T. merus* and *A. riograndensis* were the most representative species throughout the evaluation period. *Panonychus ulmi* and *N. californicus* stood out in conventionally managed orchards, where low levels of mite diversity were observed. Differently, there was greater diversity in organic crops and similarity between them. It was also observed that organic orchards with Fuji and Gala had similar diversity, differing from Eva. Most of the mites collected were present in organic orchards, confirming that this management favors the conservation of a more diverse community, mainly of natural enemies that control phytophagous species (Maeyer et al. 1993; Rode et al. 2024b), while the use of pesticides can reduce the richness and diversity (Meyer et al. 2009; Farahy et al. 2021). Altering a natural system is a key factor in pest outbreaks, as it can cause disruption by drastically reducing populations of predators, parasites, and pathogenic organisms that naturally control these pests (Geiger et al. 2010; Janssen and Rijn 2021).

The presence of *A. schlechtendali* alerts researchers and producers, as it is a species of quarantine importance present in Brazil (Ferla et al. 2018; Nascimento et al. 2020; Silva et al. 2022). Although this phytophagous is present in large populations in different cultivars, the species has not yet been reported, causing economic damage to orchards in the country (Ferla et al. 2018; Nascimento et al. 2020; Silva et al. 2022), as observed in this study. In organic orchards, the control of *A. schlechtendali* is possibly being carried out by the natural enemies that presented greater diversity in orchards with this type of cultivation (Solomon et al. 2000), highlighting *A. riograndensis* and other species of the genus *Agistemus*. In conventional orchards, the control of *A. schlechtendali* may be occurring through the use of pesticides or through the presence of *N. californicus*, a predatory species that, even though there is no record of preying on this phytophage, has greater representation and is reported to be resistant to certain agrochemical (Meyer et al. 2009). Some authors have emphasized the role of *A. schlechtendali* as an alternative prey for phytoseiids when tetranychids are scarce (Easterbrook 1996; Hill and Foster 1998; Duso and Pasini 2003; Duso et al. 2010).

In this study, *T. urticae* populations were minimal, similar to the results presented by Silva et al. (2022) who did not observe this species in their study. However, in older surveys, the most economically important tetranychid species found on apple trees were *P. ulmi* and *T. urticae*


Tyrophagus putrescentiae
Asca sp.
Aculus schlechtendali
Benoinyssus sp.
Pseudopronematulus sp.
Undetermined
Amblyseius chiapensis
Arrenoseius sp.
Euseius mesembrinus
Euseius inouei
Galendromus annectens
Metaseiulus eiko
Neoseiulus californicus
Neoseiulus fallacis
Neoseiulus tunus
Proprioseiopsis cannaensis
Agistemus brasiliensis
Agistemus floridanus
Agistemus riograndensis
Agistemus sp.
Daidalotarsonemus esalqi
Daidalotarsonemus savanicus
Fungitarsonemus sp.
Polyphagotarsonemus latus
Rhynchotarsonemus sp.
Tarsonemus (T.) confusus
Tarsonemus (T.) merus
Tarsonemus (T.) waitei
Xenotarsonemus sp.
Brevipalpus sp.
Tenuipalpus sp.
Panonychus ulmi
Tetranychus sp.1
Tetranychus sp.2
Triophtydeus sp.1
Quasitydeus sp.1
Lorryia aberrans
Pretydeus henriandrei
Tydeus californicus
Czenskinspia transversostriata
NMDS2 =>
NMDS1 =>
-1.0
-0.5
0.0
0.5
1.0
-0.4
0.0
0.4

◂**Fig. 4** Non-parametric multidimensional (NMDS) sizing of the mite community. The points (*scatter plots*) were plotted as *bubble points*, that is, the standardized abundance (Hellinger's method) of mites was added to the function so that the size of the points indicates the proportional number of individuals sampled according to each of the three conditions of possible interpretations (Fig. S1). The contours delimit gradients along the two dimensions of the graph and are based on generalized additive models generated in the *vegan* package (Oksanen et al. 2018) in R

(Ferla and Moraes 1998; Monteiro 2002a, b). While *P. ulmi* was present in all orchards and throughout the evaluation period as the second most common phytophagous mite species. This mite has already been cited as one of the main phytophages present in apple trees (Lorenzato et al. 1986; Silva et al. 2022). Less richness of phytoseiids and greater abundance of *P. ulmi* was observed in the conventional orchards evaluated, may indicate that the use of pesticides may be affecting populations of natural enemies in these orchards. Possibly, populations of *P. ulmi* and the predator *N. californicus* may have acquired resistance to pesticides, considering that in conventional orchards these species stood out over the others. In addition, the results show low levels of diversity in these places, since high populations of *P. ulmi* may be indicative of resistance of this mite to

