UNIVERSIDADE DO VALE DO TAQUARI - UNIVATES
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ÁCAROS EM POMARES DE MACIEIRAS (*Malus domestica*: Rosaceae) NO SUL DO BRASIL: OCORRÊNCIA, CARACTERIZAÇÃO DE DANOS E EFEITO DO MANEJO

Priscila de Andrade Rode

Lajeado/RS, março de 2024

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Tese de doutorado apresentada ao Programa de Pós-Graduação em Biotecnologia, da Universidade do Vale do Taquari - UNIVATES, como parte da exigência para obtenção do título de Doutora em Biotecnologia na área de concentração de Biotecnologia agroalimentar.

Orientador: Prof. Dr. Noeli Juarez Ferla

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Prof. Dr. Noeli Juarez Ferla - orientador
Universidade do Vale do Taquari - Univates

Profa. Dra. Lucélia Hoehne
Universidade do Vale do Taquari - Univates

Prof. Dr. Luiz Liberato Costa Corrêa
Universidade do Vale do Taquari – Univates

Dr. Maicon Toldi
Dillon Biotecnologia

Lajeado/RS, 25 de março de 2024

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Dedico.

"Enquanto eu respirar vou me lembrar de você"

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RESUMO

O Brasil está entre os maiores produtores mundiais de maçã (*Malus domestica* Bork: Rosaceae), com a produção concentrada principalmente na região Sul do país. Devido a alterações nos agroecossistemas, ácaros fitófagos estão atingindo o nível de dano econômico na cultura. Este estudo objetivou avaliar a acarofauna e sua dinâmica em pomares de macieiras da região Sul do Brasil, caracterizando injúrias, comportamento e manejo de ácaros em plantas de macieira. Coletas mensais no período de um ano foram realizadas em pomar convencional (Fuji e Gala) nos municípios de Muitos Capões (RS), São Joaquim (SC) e orgânicos (Gala, Fuji e Eva) no município de Antônio Prado (RS). Foram amostradas 40 macieiras por pomar, de onde eram retiradas três folhas (estratos apical, mediano e basal) e cinco amostras de vegetação espontânea /mês. O material foi triado e identificado no Laboratório de Acarologia da Univates. Testes de comportamento de espécies acarinas e avaliações de injúrias de ácaros fitófagos em macieiras foram realizados. Com os resultados obtidos foi confeccionado um manual técnico e uma chave dicotômica foi apresentada, contemplando as espécies acarinas que até o momento foram reportadas em macieiras no Brasil. Nas avaliações foram encontrados 7.193 ácaros nas macieiras e 540 na vegetação espontânea. Além disso, foram encontrados 692 ácaros da subordem Oribatida. *Plantago australis* Lam. (Plantaginaceae) e *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) foram as espécies de vegetação espontânea com maior importância nas avaliações. Tanto em macieiras quanto em vegetação espontânea, os pomares orgânicos foram os mais diversos e os predadores mais importantes foram os Phytoseiidae. Nas macieiras, *Neoseiulus californicus* (McGregor) (Phytoseiidae) foi o principal predador em áreas de cultivo convencional, e teve baixa ocorrência em áreas orgânicas. Nos pomares orgânicos, espécies de *Euseius* foram mais abundantes. Em avaliações de laboratório foi relatado a presença de injúrias causadas por *Tetranychus ludeni* Zacher (Tetranychidae) em mudas de macieira. Também foi apresentado *Phytoseiulus macropilis* (Banks) (Phytoseiidae) como possível controlador deste fitófago. Nas avaliações de comportamento dos ácaros fitófagos, a presença de teias e pistas de coespecífico aumentou a oviposição de *Panonychus ulmi* (Koch) (Tetranychidae), enquanto a presença de teia e ovo de *Aculus schlechtendali* (Nalepa) (Eriophyidae) e *Tetranychus urticae* Koch (Tetranychidae) e pistas de *A. schlechtendali* diminuíram sua oviposição. Na avaliação de clorofila, folhas de macieira infestadas com *T. urticae* apresentaram maior perda de clorofila e folhas infestadas por *P. ulmi* e *T. ludeni* tiveram as médias de clorofila diminuídas nos tratamentos a partir de 25 ácaros/folha. A avaliação da perda da estabilidade de membrana elencou *T. ludeni* como potencial causador de injúrias em macieiras. Além disso, foi demonstrado que quanto maior o número de ácaros na superfície foliar, maior é a área danificada. Este trabalho serve de alerta à cadeia produtiva de maçãs para monitoramento das infestações e prevenção de possíveis ameaças à cultura da macieira. Estes resultados são promissores, pois embasam pesquisas sobre o potencial dos ácaros fitófagos da macieira, e à interação entre esses herbívoros, e deles com os predadores.

Palavras-chave: *Aculus schlechtendali*; *Panonychus ulmi*; cultura da maçã; *Malus domestica.*

ABSTRACT

Brazil is among the world's largest producers of apples (*Malus domestica* Bork: Rosaceae), with production concentrated mainly in the southern region of the country. Due to changes in agroecosystems, phytophagous mites are reaching the level of economic damage to crops. This study aimed to evaluate the mite fauna and its dynamics in apple orchards in the southern region of Brazil, characterizing injuries, behavior and management of mites on apple plants. Monthly collections over a period of one year were carried out in conventional orchards (Fuji and Gala) in the municipalities of Muitos Capões (RS) and São Joaquim (SC) and organic orchards (Gala, Fuji and Eva) in the municipality of Antônio Prado (RS). 40 apple trees were sampled per orchard, from which three leaves were taken (apical, middle and basal layer), and five samples of spontaneous vegetation/month. The material was screened and identified at the Univates Acarology Laboratory. Behavioral tests of mite species and assessments of injuries from phytophagous mites on apple trees were carried out. With the results obtained, a technical manual was prepared, and a dichotomous key was presented, covering the mite species that have so far been reported on apple trees in Brazil. In the assessments, 7.193 mites were found on apple trees and 540 in spontaneous vegetation. In addition, 692 mites from the Oribatida suborder were found. *Plantago australis* Lam. (Plantaginaceae) and *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) were the spontaneous vegetation species with the greatest importance in the evaluations. Both in apple trees and in spontaneous vegetation, organic orchards were the most diverse and the most important predators were the Phytoseiidae. In apple trees, *Neoseiulus californicus* (McGregor) (Phytoseiidae) was the main predator in conventional cultivation areas, and had low occurrence in organic areas. In organic orchards, *Euseius* species were more abundant. In laboratory evaluations, the presence of injuries caused by *Tetranychus ludeni* Zacher (Tetranychidae) on apple seedlings was reported. *Phytoseiulus macropilis* (Banks) (Phytoseiidae) was also presented as a possible controller of this phytophagous. In the evaluations of the behavior of phytophagous mites, the presence of webs and conspecific cues increased oviposition of *Panonychus ulmi* (Koch) (Tetranychidae), while the presence of web and egg of *Aculus schlechtendali* (Nalepa) (Eriophyidae) and *Tetranychus urticae* Koch (Tetranychidae) and clues of *A. schlechtendali* decreased their oviposition. In the evaluation of chlorophyll, apple leaves infested with *T. urticae* showed greater loss of chlorophyll and leaves infested by *P. ulmi* and *T. ludeni* had chlorophyll averages reduced in treatments starting at 25 mites/leaf. The evaluation of the loss of membrane stability listed *T. ludeni* as a potential cause of injuries in apple trees. Furthermore, it has been shown that the greater the number of mites on the leaf surface, the greater the damaged area. This work serves as an alert to the apple production chain to monitor infestations and prevent possible threats to apple cultivation. These results are promising, as they support research into the potential of phytophagous mites on apple trees, and the interaction between these herbivores, and between them and predators.

Keywords: *Aculus schlechtendali*; *Panonychus ulmi*; apple culture; *Malus domestica*.

RESUMEN

Brasil se encuentra entre los mayores productores mundiales de manzanas (*Malus domestica* Bork: Rosaceae), con una producción concentrada principalmente en la región sur del país. Debido a los cambios en los agroecosistemas, los ácaros fitófagos están alcanzando niveles de daño económico a los cultivos. Este estudio tuvo como objetivo evaluar la fauna de ácaros y su dinámica en huertos de manzanos en la región sur de Brasil, caracterizando las lesiones, el comportamiento y el manejo de los ácaros en plantas de manzano. Se realizaron colectas mensuales durante un período de un año en huertos convencionales (Fuji y Gala) en los municipios de Muitos Capões (RS) y São Joaquim (SC) y en huertos orgánicos (Gala, Fuji y Eva) en el municipio de Antônio Prado (RS). Se muestrearon 40 manzanos por huerto, de los cuales se tomaron tres hojas, una de la capa apical, una de la capa media y otra de la capa basal, y cinco muestras de vegetación espontánea/mes. El material fue tamizado y identificado en el Laboratorio de Acarología de la Univates. Se llevaron a cabo pruebas de comportamiento de especies de ácaros y evaluaciones de lesiones causadas por ácaros fitófagos en manzanos. Con los resultados obtenidos se elaboró un manual técnico y se presentó una clave dicotómica que abarca las especies de ácaros que hasta el momento han sido reportadas en manzanos en Brasil. En las evaluaciones se encontraron 7.193 ácaros en manzanos y 540 en vegetación espontánea. Además se encontraron 692 ácaros del suborden Oribatida. *Plantago australis* Lam. (Plantaginaceae) y *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) fueron las especies de vegetación espontánea de mayor importancia en las evaluaciones. Tanto en manzano como en vegetación espontánea, los huertos orgánicos fueron los más diversos y los depredadores más importantes fueron los Phytoseiidae. En manzanos, *Neoseiulus californicus* (McGregor) (Phytoseiidae) fue el principal depredador en áreas de cultivo convencional, y tuvo baja ocurrencia en áreas orgánicas. En los huertos orgánicos, las especies de *Euseius* fueron más abundantes. En evaluaciones de laboratorio se reportó la presencia de lesiones causadas por *Tetranychus ludeni* Zacher (Tetranychidae) en plántulas de manzano. También se presentó *Phytoseiulus macropilis* (Banks) (Phytoseiidae) como posible controlador de este fitófago. En las evaluaciones del comportamiento de los ácaros fitófagos, la presencia de redes y señales conespecíficas aumentó la oviposición de *Panonychus ulmi* (Koch) (Tetranychidae), mientras que la presencia de redes y huevos de *Aculus schlechtendali* (Nalepa) (Eriophyidae) y *Tetranychus urticae* Koch (Tetranychidae) y indicios de *A. schlechtendali* disminuyeron su oviposición. En la evaluación de clorofila, las hojas de manzano infestadas con *T. urticae* mostraron mayor pérdida de clorofila y las hojas infestadas por *P. ulmi* y *T. ludeni* tuvieron promedios de clorofila reducidos en tratamientos a partir de 25 ácaros/hoja. La evaluación de la pérdida de estabilidad de la membrana incluyó a *T. ludeni* como una causa potencial de lesiones en los manzanos. Además, se ha demostrado que cuanto mayor es el número de ácaros en la superficie de la hoja, mayor es la superficie dañada. Este estudio sirve como alerta a la cadena productiva de la manzana para monitorear las infestaciones y prevenir posibles amenazas al cultivo de la manzana. Estos resultados son prometedores, ya que respaldan la investigación sobre el potencial de los ácaros fitófagos en los manzanos y la interacción entre estos herbívoros y entre ellos y los depredadores.

Palabras clave: *Aculus schlechtendali*; *Panonychus ulmi*; cultura de la manzana; *Malus domestica*.

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INTRODUÇÃO

A maçã (*Malus domestica* Borkh: Rosaceae) é a fruta de clima temperado mais consumida no mundo, representando 12,45% das frutíferas produzidas (O'Rourke, 2018; Faoro, 2022). A produção mundial de maçãs tem evoluído ao longo dos anos, com previsão de crescimento até 2025 (O'Rourke, 2018). O Brasil está entre os maiores produtores de maçãs do mundo (Kist *et al*., 2019; 2022). As áreas de maior cultivo no país estão localizadas nas regiões mais altas dos três estados do Sul do país (Kist et *al*., 2019; IBGE, 2022). Entre os principais cultivares de maçã produzidos, Gala e Fuji são os mais importantes, sendo que novos cultivares estão surgindo e agradando o paladar do consumidor e permitindo a expansão geográfica da área produtiva, como é o caso do cultivar Eva (Fioravanço *et al*., 2010; Faoro, 2022).

O crescente aumento da utilização de agrotóxicos vem deixando a cultura mais suscetível ao ataque de herbívoros causadores de danos, sendo que alguns deles estão criando resistência a esses insumos agrícolas (Van De Vrie, 1985; Gutiérrez-Moreno *et al*., 2019). Eriophyidae e Tetranychidae são ácaros fitófagos encontrados associados à cultura da macieira (Jeppson *et al*., 1975; Ferla; Moraes, 1998; Nascimento *et al*., 2020; Silva *et al*., 2022). Dentre estes, *Panonychus ulmi* (Koch) (Tetranychidae), que já é considerado causador de danos econômicos no Brasil e *Aculus schlechtendali* (Nalepa) (Eriophyidae), que era considerado de importância quarentenária no país, e que recentemente foi reportado ocorrendo, ainda sem registro de danos nos pomares brasileiros (Ferla *et al*., 2018).

Após longo período com ausência de estudos acerca de ácaros da cultura da maçã (Lorenzato *et al*., 1986; Ferla; Moraes, 1998; Monteiro, 2002a, b), este estudo apresenta resultados relevantes principalmente a partir dos recentes registros de *A. schlechtendali* na cultura (Ferla *et al*., 2018; Nascimento *et al*., 2020; Silva *et al*., 2022; Rode *et al.,* 2023). As informações apresentadas são importantes para a localização dos produtores e demais envolvidos na cadeia de maçãs, para que possam ser tomadas as melhores decisões com relação ao manejo e controle, objetivando melhores resultados de produção. Além disso, este também é o primeiro estudo sobre a avaliação da acarofauna em pomares com produção de maçãs orgânicas no Brasil.

Assim sendo, o objetivo deste trabalho foi avaliar a acarofauna e sua dinâmica em pomares de macieiras da região Sul do Brasil, caracterizando injúrias, comportamento e manejo de ácaros em plantas de macieira.

1.1 Definição do problema

- Como acontece a flutuação populacional da fauna acarina ao longo do ano nos pomares de macieira?
- Ocorre interação entre espécies acarinas nos pomares de macieira?
- Qual vegetação de ocorrência espontânea associada aos pomares de macieira tem potencial como reservatório de inimigos naturais?
- Quais as características das injúrias causadas por ácaros fitófagos presentes nas folhas de macieiras?

1.2 Hipóteses

- *Aculus schlechtendali* e as demais espécies fitófagas ocorrem no Sul do país com picos populacionais durante os períodos de temperaturas climáticas mais elevadas, sendo influenciadas pelo cultivar, pelo manejo do pomar e pela região do ramo.
- A presença de *A. schlechtendali* antecipa a chegada dos inimigos naturais nos pomares, servindo de alimento até que *P. ulmi* chegue ao pomar e possa ser controlado.

1.3 Objetivos

1.3.1 Objetivo Geral

- Avaliar a acarofauna e sua dinâmica em pomares de macieiras da região Sul do Brasil, caracterizando injúrias, comportamento e manejo de ácaros em plantas de macieira.

1.3.2 Objetivos Específicos

- Avaliar a acarofauna e sua flutuação populacional ao longo de um ano em pomares de macieiras;
- Comparar a fauna acarina de pomares de diferentes manejos e cultivares;
- Observar o comportamento e a distribuição de ácaros associados a macieira;
- Definir as espécies de vegetação espontânea com maior potencial como reservatório de inimigos naturais em pomares de macieira;
- Avaliar as injúrias ocasionadas por espécies fitófagas a membrana foliar de macieiras expostas a diferentes graus de infestação;

1.4 Justificativa

O Brasil está entre os maiores produtores mundiais de macieira e a qualidade das frutas no país vem aumentando a cada ano (Kist *et al*., 2019). A produção brasileira está concentrada principalmente na região Sul, onde o ambiente é mais favorável à cultura, sendo que os estados de Santa Catarina e Rio Grande do Sul são os maiores produtores do país, seguidos pelo Paraná (IBGE, 2022). Outros estados brasileiros como São Paulo e Minas Gerais também produzem maçãs, porém em menor escala (IBGE, 2022). Os municípios de Vacaria (RS), São Joaquim e Fraiburgo (SC) são referências na produção macieira, com dados de aproximadamente 1,16 milhão de toneladas produzidas em 2013-14 em 36 milhões de hectares (Kist *et al*., 2015). A importância das macieiras não se dá somente por ser um cultivo generalizado, e pela sua riqueza nutricional (Pires *et al*., 2018; Estrada-Beltrán *et al*., 2024), mas também por apresentar grande importância social e econômica na geração de empregos no país e é uma alternativa de renda nas propriedades rurais, por proporcionar e permitir a fixação do homem no meio rural (Kist *et al*., 2019). Mesmo se tratando de uma cultura economicamente forte, novos desafios surgem, sendo necessário o desenvolvimento e adoção de novas tecnologias (Reganold *et al*., 2001). Desta forma, para haver avanço na produção de maçãs e para que ela se torne cada vez mais sustentável e se mantenha como uma cultura economicamente competitiva e geradora de renda e empregos no país é necessária a adoção de novas tecnologias pelo setor produtivo (Faoro, 2022).

Alterações nos agroecossistemas favorecem o surgimento de problemas fitossanitários, como a ocorrência de populações que alcançam o *status* de praga, ocasionando perdas significativas à produtividade na cultura (Reganold *et al*., 2001). O uso indiscriminado de pesticidas nos pomares frutíferos pode ocasionar a redução dos inimigos naturais, e consequentemente, o aumento populacional de ácaros fitófagos possíveis causadores de danos econômicos (Van De Vrie, 1985; Pålsson *et al*., 2022; Rode *et al*., 2023). Através da expansão das áreas de cultivo, ocorre a ampliação da distribuição geográfica de pragas agrícolas, pelo processo natural de dispersão, característicos de cada espécie ou através do transporte indevido de material vegetal infestado com os fitófagos, de uma região para outra (Morgante, 1991; Navia; Moraes; Flechtmann, 2007; Navia *et al*., 2010). Algumas espécies distribuídas mundialmente de forma intencional ou não, podem causar impacto econômico, social e ambiental (Wheeler; Hoebeke, 2009). Devido à ausência dos inimigos naturais, estas espécies podem aumentar suas populações e atingir o *status* de praga em diversas culturas (Brown; Hovmøller, 2002; Anderson *et al*., 2004). A introdução de ácaros fitófagos exóticos é facilitada pelo seu potencial de colonização de novas áreas, dificuldade de detecção nas alfândegas, alta capacidade de sobrevivência em condições adversas, potencial adaptativo a novos hospedeiros, fácil dispersão através do vento, desenvolvimento de resistência a produtos químicos, potencial de danos às plantas hospedeiras e transmissão de determinados vírus vegetais (Navia; Moraes; Flechtmann, 2007; Navia *et al.*, 2010). O registro de presença de *A. schlechtendali* na região Sul do Brasil serve como alerta para a cadeia produtiva da maçã por se tratar de uma espécie de importância quarentenária presente no Brasil (Ferla *et al*., 2018; Nascimento *et al*., 2020; Silva *et al*., 2022). Identificar a abundância da espécie na região, e de espécies associadas, auxilia no monitoramento e no planejamento de futuras ações de manejo da cultura, bem como no entendimento do padrão de distribuição e de dispersão desse ácaro nos locais de ocorrência. Além disso, aparentemente a presença de *A. schlechtendali* na macieira ainda não está causando danos à cultura, sendo possível estabelecer de forma preventiva um manejo para possíveis ataques severos do ácaro aos pomares.

É de extrema importância, a identificação e o conhecimento do comportamento das espécies, a estimativa de suas populações e o conhecimento dos períodos de maior abundância em campo. Estes fatores são fundamentais para a definição de estratégias eficientes de manejo, que permitam maiores taxas de produtividade e qualidade, agregando valor ao produto final, mediante tecnologias sustentáveis e adequadas para a produção mais limpa e a redução dos

custos de produção.

Após longo período com ausência de estudos relacionados a acarofauna em pomares brasileiros de maçã (Lorenzato *et al*., 1986; Ferla; Moraes, 1998; Monteiro 2002 a, b), este estudo apresenta resultados relevantes principalmente a partir do recente registro de *A. schlechtendali* na cultura (Ferla *et al*., 2018; Nascimento *et al*., 2020; Silva *et al*., 2022). O presente estudo avalia a acarofauna e sua dinâmica em macieiras e vegetação espontânea associada da região Sul do País (Rode *et al.*, 2023; 2024 a, 2024b) e caracteriza as injúrias causadas por ácaros fitófagos em plantas de macieiras. Este também é o primeiro estudo sobre a avaliação da acarofauna em pomares com produção de maçãs orgânicas no Brasil (Rode *et al*., 2023; 2024 a, 2024b). As informações aqui apresentadas são importantes para a localização dos produtores e demais envolvidos na cadeia produtiva de maçãs, pois auxilia na elaboração de um plano de manejo alternativo, que visa melhores resultados de produção, redução do uso de pesticidas agrícolas, e consequentemente, a conservação dos recursos naturais e da saúde humana e animal.

Este estudo é vinculado ao Programa de Pós-Graduação em Biotecnologia da Univates (PPGBiotec), na área de concentração de Biotecnologia Agroalimentar e na linha de pesquisa de Biotecnologia na Produção Primária de Alimentos. Esta pesquisa, juntamente aos objetivos do programa, busca a introdução de estratégias sustentáveis na cadeia produtiva de maçãs a fim de minimizar os danos causados pelo manejo agrícola inadequado. Este estudo traz inovação e possibilidades de melhora socioeconômica ao setor produtivo de macieiras do Sul do Brasil. Tendo em vista as riquezas naturais presentes nesta região, é possível ser agregado valor ao produto final, unindo sustentabilidade e biotecnologia à produção de maçãs. Com isso possibilita-se, além do crescimento econômico regional, a conservação da saúde humana, animal e ambiental.

2 REFERENCIAL TEÓRICO

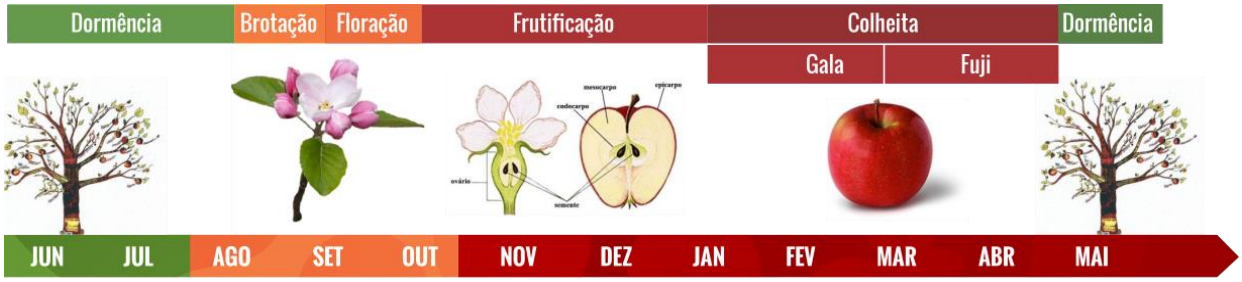
2.1 *Malus domestica*. Rosaceae está presente dentro do grupo das angiospermas, o que a torna capaz de produzir flores e frutos (Da Silva Simões *et al*., 2019). A família possui grande importância agronômica e econômica, sendo que algumas oferecem frutas que servem de alimento e auxiliam na saúde humana (Da Silva Simões *et al*., 2019; Kamusiime; Nantongo; Wacal, 2023). Rosáceas dos gêneros *Malus*, *Pyrus* e *Prunus* são cultivadas principalmente por seus frutos (Vavilov, 1951). As primeiras linhagens dos gêneros *Malus* e *Pyrus* originaram *Malus domestica* (Smartt; Simmonds, 1995). A macieira (*Malus* x *domestica* Borkh) se originou em uma região situada entre o oeste da China e o sul da Rússia, sendo seu principal ancestral selvagem a espécie *Malus sierversii* (Ledeb.) Roem (Hancock, 2014). *Malus sieversii* foi possivelmente a primeira espécie de macieira que tenha sido domesticada pelos humanos, sendo que esta espécie apresenta muitas das boas características da *M. domestica*, mesmo que ambas mantenham 35,3% de divergências genéticas entre elas (Forsline; Aldwinckle, 2004). Por ser um complexo de hibridações, os cultivares de macieira hoje cultivados são designados como *Malus* x *domestica* Borkh. ou *Malus domestica* Borkh, segundo o Código Internacional de Nomenclatura para plantas Cultivadas (Petry; Leite, 2009). Não é correto o uso dos nomes *Pyrus malus* L., *Malus ioensis* Britt., *Malus pumila* Mill. e *Malus sylvestris* Mil. (Luby, 2003; Faoro, 2022). A macieira pertence à divisão Angiospermae, classe Dicotyledonae, subtribo Pomoideae, ordem Rosales, família Rosaceae, subfamília Maloideae e ao gênero *Malus* (Faoro, 2022).

Estudos *in vitro* e *in vivo* indicam que o consumo de frutas da família Rosaceae pode trazer benefícios à saúde humana, pois são consideradas uma valiosa fonte de antioxidantes (Wolfe *et al*., 2003; Shulaev *et al*., 2008; Pieniz *et al*., 2009). Espécies deste grupo são

conhecidas como grandes contribuintes de fitoquímicos, como flavonoide e outros compostos fenólicos, glicosídeos cianogênicos, fitoestrogênios e fenóis que podem auxiliar no combate a doenças (Swanson, 1998; Selmar, 1999; Mazur *et al*., 2000; Pires *et al*., 2018; Alongi *et al*., 2019; Estrada-Beltrán *et al*., 2024). Ácido L-ascórbico, quercetina, kaempferol, miricetina, ácido p-cumárico, ácido gálico e ácido elágico são antioxidantes conhecidos e alguns compostos inibidores do câncer já foram identificados em frutas rosáceas (Shulaev *et al*., 2008). Com relação à maçã, estudos *in vivo* e *in vitro* indicam que seu consumo pode reduzir o risco de doenças crônicas, têm efeitos antioxidantes, antiproliferativos e de sinalização celular (Hyson, 2011). Estas pesquisas demonstram que consumir maçãs pode auxiliar no combate ao Alzheimer, no aumento da produção de enzimas antioxidantes, na redução do risco de câncer, de doenças ósseas, coronárias, gastrointestinais, algumas desordens pulmonares, no diabete e na ingestão de remédios (Hyson, 2011; Faoro, 2022). Além do consumo *in natura*, a maçã pode ser consumida mediante produtos secos, aromas, sucos, vinagres, sidras, polpas, que apresentam grande variedade de sabor, texturas, níveis de doçura e acidez (Schuch, 2005; Shulaev *et al*., 2008).

A maior qualidades dos frutos de macieira e altos níveis de produção são encontrados em regiões que se caracterizam por estações do ano bem definidas e inverno com temperaturas baixas. Essas exigências se dão pela total dependência da espécie e as características climáticas de cada época do ano (Pomifrutas, 2024) (Figura 1).

Figura 1 - Ciclo produtivo de maçãs dos cultivares Gala e Fuji ao longo do ano.



Fonte: Adaptado de Pomifrutas (2024).

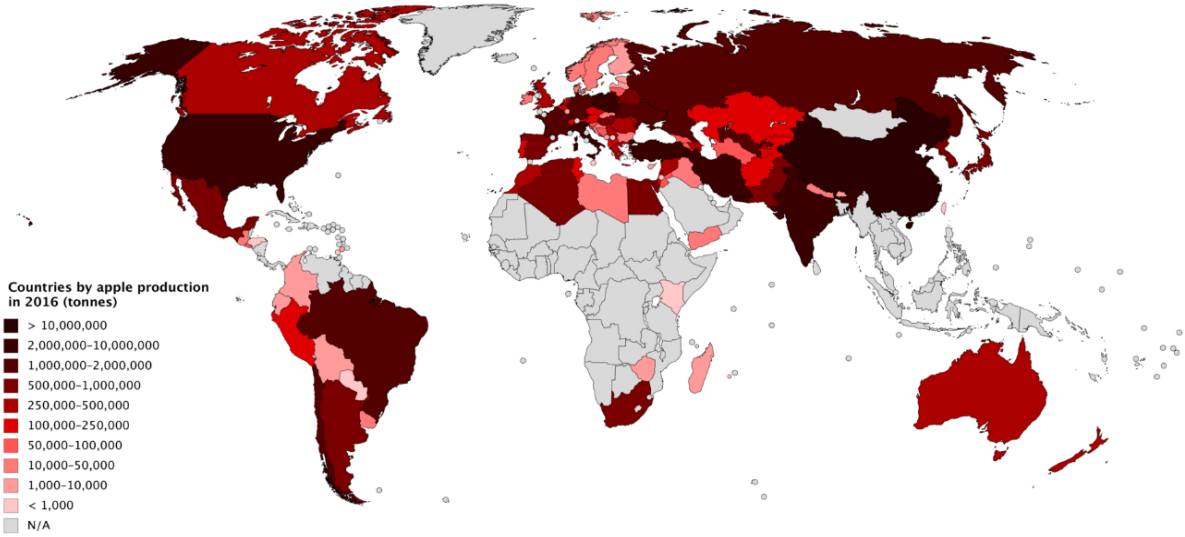
2.1.1 Histórico da macieira no Brasil.

O primeiro registro brasileiro da presença de macieiras é do ano de 1903, quando Rossi menciona o cultivar Bismark crescendo no jardim do Sr. Donner, em uma localidade próxima de Indaial e Brusque, no estado de Santa Catarina (Santos, 1994). No Rio Grande do Sul, em

1948, já havia pomares com alguns cultivares, entre elas a Ohio Beauty, no município de Caxias do Sul e Veranópolis, onde foi plantado o cultivar José Bin. No final da década de 1960, fruticultores das famílias Evrard e Mahler, mudaram da Argélia para Fraiburgo, fundando a im, com o objetivo inicial de desenvolver a vitivinicultura, porém, outras frutíferas de clima temperado, como a macieira, foram instaladas (Petri *et al*., 2011). Em 1969, a empresa Reflorestamento Fraiburgo, implantou o primeiro pomar comercial de macieira, conforme a Lei federal dos incentivos fiscais nº 5.106, que aceitava o abate de 50% do Imposto de Renda para aplicação em reflorestamento, podendo ser feita com árvores frutíferas. A lei impulsionou o desenvolvimento da cultura da macieira no Brasil. Após, na década de 1970, a macieira começou a ser plantada principalmente em Santa Catarina e Rio Grande do Sul, formando-se três polos produtivos que perpetuam até os dias atuais: Fraiburgo, São Joaquim e Vacaria (Petri *et al*., 2011).

Atualmente, a planta é cultivada em todos os continentes, com exceção da Antártida (Assouguem *et al*., 2024), sendo o Brasil um dos países com maior produção de maçãs no mundo, com produção de aproximadamente um milhão de toneladas por ano (Kist *et al*., 2019) (Figura 2).

Figura 2 - Principais países produtores de maçã.



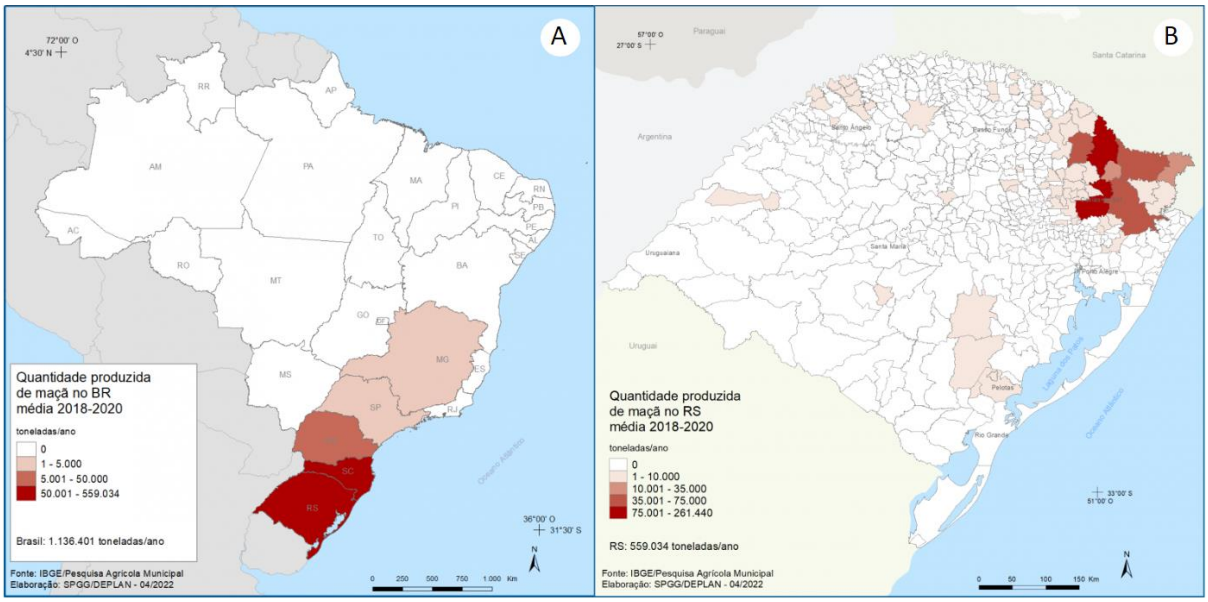
Fonte: FAOSTAT (2016).

A qualidade das frutas no país vem aumentando gradativamente ano após ano (Kist *et al*., 2019). Além disso, o país vem crescendo no mercado externo de maçã e é responsável pela exportação do produto *in natura* para 66 países (Kist *et al*., 2019). A maior quantidade de maçãs

Gala *in natura* exportada entre os anos de 2015 e 2018 se originou nos estados do Rio Grande do Sul (73,5%) e Santa Catarina (26,4%) (Kist *et al*., 2016; Goulart Jr. 2020a). Em 2020, a exportação brasileira de maçãs foi de US$ 41,27 milhões, sendo o Rio Grande do Sul responsável por US$ 35,78 milhões e Santa Catarina por US$ 4,98 milhões (Faoro, 2022).

A maior produção brasileira é localizada principalmente em regiões mais altas dos três estados do Sul do país (Kist *et al*., 2019), em cidades onde o ambiente é mais favorável a essa cultura (Figura 3).

Figura 3 - Quantidade produzida de maçã no Brasil, média 2020-2022 (A). Quantidade produzida de maçã no estado do Rio Grande do Sul, média 2020-2022 (B).



Fonte: IBGE/Pesquisa agrícola municipal (2023).

Cidades onde as temperaturas são baixas no período do inverno são ideais para os processos de brotação e floração das macieiras (Petri, 2006). Desta forma, os estados de Santa Catarina e Rio Grande do Sul são os maiores produtores, seguidos pelo Paraná (Faoro, 2022). Na safra 2018/2019, o Rio Grande do Sul possuía a maior área destinada ao plantio de macieiras (15.917ha ou 46,9%), e foi o primeiro em produção (603.293t ou 49,3%), mas apresentou menor produtividade (37.969kg ha-1) com relação à Santa Catarina (38.544kg ha-1) (Faoro, 2022). O estado de Santa Catarina possui a segunda maior área de plantio, na qual, em 2019, foram produzidas 47,9% da produção nacional (ABPM, 2019; Faoro, 2022). O estado do Paraná, nos últimos anos, reduziu ainda mais a sua área de plantio (31,5%), ostenta menor produtividade média (29.150kg ha-1), da mesma forma, a mesma situação é observada nos outros estados

produtores, que reduziram 25,1% da área de plantio (Faoro, 2022). Os Campos de Cima da Serra é a região com maior concentração da produção, sendo os municípios de Vacaria, Muitos Capões, Ipê (RS), São Joaquim, Bom Jesus e Fraiburgo (SC) referência na produção macieira (Kist *et al*., 2015; 2019) (Figura 4).

Na safra de 2013/2014, essa região foi responsável por aproximadamente 1,16 milhão de toneladas produzidas em 36 milhões de hectares (Kist *et al*., 2015; 2019). E na safra de 2014/2015, São Joaquim e Fraiburgo (SC) e Vacaria (RS), representaram 81,9% da maçã brasileira colhida, o que evidencia a forte concentração da produção nacional nos dois estados (Faoro, 2022).

Mesmo com os avanços tecnológicos na agricultura, a cultura da macieira proporciona um dos maiores índices de demanda de mão de obra no agronegócio brasileiro, oportunizando o emprego de aproximadamente 148 mil pessoas, entre empregados fixos e temporários (Kist *et al*., 2019; Faoro, 2022) (Figura 4). Seu cultivo gera movimentação econômica e propicia o acesso a uma fruta com qualidade funcional que auxilia na saúde humana (Faoro, 2022). As principais formas de consumo da maçã são os frutos frescos, porém, outros produtos podem ser produzidos a partir da fruta, como bebidas, compotas, geleias e doces (Landau; Silva, 2020).

Figura 4 - Colheita de maçãs sendo realizada nos pomares (A, B).

Fonte: Aires, M (2020) (A). Mandarino, D (2018) (B).

2.1.2 Cultivares de macieira. O desenvolvimento de diferentes cultivares de macieiras apresenta vantagens com relação à diversidade genética e a variação de algumas características e a manutenção de outras ao longo das gerações. Além disso, maior disponibilidade de cultivares permite que a produção seja realizada em maiores períodos, demanda menor mão-

de-obra na colheita, e auxilia no gerenciamento dos pomares, diminui o risco de perda devido a eventos climáticos em determinados estádios de desenvolvimento e torna as plantas menos vulneráveis a pragas e a doenças (Fioravanço *et al*., 2010; Denardi *et al*., 2023).

Dentre os milhares de cultivares de macieiras distribuídas pelo mundo, somente algumas dezenas são cultivadas de forma extensiva (Way *et al*., 1990). Os cultivares mais importantes são os pertencentes aos grupos Golden delicious, Gala, Fuji e Red delicious (Iglesias *et al*., 2008; Denardi *et al*., 2023) (Figura 5). Em países tradicionais a produção dos cultivares Gala e Fuji está se aproximando ou ainda se sobressaindo com relação à Golden Delicious e Red Delicious (Fioravanço *et al*., 2010; Faoro, 2022).

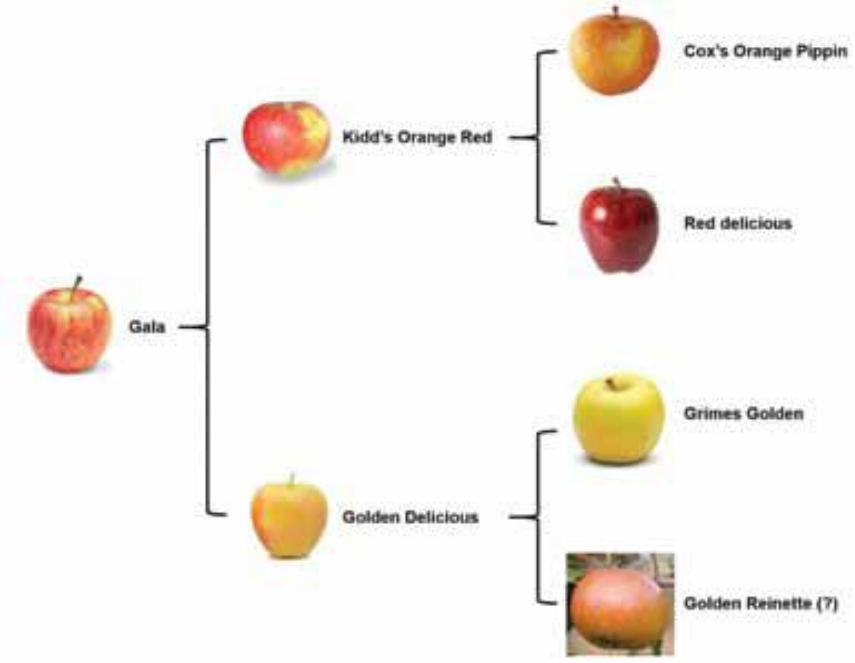
Figura 5 - Alguns dos cultivares de maçãs produzidos no Brasil.

Fonte: Pires, T. (2019).

Os grupos de cultivares possuem clones com melhores características que o cultivar original, sendo estes de interesse para os produtores. As principais mutações estão relacionadas às alterações da coloração da epiderme do fruto, e algumas vezes ao tamanho do fruto, vigor da planta, hábito de frutificação, resistência a doenças e diferença nas épocas produtivas. Os cultivares Gala e Fuji apresentaram o maior crescimento em área plantada nos últimos anos (Kist *et al*., 2015, 2019; Faoro, 2022).

Gala é originária de um cruzamento entre os cultivares Kidd´s Orange Red x Golden Delicious realizado por volta de 1932 na Nova Zelândia (Faoro, 2022) (Figura 6).

Figura 6 - Árvore genealógica do cultivar Gala.



Fonte: Faoro (2022).

O plantio comercial de maçãs Gala iniciou em 1965, mas o cultivar tornou-se mais conhecido e teve seu plantio difundido em outros países somente após serem lançadas suas mutações espontâneas, pois passaram a produzir frutos com maior área de coloração vermelha estriada (Faoro, 2022). No Brasil, Gala foi testado pela primeira vez em Fraiburgo, SC, indicado como um dos cultivares potenciais para plantio nessa região em 1975 e o primeiro plantio comercial ocorreu em 1976 no mesmo município (Faoro, 2022). Desde então, Gala passou a ser o cultivar mais plantado no Brasil.

O cultivar Gala é muito importante na Austrália, Nova Zelândia, China, Polônia, República Checa, França, Espanha, Chile, Argentina e Brasil (Hampson; Kemp, 2003; Iglesias *et al*., 2008). Entre as safras de 2007/2008 e 2019/2020 o grupo 'Gala', correspondeu por uma média de 57,4% da produção brasileira de maçãs, sendo que na safra de 2019/2020 o cultivar respondeu por 59,9% da produção, correspondendo a 562 mil toneladas de maçãs (Faoro, 2022). Gala e seus clones se destacam na produção devido às suas propriedades organolépticas que agradam ao paladar do consumidor (Fioravanço *et al*., 2010). Este cultivar apresenta floração abundante, elevada frutificação e pouca alternância de produção e desde o início da produção no Brasil seus frutos sofreram relevantes alterações até chegar ao produto que é consumido atualmente (Faoro, 2022). Os frutos de Gala são arredondados com tamanho que varia de pequeno a médio, amadurecimento desuniforme, coloração vermelho-rajada e polpa doce,

crocante, aromática e suculenta (Faoro, 2022). O cultivar requer entre 600 e 800 horas de frio (temperatura abaixo de 7,2 °C) (Cardoso *et al*., 2015; Faoro, 2022).

O cultivar Fuji foi originado de um cruzamento realizado no Japão. Este cultivar tem grande importância no Japão, China, Coreia, Austrália, Espanha, Brasil, Argentina e Chile (Hampson; Kemp, 2003; Iglesias *et al*., 2008). Fuji foi introduzido no Brasil no ano de 1967 e é atualmente o segundo grupo mais cultivado (Camilo; Denardi, 2002). Entre as safras de 2007/2008 e 2019/2020, o cultivar correspondeu a uma média de 36,6% da produção brasileira de maçãs (Faoro, 2022).

Fuji apresenta intensa floração e elevada produção, com frutos de tamanho médio a grande e maturação desuniforme. Requer elevado tempo de horas de frio (600 a 800h de temperatura abaixo de 7,2 °C). O cultivar possui mais de cem clones com características que variam quanto à adaptação climática, época de colheita, qualidade e coloração da fruta (Komatsu, 1998; Hampsom; Kemp, 2003). Os clones que tendem a ser mais cultivados são os que apresentam coloração de epiderme mais avermelhada, clones menos vigorosos e com frutas mais uniformes.

Outros cultivares são descritos como relevantes, apesar de possuírem menor importância se comparados com Fuji e Gala. Estes novos cultivares, por apresentarem menor exigencia de frio estão viabilizando o cultivo da fruta em outras regiões do Brasil, como em Minas Gerais, onde a cultura encontra-se em expansão (Oliveira *et al*., 2011; 2014; Denardi *et al*., 2023). A chegada deles permite a ampliação do calendário de colheita e da região de produção, sendo uma boa opção de plantio tanto para pequenos agricultores quanto para grandes empresas (Denardi *et al*., 2023). Entre as safras de 2007/2008 e 2019/2020 estes cultivares corresponderam por uma média de 6% da produção brasileira de maçãs (Faoro, 2022). Já na safra de 2019/2020, estes grupos representaram apenas 5,1% da produção brasileira, sendo produzidas 48 mil toneladas de maçãs (Faoro, 2022). Dentre os cultivares mais recentes e pouco conhecidos estão Eva, Anna, Anabela, Carícia e Condessa que são considerados precoces e de pouca necessidade de frio, indicados para cultivo em regiões mais quentes (Hauagge; Tsuneta, 1999; Fioravanço *et al*., 2010; Denardi *et al*., 2023).

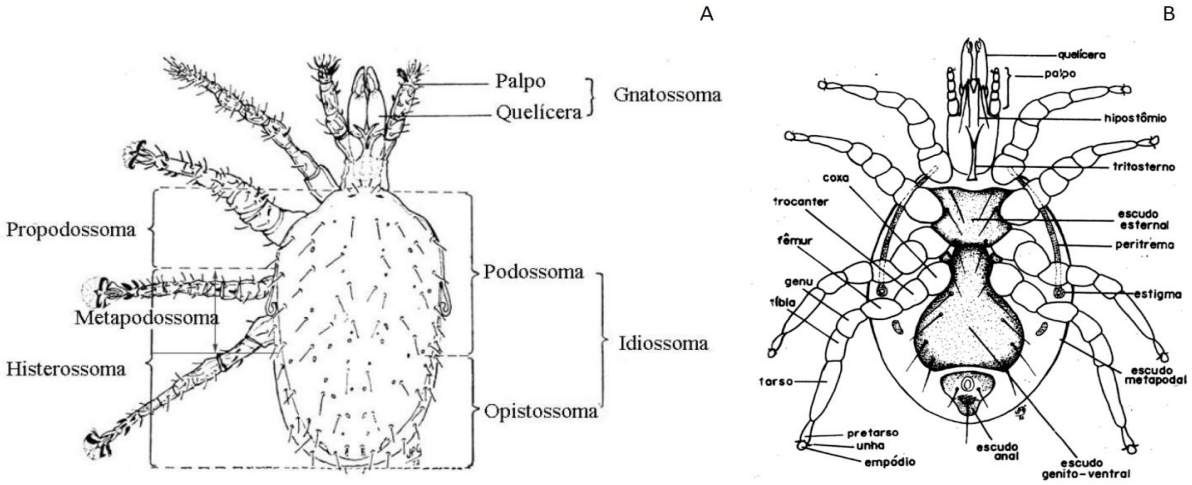
O cultivar Eva foi desenvolvido pelo Instituto Agronômico do Paraná (Iapar), como resultado de um cruzamento entre Anna e Gala e é considerado precoce, com colheita dos frutos a partir do mês de dezembro, o que permite a sua comercialização neste período como maçã

“fresca”, favorecendo a obtenção de bons preços pelos produtores (Hauagge; Tsuneta, 1999; Faoro, 2022). Eva tem baixa necessidade de frio, precisando de 300 a 350 horas de frio para ocorrência da quebra de dormência (Hauagge; Tsuneta, 1999; Faoro, 2022). Os programas de melhoramento genético do Instituto de Desenvolvimento Rural do Paraná (IDR), ex-Iapar, estão em constante evolução, e na busca de novas estirpes mutantes (Faoro, 2022). Recentemente uma nova seleção do cultivar Eva, com maior área de cobertura vermelha na epiderme dos frutos, foi obtida Eva Rubi (Faoro, 2022).

Com relação à presença de herbívoros, os cultivares podem variar em sua suscetibilidade a pragas e doenças, sendo importante conhecer os níveis de resistência ou suscetibilidade para o planejamento do manejo de pragas (Valadão *et al*., 2012).

2.2 Ácaros. Na subclasse Acari estão inclusos carrapatos e ácaros. É um grupo diversificado de quelicerados que apresenta divisão corporal diferenciada e sem segmentação aparente (Krantz; Walter, 2009) (Figura 7).

Figura 7 - Esquema de um ácaro Mesostigmata, em vista dorsal, mostrando as principais estruturas do idiossoma (A). Esquema de um ácaro Mesostigmata, em vista ventral, mostrando as principais estruturas do idiossoma (B).

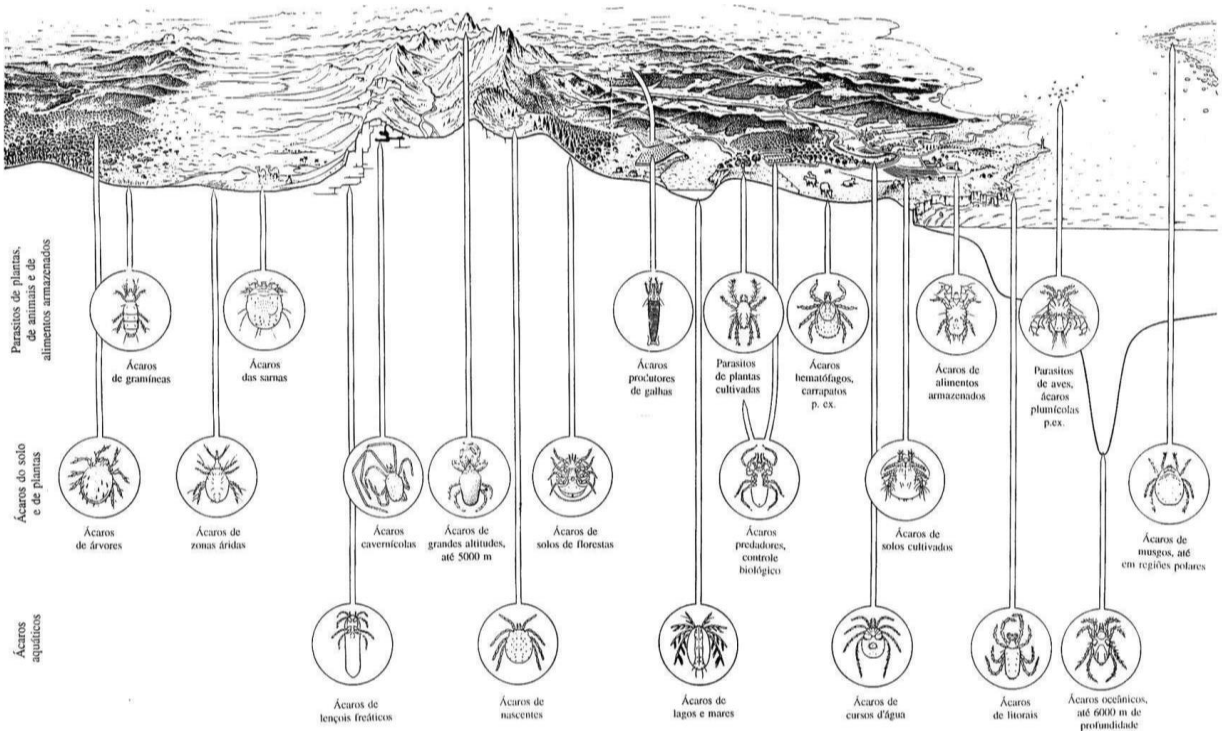


Fonte: modificado de Krantz (1978) (A). Fonte: Flechtmann (1973) (B).