Table 3 Dissimilarity analyzes showing the individual gross and cumulative contributions (within []) of the most important species in differentiating mite communities across different cropping systems and apple cultivars. The percentage inside the parentheses indicates the degree of dissimilarity between the pairs in question. This analysis displays the most important species for each pair of groups that contributed at least 70% of the differences between groups

Cultivation Systems		
(62%)		
Conventional	**Organic**	**Mite species**
1180	41	*Panonychus ulmi* [0.14]
0	770	*Polyphagotarsonemus latus* [0.26]
1497	1835	*Aculus schlechtendali* [0.37]
522	21	*Neoseiulus californicus* [0.46]
75	244	*Agistemus riograndensis* [0.51]
36	199	*Agistemus brasiliensis* [0.56]
4	119	*Tydeus californicus* [0.60]
106	38	*Tarsonemus (T.) merus* [0.65]
0	35	*Metaseiulus eiko* [0.68]
2	53	*Pseudopronematulus sp* [0.71]

Apple cultivars			
Eva-Fuji (65%)			
Eva	**Fuji**	**Gala**	**Mite species**
1	869	N/A	*Panonychus ulmi* [0.17]
1370	318	N/A	*Aculus schlechtendali* [0.30]
5	228	N/A	*Neoseiulus californicus* [0.37]
177	20	N/A	*Agistemus brasiliensis* [0.43]
209	27	N/A	*Agistemus riograndensis* [0.49]
105	8	N/A	*Tydeus californicus* [0.55]
49	2	N/A	*Euseius mesembrinus* [0.59]
0	188	N/A	*Polyphagotarsonemus latus* [0.63]
37	1	N/A	*Euseius inouei* [0.67]
40	5	N/A	*Pseudopronematulus sp* [0.71]
Eva-Gala (55%)			
1	N/A	351	*Panonychus ulmi* [0.11]
5	N/A	310	*Neoseiulus californicus* [0.20]
1370	N/A	1644	*Aculus schlechtendali* [0.29]
105	N/A	10	*Tydeus californicus* [0.36]
177	N/A	38	*Agistemus brasiliensis* [0.43]
0	N/A	582	*Polyphagotarsonemus latus* [0.50]
209	N/A	83	*Agistemus riograndensis* [0.56]
49	N/A	0	*Euseius mesembrinus* [0.62]
37	N/A	1	*Euseius inouei* [0.67]
11	N/A	80	*Tarsonemus (T.) merus* [0.71]
Fuji-Gala (49%)			
N/A	318	1644	*Aculus schlechtendali* [0.16]
N/A	869	351	*Panonychus ulmi* [0.30]
N/A	188	582	*Polyphagotarsonemus latus* [0.42]
N/A	228	310	*Neoseiulus californicus* [0.49]
N/A	53	80	*Tarsonemus merus* [0.55]
N/A	27	83	*Agistemus riograndensis* [0.61]
N/A	15	10	*Undetermied* [0.64]
N/A	20	38	*Agistemus brasiliensis* [0.68]
N/A	8	10	*Tydeus californicus* [0.71]

the acaricides used (Khajehali et al. 2021). According to Arthropod Pesticide Resistance Database (APRD) (Mota-Sanchez and Wise 2023), *P. ulmi* is among the mites with the highest number of reports of resistance to compounds present in pesticides. *Neoseiulus californicus*, on the other hand, is a predator with a wide geographic distribution and highly adaptable, commercially used for the biological control of agricultural pests in a wide variety of cultivars and environments (Moraes et al. 1986; Vásquez et al. 2023). This predatory mite is resistant to many of the pesticides used to control agricultural pests, so this phytoseiid mite can be found in large numbers in production areas that use pesticides (Inak and Yorulmaz 2022).

Mite diversity in organic crops was similar when compared to conventional crops, demonstrating greater balance and stability. The structure of communities present in organic and conventional orchards were different, demonstrating the importance and influence that management has on the environment. Possibly, pesticide sprayings may have potentially modified the environment, directly or indirectly interfering with interactions between species within the community (Dalkvist et al. 2009; Guedes et al. 2016; Zhao et al. 2020; Hulsmans et al. 2023). Even if conventional cultivation is widely used, due to the high productive potential, it has several negative points, highlighting the loss of biodiversity (Gomiero et al. 2011; Campbell et al. 2017; Hulsmans et al. 2023). On the other hand, organic agriculture is beneficial for maintaining biodiversity and also for improving the chemical and physical quality of the soil, reducing pollution and increasing agricultural income (Reganold and Wachter 2016; Seufert and Ramankutty 2017). When populations are exposed to the action of pesticides, there is an increase in mortality, emigration of organisms due to contamination of habitat, food and changes that other species within the food web undergo and that interfere with the structure of the community (Sánchez-Bayo 2021). The ecological effects of pesticides cannot be determined by the sensitivity of a single species to the products, as interactions between species can reduce or increase the toxic effects of chemicals on organisms (Sánchez-Bayo 2021).