Os ácaros são encontrados tanto em ecossistemas terrestres quanto aquáticos (Flechtmann, 1975), possuem ampla gama de hábitos alimentares, maior do que o observado em qualquer outro aracnídeo (Figura 8). Este grupo pode ingerir diferentes partes de origem vegetal, pólen, fungos e algas, podendo ainda possuir hábitos parasitários, ser predadores ou

ainda se alimentar de matéria orgânica em decomposição, bactérias, nematoides, entre outros (Flechtmann, 1975; Moraes; Flechtmann, 2008).

Figura 8 - Ácaros em todos os biótipos.



Fonte: Flechtmann.

Ácaros das subordens Prostigmata e Mesostigmata são os ácaros de maior importância econômica agrícola (Evans, 1992). Entre os Prostigmata estão os fitófagos das famílias Eriophyidae, Tarsonemidae, Tenuipalpidae e Tetranychidae e o predador Stigmaeidae (Jeppson *et al*., 1975) e entre os Mesostigmata, destacam-se os predadores, Phytoseiidae (Demite, McMurtry; Moraes, 2014).

2.2.1 Espécies quarentenárias. Organismos e patógenos invasores estão ameaçando a segurança alimentar no mundo todo, causando a diminuição da qualidade e redução nos rendimentos de produção (Strange; Scott, 2005; Flood, 2010; Fischer *et al*., 2012). Estas espécies podem se tornar pragas em diversas culturas, distribuídas mundialmente de forma intencional ou não pelos seres humanos (Di Castri, 1990; Brown; Hovmøller, 2002; Anderson *et al*., 2004; Wheeler; Hoebeke, 2009). A disseminação de insetos e ácaros pode ocorrer devido ao aumento da circulação de materiais vegetais, pelo desenvolvimento de novas tecnologias em

transporte e comércio livre, e ainda por conta do aumento do turismo e da circulação humana. Estes fatores facilitam o ingresso e o estabelecimento de espécies que podem se tornar invasoras (Yan *et al*., 2001; Anderson *et al*., 2004; Wheeler; Hoebeke, 2009; Fisher *et al.*, 2012). A dispersão intercontinental de organismos com este potencial pode causar danos e doenças às plantas de diversas culturas em escala global (Brown; Hovmøller, 2002). A introdução de espécies de ácaros fitófagos em locais que não são de sua origem acaba causando impacto econômico, social e ambiental (Navia *et al*., 2010). Espécies de ácaros fitófagos são fortes candidatas a se tornarem pragas introduzidas em novas áreas devido à dificuldade para sua detecção, capacidade de sobrevivência a condições desfavoráveis, reprodução por partenogênese e endogâmica, dispersão facilitada através do vento, potencial adaptativo a novas plantas hospedeiras principalmente para espécies polifágicas, desenvolvimento de resistência a produtos químicos, potencial para causar danos às plantas hospedeiras e transmissão de determinados vírus vegetais (Navia; Moraes; Flechtmann, 2007; Navia *et al*., 2010). Maior atenção deve ser dada aos ácaros eriofiídeos, que apresentam maior potencial para se tornarem espécies invasoras devido às suas características físicas e biológicas (Ferla *et al.*, 2018; Nascimento *et al*., 2020).

2.2.2 Disseminação de ácaros. Devido ao pequeno tamanho, os ácaros são facilmente transportados dentro de mercadorias. Além disso, se uma única fêmea estiver presente no ambiente pode-se iniciar uma população, devido a sua capacidade de reprodução por partenogênese e a alta taxa de reprodução (Sabelis, 1985). O estudo desenvolvido por Anderson *et al*. (2004) sobre as causas do surgimento de novas doenças em plantas, demonstrou que 56% eram resultantes de introduções associadas ao comércio de plantas e produtos vegetais e à circulação humana. Recentemente houve a introdução de *Tetranychus evansi* (Baker & Pritchard) na Europa e na África, uma espécie provavelmente nativa da América do Sul (Migeon *et al*., 2009), que demonstra natureza invasora para a agricultura mundial (Boubou *et al*., 2011). O crescente aumento do trânsito humano e de mercadorias entre países tem favorecido a propagação internacional de organismos para fora de seus locais de origem. As espécies exóticas em áreas recém colonizadas, podem causar danos, com sérias consequências para a biodiversidade, a agricultura e a saúde humana (Boubou *et al*., 2011). Algumas das espécies que recentemente foram introduzidas no Brasil são *Raoiella indica* Hirst em Roraima (Navia *et al*., 2011), *Aceria tosichella* Keifer no Rio Grande do Sul em 2006 (Pereira *et al*., 2009), *Schizotetranychus hindustanicus* (Hirst) em 2008 pela segunda vez na América do Sul e

pela primeira vez no país, em Roraima (Navia; Marsaro, 2011) e *Aculus schlechtendali* pela primeira vez no país (Ferla *et al*., 2018) e já possui registro nos três estados sul brasileiros (Nascimento *et al*., 2020). A possibilidade de introdução de outros ácaros no país, através da entrada de produtos potencialmente infestados e a movimentação de material vegetal, pode causar a introdução de biótipos nocivos às plantas brasileiras (Mendonça *et al*., 2011).

2.2.3 Identificação de ácaros. A identificação taxonômica realizada de forma correta é importante em todos os grupos animais e vegetais, sendo base para todos os estudos biológicos (Rosen, 1986). Porém, em estudos acarológicos, alguns grupos possuem caracteres taxonômicos limitados para diferenciação ao nível específico, e o controle eficaz das pragas agrícolas depende do conhecimento taxonômico das espécies envolvidas (Knapp; Wagener; Navajas, 2003). Os biótipos são cepas biológicas que se diferenciam fisiologicamente dentro de espécies, são morfologicamente distintos e têm diferentes capacidades de sobrevivência em plantas com diferentes genes de resistência (Painter, 1951). Para os insetos e ácaros de importância agrícola, identificar e conhecer a existência de biótipos é essencial para o manejo integrado (Gallo *et al*., 2002). Estudar as populações de organismos fitófagos associados a hospedeiros implica na resistência a acaricidas e no conhecimento do fluxo gênico entre populações (Fytrou; Tsagkarakou, 2014). Este tipo de conhecimento também é importante para auxiliar em estudos evolutivos do processo de diferenciação genética. Quando há mudança no hospedeiro, pode rapidamente gerar novas espécies, com isolamento reprodutivo de seus progenitores (Bush, 1975). O termo biótipo pode ser associado a outros termos semelhantes, como subespécie, espécie críptica, raça biológica e raça hospedeiro especialista (*host race*).

2.2.3.1 Caracterização morfológica. Em acarologia, a descrição morfológica é amplamente utilizada para fins taxonômicos e as técnicas envolvidas, em geral, utilizam observação das diferenças fenotípicas entre os organismos (Navajas; Fenton, 2000). Caracteres morfológicos como tamanho do corpo, comprimento das setas do dorso, quetotaxia das pernas, tamanho e forma da espermateca e comprimento das quelíceras são muito utilizados nas identificações e em estudos evolutivos e taxonômicos (Sourassou *et al*., 2012). Porém, a falta de diferenças morfológicas qualitativas entre espécies em alguns casos faz com que a distinção entre elas se dificulte. Nesses casos, a análise morfológica pode ser complementada por estudos ecológicos, biológicos e moleculares, que auxiliam na distinção de espécies próximas (Caterino; Cho; Sperling, 2000; Noronha, 2002; Navia *et al*., 2005; Mahani *et al*., 2009). Muitas vezes, os

critérios utilizados para distinção de espécies são frágeis e podem se sobrepor para duas formas estudadas, dificultando a separação em espécies distintas (Mendonça, 2009). Algumas espécies de ácaros são muito parecidas ou idênticas em suas formas, mas se diferem uma da outra na preferência pelo hospedeiro (Diehl; Bush, 1984). Existem populações morfologicamente similares, mas incompatíveis reprodutivamente e desta forma são consideradas espécies diferentes (Gondim; Moraes, 2002). O estabelecimento de chaves dicotômicas específicas para a separação de grupos zoológicos para determinada região facilita as atividades de pesquisa, taxonômicas e de outras especialidades científicas (Mayr; Bock, 2002).

2.2.4 Ácaros fitófagos associados à macieira. Clorofilas são os pigmentos naturais mais abundantes presentes nas folhas das plantas, elas contribuem para a absorção da radiação fotossinteticamente ativa e são fundamentais para a produção de oxigênio e açúcares (Blackburn, 2007; Jay *et al*., 2017). O conteúdo de clorofila é um importante indicador do estado fisiológico das plantas e é bastante utilizado para analisar o desenvolvimento e crescimento da planta (Blackburn, 2007; Steele; Gitelson; Rundquist, 2008; Sperotto, 2014). A perda de clorofila nos tecidos vegetais, especialmente nas folhas, é um indicador que permite determinar a tolerância de uma planta ao ataque de pragas fitófagas (Smith, 2005).

Infestações de ácaros fitófagos são problemáticas para plantas frutíferas, pois causam injúrias e perda da qualidade foliar e da fruta (Flechtmann, 1975; Ochoa, 1991). Os danos causados por esses herbívoros provém sobretudo de efeitos diretos, que ocasionam a destruição do parênquima foliar levando a um aumento na transpiração da folha atacada (Moraes; Flechtmann, 1981). Os ácaros fitófagos alimentam-se por exsudação do fluido celular vegetal, por meio de peças bucais adaptadas denominadas estiletes (Walter; Proctor, 1999). Os estiletes são inseridos e perfuram o tecido foliar, removendo o conteúdo celular, causando a destruição dos cloroplastos, perda de clorofila e redução da capacidade fotossintética (Figura 9).

Figura 9 - Ácaro fitófago, *Tetranychus ludeni* Zacher (Acari: Tetranychidae) visto sob microscópio estereoscópico (A). Gnatossoma de *Tetranychus ludeni* visto sob microscópio óptico com contraste de fases - Estiletes indicados por seta (B).

Fonte: Da-Costa, T. (2024) (A). Fonte: de Castro e Castro, B.M. (2015) (B).

Após a alimentação, são visivelmente notados sobre a folha pontos regulares que se aglutinam formando áreas cloróticas características, chamadas de bronzeamento foliar (Cuthbertson; Murchie, 2010). As lesões podem alterar processos fisiológicos da planta, prejudicando o crescimento, a floração e os rendimentos da planta (Tomczyk; Kropczynska, 1985) (Figura 10). A intensidade dos danos causados na planta pode ser influenciada por diferentes fatores como o cultivar, o vigor da planta, a densidade populacional do fitófago, o tempo de alimentação, tempo da colheita e as condições ambientais (Marini *et al*., 1994).

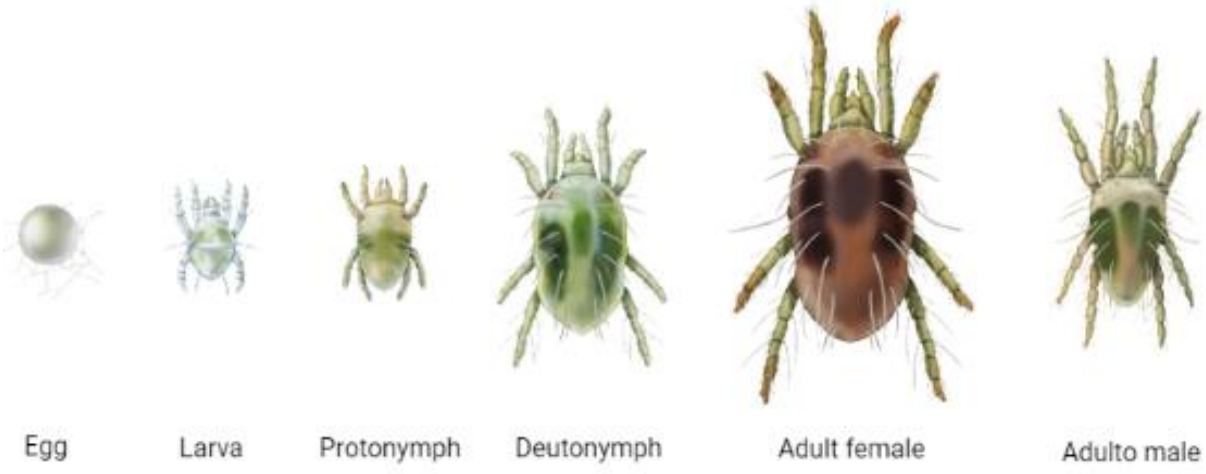
Figura 10 - Tomateiro infestado por *Tetranychus evansi* (A). Tomate infestado e apresentando danos de *T. evansi* (B).

Fonte: Terra Magna (A). Agrolink (2023) (B).

Dentre os grupos causadores de danos na macieira estão os organismos Tetranychidae e Eriophyoidea (Ferla; Moraes, 1998). *Panonychus ulmi* e *Tetranychus urticae* (Koch) (Tetranychidae) são reportados ocorrendo em pomares de maçã nas culturas das regiões Sul do Brasil (Ferla; Moraes, 1998; Monteiro, 2001, 2002; Nascimento *et al*., 2020; Kasap; Atlihan, 2021). Porém, foi recentemente reportada a ocorrência de *A. schlechtendali*, uma espécie de eriofiídeo anteriormente considerada quarentenária para o Brasil (Ferla *et al*., 2018), tendo sido registrada posteriormente ocorrendo nos três estados do Sul do Brasil (Nascimento *et al*., 2020).

Tetranychidae. Uma das famílias acarinas, com maior relevância em termos de impacto econômico, é Tetranychidae, que compreende diversas espécies consideradas pragas agrícolas (Migeon *et al*., 2010). *Panonychus ulmi* e *T. urticae* são espécies fitófagas reportadas como causadoras de danos econômicos nas macieira no Sul do Brasil (Ferla; Moraes, 1998; Monteiro, 2001, 2002). O Ciclo de vida dos ácaros desta família é caracterizado pelas fases de ovo, larva, protoninfa, deutoninfa e adulto (Figura 11).

Figura 11 - Ciclo de vida de *Tetranychus urticae*.



Fonte: Adaptado de Koppert (2020).

Em cada estádio, o ácaro passa por um período em que se alimenta intensamente e após um período de repouso, seguido pela ecdise. Altas temperaturas e clima seco favorecem a reprodução e a multiplicação das espécies (Cuthbertson; Murchie, 2005). Durante as fases móveis, perfuram as células da planta com os estiletes e o conteúdo celular é exsudado devido à pressão de turgescência. Nos locais onde se alimentam se formam pontos regulares, e quando

se aglutinam, surgem áreas cloróticas características denominadas de bronzeamento foliar (Cuthbertson; Murchie, 2010). Em elevadas populações, pode causar queda prematura das folhas, o comprometimento da produção, com frutos pequenos e de coloração alterada e a diminuição das taxas de câmbio de CO_2 (Huffaker *et al*., 1969; Rilling; During, 1990; Ferla; Botton, 2008; Moraes; Flechtmann, 2008; Duso *et al*., 2012).

Panonychus ulmi, conhecido como ácaro-vermelho-europeu, foi descrito por Koch no ano de 1835 primeiramente como *Tetranychus ulmi* (Blair; Groves, 1952). Mais tarde, a partir da nova reorganização dos grupos, adicionou-se o gênero *Panonychus*, obtendo-se a nomenclatura atual. A espécie tem como principais hospedeiros frutíferas e arbustos da família Rosaceae (Baker; Tuttle, 1994; Bolland *et al*., 1998; Assouguem *et al*., 2024). Ácaros desta espécie possuem aproximadamente 0,3 a 0,7 mm de comprimento, sendo a fêmea de coloração vermelho-escuro, com corpo globoso e com protuberâncias brancas bem visíveis na base das setas dorsais (Figura 12A) (Kovaleski; Vendramim, 1993). O macho de *P. ulmi* é menor que a fêmea, e apresenta corpo delgado, pernas longas e coloração amarelo-avermelhada ou amarelo-escura, sem protuberâncias brancas nas setas dorsais (Figura 12B) (Kovaleski; Vendramim, 1993).

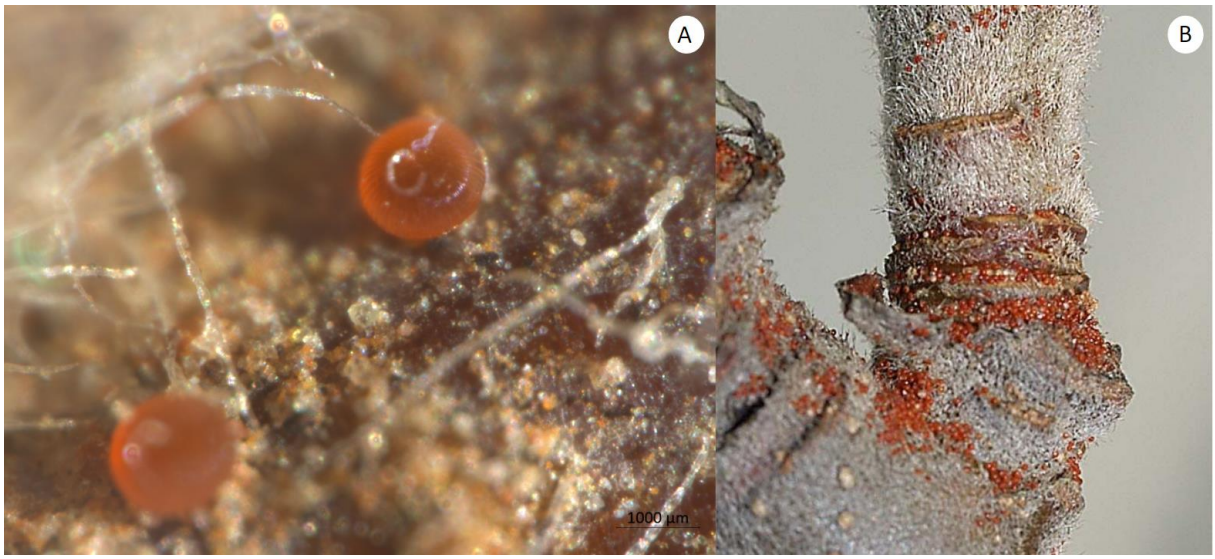
Figura 12 - Fêmea de *Panonychus ulmi* (A). Macho de *Panonychus ulmi* (B).

Fonte: Labacari (2022).

Panonychus ulmi apresenta dois tipos de ovos, dependendo da época do ano: ovos de inverno, de coloração alaranjada, dos quais eclodem as primeiras gerações anuais, e ovos de verão de coloração avermelhada, de onde eclodem as demais gerações (Rodrigues, 2005)

(Figura 13). Quando estão próximos da eclosão, pode-se notar duas manchas mais escuras nos ovos, que correspondem aos ocelos da futura larva (Kovaleski; Vendramim, 1993). O tipo de ovo a ser colocado é regulado por condições do clima como o fotoperíodo e a temperatura e pelo estado nutricional da fêmea (Cuthbertson; Murchie, 2010). Os ovos de inverno são geralmente depositados nos galhos da planta no período de senescência e são diapáusicos, enquanto os ovos de verão são colocados nas folhas da planta (Cuthbertson; Murchie, 2010).

Figura 13 - Ovo de *Panonychus ulmi* (A). Ovos de *Panonychus ulmi* durante o período de senescência, localizados junto ao ramo da macieira (B).



Fonte: Meira, A.A. (2023) (A). Agrolink (2023) (B).

O tamanho dos ácaros faz com que em determinadas situações eles não sejam percebidos pelos fruticultores, que acabam observando injúrias quando a população já se encontra elevada nos pomares (Monteiro, 2002). Tanto as formas jovens quanto os adultos de *P. ulmi* se alimentam da seiva das folhas, causando extravasamento celular, o que diminui a capacidade fotossintética, e de transpiração, levando ao bronzeamento e a queda prematura das folhas (Huffaker; Van De Vrie; McMurtry, 1969; Moraes; Flechtmann, 2008; Qadir; Qamar, 2019). Além disso, devido à diminuição do acúmulo de nutrientes, há a redução do teor de açúcar, crescimento dos ramos, floração e formação de gemas floríferas para o ano seguinte, afeta consequentemente o tamanho, a coloração e a qualidade dos frutos e o vigor das plantas, resultando em baixa produção (McMurtry *et al*., 1970; Croft, 1975; Lorenzato, 1987; Botha *et al*., 2005; Ferla; Botton, 2008). Contudo, são poucas as informações disponíveis na literatura, até o momento, quantificando as injúrias e os danos causados por *P. ulmi* em macieiras,

principalmente no Brasil. Em estudo conduzido na Ucrânia, populações de 100 ou mais ácaros/folha causaram perdas de 40 a 65% de produção (Bulgak, 1979).

A dispersão de *P. ulmi* ocorre em função da degradação das condições do habitat, em razão da falta do produto fotossintético das folhas ou do aumento na densidade populacional, fazendo com que os ácaros se locomovem para outros ramos ainda sadios ou com menor competição (Karban; English-Loeb, 1988; Duso *et al*., 2012). Estes ácaros são facilmente transportados por fios de teia, animais e pelo vento (Uesugi; Sasawaki; Osakabe, 2009). A dispersão de *P. ulmi* para novas áreas é favorecida por seu pequeno tamanho, pela ocorrência de diapausa, pelo transporte de plantas infestadas com ovos de inverno e pela alta taxa reprodutiva e modo de reprodução arrenótoca (fêmeas diplóides provenientes de ovos fecundados e machos haplóides de ovos não fertilizados), que possibilita que uma pequena população ou mesmo uma única fêmea possa iniciar uma colônia com rápido crescimento (Helle; Sabelis, 1985).

A espécie já foi reportada com populações acima do nível de dano econômico em plantas de maçã em pomares de diversas partes do mundo (Yin *et al*., 2013; Kasap; Atlihan, 2021; Assouguem *et al*., 2024). O primeiro relato brasileiro em pomares de maçã foi feito por Flechtmann (1967) que encontrou o ácaro em maçãs importadas da Argentina. No entanto, o primeiro registro de alta infestação desta espécie no Brasil foi em 1972, em pomares de maçã de Fraiburgo (SC) (Bleicher, 1974). Segundo Ferla e Botton (2008), o ácaro pode ter migrado da videira para as macieiras devido à proximidade dos pomares de macieira e dos vinhedos. Outra possibilidade seria que as disseminações possam ter ocorrido a partir da circulação de material vegetal contaminado dentro do país. Atualmente o ácaro está presente em altas populações nos pomares brasileiros (Silva *et al*., 2022; Rode *et al.*, 2023; 2024a).

Sobre o controle biológico desse fitófago, já são conhecidos ácaros predadores que podem realizar o controle deste fitófago destacando-se *Phytoseiulus persimilis* Athias-Henriot (Gerson *et al*., 2008) e no Brasil, *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) foi liberado para o controle de *P. ulmi* em macieiras, apresentando resultados satisfatórios (Monteiro, 2002).

Tetranychus urticae, é considerado como causador de danos em diversas culturas, incluindo árvores frutíferas, vegetais e flores, sendo considerada uma importante praga em estufas, campos de cultivo e pomares (Bolland *et al*., 1998; Van Leeuwen *et al*., 2010) (Figura 14). Estes ácaros podem se dispersar aereamente por longas distâncias, ao mesmo tempo, em

que fazem viagens mais curtas entre as árvores próximas, nos pomares de macieiras (Uesugi; Sasawaki; Osakabe, 2009). Nesta cultura, *T. urticae* é relatado ocorrendo em diversas partes do mundo (Funayama, 2010; Kamusiime; Nantongo; Wacal, 2023). No Brasil, já foi relatado em cultivos de macieiras (Moraes; Flechtmann, 2008), no entanto, em levantamentos recentes a espécie não está ocorrendo ou quando ocorre é em baixas populações (Silva *et al*., 2022; Rode *et al.*, 2023; Rode et al., 2024a).

Figura 14 - Fêmeas e ovo de *Tetranychus urticae* (A). *Tetranychus urticae* andando sobre a própria teia (B).

Fonte: PROMIP (2019) (A). Agrolink (2023) (B).

Tetranychus ludeni Zacher (Tetranychidae) está associado a mais de 300 espécies de plantas, algumas das quais de importância econômica, como cenoura, feijão, berinjela, abóbora e mamão (Zhang, 2003; Gotoh *et al*., 2015) (Figura 15). A espécie ataca preferencialmente as folhas apicais e medianas das plantas, utilizando seus estiletes para perfurar a epiderme e sugar o conteúdo celular (Moraes; Flechtmann, 2008). No Brasil, *T. ludeni* pode ocorrer em altas populações em diversas culturas, como algodão, soja e feijão, causando injúrias e danos (Moraes; Flechtmann, 2008; Mendonça *et al*., 2011; Reichert *et al*., 2014; 2016). Em temperaturas próximas a 30 °C, há aumento da reprodução e da fecundidade, elevando as populações ao nível de dano econômico (Silva, 2002; Gotoh *et al*., 2015). Gotoh *et al*. (2015) sugeriram que, como *T. ludeni* está bem-adaptado a climas mais quentes, poderia substituir *T. urticae* em algumas culturas e tornar-se uma das principais pragas agrícolas do mundo. Em macieiras, até o momento, há apenas uma ocorrência relatada por Flechtmann (1996) no município de Porto Alegre, estado do Rio Grande do Sul.

Figura 15 - Fêmea de *Tetranychus ludeni* (A). Planta de soja infestada por *T. ludeni* (B).

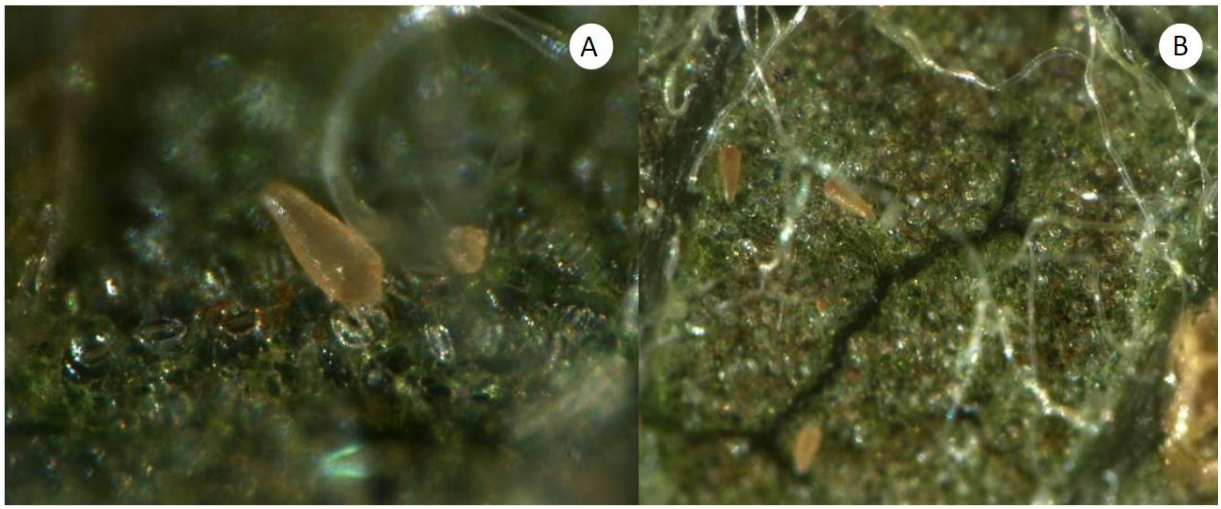
Fonte: Da-Costa, T. (2024) (A). Wurlitzer, W.B. (2024) (B).

Eriophyidae. Possui hábitos estritamente fitófagos, são considerados ácaros-praga em diversas partes do mundo, sendo superados apenas pelos tetraniquídeos (Lindquist *et al*., 1996; Moraes; Flechtmann, 2008). Cerca de seis espécies são relatadas como causadoras de danos econômicos no Brasil (Moraes; Flechtmann, 2008). Os níveis de danos causados pelos eriofiídeos e a avaliação das perdas de rendimento na agricultura ainda sugerem estudos mais detalhados que visem um melhor planejamento de estratégias de controle e mitigação dos riscos. Fatores como a dificuldade de manuseio e de estabelecimento de criação fazem com que as pesquisas relacionadas a comportamento deste grupo sejam limitadas (Michalska *et al*., 2010). A ocorrência de ácaros eriofiídeos vem aumentando no mundo todo e diversas espécies estão atingindo o *status* de praga em diferentes culturas, enquanto outras representam uma ameaça de quarentena para vários países. Ácaros desse grupo têm alto potencial como espécies invasoras devido ao seu pequeno tamanho, o que dificulta a detecção e facilita a disseminação no comércio mundial (Návia *et al*., 2010).

Aculus schlechtendali descrito a partir de espécimes encontrados em folhas de macieira na Alemanha (Nalepa, 1890; Amrine; Stasny, 1994), é comumente chamado de Ácaro da ferrugem da maçã (ARM) nos EUA ou Ácaro do caroço da gema de maçã na Europa (Figura 16). A partir da década de 1960 passou a ser considerada espécie praga devido à substituição

de fungicidas com propriedades acaricidas, uso de inseticidas não seletivos para ácaros predadores e resistência de *A. schlechtendali* a organofosforados e piretróides (Easterbrook, 1996).

Figura 16 - *Aculus schlechtendali* em folhas de macieira (A). Injúrias causadas por *Aculus schlechtendali* em folhas de macieira (B).



Fonte: Meira, A.A. (2023).

A espécie é considerada praga na macieira em diversos países (Duso *et al*., 2010), principalmente em viveiros e pomares, onde pode ser encontrada se alimentando de flores, frutos e folhas, afetando a atividade fisiológica das plantas, a qualidade e a estética das plantas (Easterbrook, 1996; Walde; Hardmann; Magagula, 1997; Spieser *et al*., 1998; Duso *et al*., 2010). Os danos causados por *A. schlechtendali* são devido à perfuração das células epidérmicas da planta através de seus estiletes, que resulta em prejuízo caracterizado pelo bronzeamento da superfície das folhas, flores e frutos (Duso *et al*., 2010). A alimentação do ácaro durante o desenvolvimento da macieira danifica as células da camada epidérmica da planta e os danos podem ser melhor observados ao redor do cálice. Além disso, a lâmina da folha de macieira pode ser enrolada longitudinalmente e, juntamente com a fruta, em casos de grandes infestações pode ocorrer queda prematura destas folhas (Jeppson *et al*., 1975; Easterbrook, 1996). A intensidade dos sintomas depende do tamanho da população de ácaros, do cultivar e da idade das plantas (Easterbrook; Fuller, 1986). Quando a quantidade de espécimes de *A. schlechtendali* ultrapassa os 50 ácaros por cm^2 de folha, aumenta a taxa de transpiração da folha e diminui sua taxa fotossintética (Kozlowski, 1980; Solhoy *et al*., 1991; Duso *et al*., 2010; Hoy, 2011). Em

estudos realizados na suíça por Spieser *et al*. (1998, 1999), as alterações que ocorreram na coloração das folhas causadas por *A. schlechtendali* foram associadas ao aumento da população de ácaros e afetou a troca líquida de CO_2 e as taxas de transpiração. Na ocasião, a análise mostrou que o ácaro causa múltiplas perfurações nas células epidérmicas e dessecação das mesmas, assim como das células do parênquima esponjoso. Em altas infestações, os estômatos estavam parcialmente abertos e as células-guarda perderam a turgescência. Efeitos semelhantes foram observados por Kozowski e Zielinska (1997) mostrando que estes ácaros não se alimentam de mesofilo fotossinteticamente ativo. Porém, podem afetar a fotossíntese, danificando a epiderme e induzindo efeitos negativos no mesofilo da folha. Em estudos com densidades populacionais menores, os efeitos do ácaro na fotossíntese foram menos severos (Easterbrook; Palmer, 1996).

O aumento das populações de *A. schlechtendali* pode ser influenciado por diferentes fatores como ambientes, cultivares, clima, localização do pomar e ocorrência de inimigos naturais (Denizhan, 2011; Danelski; Badowska-Czubik; Rozpara, 2015; Maula; Khan, 2015). No início do verão, com o aumento das temperaturas, *A. schlechtendali* é encontrado na região abaxial das folhas das plantas e passa a habitar a região adaxial assim que ocorre o aumento das densidades populacionais (Easterbrook, 1978). Neste período, a reprodução ocorre de forma rápida e uma geração leva cerca de 10 dias quando submetidos a temperaturas de aproximadamente 22 °C e 16 dias quando estão a 16 °C. Uma fêmea é capaz de colocar de 67 a 100 ovos, sendo um máximo 3,8 ovos por dia (Easterbrook, 1979; Kozlowski; Boczek, 1989). O pico populacional da espécie geralmente é no período do verão (Simoni *et al*., 2018), podendo ser encontrados mais de 2.000 espécimes por folha. Após este período a quantidade de ácaros diminui juntamente com a qualidade das folhas que vão se deteriorando. Segundo Kozlowski e Boczek (1989) a temperatura ideal para este ácaro varia de 23 a 28 °C.

Na América Latina esta espécie foi relatada na Argentina, Brasil e Chile. Na Argentina foi descrito como *Aculus malivagrans* (Keifer) (Rossi Simons) e posteriormente considerado sinônimo júnior de *A. schlechtendali* (Gonzalez, 1981). No Chile, foi reportado em variedades de maçã trazidas da Argentina, onde *A. schlechtendali* ocorria em baixas populações e seus sintomas eram pouco reconhecíveis (Gonzalez, 1985). No Brasil a espécie foi reportada pela primeira vez por Ferla *et al*. (2018) em macieiras na região Sul do país, sem o registro de danos aparentes nas plantas. A situação dos pomares localizados nos estados de Santa Catarina e Paraná era desconhecida até recentemente (Nascimento *et al*., 2020) quando foi confirmada a

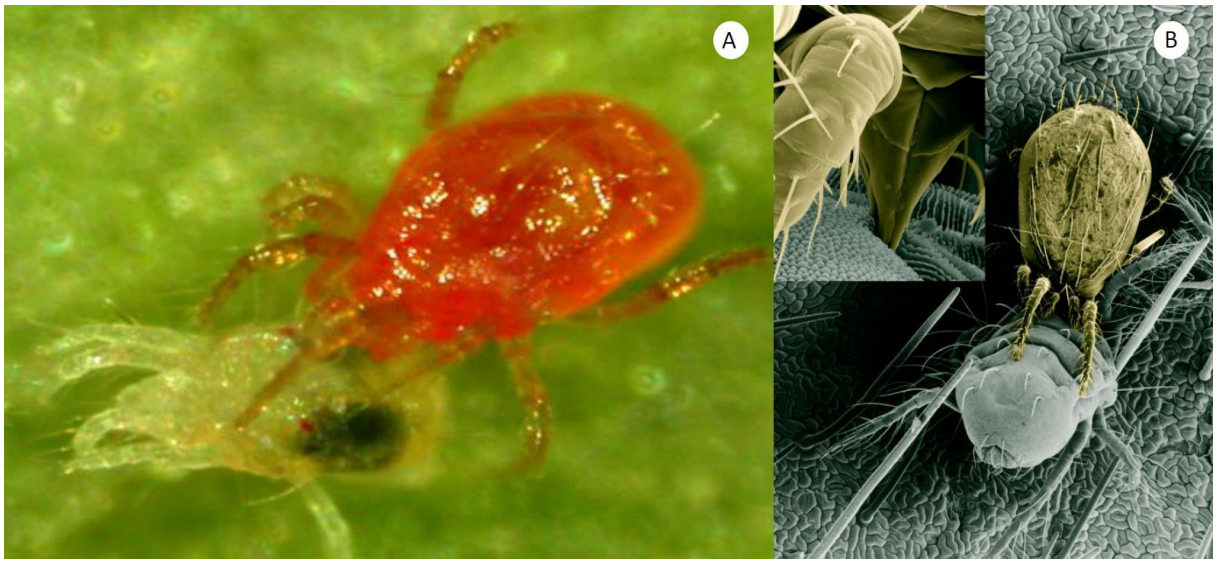
presença de *A. schlechtendali* em 17 locais, dessas regiões que são consideradas as principais produtoras de maçã do Brasil. No levantamento foram encontrados 1.647 ácaros eriofiídeos em 66 pontos de coleta/pomares e 17 municípios. O número médio de ácaros diferiu entre cultivares e estados, com o menor número no cultivar Gala (Nascimento *et al*., 2020). A maior abundância de ácaros foi encontrada em Santa Catarina e Paraná e menor no Rio Grande do Sul, mesmo que este último seja o segundo estado com maior produção, e o local onde houve o primeiro relato da espécie para o Brasil. Esses resultados podem ter sido influenciados pelo clima favorável ao cultivo da maçã (Nascimento *et al*., 2020). Além disso, a espécie foi amostrada no período de um ano e esteve presente em pomares de Fuji, Gala e Eva com manejo convencional, orgânico e regenerativo nos estados de Santa Catarina e Rio Grande do Sul (Rode *et al.*, 2023; 2024a) De acordo com Corrêa *et al*. (2021) em um estudo de predição da distribuição potencial de *A. schlechtendali*, além dos estados da região sul do país, outras áreas no estado de São Paulo e possivelmente em Minas Gerais demonstraram ser potencialmente aptas para sua ocorrência.

A chegada da espécie no Brasil pode ter ocorrido através das fronteiras, passando pelas barreiras alfandegárias do serviço público de quarentena ou devido ao intenso cruzamento de frutas provenientes da Argentina e do Chile para o Brasil. Mesmo com um controle rigoroso no sistema de importação brasileiro, a introdução do ácaro pode estar associada ao tráfego de material vegetal, principalmente mudas ou ainda, por meio de material de propagação legalmente importado (Ferla *et al*., 2018). Além disso, a dispersão a longa distância através do ar é uma importante estratégia de sobrevivência para diversos organismos, o que permite uma rápida colonização em novos territórios e migração entre habitats (Gage; Isard; Colunga-g, 1999).

Não há relatos de que essa espécie tenha atingido o *status* de praga no Brasil, tampouco o quão prejudicial o fitófago pode ser a cultura no país (Nascimento *et al*., 2020). Porém, a espécie tem potencial para atingir pomares nas diferentes regiões produtoras brasileiras, por não existir até o momento um sistema de controle definido para essa espécie (Nascimento *et al*., 2020; Corrêa *et al*., 2021). A presença de *A. schlechtendali* alerta sobre a possibilidade desta espécie atingir o *status* de praga caso não haja o controle antecipado, podendo tornar-se um problema para os agricultores (Nascimento *et al*., 2020; Corrêa *et al*., 2021). O monitoramento das infestações é importante para avaliar e acompanhar os danos reais, identificar os inimigos naturais nativos associados, e verificar quais locais são atingidos com maior intensidade pelas espécies.

2.2.5 Ácaros predadores associados à macieira. Os ácaros predadores possuem quelíceras, as quais são utilizadas para agarrar e preparar suas presas para a digestão (Figura 17). Apresentam pernas longas e que lhes permitem movimentos rápidos, sendo comumente encontrados no solo, em musgos, em restos vegetais e animais e em plantas. Nas plantas esse grupo acarino se alimenta de pequenos artrópodes como insetos e ácaros fitófagos e seus ovos e de nematóides (Vangansbeke *et al*., 2023).

Figura 17 - Ácaro predador se alimentando de um ácaro fitófago sob microscópio de optico de contraste de fases (A). Ácaro predador se alimentando de um ácaro fitófago sob microscópio eletronico de varredura (B).



Fonte: FAEP (2018).

Nos pomares brasileiros de macieiras, os predadores mais abundantes são os Phytoseiidae e os Stigmaeidae (Ferla; Moraes, 1998; Meyer; Kovaleski; Valdebenito-Sanhueza, 2008, 2009; Klock *et al*., 2011; Silva *et al*., 2022; Rode *et al.*, 2023, 2024 a, b). Os inimigos naturais já reportados ocorrendo nos pomares brasileiros associados a *A. schlechtendali* e *P. ulmi* são os Phytoseiidae, *Arrenoseius* sp., *Amblyseus chiapensis* (DeLeon), *N. californicus*, *Neoseiulus tunus* (DeLeon), *Neoseiulus fallacis* (Garman), *Proprioseiopsis cannaensis* (Muma), *Euseius inouei* (Ehara & Moraes), *Galendromus annectens* (De Leon), *Euseius mesembrinus* (Dean) e *Metaseiulus eiko* (El-Banhawy) e os Stigmaeidae, *Agistemus riograndensis* (Johann & Ferla), *Agistemus brasiliensis* Matioli, Ueckermann & Oliveira, *Agistemus floridanus* Gonzalez e *Zetzellia ampelae* (Johann & Ferla) (Ferla, Moraes, 1998; Monteiro, 2001; 2002; Meyer;

Kovaleski; Valdebenito-Sanhueza, 2008; Silva *et al*., 2020, 2022; Rode *et al*., 2023, 2024a, b) (Figura 18). Em um ensaio laboratorial preliminar, *A. floridanus* foi mantido com *A. schlechtendali* coletado em campo e em um estudo conduzido por Silva *et al*. (2020), o predador demonstrou capacidade de sobrevivência e reprodução ao se alimentar exclusivamente de *P. ulmi*. As mesmas espécies de predadores já foram relatadas associadas a *P. ulmi* e *T. urticae* em macieiras nos estados do Rio Grande do Sul e Santa Catarina (Ferla; Moraes, 1998; Meyer; Kovaleski; Valdebenito-Sanhueza, 2008; Monteiro, 2001, 2002; Silva *et al*., 2022; Rode *et al*., 2023, 2024 a, b).

Figura 18 - Ácaro Stigmaeidae do gênero *Agistemus.*

Fonte: Ferla, N.J.; Johann, L.; Silva, G.L (2018).

Ácaros Phytoseiidae podem se alimentar de ácaros fitófagos e possuem outras fontes alimentares alternativas, como pólen, fungos, exsudato de plantas e insetos (McMurtry, Huffaker; Vrie, 1970; McMurtry; Rodriguess, 1987; McMurtry *et al*., 2013). Esse grupo de ácaros passou a ser estudado de forma intensiva a partir da década de 1950 e diversas espécies têm sido consideradas importantes agentes de controle de tetraniquídeos em agroecossistemas (Moraes; Mesa; Braun, 1991; Moraes *et al*., 2004; Aly, 2023). A família contém mais de 2.800 espécies em todo o mundo (Demite *et al*., 2024). Outras famílias de ácaros predadores são encontradas em plantas cultivadas e silvestres (Gerson; Smiley, 1990), porém em menores quantidades que os Phytoseiidae. Em um pomar comercial de maçãs foi desenvolvida uma

proposta para o melhoramento do controle biológico aplicado de *P. ulmi* baseado em sucessivas liberações inoculativas de *N. californicus* (Monteiro, 2001, 2002; Huang *et al*., 2020; Göçer; Ay, 2021). Além disso, estratégias de controle integrado foram estudadas com a utilização de *N. californicus* para o controle biológico de *P. ulmi* (Monteiro, 1994) (Figura 19).

Figura 19 - Fêmea de *Neoseiulus californicus* predando fêmea de ácaro fitófago.

Fonte: Institut Agro Montpellier (2023).

2.2.6 Acarofauna em vegetação espontânea. A vegetação espontânea, também conhecida como plantas invasoras, plantas associadas, plantas não cultivadas ou ervas daninhas, ocorre de forma natural e o seu crescimento é espontâneo nos pomares (Lykouressis *et al*., 2008; Diehl; Ferla; Johann, 2012; Faoro, 2022). Geralmente, durante o manejo dos pomares essas plantas são eliminadas (Souza; Palladini, 2023). No entanto, a presença de determinadas plantas espontâneas as margens dos pomares e entre as linhas pode servir de reservatório e favorecer o aumento das populações de ácaros predadores, auxiliando na manutenção dos agroecossistemas, através do controle biológico (Altieri; Liebman, 1986; Prischmann; James, 2003; Lykouressis *et al*., 2008; Araujo *et al*., 2022). Estas plantas podem apresentar diferentes estruturas morfológicas como tricomas e domácias que servem como locais de refúgio, abrigo e cortejo devido ao microclima favorável, ou ainda podem servir como fontes alternativas de alimento (pólen, néctar, presa ou hospedeiro), que em determinados casos são importantes para a manutenção dos inimigos naturais nas culturas e auxiliando no controle de diversas pragas (Agrawal; Karban; Colfer, 2000; Landis; Wratten; Gurr, 2000; Matos *et al*., 2006).

Em levantamento realizado em vegetação espontânea associada à vitivinicultura em

municípios do Rio Grande do Sul foram encontradas 43 espécies acarinas, destas, 27 espécies eram predadoras (Johann *et al*., 2009). Diehl, Ferla e Johann (2012) avaliaram a vegetação espontânea associadas a videiras em 80 espécies de plantas, na ocasião foram encontrados ácaros predadores das famílias Phytoseiidae, Stigmaeidae e Iolinidae em 58 espécies vegetais. Moura *et al*. (2013) em levantamento da vegetação espontânea associada a videira no mesmo estado, verificaram 14 espécies de ácaros, sendo sete espécies predadoras. Com base nos trabalhos realizados em videira é possível verificar que a vegetação espontânea associada aos pomares apresenta grande número de ácaros predadores, sendo estas plantas possíveis reservatórios de inimigos naturais para controlar ácaros praga também na cultura da macieira (Rode *et al*., 2024 b). *Vernonanthura tweediana* (Baker) (Asteraceae) e plantas do gênero *Plantago* (Plantaginaceae) de crescimento espontâneo nos pomares de macieiras, são hospedeiras de ácaros predadores e a sua manutenção é recomendada nestes locais (Faoro, 2022; Rode *et al*., 2024 b).

2.2.7 Controle dos ácaros da macieira. O uso de inseticidas organofosforados iniciou no final da década de 1950 e teve rápido aumento nos anos seguintes (Walker *et al*., 2017). O Brasil é um dos maiores consumidores de agrotóxicos do mundo, sendo o glifosato o agrotóxico mais utilizado no país (FAO, 2018; Demetrio *et al*., 2020). No Brasil, a cultura da macieira ainda depende na maior parte de elevada quantidade deste tipo de defensivo para combater organismos que atacam os pomares, resultando na diminuição de determinados inimigos naturais e favorecendo o aumento populacional de pragas secundárias (Meyer; Kovaleski; Valdebenito-Sanhueza, 2009; Santos *et al*., 2018). Nas regiões brasileiras de maior produção realizam-se de 3 a 4 pulverizações de acaricidas por ciclo vegetativo, muitas vezes, de forma preventiva para o controle de ácaros fitófagos (Monteiro, 1994). Nestes mesmos pomares, o controle de plantas daninhas é geralmente realizado com herbicidas na linha de plantio, para facilitar os tratos culturais mantendo o solo sem vegetação desde o outono até meados da primavera (Altieri; Liebman, 1986).

O controle químico já se mostrou eficiente quando abamectina, espirodiclofeno e lambda cialotrina foram pulverizados (Raudonis *et al*., 2007; Angeli *et al*., 2008) e aplicações de óleo mineral mostraram efeitos de controle sobre ácaros fitófagos (Fernandez *et al*., 2006). Porém, a utilização desses produtos logo resultou na resistência de *P. ulmi* e, predadores como *Typhlodromus pyri* Scheuten (Phytoseiidae) e *Typhlodromus occidentalis* Nesbitt

(Phytoseiidae) (Hoyt, 1969; Collyer; Geldermalsen, 1975; Penman; Ferro; Wearing, 1976). Mesmo que algumas espécies de predadores como *N. californicus* estejam adquirindo resistência a pesticidas agrícolas, estes produtos químicos não devem ser aplicados sucessivamente nos pomares comerciais de macieira, pois seus efeitos impedem que o inimigo natural controle de forma efetiva os fitófagos (Meyer; Kovaleski; Valdebenito-Sanhueza, 2009). A intensificação da adubação química, o cultivo intensivo do solo e o uso em grande escala de pesticidas na agricultura, além de provocar a seleção de populações resistentes de pragas e a morte de organismos não alvos, vem causando também a contaminação dos alimentos, do solo e da água, sendo prejudicial ainda para a saúde humana e animal (Gallo *et al*., 2002; Gliessman, 2005).

A resistência das pragas aos agroquímicos e a crescente demanda do consumidor pela diminuição da quantidade de resíduos de pesticidas presentes nas frutas, levaram à implementação do Manejo Integrado de Pragas (MIP) na cultura (Raudonis; Surviliene; Valiuskaite, 2004; Walker *et al*., 2017). Desta forma, estudos visando o controle integrado de ácaros fitófagos associados a macieira passaram a ser desenvolvidos no mundo (Hoyt, 1969; Collyer; Geldermalsen, 1975). Esse tipo de manejo nas macieiras, busca a redução das pulverizações de pesticidas através da utilização de produtos seletivos e a seleção de fitoseiídeos resistentes o suficiente para controlar *P. ulmi* e *T. urticae.* Assim, a adoção do MIP já eliminou substancialmente o uso de inseticida organofosforados, sendo implantados sistemas de monitoramento de pragas, reduziu o *status* de diversas pragas anteriormente importantes, incluindo alguns insetos e ácaros, melhorando o desempenho fitossanitário e contribuindo para a redução no uso de inseticidas (Walker *et al*., 2017). Alguns fungicidas utilizados na cultura já foram capazes de reduzir a densidade populacional de *A. schlechtendali* sem causar prejuízos aos ácaros predadores, podendo ter o uso incentivado em programas de (Maeyer *et al*., 1993).

A partir do registro de presença de *A. schlechtendali* é interessante serem planejadas formas de adoção de estratégias de controle biológico em pomares de maçã brasileiros, pois futuramente o ácaro pode atuar como um agente causador de danos. Antes de ser aprovado algum tipo de controle alternativo é necessário ser realizada a análise dos possíveis efeitos colaterais dos produtos frequentemente usados para controlar as pragas, devido ao perigo de afetar as populações da fauna predatória. Pesticidas prejudiciais a ácaros predadores podem ocasionar surtos de ácaros fitófagos na agricultura (Funayama, 1999; Harman *et al*., 2003). Além disso, o aumento nos custos produtivos, a redução da biodiversidade, a necessidade de

recursos não renováveis, a degradação do solo, a contaminação da água, os resíduos químicos nos alimentos, e os riscos para a saúde dos trabalhadores, demonstram a necessidade de desenvolvimento de tecnologias sustentáveis como alternativa aos sistemas agrícolas convencionais (Reganold *et al*., 2001).

2.2.8 Controle biológico. Objetivando a redução dos problemas causados pela utilização de pesticidas na macieira, a sociedade científica tem buscado novas tecnologias que objetivam a sustentabilidade no meio agrícola, para a produção de alimentos mais saudáveis e melhora na qualidade de vida dos produtores e do consumidor final (Gliessman, 2005; Pålsson *et al*., 2022). Neste contexto se apresenta o Controle Biológico como uma técnica que utiliza meios naturais, como a utilização de organismos vivos, visando à diminuição de populações de organismos que atingem os níveis de dano econômico na agricultura (Obryck; King, 1998; Pålsson *et al*., 2022).