When analyzing the mite communities from the perspective of different apple cultivars, a significant difference is observed between them. The species overlap observed in Fuji and Gala makes the diversity of these two cultivars more similar to each other, possibly because they were tested both in organic and conventional orchards. In addition, the fact that Fuji and Gala are long-established cultivars and have already undergone several natural selective processes of speciation over the years and artificial selection processes carried out by man can make the mite communities present in plants similar to each other both (Fioravanço et al. 2010; Faoro 2018). There is an increased risk of losses due to weather events at certain stages of development that make plants more vulnerable to pests and diseases (Fioravanço et al. 2010). Fuji and Gala are cultivars that have a high demand for chilling hours, between 600 and 800 h (Komatsu 1998; Hampsom and Kemp 2003; Fioravanço et al. 2010), and production is concentrated in a short period of time, with high demand of labor in harvesting, which makes handling difficult.

Eva differed significantly from the others, possibly because it is a relatively new cultivar (Fioravanço et al. 2010), in addition to the fact that, in this study, it belongs to the cultivation with organic management. Eva was developed by the Agronomic Institute of Paraná (Iapar) for the production of apples in regions with little winter cold and in a subtropical climate (Hauagge and Tsuneta 1999). It is possible that crossings and development of new cultivars may also be influencing the establishment and structuring of mite communities present in environments. In addition, because Eva was sampled in organic orchards, management may also have influenced the structuring of the mite community. Still, the Eva orchard, even though it was less sampled in this study, has a greater abundance of mites, followed by Gala and Fuji.

The observed results can be explained by the fact that the Eva orchard had the highest mite richness and also because it is an organic orchard that also had the greatest diversity of mites. In addition, a greater abundance of *A. schlechtendali* was observed in Eva's orchard and whenever Gala and Fuji orchards were compared, Gala had higher populations of this eriophyid. Because Eva is a new cultivar and originated from the crossing of Anna and Gala (Hauagge and Tsuneta 1999), it is possible that Gala is a cultivar with more suitable properties for the establishment of *A. schlechtendali*, which consequently could be making Eva a cultivar prone to infestations by this phytophage. For Nascimento et al. (2020) and Silva et al. (2022), *A. schlechtendali* showed greater abundance in Fuji orchards, followed by Gala and Eva, however several variables must be considered. The difference between these surveys (Nascimento et al. 2020; Silva et al. 2022) and the present study may be related to the collection time, sampling frequency, number of sampled orchards, geographic regions where the orchards are inserted and sampling frequency. The previous samplings were carried out in March (Nascimento et al. 2020; Silva et al. 2022), a period in which, as observed in this study, *A. schlechtendali* already has low populations in the environment. In this study, population peaks occurred in December and January, and in some orchards, the mite had already been present since October and in February there had already been a considerable decrease in populations, being absent in March.

The apical stratum of the plants had the highest mite abundance, followed by the median and basal regions. Knowing that eriophyid mites occur more frequently on leaves in the apical region of plants (Castagnoli and Simoni 2000), this result may be related to the high abundance of *A.*

schlechtendali present in the orchards. Furthermore, when comparing the three variables, apical leaves from organic Eva orchards were more abundant, possibly influenced by the high populations of *A. schlechtendali*.

The relationship between diversity and pest control is of great interest for sustainable agricultural production (Philpott 2013; Crowder and Jabbour 2014). In this study, the communities of organic orchards and management using pesticides were different. *Panonychus ulmi* was the most representative species in orchards that received pesticides in their management, together with the predatory mite *N. californicus*, indicating adaptation to the conventional production system. The results obtained strongly suggest that the conservation of the environment, through organic management, keeps the mite community in balance, with high mite richness and diversity, mainly those of natural enemies.

In conclusion, different apple cultivars influence the mite community. Eva and Gala demonstrated greater susceptibility to the presence of the species and apical leaves present a greater abundance of mites, mainly from populations of *A. schlechtendali*. Therefore, greater attention must be given to this region of the plant to carry out a management plan for phytophagous mites in these orchards. New studies are suggested on the preference of A. schlechtendali for the Eva cultivar and its potential to cause damage to different apple cultivars.

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