O controle biológico pode ser clássico, natural ou aplicado (Parra, 2014). O Controle Biológico Clássico constitui na importação e colonização de parasitóides ou predadores, buscando o controle de pragas exóticas. Este tipo de controle biológico é considerado uma medida de controle a longo prazo, pois as populações de inimigos naturais tendem a aumentar com o passar do tempo e, assim, se aplica somente a culturas semi perenes e perenes (Parra *et al*., 2002; Parra, 2014). O Controle Biológico Aplicado (CBA) é uma estratégia que vem se destacando e sua utilização vem crescendo constantemente, destacando a utilização de agentes de controle, como: entomopatógenos, extratos vegetais, óleos essenciais, produtos alternativos e inimigos naturais (Penteado, 2006). O CBA visa a regulação de populações de plantas e animais por meio de liberações inundativas de um agente de controle biológico após criação massal, em laboratório (Parra *et al*., 2002; Parra, 2014). A técnica tem sido eficiente em diversas culturas, por se tratar de métodos mais seguros, sem o uso de pesticidas, sem deixar resíduos no ambiente e por causar a redução rápida das populações da praga para seu nível de equilíbrio (Parra *et al*., 2002; Oliveira; Ávila, 2010). Esse tipo de controle pode ser conservativo ou aumentativo. O controle biológico de conservação busca preservar os inimigos naturais em um agroecossistema, sendo a manutenção dos inimigos naturais essencial para o estabelecimento do equilíbrio biológico e na redução dos custos de produção. No controle biológico aumentativo, os inimigos naturais são introduzidos e liberados em determinados períodos, ocorrendo a liberação dos organismos via criação massal ou coleta a campo. O CBA, através dos ácaros predadores, tem potencial para o controle de ácaros praga, bem como, para a

preservação de inimigos naturais e a proteção do meio ambiente (Parra *et al*., 2002; Parra, 2014).

O controle biológico, com o uso de inimigos naturais, vem sendo estudado como uma alternativa em macieiras (McMurtry; Huffaker; Vrie, 1970; Monteiro, 1994, 2002). Os Phytoseiidae apresentam grande importância como inimigos naturais em diversas culturas, sendo que esta é a família de predadores mais importantes na macieira (Ferla; Moraes, 1998). Uma das espécies mais pesquisadas é *N. californicus* por ser tolerante às mudanças climáticas e sincronizar sua ocorrência com a do *P. ulmi* (Hoy, 2011). *Neoseiulus californicus* se alimenta dos ovos e das formas móveis de *P. ulmi*, mantendo suas populações abaixo do nível de dano econômico nos pomares (Monteiro, 1994). Em 1995, o controle biológico de *P. ulmi* foi implantado em pomares de macieiras em Fraiburgo, SC, através de criação massal de *N. californicus* em estufas e de liberações inoculativas (Monteiro, 2002). No Brasil, algumas empresas comercializam ácaros predadores para a liberação em pomares, visando ao controle de *P. ulmi*. Na região Sul, *N. californicus* tem sido criado por empresas produtoras de maçãs (Faoro, 2022).

2.2.9 Produção orgânica

A agricultura orgânica busca limitar o impacto ambiental, utilizando de forma responsável os recursos naturais, mantendo a biodiversidade, o equilíbrio ecológico, a qualidade das águas e evitando a degradação do solo (Glover *et al*., 2000; Maluche-Baretta; Amarante; Klauberg Filho, 2006; Vogeler *et al*., 2006; Shuttleworth, 2021).

Devido aos benefícios que produtos orgânicos proporcionam ao meio ambiente, à saúde humana, tanto do consumidor quanto dos trabalhadores agrícolas e aos aumentos dos custos de produção, a demanda mundial por maçãs livres de resíduos químicos é crescente (Reganold *et al*., 2001; Sacilik; Elicin, 2006; Peck *et al*., 2006; Shuttleworth, 2021). Essas preocupações levaram a um interesse mundial pela produção orgânica e integrada de maçãs (Amarante *et al*., 2008).

Nas práticas de manejo agrícola orgânico não é permitida a utilização de pesticidas e de fertilizantes sintéticos. Nesse tipo de cultivo podem ser utilizados adubos animais e verdes, compostos orgânicos, bioagentes, armadilhas e métodos de controle biológico (Peck *et al*., 2006).

Tanto no Brasil, quanto na maioria dos países a produção orgânica de maçã ainda é bastante limitada, principalmente devido ao controle inadequado de pragas e doenças e a falta de tecnologia que limita a lucratividade dos pomares orgânicos (McArtney; Walker, 2004; Cesa *et al*., 2006; Meyer; Kovaleski; Valdebenito-Sanhueza, 2009).

3 RESULTADOS

Objetivando auxiliar no preenchimento das lacunas existentes sobre a situação atual da acarofauna associada a poamres de macieira no Sul do Brasil, e, buscando incentivar os envolvidos na cadeia produtiva de maçãs a buscarem alternativas sustentáveis para o manejo da cultura, oito artigos e um manual técnico foram produzidos.

CAPITULO 1

Rode, P.A., Bizarro, G.L., Spohr, G.A., Mallmann, D., Schussler, M., Ferla, N.J. Mite fauna on apples in southern Brazil - Review and perspectives. Artigo submetido no periódico “Anais da Academia Brasileira de Ciências” (Situação: Publicado).

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Mite fauna on apples in southern Brazil - Review and perspectives

PRISCILA A. RODE, GABRIEL L. BIZARRO, GUILHERME ANDRÉ SPOHR, DANIELE MALMANN, MATHEUS SCHUSSLER & NOELI JUAREZ FERLA

Abstract. Brazil is among the largest apple producers in the world (*Malus domestica* Bork, Rosaceae), with production concentrated mainly in the southern of the country. *Panonychus ulmi* (Koch) (Tetranychidae) have economic importance in apple and, recently, *Aculus schlechtendali* (Nalepa) (Eriophyidae), was reported in Brazil. This review aims to delineate the distribution of the acarofauna associated to apple, with emphasis on the main groups of economic importance and their potential natural enemies and highlight the problems related to phytophagous species and management possibilities. Searches were carried out in databases, and the principal keywords were *Aculus schlechtendali*, *Malus domestica* and *Panonychus ulmi*. After the exclusion criteria resulted 166 publications. The social and economic importance of the apple has been increasing on the world, however, due to environmental imbalance, phytophagous mites are increasing their populations and acquiring resistance against acaricides. *Panonychus ulmi* has been reported in America for decades, being of economic importance for Brazil and the record of *A. schlechtendali* alerts to the possibility of damage in orchards in the country. Therefore, it is important that the literature be evaluated, that the mite species are identified and that forms of conscious management are developed. Prioritizing the human and animal health and environmental balance.

Key words: *Malus domestica*, mites, phytophagous, Phytoseiidae.

INTRODUCTION

The apple tree (*Malus domestica* Borkh, Rosaceae) is a temperate climate plant, with specific climate requirements for production. The first Brazilian report of the presence of apple trees is from the beginning of the 20th century in the state of Santa Catarina (Santos 1994) and commercial-scale cultivation began in the 1970s, although the introduction of cultivars and the beginning of planting occurred before this period (Petri et al. 2011). Nowadays, Brazil is among the ten largest apple producers in the world and has been growing as an exporter, being responsible for selling the product to 66 countries (Kist et al. 2019).

There is a significant number of apple cultivars (Way et al. 1990, Kvitschal et al. 2022), but Fuji and Gala cultivars and their clones are the most important and are responsible for approximately 95% of the brazilian production (Fioravanço et al. 2010, Kvitschal et al. 2022). These cultivars have qualities that please the consumer's palate, constituting the best option for producers (Iglesias et al. 2008, Fioravanço et al. 2010). Other cultivars have a relevance of about 5% of national production and have been conquering their space in the market (Fioravanço et al. 2010, Kvitschal et al. 2022).

The production of apple trees is an activity of great social and economic importance, being an alternative income in rural properties.

However, changes in agroecosystems favor the emergence of phytosanitary problems, such as the emergence of populations that reach the economic threshold of phytophagous agents (Santo et al. 2022). The use of pesticides to control the pests in orchards can cause adverse effects on the natural enemies, and consequently, an increase in the population of phytophagous mites causing economic damage (Meyer et al. 2009, Van Leeuwen & Dermauw 2016, Walker et al. 2017, Schmidt-Jeffris & Beers 2018). With the expansion of cultivation areas, the geographic distribution of agricultural pests has increased through the natural process characteristic of each species or through the improper transport of plant material infested with phytophagous mites taken from one region to another (Morgante 1991, Navia 2022). Due to the absence of the natural enemies, these species can increase their populations and reach pest status in several cultures (Brown & Hovmøller 2002, Anderson et al. 2004). In addition, the presence of exotic phytophagous mites can cause environmental, social and economic impacts (Navia et al. 2007, 2010). In this case, greater attention should be given to eriophyid mites, as they are a group with greater potential as invasive species due to their physical and biological characteristics. The record of the presence of *A. schlechtendali* in the southern region of Brazil serves as a warning 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).

Therefore, the objective of this work was to carry out a review of the literature regarding the mite fauna associated with the apple tree culture with emphasis on those from southern Brazil, of economic importance and their potential natural enemies. In addition, describe possible strategies reported to control these species.

MATERIALS AND METHODS

In this literature review with an exploratory and bibliographic character, the searches were carried out in different databases - Scientific Electronic Library Online (SCIELO) and Google Scholar. There was no time limit for the selection of articles and books. The articles and books were searched in a virtual way using as keywords: Acari, *Aculus schlechtendali*, *Agistemus*, agricultural management, apple orchards, crop, *Malus domestica*, mite species, *Neoseiulus californicus*, *Panonychus ulmi*, pest control, *Tetranychus urticae* and *Zetzellia mali*. These words were searched in the title, keywords or in texts of English or Portuguese language. Publications that did not answer the guiding question, or that were written in other languages, dissertations, theses and studies available only in abstracts were discarded.

RESULTS

From the initial consultation with 233 articles, 67 were discarded because they were considered inappropriate. We selected scientific articles and book chapters in databases. The remaining 166 were then read and analyzed. All selected works were published between 1890 and 2023. Articles not found or not freely accessible were requested from the respective authors via ResearchGate or email.

This research was carried out from August 2021 to August 2022. The review considered ethical aspects, maintaining the authenticity of the researched authors' ideas and references. Literature was reviewed reporting the origin and advances of the apple tree culture in Brazil and in the world, the occurrence of Acarian species and the perspectives in relation to sustainable management in the culture.

Apple tree in Brazil

The apple tree originated from Asia Minor and Central (Hancock 2014), in this region, 25 species of plants belonging to the genus *Malus* occur naturally (Brown 2012). The beginning of domestication is dated to 20.000 years ago in northern China and has been cultivated for over 5.000 years (Harlan 1992, Petri & Leite 2008). *Malus sieversii* (Lebed.) M. Roem. (Rosaceae) is the progenitor species of *M. domestica* (Hancock 2014).

Cultivation began in the 1970s on a commercial scale. However, the introduction of cultivars and planting had already been carried out previously (Petri et al. 2011). The first Brazilian record of apple trees in the country was from the beginning of the 20th century in Santa Catarina (Santos 1994). It is believed that the first commercial cultivation took place in 1926, in the municipality of Valinhos, São Paulo (Petri et al. 2011). In the state of Rio Grande do Sul, in 1948, there were already orchards with some cultivars, in the municipalities of Caxias do Sul and Veranópolis. At the end of the 1960s, fruit growers moved from Algeria to Fraiburgo, Santa Catarina, founding the Sociedade Agrícola Fraiburgo Ltda - Safra. The initial objective was the development of viticulture, however, other collections of temperate fruit trees, such as the apple tree, were installed (Petri et al. 2011). In 1969, the company Reflorestamento Fraiburgo, implemented the first commercial apple orchard, based on reduction in Income Tax of 50% for application in reforestation, which could be done with fruit trees (Law #5.106). This law boosted the development of culture in Brazil. Then, the apple tree started to be planted mainly in the states of Santa Catarina and Rio Grande do Sul, forming three important productive poles that last until the present day: Fraiburgo, São Joaquim and Vacaria (Petri et al. 2011).

Currently, Brazilian production is mainly located in the higher regions of the three southern states, in cities where the environment is more favorable, with the states of Santa Catarina and Rio Grande do Sul being the largest producers, followed by Paraná (Kist et al. 2022). Brazil is among the ten largest apple producers in the world, and the quality of its product has gradually increased over the years (Kist et al. 2019, 2022). In the year 2020 the fruit was considered one of the ten most relevant in the country in terms of production value (Kist et al. 2022). The main form of consumption is *in nature*, however, other products are produced from the fruit, such drinks, vinegar, jams, jellies and sweets (Landau & Silva 2020).

Economic importance of the chain

The production of apples presents continuous growth all over the world being the largest producers are China, India and Brazil, with around 45.9% of world production (Deral 2020). Among the temperate fruit species produced in Brazil, the apple tree showed the highest growth, with total production increasing from 28.864 to 1.378.617 tons in the last 50 years (Pio et al. 2018). Actually, the Brazilian production increased from 946.165.0 tons in the 2019/2020 crop to 1.284.284.0 tons in the 2020/2021 crop (Kist et al. 2022). Brazil has a production of around 45 million tons per year, 65% of which is destined for the domestic market and the rest for export (Landau & Silva 2020). However, the country has been exporting the product to 66 countries (Kist et al. 2019).

The Brazilian production is mainly located in the south (Kist et al. 2019). The states of Rio Grande do Sul and Santa Catarina are the largest producers, followed by Paraná (IBGE 2021). The municipalities of Vacaria, Rio Grande do Sul, São Joaquim and Fraiburgo, Santa Catarina, are important in the production of apple trees, with production of approximately 300 thousand, 340

thousand and 47 thousand tons, respectively (IBGE 2021, Kvitschal et al. 2022).

Even with technological advances, the apple tree culture provides one of the highest rates of demand for labor in Brazilian agribusiness, providing the employment of approximately 148 thousand people, between fixed and temporary jobs (Kist et al. 2019). The apple production chain is of great importance in southern Brazil and many farmers are economically dependent on the crop (Kist et al. 2019).

Cultivar used

During the natural evolutionary processes of speciation and by artificial selection, the diversity of genotypes was becoming greater and greater. Several characteristics related to resistance, sizes of fruits, shapes and colors, growth habits and plant vigor, were emerging (Kvitschal et al. 2022). Through genetic improvement, it is possible to obtain new commercial apple cultivars (Faoro 2018) from the existing cultivars. This allows the selection of genotypes of high commercial value with desirable agronomic characteristics and, in general, the replacement of the original cultivar by the natural mutant. The new cultivars have better characteristics than the original cultivars, arousing greater interest from producers (Iglesias et al. 2008, Fioravanço et al. 2010). For example, Gala and Fuji can be cited, whose original cultivars are no longer planted, only their mutants, such as Maxi Gala, Baigent (=Brookfield), Royal Gala and Fuji Supreme (Faoro 2018). Although the significant number of apple cultivars (Way et al. 1990, Kvitschal et al. 2022), Fuji and Gala cultivars and their clones (Fuji Suprema, Fuji Mishima, Fuji Brak, Fuji Standard, Galaxy, Maxy-Gala, Brookfield, Royal gala, Imperial Gala) are the most important and are responsible for approximately 95% of the Brazilian production (Fioravanço et al. 2010, Kvitschal et al. 2022).

The cultivar Gala and its clones stand out in production due to the organoleptic properties that please the taste of the Brazilian consumer (Fioravanço et al. 2010). From interbreeding realized in New Zealand, Gala cultivar has abundant flowering and fructification, little alternation of production, fruits varying from small to medium, with uniform sizes and slightly uneven ripening. The cultivar requires between 600 and 800 hours of chilling (Fioravanço et al. 2010).

The Fuji cultivar originated from crosses carried out in Japan and was introduced in Brazil in the 1960s and is currently the second most cultivated (Camilo & Denardi 2002, Hampson & Kemp 2003, Iglesias et al. 2008). This cultivar presents intense flowering and high production, with medium to large fruits, uneven maturation and requires a long chilling time, from 600 to 800 hours. It has clones with characteristics that vary according to climate adaptation, harvest season, quality and color of the fruit. The more cultivated are those with a more reddish skin color, less vigorous and more uniform fruits (Komatsu 1998, Hampsom & Kemp 2003).

The production of Fuji and Gala is concentrated in a short period of time, with high demand for labor at harvest, making it difficult to manage the orchards. In addition, there is a bigger risk of loss due to climatic events that make plants more vulnerable to pests and diseases (Fioravanço et al. 2010). Greater diversity of cultivars allows the expansion of the harvest calendar and the region of production, being a good planting option for the farmers. In this way, other cultivars such as Daiane, Eva, Princesa, Condessa, Granny Smith, have a relevance of about 5% of national production and have been conquering their space in the market (Fioravanço et al. 2010, Kvitschal et al. 2022).

Mites and apple culture

Dissemination of phytophagous mites

The mites take shelter in protected places offered by the hosts, especially in midribs, petioles and bark grooves. In apple fruits, they can be found close to the peduncle that forms a chamber-like structure (Flechtmann 1967). The dispersion of mites occurs mainly passively, through air currents or by transport on animals (Evans 1992). Due to their size, they are easily transported to different environments on merchandise or other substrates (Sabelis 1985). Active dispersal, on the other hand, can occur as a means of dissemination over short distances (Evans 1992). In a study on the emergence of new diseases in plants, it was shown that 56% were the result of introductions associated with the trade of plants and plant products and human circulation (Anderson et al. 2004). The growing increase in human and merchandise transit between countries has favored the international propagation of organisms outside their places of origin. Exotic species in newly colonized areas can cause damage, with serious consequences for biodiversity, agriculture and human health (Boubou et al. 2011). In addition, a single female present can colonize an entire environment due to her ability to reproduce by parthenogenesis and due to her high reproductive rate (Sabelis 1985).

Phytophagous mite species are strong candidates to become pests introduced in new areas due to their difficulty in detection, ability to survive in unfavorable conditions, reproduction by parthenogenesis and inbreeding, facilitated dispersion through wind, adaptive potential to new host plants, development of resistance, potential to cause harm, and transmission of certain plant viruses (Navia et al. 2007, 2010, Mota-Sanchez & Wise 2023). Greater attention should be paid to eriophyid mites, which have a greater potential to become invasive species due to their physical and biological characteristics (Nascimento et al. 2020). Some recently introduced phytophagous species in Brazil are *Raoiella indica* Hirst (Tenuipalpidae) and *Schizotetranychus hindustanicus* (Hirst) (Tetranychidae) in Roraima state (Navia & Marsaro 2010, Navia et al. 2011); *Aceria tosichella* Keifer (Eriophyidae) and *A. schlechtendali* in Rio Grande do Sul state (Pereira et al. 2009, Ferla et al. 2018). Recently there was the introduction of *Tetranychus evansi* Baker & Pritchard (Tetranychidae) in Europe and Africa, a species native to South America (Migeon et al. 2009), thus demonstrating the invasive nature for world agriculture (Boubou et al. 2011). The arrival of other mites into the country, through the entry of potentially infested products and the movement of plant material, can introduce harmful biotypes to Brazilian plants (Mendonça et al. 2011).

The increase in the circulation of plant materials, the development of new technologies in transport and free trade, and the increase in tourism and human circulation, facilitate the spread of mites and the entry and establishment of species in different locals (Yan et al. 2001, Anderson et al. 2004, Wheeler & Hoebeke 2009, Fisher et al. 2012). The intercontinental dispersion of organisms intentionally or not, can cause damage and diseases to plants of different crops on a global scale (Di Castri 1990, Brown & Hovmøller 2002, Anderson et al. 2004, Wheeler & Hoebeke 2009). Organisms and pathogens of quarantine importance threaten food security, causing decrease in quality and reduction in production yields (Strange & Scott 2005, Flood 2010, Fisher et al. 2012). When they reach the status of pest, it becomes necessary to use strategies to control infestations, causing an increase in the cost of production (Navia et al. 2006).

Phytophagous mites

This group feeds on plant cellular fluid by exudation, through the use of mouthparts called stylets (Walter & Proctor 1999) inserted into the leaf tissue, removing the cellular content, causing the destruction of chloroplasts, loss of chlorophyll and reduction of photosynthetic capacity. Lesions can alter physiological processes in the plant, impairing growth, flowering and yield (Tomczyk & Kropczynska 1985). The intensity of the damage caused can be influenced by different factors, such as the cultivar, plant vigor, phytophagous population density, feeding and harvesting time, and environmental conditions (Marini et al. 1994). In environmentally balanced orchards, phytophagous mites do not harm apple plants, serving only as food for predators present in the environment (Lorenzato 1987).

The increase in phytophagous mite populations in apple orchards is mainly due to the absence or low density of natural enemies present in the environment. This decrease can be caused both by natural factors and by inadequate management of the orchards, such as the bad use of pesticides, resistance of pest species to pesticides and possible nutritional imbalances of the host plants (Lorenzato et al. 1986, Lorenzato 1987, 1988, Van Leeuwen et al. 2015). Phytophagous mites are a problem for apple trees when they reach pest status, decreasing the quality of leaves and fruits and leading to production losses (Flechtmann 1975, Ochoa 1991). The most important phytophagous mites for apple trees belong to the Tetranychidae and Eriophyidae families (Ferla & Moraes 1998, Moraes & Flechtmann 2008, Nascimento et al. 2020, Silva et al. 2022). In addition to these groups, *Brevipalpus phoenicis* (Geijskes) (Tenuipalpidae) is a harmful species for citrus, it can occur in apple trees, but sporadically (Lorenzato 1987, Lorenzato & Secchi 1993).

Tetranychidae are phytophagous and pierce leaf cells with their retractable stylets, causing cell contents to be extravasated and exuded due to turgor pressure (Moraes & Flechtmann 2008). In places where the mites feed, regular spots are formed, and when they agglutinate, characteristic chlorotic areas appear called leaf tanning (Cuthbertson & Murchie 2010). In high populations, it can cause tanning and premature leaf fall, compromising production, with small fruits and altered color (Huffaker et al. 1969, Botha & Learmonth 2005). The most economically important tetranychid species found in apple trees are *Panonychus ulmi* (Koch) (Tetranychidae) and *Tetranychus urticae* Koch (Tetranychidae) (Ferla & Moraes 1998, Monteiro 2002, Monteiro et al. 2002, Botha & Learmonth 2005). These species are widely distributed and have been reported to cause damage to apple plants in several parts of the world (Moraes & Flechtmann 2008, Joshi et al. 2023, Migeon & Dorkeld 2023), even in those producing regions of southern Brazil (Ferla & Moraes 1998, Monteiro 2002, Monteiro et al. 2002, Migeon & Dorkeld 2023).

Panonychus ulmi, known as the European red mite, has been reported with populations above the economic damage level on apple plants in orchards worldwide (Yin et al. 2013). The first Brazilian report in apple orchards was made by Flechtmann (1967) who found the mite in apples imported from Argentina. However, the first record of high infestation of this species in Brazil was in 1972, in apple orchards in Fraiburgo, state of Santa Catarina (Bleicher 1974). According to Ferla and Botton (2008), the mite may have migrated from the vine to the apple trees due to the proximity of apple orchards and vineyards. Another possibility would be that the disseminations may have

occurred from the circulation of contaminated plant material within the country. For decades *P. ulmi* has been cited as the most relevant phytophagous species in the crop (Lorenzato et al. 1986, Lorenzato 1987, Ferla & Botton 2008). This species causes loss of chlorophyll in the attacked sites, darkening and reddish spots on the adaxial surface of the leaves and, in severe attacks, it causes premature leaf fall (Botha & Learmonth 2005, Moraes & Flechtmann 2008, Duso et al. 2012). *Panonychus ulmi* reaches its peak population in the apple tree during the hottest months of the year (Lorenzato et al. 1986, Botha & Learmonth 2005). Dispersion and aptitude for new areas are favored by their small size, occurrence of diapause, transport of plants infested with winter eggs, high reproductive rate and by the arenotoco reproduction mode, which allows a small number or even a single female to start a colony with rapid growth (Helle & Sabelis 1985, Botha & Learmonth 2005). The increase in the use of acaricides in apple plants has caused *P. ulmi* to become resistant to some of these products, making their control difficult (Bajda et al. 2015, Rameshgar et al. 2019, Mota-Sanchez & Wise 2023).

Tetranychus urticae, the two-spotted spider mite (TSSM), is a serious problem in apple orchards and other agricultural crops around the world (Helle & Sabelis 1985, Lorenzato 1987, Funayama et al. 2015). In crops where it occurs, including apple trees, it produces webs and in large infestations it can cause leaf fall (Lorenzato 1988). The economic importance of the damage caused by this species varies according to the region where the orchards occur. Commonly found on the underside of apple tree leaves, producing webs that can be used for displacement as well as dispersing through the wind (Helle & Sabelis 1985, Lorenzato 1987). The species has been studied due to the resistance it has acquired in apple trees, quickly adapting to the pressure of selection of pesticides (Suh et al. 2006, Hoy 2016, Van Leeuwen & Dermauw 2016).

The Eriophyidae are of economic importance, being surpassed only by the tetranychids (Lindquist et al. 1996, Moraes & Flechtmann 2008). With strictly phytophagous habits and considered pests throughout the world, the mites of this group have high potential as adventitious species due to their small size, which makes detection difficult and facilitates the spread in world trade (Navia et al. 2010). The economic importance of eriophyid mites is increasing worldwide and several species are reaching pest *status* in different cultures, while others pose a quarantine threat to several countries. *Aculus schlechtendali*, described from specimens found on apple leaves in Germany (Nalepa 1890, Amrine & Stasny 1996), it is known as apple rust mite (ARM) in the USA, or apple stone and yolk mite, in Europe. The species was considered a pest from the 1960s onwards due to the use of fungicides with acaricidal properties, use of non-selective insecticides for predatory mites and resistance to organophosphates and pyrethroids (Easterbrook & Palmer 1996). In Latin America, this species has been reported in Argentina (Gonzalez 1981), Chile (Gonzalez 1985) and Brazil (Ferla et al. 2018). In Brazil, it was considered to be absent quarantine importance, but it was first reported in apple trees in the municipality of Vacaria, Rio Grande do Sul (Ferla et al. 2018) and later in all states in the southern region of the country (Nascimento et al. 2020, Silva et al. 2022), with no record of apparent damage to the plants. Considered an important pest in several countries (Duso et al. 2010, Simoni et al. 2017), especially in nurseries and orchards, where it can be found feeding on flowers, fruits and leaves, affecting the physiological activity of plants, the quality and aesthetics of plants (Easterbrook & Palmer 1996, Walde et al. 1997,

Spieser et al. 1998, Duso et al. 2010). The damage caused by *A. schlechtendali* is due to the perforation of the epidermal cells of the plant through its stylets, which results in damage characterized by the tanning of the surface of leaves, flowers and fruits (Duso et al. 2010). When feeding it damages the epidermal cells of the plant and the damage can be better observed around the calyx. Furthermore, the apple leaf blade can be rolled longitudinally and, together with the fruit, in cases of large infestations, premature leaf drop may occur (Jeppson et al. 1975, Easterbrook & Palmer 1996). Studies carried out in Switzerland have shown changes in leaf color due to population growth that affected net CO_2 exchange and transpiration rates (Spieser et al. 1998). At the time, the analysis showed that the mite causes multiple perforations in the epidermal cells and desiccation of the same as well as the cells of the spongy parenchyma. In high infestations, the stomata were partially open and the guard cells lose turgor. Similar effects were observed in studies that showed that this species does not feed on the photosynthetically active mesophyll, however, it can affect photosynthesis by damaging the epidermis and inducing negative effects on the leaf mesophyll (Kozlowski & Zielinska 1997). The population peak of *A. schlechtendali* occurs in the summer, and more than two thousand specimens/leaves can be found. After this period, the quantity of mites decreases, as well as the quality of the leaves. In young plants, the highest proportion of individuals occurs in the lateral shoots, between the vegetative shoots and the main shoot. In older plants they overwinter under bark cracks and in dormant shoots. (Kozlowski & Boczek 1987, Funayama & Takahashi 1992, Easterbrook & Palmer 1996). The ideal temperature for this mite ranges from 23-28°C (Kozlowski & Boczek 1989). In late summer, deutogynes return to hibernation sites. The presence in orchards of southern Brazil was unknown until recently (Nascimento et al. 2020), when the presence of *A. schlechtendali* was confirmed at 17 points in the three states. The arrival in the country may have taken place across the borders, passing through the customs barriers of the public quarantine service or due to the intense crossing of fruits from Argentina and Chile to Brazil. So far, there are no reports that this species has reached pest status in the regions where it was found, nor how harmful this mite can be to the crop (Nascimento et al. 2020, Corrêa et al. 2021, Silva et al. 2022). Factors such as difficulty in handling and establishment of breeding make research related to the behavior of this group limited (Michalska et al. 2010).

Predatory mites

This group are present in several apple producing Brazilian regions, with the most abundant Phytoseiidae, followed by Stigmaeidae (Lorenzato et al. 1986, Ferla & Moraes 1998, Klock et al. 2011, Johann & Ferla 2012, Silva et al. 2022). 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 & Rodriguez 1987, Tixier 2018). This family began to be studied intensively from the 1950s onwards and several species have been considered important agents of applied biological control of tetranychids in agroecosystems (Moraes et al. 1991, 2004). In a survey carried out by Lorenzato et al. (1986), Phytoseiidae occurred during the entire vegetative period of apple trees, with greater intensity in the months of February and March, coinciding with the decline of *P. ulmi* and other phytophagous in the orchards. Likewise, it was observed by Lorenzato (1987) that populations of Phytoseiidae mites managed to naturally control the mobile forms and eggs of *P. ulmi* in the field in a few days. The main

phytoseiid associated with apple cultivation in North America is *Neoseiulus fallacis* (Garman) and in South America, *Neoseiulus californicus* (McGregor) (Croft & McGroarty 1977, Monetti & Fernandez 1995, Khajuria 2009, Toyoshima et al. 2011). Studies show the potential of these species to control *P. ulmi* and *T. urticae*, in addition to feeding on apple pollen and weeds, as an alternative source of food to maintain these predators in orchards (Coli et al. 1994, Khajuria 2009, Markó et al. 2012). In North America, *N. fallacis* is commonly found in high populations in apple orchards in wetter areas (Croft & McGroarty 1977, Welty 1995), preying on *P. ulmi*, *T. urticae*, and other phytophagous mites, such as eriophyid mites (Croft & McGroarty 1977). This species has potential to control pests in orchards, however, it does not have significant resistance to pesticides (Jamil et al. 2019). In Canada, phytoseiids frequently found are *N. fallacis* and *Typhlodromus caudiglans* Schuster. In South America, *Phytoseiulus macropilis* (Banks) and *N. californicus* are the predominant predatory species, standing out for their potential to control *T. urticae* and *P. ulmi* (Monteiro et al. 2008). *Neoseiulus californicus* is the most common species (Moraes et al. 2004) and has a high survival rate when exposed to agrochemicals used in pest management.

Stigmaeidae are widely distributed in a variety of habitats (Fan & Zhang 2005). The species belonging to the genera *Eustigmaeus* and *Ledermulleriopsis* inhabit soil with leaf litter where they feed on moss and lichen (Gerson 1972, Lorenzato et al. 1986). While, the free-living predators are found on leaves and branches of plants feeding eggs, mites and small insects or pollen, and belong mainly to the genera *Agistemus* and *Zetzellia* (Gerson 1972, Lorenzato et al. 1986). These predators are generalists and feed mainly on species of Eriophyoidea, Tetranychidae, Tenuipalpidae, Tarsonemidae and other mite groups in the field (Gerson et al. 2008) and in greenhouses (Zhang 2003). Some species of economic importance, such as *A. schlechtendali*, *Aculops lycopersici* (Massee) (Eriophyidae), *Panonychus citri* (McGregor) (Tetranychidae), *P. ulmi, T. urticae*, *Eutetranychus orientalis* (Klein) (Tetranychidae), *B. phoenicis* among others, are considered prey of species of the genera *Agistemus* and *Zetzellia* (Fan & Flechtmann 2015). Species of the genus *Agistemus* are known for being associated with pests of economic importance in several crops around the world (Santos & Laing 1985, Ferla & Moraes 1998), including apple trees (Lorenzato & Melzer 1984). *Agistemus fleschneri* (Summers) (Stigmaeidae) has been reported in apple trees (Strickler et al. 1987) preying on *A. schlechtendali* and *P. ulmi* in North America. *Zetzellia mali* (Ewing) (Stigmaeidae) is known to be associated with apple orchards with the presence of *P. ulmi* and *A. schlechtendali*. This predator has also been associated with species of Tarsonemidae, Tydeidae, eggs of small arthropods and also been shown to feed on *T. urticae* eggs and nymphs kept on apple leaves (Jamali et al. 2001). The average time required to complete egg-adult development was 20.8 days and the immature stages consumed 5-8 prey eggs/period. Feeding on *A. schlechtendali*, it presented a mean duration of a generation of about 21 days and a net reproduction rate (R0) of 0.109 (White & Laing 1977). Santos (1982) observed that *Z. mali* survived 23.6 days without any food on the leaves. The average egg-adult development time was 16 days when fed on *P. ulmi* eggs and 13 days on *A. schlechtendali* eggs (Ellingsen 1971, White & Laing 1977). *Zetzellia mali* prefers less mobile prey, which is perhaps why breeding with eriophyid mites is more successful than with tetranychid mites. This predator consumed 40-50 eriophyid mites during one generation in the laboratory (White

& Laing 1977). Although *Z. mali* is less active and voracious than many phytoseiids, they produce more eggs for a given number of prey consumed (Clements & Harmsen 1990). In addition, the species can maintain itself at low prey densities and under adverse environmental conditions, reaching high population densities in orchards (Delattre 1974, Strapazzon & Monta 1988). This mite can therefore be considered a successful predator of phytophagous mites during the early and late seasons of apple orchards. This species manages to maintain itself in adverse environmental conditions, reaching high population densities in the orchards (Clements & Harmsen 1990).

In a survey carried out by Lorenzato et al. (1986), the main genus found was *Agistemus*, occurring between March and April, coinciding with the decline of *P. ulmi* and other phytophagous populations in the orchards. *Typhlodromalus aripo* DeLeon was the most abundant species in orchards without pesticide application in southern Brazil (Ferla & Moraes 1998). In addition to these, other species were reported occurring in orchards in Rio Grande do Sul: *Amblyseius chiapensis* DeLeon, *Euseius mesembrinus* (Dean), *Galendromus annectens* (De Leon), *Metaseiulus mexicanus* (Muma), *N. fallacis*, *Typhlodromalus marmoreus* El-Banhawy, *Typhlodromalus peregrinus* (Muma), *Metaseiulus camelliae* (Chant & Yoshida-Shaul), *Neoseiulus neotunus* (De Leon), *Neoseiulus tunus* (De Leon) and *P. macropilis* (Lorenzato et al. 1986, Lorenzato & Secchi 1993, Ferla & Moraes 1998). In Santa Catarina and Paraná was reported occurring *Agistemus riograndensis* Johann and Ferla (Silva et al. 2022).

Control of mites associated with apple trees

In the 1980s to the early 1990s, chemical control was the only resource available for apple orchards. At this time, three to four sprays were used per vegetative cycle (Monteiro 1994, 2001). In Brazil, apple cultivation still depends mostly on high amounts of pesticides to combat pest organisms that attack orchards (Lorenzato & Melzer, 1984, Lorenzato & Secchi 1993, Fernandez et al. 2006, Raudonis et al. 2007). This strategy results in the reduction of natural enemies and favors the population increase of secondary pests, such as *P. ulmi* (Lorenzato & Secchi 1993, Meyer et al. 2009). Miticides of different chemical structures and modes of action have been used to control spider mites, including neurotoxic insecticides and specific miticides (Marcic 2012, Van Leeuwen et al. 2015, Brown et al. 2017). Chemical control is generally conducted in two phases. At first, there is the control of winter eggs, associated with breaking dormancy with the use of mineral oil and then in the vegetative phase. In this phase, miticides are used, usually abamectin, together with a mixture of mineral oil, right after the petals fall, without population level analysis and use of fenpyroximate and spirodiclofen, when the population exceeds the level of economic damage (Kovaleski & Ribeiro 2002). Tetranychidae species have the ability to rapidly acquire resistance to insecticides and miticides (Knowles 1997, Van Leeuwen et al. 2010, 2015) due to their short life cycle, high reproduction rate, haplodiploidy and high fertility rates (Van Leeuwen et al. 2009, 2010). There are several reports of populations that have created resistance to pesticides, especially *T. urticae* (Cho et al. 1995, Beers et al. 1998, Stumpf & Nauen 2001, Sato et al. 2004, Suh et al. 2006, Mota-Sanchez & Wise 2023). The use of organophosphate insecticides began in the late 1950s and rapidly increased (Walker et al. 2017). The use resulted in the resistance of *P. ulmi* and the predators *Typhlodromus pyri* Scheuten (Phytoseiidae), *Galendromus occidentalis* (Nesbitt) (Phytoseiidae) and *N. californicus* (Hoyt

1969, Collyer & Van Geldermalsen 1975, Penman et al. 1976, Meyer et al. 2009).

The intensification of chemical fertilization, intensive soil cultivation and the large-scale use of pesticides in agriculture have led to the selection of resistant populations of pests, death of non-target organisms, contamination of food and also of soil and water, being harmful still for human health (Gallo et al. 1988, Gliessman 2005). Given this scenario, the scientific society has sought new technologies that aim at sustainability in the agricultural environment, for the production of healthier foods and improvement in the quality of life of producers and the final consumer (Gliessman 2005, Monteiro et al. 2006, Marcic 2012, Joshi et al. 2023). For Gonzalez (1981), the occurrence of *P. ulmi* in apple trees is more influenced by the type of management used than by climatic conditions. The resistance of pests such as *P. ulmi* to non-selective pesticides (Lorenzato 1987) and the growing consumer demand for reducing the amount of pesticide residues present in fruits led to the implementation of new techniques to control these organisms (Walker et al. 2017). From this, studies of integrated control strategies of phytophagous mites associated with apple trees were being developed, so that pesticide sprays were minimized and that phytoseiids had sufficient resistance to control mainly *P. ulmi* and *T. urticae* in apple trees (Hoyt 1969, Collyer & Van Geldermalsen 1975, Baillod et al. 1982, Joshi et al. 2023). As a result, the use of organophosphate insecticides has been reduced, with pest monitoring, control with the use of selective insecticides and biological control systems being implemented.

Some fungicides reduce the population density of *A. schlechtendali* without causing damage to predatory mites, and their use may be encouraged in Integrated Pest Management programs (IPM) (Maeyer et al. 1992). Before any type of alternative control is approved, an analysis of the possible side effects of products frequently used to control pests must be carried out, due to the danger of affecting populations of predatory fauna. Pesticides harmful to predatory mites can cause outbreaks of phytophagous mites in agriculture (Hardman et al. 2003). The adoption of selective pest management can reduce the status of several organisms previously of economic importance, including some insects and mites, improving phytosanitary performance and contributing to a reduction in the use of pesticides (Walker et al. 2017). Some studies related to the selectivity of pesticides for use in IPM programs in apple trees have been developed mainly to control *P. ulmi* (Monteiro 1994, 2001, 2002, Monteiro et al. 2002). Monteiro et al. (2006), when carrying out an economic analysis between conventional management and biological control in the apple tree, found that the costs of machinery and labor did not present a significant difference in the evaluated orchards. However, the amounts spent on acaricides were significantly lower in the orchard where the biological control was carried out, indicating that, even with the investments in structure and maintenance, necessary for the creation of predatory mites, the biological management was presented as the most viable economically. Biological control is the most practical, economical and ecologically correct way to control mites that cause damage in apple trees (Lorenzato et al. 1986, Monteiro et al. 2006).

Biological control

The richness of predators naturally established in the environment is related to the quantity and diversity of phytophagous mites, being directly correlated with the balance of the ecosystem (Kazmierczak & Lewandowski 2006, Mailloux et al. 2010). Biological control is presented as a technique that uses living organisms to reduce

populations of organisms that reach the status of pest or economic damage in agroecosystems. This is a technique studied for a long time to control the most diverse groups of mites that cause damage to plants in the world (Sabelis 1985, Lorenzato 1987, Lorenzato & Secchi 1993, Lindquist et al. 1996, Monteiro et al. 2006). The applied biological control (CBA) is a strategy that has been standing out and its use is constantly growing (Penteado 2006). The CBA aims to regulate plant and animal populations through inundative releases of a biological control agent after mass rearing, in the laboratory (Parra et al. 2002). The success of applied biological control is based on the use of several management strategies (Monteiro 2002, Monteiro et al. 2002).

For the biological control of phytophagous mites, the Phytoseiidae stand out with a large number of species being used today (McMurtry et al. 2013, 2015). Some species are known to be effective natural controllers of Tetranychidae and Eriophyidae mites, especially *N. californicus*, which is already commercialized for use in biological control programs. In Brazil, *N. californicus* is a predatory species that has been studied and has been shown to be efficient for the biological control of *P. ulmi* in apple trees (Monetti & Fernandez 1995, Monteiro 2002, Monteiro et al. 2002). In 1995, the biological control of *P. ulmi* was implemented in commercial apple orchards in Fraiburgo, through the introduction of *N. californicus* in greenhouses and successive inoculation releases in the field (Monteiro 2002, Monteiro et al. 2002). For Lorenzato et al. (1986) the biological control of mites that cause damage in apple trees proved to be the most practical and economical to be carried out and safer for the environment. *Neoseiulus californicus* is a highly adaptable generalist predator with a wide geographic distribution, used commercially for a wide variety of cultivars and environments (Moraes et al. 1986). The species is easy to establish as it can survive and reproduce on alternative food sources, including various mites, insects and pollen (Croft et al. 1998), although it prefers spider mites (McMurtry & Croft 1997). Even though some predator species such as *N. californicus* are acquiring some resistance to agricultural pesticides, these chemicals should not be applied successively in commercial apple orchards, as their effects prevent the natural enemy from effectively controlling *P. ulmi* (Meyer et al. 2009). *Neoseiulus californicus* has already proven its ability to control *P. ulmi* in apple orchards (Monetti & Fernandez 1995, Monteiro 2002, Monteiro et al. 2002). However, in places where *T. urticae* is more common, it may not be as efficient. In this case, other phytoseiids can be used more effectively, such as *N. fallacis* and *G. occidentalis*, known biological control agents in apple orchards (Wearing & Penman 1975, Wearing & Gunson 1976). In the USA *N. fallacis* is also a known phytoseiid mite present in orchards where it is adapted to moderate cold climates, being an effective predator of *P. ulmi* and *T. urticae* (Croft & Brown 1975). It is important because it does not disperse from the environment if it is not handled correctly. In that region, *N. fallacis* spends the winter hiding in the ground cover, feeding on mites in the spring and migrating to the apple trees in the summer, a period when prey on the ground begins to become scarce, always looking for food (Croft & McGroarty 1977). Once on the apple tree, *N. fallacis* seeks to feed mainly on *P. ulmi,* looking for other options such as *T. urticae* and *A. schlechtendali*, when the main food is lacking (Croft & McGroarty 1977). Thus, using the association of these predators against the phytophagous mites at the beginning of the season can be even more efficient, avoiding a large proliferation and reducing the need for acaricide applications during production (Penman et al. 1976).

CONCLUSIONS

his review brings information about the acarofauna of the apple crop in the world, contributing to the recognition of the potential of apple cultivation in several countries. Briefly reports the social and economic importance, as well as the mite species that are present in the apple chain and the pest species control methods. The apple crop has been standing out and increasing its importance on the world stage, however, due to inadequate management, there is an imbalance in the environment and phytophagous mite species are increasing their populations and acquiring resistance against acaricides. The problem tends to increase if more sustainable alternatives for crop management are not defined. Before approving conventional control, it is necessary to carry out an analysis of the possible side effects of the products used on the populations of natural enemies. Pesticides harmful to predatory mites can cause outbreaks of phytophagous mites in agriculture. Due to the presence of *A. schlechtendali*, it is interesting to plan ways of adopting biological control strategies in Brazilian apple orchards, as this mite can reach the status of a pest in the crop. Thus, it is important that the available literature be evaluated, that the mite species present in the culture are identified and that, based on that, forms of conscious management are developed for the species of economic importance in the apple tree. Bearing in mind that human and animal health and environmental balance must be maintained and prioritized.

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PRISCILA A. RODE[1,2]
https://orcid.org/0000-0001-9172-8483

GABRIEL L. BIZARRO[1]
https://orcid.org/0000-0001-6142-872X

GUILHERME ANDRÉ SPOHR[1]
https://orcid.org/0000-0002-0813-7939

DANIELE MALMANN[1]
https://orcid.org/0000-0002-2212-1044

MATHEUS SCHUSSLER[1]
https://orcid.org/0000-0001-5669-3633

NOELI JUAREZ FERLA[1, 2, *]
https://orcid.org/0000-0003-0771-6864

[1]Universidade do Vale do Taquari/Univates, Laboratório de Acarologia, Tecnovates, Rua Alberto Muller, 1151, Carneiros, 95913-528 Lajeado, RS, Brazil

[2]Programa de Pós-Graduação em Biotecnologia, Universidade do Vale do Taquari/Univates, Avenida Avelino Talini, 171, Universitário, 95914-014 Lajeado, RS, Brazil

Correspondence to: **Priscila de Andrade Rode**
E-mail: pdrode@universo.univates.br
*CNPq researcher

Author contributions

PAR, GAS, DM, GLB and MS with the concept of the manuscript; PAR with manuscript revisions; NJF with major revisions.

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CAPITULO 2

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Article

Mite fauna (Acari) associated with apple orchards (*Malus domestica*) and spontaneous vegetation as reservoir for predatory mites

***Priscila de Andrade Rode*[1,2], *Júlia Jantsch Ferla*[3], *Gabriel Lima Bizarro*[1], *Matheus Schussler*[1] & *Noeli Juarez Ferla*[1,2,4]**

[1]*Universidade do Vale do Taquari, Laboratório de Acarologia, 95914-014, Lajeado, RS, Brasil.*
[2]*Universidade do Vale do Taquari, Programa de pós-graduação em Biotecnologia, 95914-014, Lajeado, RS, Brasil.*
[3]*Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", 13418-900 Piracicaba, SP, Brasil.*
[4]*Conselho Nacional de Desenvolvimento Científico e Tecnológico, Lago Sul, DF, Brasil.*

**Corresponding author: pdrode@universo.univates.br*

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Abstract: The aim of this study was to recognize the mite fauna associated with apple orchards in southern Brazil and present a dichotomous key of the species sampled and those already reported in apple trees in southern Brazil. The studies were carried out in the 2020/2021 harvest in seven apple orchards of the Eva, Fuji and Gala cultivars located in the municipalities of Muitos Capões, Antônio Prado (Rio Grande do Sul state) and São Joaquim (Santa Catarina state). The orchards were divided into quadrants and sampling was carried out monthly. In each orchard, 40 plants were sampled, with three leaves of each plant collected in apical, median and basal regions of a median branch. In addition, monthly five species of spontaneous plants per orchard were sampled. A total of 8,425 mites were found, with the greatest abundance in Antônio Prado (50%), followed by Muitos Capões (35.5%) and São Joaquim (14.5%). The specimens found belong to 29 families, 64 genera and 99 species, in addition to mites of the order Oribatida. The greatest diversity was found in spontaneous vegetation (59 species), being 19 exclusives to apple trees and 21 species common to apple trees and spontaneous vegetation. Phytoseiidae was the family that presented the greatest richness, with 16 species, of which seven were common in apple trees and spontaneous plants. The most abundant species was *Aculus schlechtendali* Nalepa (Eriophyidae) (39.5%), followed by *Panonychus ulmi* (Koch) (Tetranychidae) (14.6%), *Polyphagotarsonemus latus* (Banks) (Tarsonemidae) (9.4%) and *Neoseiulus californicus* (McGregor) (Phytoseiidae) (7.4%). These results suggest that the mite fauna present in apple orchards in different landscapes and management are distinct, with a greater diversity of phytoseiid mites present in organic areas. Therefore, to maintain a greater diversity of predatory mites in these orchards, organic management seems to be the most appropriate. Furthermore, the high acarine diversity found in spontaneous vegetation demonstrates the importance of maintaining these plants in orchards that serve as refuges and reservoirs, favoring the permanence of natural enemies in these environments.
Keywords: *Aculus schlechtendali; Eva; Fuji; Gala; Neoseiulus californicus; Panonychus ulmi.*

Acarofauna (Acari) associada a pomares de maçã (*Malus domestica*) e vegetação espontânea como reservatório de ácaros predadores

Resumo: O objetivo deste estudo foi reconhecer a acarofauna associada a pomares de macieira no sul do Brasil e apresentar uma chave dicotômica das espécies amostradas e daquelas já relatadas em macieiras no sul do Brasil. Os estudos foram realizados na safra 2020/2021 em sete pomares de macieiras das cultivares Eva, Fuji e Gala localizados nos municípios de Muitos Capões, Antônio Prado (RS) e São Joaquim (SC). Os pomares foram divididos em quadrantes e a amostragem foi realizada mensalmente. Em cada pomar foram amostradas 40 plantas, sendo três folhas de cada planta coletadas nas regiões apical, mediana e basal de um ramo mediano. Além disso, mensalmente foram amostradas cinco espécies de vegetação espontânea por pomar. Foram encontrados 8.425 ácaros, com maior abundância em Antônio Prado (50%), seguido por Muitos Capões (35,5%) e São Joaquim (14,5%). Os exemplares encontrados pertencem a 29 famílias, 64 gêneros e 99 espécies, além de ácaros da ordem Oribatida. A maior abundância foi encontrada em vegetação espontânea (59 espécies), sendo 19 exclusivas de macieiras e 21 espécies comuns a macieiras e vegetação espontânea. Phytoseiidae foi a família que apresentou maior riqueza, com 16 espécies, das quais sete eram comuns em macieiras e vegetação espontânea. A espécie

mais abundante foi *Aculus schlechtendali* Nalepa (Eriophyidae) (39,5%), seguida por *Panonychus ulmi* (Koch) (Tetranychidae) (14,6%), *Polyphagotarsonemus latus* (Banks) (Tarsonemidae) (9,4%) e *Neoseiulus californicus* (McGregor) (Phytoseiidae) (7,4%). Esses resultados sugerem que a acarofauna presente em pomares de macieira em diferentes paisagens e manejos são distintas, com maior diversidade de ácaros fitoseídeos presentes em áreas orgânicas. Portanto, para manter uma maior diversidade de ácaros predadores nesses pomares, o manejo orgânico parece ser o mais adequado. Além disso, a elevada diversidade de ácaros encontrada na vegetação espontânea demonstra a importância da manutenção destas plantas em pomares que servem como refúgios e reservatórios, favorecendo a permanência de inimigos naturais nestes ambientes.

Palavras-chave: *Aculus schlechtendali; Eva; Fuji; Gala; Neoseiulus californicus; Panonychus ulmi.*

Introduction

Brazil is among the largest apple producers (*Malus domestica* Borkh: Rosaceae) in the world (Kist et al. 2019), with cultivation concentrated in the highest regions of the states of Santa Catarina and Rio Grande do Sul, largest producers, followed by Paraná (Kist et al. 2019). There is a significant number of apple cultivars, with Gala and Fuji being the most important, but more recent cultivars, such as Eva, have achieved relevance in national production (Kist et al. 2019).

Conventional agriculture is widely used in several cultures due to its high productivity, but it presents risks that include loss of biodiversity, environmental pollution and risk to human health (Gomiero et al. 2011, Campbell et al. 2017). Aiming at sustainable development and better use of natural resources (Walker et al. 2017, Zhu et al. 2018, Willet et al. 2019) the organic agriculture system has stood out in several countries (Gomiero et al. 2011, Smith-Spangler et al. 2012, Caprio et al. 2015, Gomiero 2018). Pesticide spraying has been the main criterion used to differentiate organic from conventional management (Sumberg & Giller 2022). Another alternative to conventional agriculture is regenerative agriculture, which seeks to improve soil protection, not using machinery and maintaining cover with spontaneous or non-spontaneous vegetation (The Soil Association, 2021), if necessary, this system allows the use of pesticides for pest control in the Integrated Pest Management.

Landscape management can contribute to the sustainable control of pest species, as the composition of the environment can directly affect the abundance of a herbivore, affecting its dispersal, mortality or reproduction, or indirectly, affecting its natural enemies (Veres et al. 2013). Spontaneous growth vegetation occurs associated with orchards, usually between the rows of trees and can be native or exotic, with natural germination and rapid growth (Lykouressis et al. 2008, Diehl et al. 2012). The morphology of some of these plants consists of trichomes, domatia and nectaries, which are beneficial structures for the plant and offer refuge, a safe place for oviposition and provide alternative foods such as pollen and nectar to mite species (Agrawal & Karban 1997, Ferla & Moraes 2002, Prischmann & James 2003, Matos et al. 2006, Duso et al. 2010). Certain plants, associated with orchards, play an important ecological role as they host species that help in the biological control of agricultural pests, as they naturally migrate from this spontaneous vegetation to the main crop of the orchard (Tixier et al. 2000, Altieri 2002, Kreiter et al. 2003, Lykouressis et al. 2008, Ji et al. 2022).

The indiscriminate use of pesticides in orchards can lead to a reduction in natural enemies and, consequently, to an increase in the population of phytophagous mites, causing economic losses (Van Leeuwen & Dermauw 2016, Walker et al. 2017, Schmidt-Jeffris & Beers 2018). Mites of the suborders Prostigmata and Mesostigmata are of greatest agricultural economic importance (Evans 1992). Among the Prostigmata they were the phytophagous of the families Eriophyidae, Tarsonemidae, Tenuipalpidae and Tetranychidae, and the predators Stigmaeidae (Jeppson et al. 1975), respect to Mesostigmata, Phytoseiidae stood out (McMurtry et al. 2013, 2015, Demite et al. 2014). Eriophyidae and Tetranychidae are phytophagous mites found associated with apple orchards (Ferla et al. 2018, Nascimento et al. 2020). Among these stand out *Panonychus ulmi* (Koch), *Tetranychus urticae* Koch (Tetranychidae) and *Aculus schlechtendali* Nalepa (Eriophyidae) (Ferla et al. 2018, Nascimento et al. 2020, Kasap & Atlihan 2021, Corrêa et al. 2021, Silva et al. 2022). The record of the presence of *A. schlechtendali* in southern Brazil serves as a warning for the apple production chain, as it is a species of quarantine importance present in Brazil (Ferla et al. 2018, Nascimento et al. 2020, Corrêa et al. 2021, Silva et al. 2022).

The study of the diversity and seasonality of mite populations associated with plants is of great importance for the advancement of biological control methods for pests in agroecosystems and for the assessment of damage caused and biological changes in these habitats. The aim of this study was to recognize the mite fauna associated with apple orchards, in southern Brazil as well as to perform a dichotomous key with the species associated with these orchards and those already reported in previous works carried out in the same region.

Materials and Methods

1. Study area

The studies were carried out in the 2020/2021 season in seven apple orchards of the Eva, Fuji and Gala cultivars located in the municipalities of Muitos Capões (28°23'23"S 51°15'12"W) and Antônio Prado (28°22 '44"S 49°56'12"W), state of Rio Grande do Sul and São Joaquim (28°53'23"S 51°23'06"W), state of Santa Catarina (Figure 1).

1.1. Antônio Prado

Three organic orchards of Eva, Fuji and Gala cultivars were evaluated. To control herbivores, Bordeaux mixture, lime sulfur, neem oil and Cera Trap® attractant were used. Spontaneous vegetation was maintained, and mowing was only carried out when there was a need to move. In these orchards, the soil cover was preserved, with the presence of spontaneous vegetation, such as grasses and weeds, in association with litter maintained in the area.

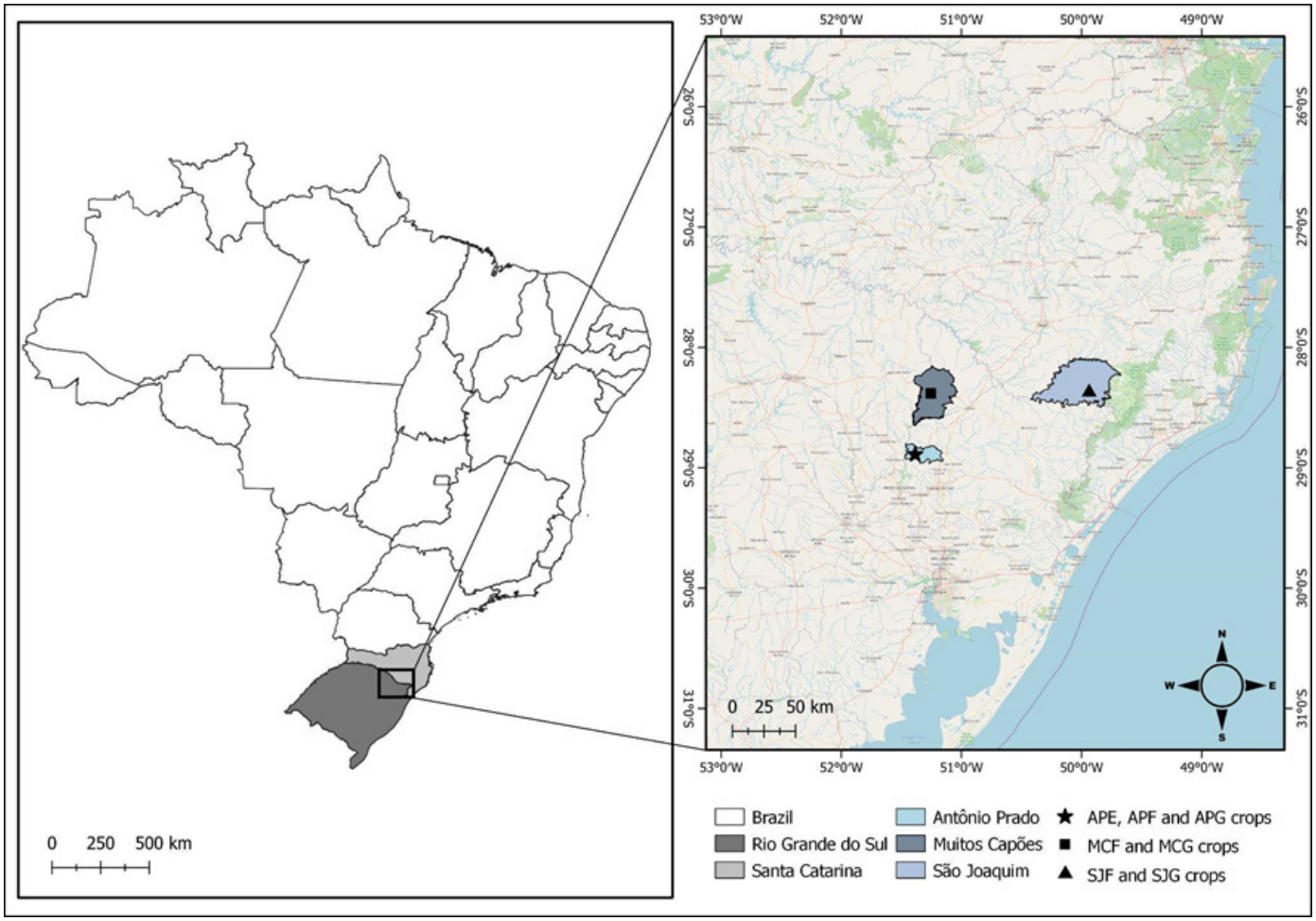

Figure 1. Collection points in apple-producing regions in the municipalities of Antônio Prado and Muitos Capões, Rio Grande do Sul, and São Joaquim, Santa Catarina, Brazil. Authorship: Castro, I. S.

1.2. Muitos Capões

Two conventional orchards were evaluated, one Fuji and the other Gala. In both orchards, the soil was kept unprotected with the use of herbicides and weeding to control pests in the orchards, as well as the spraying of pesticides to control pests.

1.3. São Joaquim

Two orchards with regenerative agriculture were evaluated, one Fuji and the other Gala. In these orchards, the soil was kept covered by spontaneous vegetation, grasses, in association with litter. Weeding was not carried out. Pigs, sheep and chickens were kept grazing throughout the area, feeding on weeds and aborted apple tree fruits. In these areas, when necessary, producers spray pesticides to control pests.

2. Sampling procedures

2.1. Apple tree plants

Samplings were carried out monthly from September 2020 to August 2021. The orchards were divided into quadrants and the sampled trees were marked to identify the origin of the sampled leaves. In each orchard, 40 plants were sampled, selected from the fifth row, counting from the edge, from which three leaves of a median branch of each plant in the apical, median and basal regions of the branch were detached, totaling 120 leaves/area. In the senescence period, branches were collected from the middle part of the plant and three buds selected from the apical, median and basal regions, totaling 120 buds/area. The material was individually packed 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.

2.2. Spontaneous vegetation

Five species of spontaneous vegetation most frequent in each month, in the evaluated orchards, were collected in sufficient quantity for a sampling effort of one hour of screening (Diehl et al. 2012). The collected vegetation was packed separately in plastic bags identified with the name of the respective cultivar and the municipality of origin, stored in a styrofoam box with artificial ice (Gelox®) and immediately transported to Labacari.

3. Identification

3.1. Mite species

The material was examined with Leica S6E stereoscopic microscope, with a fine-tipped brush. The mites were mounted on microscope

slides using Hoyer's medium (Jeppson et al. 1975) and kept in a stove at a temperature between 50 and 60 °C for approximately eight days, for medium drying, fixation and clarification of the specimens. Morphological identification was made with Zeiss Axio Scope A1 phase contrast optical microscope and proper bibliography (Baker & Tuttle 1994, Chant & McMurtry 1994, 2007, Amrine & Stasny 1994, Amrine et al. 2003, Fan & Zhang 2005, Johann et al. 2013, Skvarla et al. 2014, Silva et al. 2016). The species found in the study were deposited in the Reference Collection of Mites of the Museum of Science Univates (Sisgen: A8302CB and Sisgen: A05CB2A).

3.2. Spontaneous vegetation species

After sampling, a sample of each vegetation sampled was mounted on a specimen sheet for identification with specific bibliography (Moreira & Bragança 2011, Lorenzi 2014). Family determination was based on Angiosperm Phylogeny Group IV systems (APG IV, 2016).

4. Dichotomous key

A dichotomous key was performed with species sampled in this work and those already reported on apple trees (*Malus* spp.) from Brazil (Figueiredo 1950, Flechtmann 1966, Lorenzato et al. 1986, Lorenzato 1987, Lorenzato & Sechi 1993, Flechtmann 1996, Ferla & Moraes 1998, Lin & Zhang 2002, Monteiro 2002, Moraes & Flechtmann 2007, Ferla & Botton 2008, Oliveira et al. 2010, Mineiro et al. 2015, Ferla et al. 2018). The key was based partially on Muma (1963), André (1980), Denmark (1982), Baker (1990), Baker and Tuttle (1994), Lofego (1998), Krantz and Walter (2009), Walter et al. (2009), Johann et al. (2013), Rocha et al. (2014), Beard et al. (2015), Rezende et al. (2015), Demite et al. (2016), Fan et al. (2016), Paktinat-Saeij et al. (2016), Silva et al. (2016), Johann et al. (2017), Silva et al. (2020) and Sousa et al. (2020).

Results

A total of 8,425 mites were found, of which 1,908 were present in spontaneous vegetation. The highest abundance was found in Antônio Prado (50%), followed by Muitos Capões (35.5%) and São Joaquim (14.5%). 26 families with 67 species of spontaneous vegetation were collected. Among the plant families, eight had mites (Table 1).

The mite specimens found belong to 29 families, 64 genera and 99 species. In addition, 684 mites belonging to the suborder Oribatida were found. The greatest diversity of mite species was found in spontaneous vegetation (59 species). 19 species were exclusive from apple trees, and

Table 1. Spontaneous vegetation in apple orchards in the municipalities of Muitos Capões, Antônio Prado, state of Rio Grande do Sul and São Joaquim, state of Santa Catarina, Brazil, assessed between August 2020 and September 2021. Eating habits: P = Predator, G = Generalist and F = Phytophagous.

Botanical family	Botanical species	Abundance of mites
AMARANTHACEAE	*Amaranthus deflexus*	–
	Iresine diffusa	–
APIACEAE	*Centella asiatica*	–
	Conium maculatum	–
	Daucus pusillus	–
APOCYNACEAE	*Oxypetalum* sp.	–
ARALIACEAE	*Hydrocotyle leucocephala*	–
ASTERACEAE	*Baccharis anomala*	17
	Baccharis dracunculifolia	–
	Baccharis sp.	–
	Baccharis trimera	–
	Bidens pilosa	50
	Chromolaena laevigata	69
	Conyza bonariensis	–
	Conyza canadensis	1
	Elephantopus mollis	154
	Gamochaeta americana	–
	Hypochaeris sp.	9
	Koanophyllon sp.	–
	Senecio brasiliensis	–
	Sonchus oleraceus	1
	Taraxacum officinale	4
	Vernonanthura sp.	1
	Vernonanthura tweediana	322

Continue...

Continuation

Botanical family	Botanical species	Abundance of mites
BRASSICACEAE	*Raphanus sativus*	8
CARYOPHYLLACEAE	*Stellaria media*	–
COMMELINACEAE	*Commelina erecta*	–
CONVOLVULACEAE	*Ipomoea alba*	–
	Ipomoea indivisa	–
	Ipomoea sp.	–
CUCURBITACEAE	*Sicyos* sp.	–
EUPHORBIACEAE	*Euphorbia heterophylla*	26
FABACEAE	*Trifolium pratense*	6
	Trifolium repens	42
	Vicia cracca	1
HYPERICACEAE	*Hypericum caprifoliatum*	–
LAMIACEAE	*Cantinoa mutabilis*	12
	Leonurus japonicus	–
MALVACEAE	*Sida* sp.	–
	Sida rhombifolia	6
OXALIDACEAE	*Oxalis* sp.	–
PLANTAGINACEAE	*Plantago australis*	624
POACEAE	*Axonopus affinis*	–
	Bromus catharticus	–
	Bromus unioloides	12
	Eragrostis plana	–
	Holcus lanatus	73
	Lolium multiflorum	190
	Paspalum dilatatum	17
	Paspalum pumilum	12
	Paspalum urvillei	20
	Sporobolus indicus	1
	Steinchisma hians	8
	Urochloa plantaginea	34
POLYGONACEAE	*Rumex obtusifolius*	–
PTERIDACEAE	*Adiantopsis chlorophylla*	45
ROSACEAE	*Acaena eupatoria*	42
RUBIACEAE	*Richardia brasiliensis*	10
	Richardia sp.1	–
	Richardia sp.2	–
SCROPHULARIACEAE	*Scoparia* sp.	1
	Veronica persica	8
SOLANACEAE	*Solanum americanum*	–
	Solanum pseudocapsicum	2
TALINACEAE	*Talinum paniculatum*	73
VERBENACEAE	*Lantana camara*	–
	Verbena litoralis	7
		1.908

21 species were common to apple trees and spontaneous vegetation. Phytoseiidae was the family with the greatest diversity, with 16 species, seven of them common in both apple trees and spontaneous vegetation. Tarsonemidae was the second-diversity family with 12 species, followed by Cunaxidae with seven species and Ologamasidae, Stigmaeidae, Tetranychidae and Tydeidae, with six species each. The most abundant species was *A. schlechtendali* (39.5%), followed by *P. ulmi* (14.6%), *P. latus* (9.4%) and *Neoseiulus californicus* (McGregor) (7.4%). Of these, *A. schlechtendali* was exclusive from apple trees and the other species were found both in apple trees and spontaneous vegetation. Among the spontaneous vegetation, *Plantago australis* Lam. (Plantaginaceae) was the species with the highest mite abundance (32.7%), with 56.9% generalists and 41.7% predators. The second species was *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) (16.9%). Among the mites recorded, the highest abundance of predatory mites was on *V. tweediana* (51.9%).

Below, the mite species and its respective host plants, the municipality of origin of the samples, apple tree cultivar that was being cultivated in the orchard, month and year of collection and the number of specimens collected in parentheses.

Mesostigmata

Ascidae

Asca sp.1

Antônio Prado: EVA – *Elephantopus mollis* Kunth (Asteraceae) – I-2021 (1), IV-2021 (2), *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) – IV-2021 (3). FUJI – *Elephantopus mollis* – II-2021 (1), III-2021 (2). GALA – *Hypochaeris* sp. (Asteraceae) – IX-2020 (1). Muitos Capões: FUJI – *Trifolium repens* L. (Fabaceae) – III-2021 (4). GALA – *Plantago australis* Lam. (Plantaginaceae) – V-2021 (2), *Vernonanthura tweediana* – V-2021 (2). São Joaquim: FUJI – *Lolium multiflorum* L. (Poaceae) – XI-2020 (5), *Plantago australis* – I-2021 (2), IV-2021 (2), V-2021 (8), VIII-2021 (1), *Verbena litoralis* Kunth (Verbenaceae) – IV-2021 (2). GALA – *Plantago australis* – I-2021 (10), III-2021 (1), VI-2021 (3).

Asca sp.2

Antônio Prado: EVA – *Vernonanthura tweediana* – V-2021 (1).

Asca sp.3

Antônio Prado: FUJI – *Malus domestica* Borkh (Rosaceae) – X–2020 (1).

Blattisociidae

Lasioseius sp.

Antônio Prado: FUJI – *Plantago australis* – IV-2021 (2). GALA – *Elephantopus mollis* – V-2021 (3), *Paspalum urvillei* Steud. (Poaceae) – I-2021 (1). Muitos Capões: FUJI – *Vernonanthura tweediana* – IV-2021 (2). GALA – *Plantago australis* – V-2021 (1). São Joaquim: FUJI – *Plantago australis* – XII-2020 (3), II-2021 (1), IV-2021 (1), *Trifolium repens* – XII-2020 (1), *Verbena litoralis* – IV-2021 (1). GALA – *Holcus lanatus* L. (Poaceae) – II-2021 (1).

Digamasellidae

Dendrolaelaps sp.

Antônio Prado: FUJI – *Plantago australis* – III-2021 (1). São Joaquim: FUJI – *Acaena eupatoria* Cham. & Schltdl. (Rosaceae) – V-2021 (2), *Lolium multiflorum* – III-2021 (1), *Plantago australis* – IV-2021 (2). GALA – *Plantago australis* – IV-2021 (3).

Laelapidae

Cosmolaelaps sp.1

Antônio Prado: EVA – *Elephantopus mollis* – III-2021 (1). FUJI – *Elephantopus mollis* – XII-2020 (2), *Lolium multiflorum* – XII-2020 (1), *Paspalum dilatatum* Poir. (Poaceae) – XI-2020 (1).

Cosmolaelaps sp.2

Antônio Prado: EVA – *Elephantopus mollis* – III-2021 (1). FUJI – *Steinchisma hians* (Elliott) Nash. (Poaceae) – V-2021 (1).

Gaeolaelaps aculeiferoides (Teng, 1982)

Hypoaspis (*Gaeolaelaps*) *aculeiferoides* Teng, 1982: 161.

Muitos Capões: GALA – *Urochloa plantaginea* (Link) R. D. Webster (Poaceae) – I-2021 (1).

Pseudoparasitus sp.

Muitos Capões: FUJI – *Lolium multiflorum* – IX-2020 (1).

Macrochelidae

Macrocheles sp.1

Antônio Prado: FUJI – *Plantago australis* – III-2021 (2). GALA – *Plantago australis* – III-2021 (1), VIII-2021 (1). Muitos Capões: GALA – *Urochloa plantaginea* – I-2021 (3).

Macrocheles sp.2

São Joaquim: FUJI – *Plantago australis* – V-2021 (1).

Macrocheles subbadius (Berlese, 1904)

Holostaspis subbadius Berlese, 1904: 264.

São Joaquim: FUJI – *Plantago australis* – V-2021 (1), GALA – III-2021 (1).

Melicharidae

Orolaelaps sp.1

Antônio Prado: EVA – *Adiantopsis chlorophylla* (Sw.) Fée (Pteridaceae) – VII-2021 (3), *Elephantopus mollis* – I-2021 (1), *Plantago australis* – IV-2021 (1). FUJI – *Elephantopus mollis* – III-2021 (1), *Lolium multiflorum* – VI-2021 (2), *Trifolium repens* – VI-2021 (1). GALA – *Elephantopus mollis* – V-2021 (4), *Lolium multiflorum* – X-2020 (4), *Paspalum pumilum* Nees. (Poaceae) – IX-2020 (3).

Orolaelaps sp.2

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (1). FUJI – *Paspalum dilatatum* – XI-2020 (2).

Ologamasidae

Gamasiphis sp.

Antônio Prado: EVA – *Elephantopus mollis* – III-2021 (1). FUJI – *Elephantopus mollis* – III-2021 (1), *Paspalum dilatatum* – XI-2020 (2). GALA – *Lolium multiflorum* – IX–2020 (1). São Joaquim: FUJI – *Plantago australis* – VII-2021 (2).

Neogamasellevans ammonis Karg & Schorlemmer, 2009

Neogamasellevans ammonis Karg & Schorlemmer, 2009: 71–72

Antônio Prado: EVA – *Solanum pseudocapsicum* L. (Solanaceae) – IX-2020 (1). FUJI – *Conyza canadensis* (L.) Cronquist (Asteraceae) – X-2020 (1). GALA – *Paspalum urvillei* – II-2021 (1). Muitos Capões: GALA – *Bidens pilosa* L. (Asteraceae) – VI-2021 (1). São Joaquim: FUJI – *Lolium multiflorum* – III-2021 (1).

Neogamasellevans preendopodalis Loots & Ryke, 1967

Neogamasellevans preendopodalis Loots & Ryke, 1967: 14.

Muitos Capões: FUJI – *Lolium multiflorum* – X-2020 (1).

Ologamasus postpilus Karg & Schorlemmer, 2009

Ologamasus postpilus Karg & Schorlemmer, 2009: 77–78.

Antônio Prado: EVA – *Plantago australis* – VIII-2021 (1). FUJI – *Plantago australis* – VI-2021 (1). GALA – *Elephantopus mollis* – V-2021 (1).

Ologamasus margaridae Bizarro & Rode, 2023

Ologamasus margaridae Bizarro & Rode, 2023: 495–514.

Antônio Prado: FUJI – *Cantinoa mutabilis* (Rich.) Harley & J. F. B. Pastore (Lamiaceae) – VII-2021 (6), *Elephantopus mollis* – III-2021 (1), *Steinchisma hians* – V-2021 (1), *Plantago australis* – VI-2021 (2), *Paspalum dilatatum* – XI-2020 (8). GALA – *Elephantopus mollis* – V-2021 (1), *Hypochaeris* sp. – XII-2020 (2), *Lolium multiflorum* – X-2020 (1), *Paspalum dilatatum* – IX-2020 (1), III-2021 (4), *Trifolium repens* – VI-2021 (1), *Veronica persica* Poir. (Scrophulariaceae) – VIII-2021 (1). São Joaquim: GALA – *Holcus lanatus* – X-2020 (1), *Lolium multiflorum* – X-2020 (7), *Plantago australis* – X-2020 (1), VIII-2021 (2). FUJI – *Lolium multiflorum* – III-2021 (1), *Plantago australis* – I-2021 (1), III-2021 (1), V-2021 (2), VIII-2021 (1).

Ologamasus tuberculatus Bizarro & Rode, 2023

Ologamasus tuberculatus Bizarro & Rode, 2023: 495–514.

Antônio Prado: EVA – *Plantago australis* – III-2021 (2), IV-2021 (3). FUJI – *Elephantopus mollis* – III-2021 (3), *Lolium multiflorum* – VI-2021 (1), *Talinum paniculatum* (Jacq.) Gaertn. (Talinaceae) – VI-2021 (1). GALA – *Lolium multiflorum* – III-2021 (2), *Plantago australis* – VII-2021 (4), VIII-2021 (1), *Paspalum urvillei* – III-2021 (1), *Richardia brasiliensis* Gomes (Rubiaceae) – IV-2021 (1). Muitos Capões: FUJI – *Lolium multiflorum* – X-2020 (1). GALA – *Lolium multiflorum* – X-2020 (1), *Plantago australis* – V-2021 (1).

Pachylaelapidae

Zygoseius sp.

Antônio Prado: FUJI – *Plantago australis* – III-2021 (2).

Zygoseius furciger (Berlese, 1916)

Lasioseius (*Zygoseius*) *furciger* Berlese, 1916: 12: 19–67.

Antônio Prado: FUJI – *Cantinoa mutabilis* – VII-2021 (2). GALA – *Richardia brasiliensis* – IV-2021 (2). São Joaquim: FUJI – *Raphanus sativus* L. (Brassicaceae) – IX-2020 (1). GALA – *Holcus lanatus* – XII-2020 (1), *Plantago australis* – II-2021 (1), III-2021 (1). Muitos Capões: FUJI – *Lolium multiflorum* – VIII-2021 (1), *Plantago australis* – VIII-2021 (4).

Parasitidae

Eugamasus sp.1

Antônio Prado: GALA – *Hypochaeris* sp. – IX-2020 (2), *Paspalum pumilum* – IX-2020 (1). Muitos Capões: FUJI – *Trifolium repens* – III-2021 (1). São Joaquim: FUJI – *Plantago australis* – XII-2020 (1), III-2021 (1). GALA – *Plantago australis* – III-2021 (1).

Eugamasus sp.2

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (1). FUJI – *Paspalum dilatatum* – XI-2020 (1).

Phytoseiidae

Amblyseius chiapensis De Leon, 1961

Amblyseius chiapensis De Leon, 1961: 85.

Antônio Prado: EVA – *Malus domestica* – III-2021 (1).

Amblyseius nicola Chant & Hansell, 1971

Amblyseius nicola Chant & Hansell, 1971: 714.

São Joaquim: FUJI – *Acaena eupatoria* – IX-2020 (1), *Lolium multiflorum* – I-2021 (3), *Plantago australis* – I-2021 (12). GALA – *Acaena eupatoria* – VIII-2021 (1), *Lolium multiflorum* – X-2020 (6), *Plantago australis* – I-2021 (16), II-2021 (1), IV-2021 (3).

Amblyseius vitis Ferla & Silva, 2009

Amblyseius vitis Ferla & Silva, 2009: 509–10.

Antônio Prado: EVA – *Taraxacum officinale* F. H. Wigg. (Asteraceae) – IX-2020 (2). FUJI – *Elephantopus mollis* – XII-2020 (1), *Paspalum dilatatum* – XI-2020 (1). GALA – *Lolium multiflorum* – X-2020 (1).

Arrenoseius gaucho Ferla, Silva & Moraes, 2010

Arrenoseius gaucho Ferla, Silva & Moraes, 2010: 15.

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (6), *Elephantopus mollis* – I-2021 (2), II-2021 (1), III-2021 (8), IV-2021 (1), *Plantago australis* – IV-2021 (38), VIII-2021 (4), *Vernonanthura tweediana* – XII-2020 (2). FUJI – *Elephantopus mollis* – XII-2020 (11), II-2021 (1), III-2021 (6), *Lolium multiflorum* – XII-2020 (4), VI-2021 (4), *Plantago australis* – III-2021 (2), IV-2021 (3), *Paspalum urvillei* – I-2021 (1), *Talinum paniculatum* – VI-2021 (2), *Vernonanthura* sp. – XI-2020 (1). GALA – *Elephantopus mollis* – V-2021 (1), *Hypochaeris* sp. – XII-2020 (2), *Lolium multiflorum* – X-2020 (1), *Plantago australis* – VII-2021 (5), VIII-2021 (5), *Paspalum urvillei* – I-2021 (1), *Veronica persica* – VIII-2021 (1). São Joaquim: FUJI – *Bromus unioloides* H.B.K. (Poaceae) – X-2020 (2), *Holcus lanatus* – XII-2020 (1), *Plantago australis* – I-2021 (3), II-2021 (2), III-2021 (6), V-2021 (6), VI-2021 (2). GALA – *Acaena eupatoria* - XI-2020 (2), *Holcus lanatus* – XI-2020 (1), II-2021 (1), *Lolium multiflorum* – IX-2020 (1), I-2021 (2), III-2021 (2), *Plantago australis* – XII-2020 (1), I-2021 (3), II-2021 (2), III-2021 (2), *Raphanus sativus* – IX-2020 (6). Muitos Capões: FUJI – *Vernonanthura tweediana* – IV-2021 (2).

Arrenoseius sp.

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (2), *Malus domestica* – IV-2021 (1), *Vernonanthura tweediana* – V-2021 (1). FUJI – *Elephantopus mollis* – III-2021 (1), *Lolium multiflorum* – VI-2021 (2), *Plantago australis* – III-2021 (2), IV-2021 (1), *Steinchisma hians* – V-2021 (1).

Euseius inouei (Ehara & Moraes, 1998)

Amblyseius (*Euseius*) *inouei* Ehara & Moraes, 1998: 59.

Antônio Prado: EVA – *Chromolaena laevigata* (Lam.) R. M. King & H. Rob. (Asteraceae) – III-2021 (3), *Malus domestica* – XI-2020 (6), XII-2020 (1), II-2021 (4), III-2021 (13), IV-2021 (12), V-2021 (1). FUJI – *Malus domestica* - XI-2020 (1). GALA - *Malus domestica* – XI-2020 (1).

Euseius mesembrinus (Dean, 1957)

Typhlodromus mesembrinus Dean, 1957: 165.

Antônio Prado: EVA – *Chromolaena laevigata* – I-2021 (1), II-2021 (1), III-2021 (28), *Malus domestica* – XII-2020 (3), I-2021 (14), II-2021 (3), III-2021 (4), IV-2021 (23), V-2021 (2).

Galendromus (*Galendromus*) *annectens* (De Leon, 1958)

Typhlodromus annectens De Leon, 1958: 75.

Antônio Prado: EVA – *Malus domestica* – I-2021 (1). GALA – *Malus domestica* – II-2021 (4), III-2021 (1), IV-2021 (4).

Metaseiulus (*Metaseiulus*) *eiko* (El-Banhawy, 1984)

Typhlodromus eiko El-Banhawy, 1984: 138.

Antônio Prado: EVA – *Malus domestica* – XII-2020 (3), I-2021 (1), II-2021 (4), V-2021 (3), *Vernonanthura tweediana* – III-2021 (4).

FUJI – *Malus domestica* – XII-2020 (1), I-2021 (1), III-2021 (2), IV-2021 (2). GALA – *Malus domestica* – I-2021 (4), II-2021 (10), III-2021 (1), VI-2021 (2), VIII-2021 (1).

Neoseiulus sp.

São Joaquim: GALA – *Plantago australis* – VIII-2021 (1).

Neoseiulus californicus (McGregor, 1954)

Neoseiulus californicus McGregor, 1954: 89.

Antônio Prado: EVA – *Malus domestica* – X-2020 (1), XII-2020 (3), II-2021 (3), FUJI – *Malus domestica* – X-2020 (1), I-2021 (3), III-2021 (1). GALA – *Malus domestica* – XII-2020 (1), I-2021 (7), II-2021 (3). Muitos Capões: FUJI – *Lolium multiflorum* – XI-2020 (1), *Malus domestica* – XII-2020 (6), I-2021 (27), II-2021 (31), III-2021 (66), IV-2021 (14), V-2021 (7), VI-2021 (10), *Plantago australis* – II-2021 (1), VI-2021 (1), V-2021 (1), *Vernonanthura tweediana* – V-2021 (16). GALA – *Bidens pilosa* – V-2021 (1), *Malus domestica* – XI-2020 (2), XII-2020 (8), I-2021 (85), II-2021 (37), III-2021 (36), IV-2021 (10), V-2021 (8), VI-2021 (7), *Vernonanthura tweediana* – IX-2020 (1), XII-2020 (12), V-2021 (1). São Joaquim: FUJI – *Lolium multiflorum* – III-2021 (6), *Malus domestica* – I-2021 (11), II-2021 (5), III-2021 (32), IV-2021 (7), V-2021 (8), *Plantago australis* – I-2021 (1), IV-2021 (4), V-2021 (1), *Verbena litoralis* – IV-2021 (1). GALA – *Acaena eupatoria* – IV-2021 (2), V-2021 (1), *Holcus lanatus* – II-2021 (1), *Lolium multiflorum* – III-2021 (21), V-2021 (1), *Malus domestica* – XII-2020 (1), II-2021 (18), III-2021 (47), IV-2021 (26), V-2021 (14), *Plantago australis* – IV-2021 (3), V-2021 (1).

Neoseiulus fallacis (Garman, 1948)

Iphidulus fallacis Garman, 1948: 13.

Antônio Prado: FUJI – *Malus domestica* – X-2020 (1).

Neoseiulus mumai (Denmark, 1965)

Cydnodromus mumai Denmark, 1965: 91.

Antônio Prado: FUJI – *Lolium multiflorum* – XI-2020 (1).

Neoseiulus tunus (De Leon, 1967)

Typhlodromips tunus De Leon, 1967: 29.

Antônio Prado: EVA – *Baccharis anomala* DC. (Asteraceae) – I-2021 (2), *Malus domestica* – I-2021 (1), II-2021 (2), III-2021 (3), IV-2021 (4). FUJI – *Malus domestica* – VI-2021 (1).

Phytoseius sp.

São Joaquim: GALA – *Plantago australis* – II-2021 (1).

Proprioseiopsis ovatus (Garman, 1958)

Amblyseius ovatus Garman, 1958: 78.

Antônio Prado: EVA – *Sporobolus indicus* (L.) R. Br. (Poaceae) – IV-2021 (1). FUJI – *Veronica persica* – VIII-2021 (1). Muitos Capões: FUJI – *Malus domestica* – XI-2020 (1). GALA – *Malus domestica* – I-2021 (1), *Plantago australis* – XII-2020 (1), V-2021 (2), *Vernonanthura tweediana* – XI-2020 (1), V-2021 (1). São Joaquim: FUJI – *Holcus lanatus* – II-2021 (3), *Plantago australis* – I-2021 (9), II-2021 (1). GALA – *Acaena eupatoria* – IV-2021 (1), V-2021 (1), *Lolium multiflorum* – III-2021 (1), *Plantago australis* – I-2021 (3).

Uropodina

Antônio Prado: GALA – *Lolium multiflorum* – X-2020 (1). Muitos Capões: GALA – *Urochloa plantaginea* – I-2021 (1).

Veigaiidae

Antônio Prado: GALA – *Paspalum pumilum* – IX-2020 (1).

Trombidiformes

Alycidae

Amphialycus (*Amphialycus*) *pentophthalmus* Zachvatkin, 1949

Amphialycus pentophthalmus Zachvatkin, 1949: 30: 292–97

Antônio Prado: FUJI – *Paspalum urvillei* – I-2021 (1).

Laminamichaelia sp.

Antônio Prado: FUJI – *Lolium multiflorum* – XII-2020 (1).

Cunaxidae

Armascirus sp.

Antônio Prado: GALA – *Elephantopus mollis* – V-2021 (1), *Plantago australis* – VII-2021 (1).

Cunaxoides lajeadensis Wurlitzer & Monjarás-Barrera, 2020.

Cunaxoides lajeadensis Wurlitzer et al. 2020: 402–07.

Antônio Prado: EVA – *Baccharis anomala* – I-2021 (1), *Vernonanthura tweediana* – X-2020 (1), III-2021 (4), IV-2021 (1).

Dactyloscirus sp.

Antônio Prado: FUJI – *Elephantopus mollis* – III-2021 (1).

Neocunaxoides ovatus Lin, 2003

Neocunaxoides ovatus Lin, Zhang & Ji, 2003: 103–05.

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (1). FUJI – *Elephantopus mollis* – II-2021 (1), III-2021 (2), *Plantago australis* – V-2021 (3). GALA – *Elephantopus mollis* – V-2021 (1), *Plantago australis* – VII-2021 (2). Muitos Capões: FUJI – *Bidens pilosa* – V-2021 (1). GALA – *Vernonanthura tweediana* – V-2021 (2).

Pulaeus mormacensis Wurlitzer & Silva, 2021

Pulaeus mormacensis Wurlitzer et al. 2021: 1255–60.

Antônio Prado: FUJI – *Plantago australis* – IV-2021 (1). Muitos Capões: GALA – *Plantago australis* – V-2021 (1).

Rubroscirus grilloi Wurlitzer & Ferla, 2020

Rubroscirus grilloi Wurlitzer et al. 2020: 2228–33.

Muitos Capões: GALA – *Plantago australis* – XII-2020 (1).

Scutopalus tomentosus Rocha, Skvarla & Ferla, 2013

Scutopalus tomentosus Rocha et al. 2013: 39–42.

Antônio Prado: EVA – *Vernonanthura tweediana* V-2021 (1). FUJI – *Talinum paniculatum* – VI-2021 (1). GALA – *Elephantopus mollis* – V-2021 (1).

Eriophyidae

Aculus schlechtendali (Nalepa, 1890)

Phyllocoptes schlechtendali Nalepa, 1890: 99: 40–69.

Antônio Prado: EVA – *Malus domestica* – X-2020 (13), XI-2020 (457), XII-2020 (898), I-2021 (2), VIII-2021 (1). FUJI – *Malus domestica* – XII-2020 (46), I-2021 (36), II-2021 (3), VIII-2021 (1). GALA – *Malus domestica* – XII-2020 (17), I-2021 (206), II-2021 (100), VI-2021 (56). Muitos Capões: FUJI – *Malus domestica* – X-2020 (24), XI-2020 (12), XII-2020 (154), I-2021 (4), II-2021 (1), IV-2021 (24), VIII-2021 (5). GALA – *Malus domestica* – X-2020 (124), XI-2020 (424), XII-2020 (656), I-2021 (1), VIII-2021 (2). São Joaquim: FUJI – *Malus domestica* – I-2021 (1), III-2021 (4). GALA – *Malus domestica* – I-2021 (56), VI-2021 (1), VIII-2021 (1).

Erythraeidae

Leptus sp.

Antônio Prado: FUJI – *Plantago australis* – IV-2021 (2).

Eupodidae

Benoinyssus sp.1

Antônio Prado: EVA – *Elephantopus mollis* – III-2021 (3). FUJI – III-2021 (4), *Plantago australis* – III-2021 (1), *Richardia brasiliensis* – IV-2021 (1). GALA – *Euphorbia heterophylla* – III-2021 (2), *Plantago australis* – VII-2021 (1), VIII-2021 (1). Muitos Capões: FUJI – *Euphorbia heterophylla* – V-2021 (1), *Plantago australis* – VIII-2021 (1), *Trifolium repens* – IV-2021 (2). GALA – *Vernonanthura tweediana* – V-2021 (2). São Joaquim: GALA – *Plantago australis* – XI-2020 (1), IV-2021 (1).

Benoinyssus sp.2

Antônio Prado: GALA – *Malus domestica* – IV-2021 (1), VIII-2021 (1), *Paspalum urvillei* – III-2021 (1).

Eupodes sp.

Muitos Capões: GALA – *Bidens pilosa* – VI-2021 (1), *Plantago australis* – V-2021 (1).

Iolinidae

Pseudopronematulus sp.

Antônio Prado: EVA – *Baccharis anomala* – I-2021 (8), *Chromolaena laevigata* – III-2021 (1), *Malus domestica* – XI-2020 (2), XII-2020 (8), I-2021 (12), II-2021 (10), III-2021 (5), IV-2021 (3), *Paspalum urvillei* – II-2021 (1), *Vernonanthura tweediana* – III-2021 (3), IV-2021 (5). FUJI – *Malus domestica* – XI-2020 (3), IV-2021 (1), *Steinchisma hians* – V-2021 (2), *Talinum paniculatum* – VI-2021 (1). GALA – *Euphorbia heterophylla* – III-2021 (1), *Malus domestica* – XI-2020 (2), XII-2020 (1), I-2021 (1), II-2021 (2), III-2021 (2) – VI-2021 (1). Muitos Capões: FUJI – *Vernonanthura tweediana* – IV-2021 (1). GALA – *Bidens pilosa* – IV-2021 (4), *Euphorbia heterophylla* – IV-2021 (10), *Malus domestica* – I-2021 (1), III-2021 (1).

Scutacaridae

Scutacarus sp.

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (1). São Joaquim: FUJI – *Plantago australis* – IV-2021 (1).

Stigmaeidae

Agistemus brasiliensis Matioli, Ueckermann & Oliveira, 2002

Agistemus brasiliensis Matioli, Ueckermann & Oliveira, 2002: 106.

Antônio Prado: EVA – *Baccharis anomala* – I-2021 (1), *Chromolaena laevigata* – I-2021 (1), III-2021 (3), *Malus domestica* – XI-2020 (3), XII-2020 (10), I-2021 (69), II-2021 (40), IV-2021 (50), V-2021 (3), *Vernonanthura tweediana* – III-2021 (29), IV-2021 (31), V-2021 (24). FUJI – *Malus domestica* – XI-2020 (1), XII-2020 (1), I-2021 (2), II-2021 (4), IV-2021 (2). GALA – *Elephantopus mollis* – V-2021 (1), *Malus domestica* – XII-2020 (1), IV-2021 (2), VI-2021 (12). Muitos Capões: FUJI – *Bidens pilosa* – IV-2021 (1), *Malus domestica* – II-2021 (1), IV-2021 (1), V-2021 (1), VI-2021 (10), *Plantago australis* – VI-2021 (17), *Vernonanthura tweediana* – IV-2021 (7). GALA – *Bidens pilosa* – IV-2021 (1), *Malus domestica* – II-2021 (1), III-2021 (3), IV-2021 (1), V-2021 (2), VI-2021 (17). São Joaquim: GALA – *Malus domestica* – III-2021 (1).

Agistemus floridanus Gonzalez, 1965

Agistemus floridanus Gonzalez, 1965: 42.

Antônio Prado: FUJI – *Malus domestica* – VI-2021 (3). GALA – *Malus domestica* – II-2021 (4). São Joaquim: FUJI – *Malus domestica* – I-2021 (1). GALA – *Malus domestica* – II-2021 (1).

Agistemus riograndensis Johann & Ferla, 2013

Agistemus riograndensis Johann et al. 2013: 247.

Antônio Prado: EVA – *Chromolaena laevigata* – II-2021 (2), *Elephantopus mollis* – IV-2021 (5), *Malus domestica* – II-2021 (30), III-2021 (123), IV-2021 (49), V-2021 (8). FUJI – *Malus domestica* – III-2021 (1), IV-2021 (5), V-2021 (1). GALA – *Malus domestica* – II-2021 (6), III-2021 (5), IV-2021 (6), V-2021 (10). Muitos Capões: FUJI – *Malus domestica* - III-2021 (2), V-2021 (3). GALA – *Euphorbia heterophylla* – V-2021 (4), *Malus domestica* – III-2021 (2), IV-2021 (9), *Plantago australis* – V-2021 (1), *Vernonanthura tweediana* – V-2021 (6). São Joaquim: FUJI – *Malus domestica* – III-2021 (3), IV-2021 (4), V-2021 (9). GALA – *Malus domestica* – III-2021 (4), IV-2021 (15), V-2021 (23), *Plantago australis* – IV-2021 (1), V-2021 (2).

Agistemus sp.

Antônio Prado: FUJI – *Malus domestica* – V-2021 (1).

Eustigmaeus segnis (Koch, 1836)

Caligonus segnis Koch, 1836: 5(10).

São Joaquim: FUJI – *Acaena eupatoria* – IV-2021 (1), V-2021 (1), *Plantago australis* – V-2021 (5). GALA – *Plantago australis* – V-2021 (1), VI-2021 (4). Muitos Capões: GALA – *Vernonanthura tweediana* – V-2021 (2).

Ledermuelleriopsis punctata Soliman, 1975

Ledermuelleriopsis punctata Soliman, 1975: 244.

Muitos Capões: FUJI – *Plantago australis* – IX-2020 (1).

Tarsonemidae

Daidalotarsonemus esalqi Rezende, Lofego & Ochoa, 2015

Daidalotarsonemus esalqi Rezende, Lofego & Ochoa, 2015: 436–41.

Antônio Prado: EVA – *Malus domestica* – III-2021 (1). Muitos Capões: GALA – *Malus domestica* – XI-2020 (1).

Daidalotarsonemus savanicus Rezende, Lofego & Ochoa, 2015

Daidalotarsonemus savanicus Rezende, Lofego & Ochoa, 2015: 441–46.

Antônio Prado: EVA – *Chromolaena laevigata* – III-2021 (4), *Malus domestica* – I-2021 (1), III-2021 (2), IV-2021 (6), *Vernonanthura tweediana* – IV-2021 (1).

Fungitarsonemus sp.

São Joaquim: FUJI – *Malus domestica* – V-2021 (1).

Polyphagotarsonemus latus (Banks, 1904)

Tarsonemus latus Banks, 1904: 55.

Antônio Prado: EVA – *Baccharis anomala* – I-2021 (1), *Malus domestica* – I-2021 (1), II-2021 (16). FUJI – *Malus domestica* – XII-2020 (62), I-2021 (72), II-2021 (54). GALA – *Malus domestica* – XII-2020 (2), I-2021 (302), II-2021 (278).

Rhynchotarsonemus sp.

Antônio Prado: EVA – *Malus domestica* – III-2021 (1).

Tarsonemus confusus Ewing, 1939

Tarsonemus confusus Ewing, 1939: 26.

Antônio Prado: EVA – *Malus domestica* – IV-2021 (5). Muitos Capões: FUJI – *Vernonanthura tweediana* – IV-2021 (10). São Joaquim: FUJI – *Malus domestica* – II-2021 (2).

Tarsonemus merus Lin & Zhang, 2002

Tarsonemus merus Lin & Zhang, 2002: 248.

Antônio Prado: EVA – *Malus domestica* – XI-2020 (1), XII-2020 (1), II-2021 (1), III-2021 (10), IV-2021 (3). FUJI – *Malus domestica* – VIII-2021 (9). GALA – *Malus domestica* – II-2021 (3), IV-2021 (4), VI-2021 (3), VIII-2021 (7). Muitos Capões: FUJI – *Lolium multiflorum* – IX-2020 (1), *Malus domestica* – III-2021 (1), *Plantago australis* – II-2021 (1), *Vernonanthura tweediana* – V-2021 (16). GALA – *Malus domestica* – IX-2020 (2), XI-2020 (1), II-2021 (1), III-2021 (2), VIII-2021 (1), *Sida rhombifolia* – VIII-2021 (2), *Vernonanthura tweediana* – XII-2020 (1). São Joaquim: FUJI – *Malus domestica* – IX-2020 (11), III-2021 (12), V-2021 (1), VI-2021 (10), VII-2021 (8), VIII-2021 (2). GALA – *Malus domestica* – IX-2020 (3), II-2021 (3), III-2021 (7), IV-2021 (9), V-2021 (3), VI-2021 (17), VII-2021 (7).

Tarsonemus waitei Banks, 1912

Tarsonemus waitei Banks, 1912: 96.

Antônio Prado: EVA – *Malus domestica* – XI-2020 (3), XII-2020 (25), I-2021 (3), III-2021 (2), IV-2021 (5). FUJI – *Malus domestica* – IV-2021 (3), VII-2021 (9), VIII-2021 (1). GALA – *Adiantopsis chlorophylla* – V-2021 (1), *Malus domestica* – XII-2020 (1), I-2021 (1), II-2021 (5), IV-2021 (2), VII-2021 (4), VIII-2021 (3). Muitos Capões: FUJI – *Malus domestica* – IX-2020 (1), XI-2020 (2), XII-2020 (3), IV-2021 (4), VII-2021 (1), VIII-2021 (2), *Scoparia* sp. – IX-2020 (1). GALA – *Malus domestica* – IX-2020 (1), X-2020 (1), XI-2020 (3), XII-2020 (1), II-2021 (4), VI-2021 (2), VIII-2021 (13). São Joaquim: FUJI – *Malus domestica* – IX-2020 (2), IV-2021 (3), VIII-2021 (1). GALA – *Malus domestica* – I-2021 (2), II-2021 (6), III-2021 (2), IV-2021 (3), VII-2021 (3).

Xenotarsonemus sp.1

Muitos Capões: FUJI – *Malus domestica* – IX-2020 (1), VIII-2021 (12).

Xenotarsonemus sp.2

Antônio Prado: EVA – *Vernonanthura tweediana* – III-2021 (1). FUJI – *Talinum paniculatum* – VI-2021 (25). Muitos Capões: FUJI – *Bidens pilosa* – V-2021 (3), *Lolium multiflorum* – XI-2020 (1), *Plantago australis* – IX-2020 (3), VIII-2021 (2), *Trifolium pratense* L. (Fabaceae) – VI-2021 (5), *Vernonanthura tweediana* – IV-2021 (18), V-2021 (2). GALA – *Plantago australis* – V-2021 (43), *Vernonanthura tweediana* – V-2021 (17). São Joaquim: FUJI – *Plantago australis* – II-2021 (2), IV-2021 (2), *Verbena litoralis* – IV-2021 (1), GALA – *Acaena eupatoria* – IV-2021 (1), *Lolium multiflorum* – III-2021 (1).

Xenotarsonemus sp.3

Antônio Prado: EVA – *Elephantopus mollis* – IV-2021 (1). Muitos Capões: GALA – *Plantago australis* – V-2021 (15), *Vernonanthura tweediana* – V-2021 (33).

Xenotarsonemus sp.4

Antônio Prado: EVA – *Elephantopus mollis* – IV-2021 (1), *Plantago australis* – IV-2021 (26), *Vernonanthura tweediana* – IV-2021 (2). GALA – *Plantago australis* – VII-2021 (2). São Joaquim: FUJI – *Acaena eupatoria* – VIII-2021 (1), *Plantago australis* – I-2021 (1), II-2021 (1), VI-2021 (7), *Verbena litoralis* – VII-2021 (2). GALA – *Plantago australis* – IV-2021 (2), V-2021 (1).

Tenuipalpidae

Brevipalpus sp.1

Antônio Prado: EVA – *Malus domestica* – I-2021 (1), III-2021 (2), IV-2021 (1). FUJI – *Malus domestica* – III-2021 (7), V-2021 (2). GALA – *Malus domestica* – XII-2020 (1), I-2021 (1), IV-2021 (4), V-2021 (1), VI-2021 (1). Muitos Capões: FUJI – *Malus domestica* – III-2021 (1). GALA – *Malus domestica* – V-2021 (1).

Brevipalpus sp.2

Antônio Prado: EVA – *Elephantopus mollis* – IV-2021 (1). Muitos Capões: FUJI – *Trifolium repens* – VI-2021 (2). GALA – *Bidens pilosa* – IV-2021 (33).

Tenuipalpus sp.

Antônio Prado: EVA – *Malus domestica* – I-2021 (1).

Tetranychidae

Aponychus mauritianum Ferla & Ferla, 2020

Aponychus mauritianum Ferla et al. 2020: 1069–73.

Muitos Capões: FUJI – *Plantago australis* – VI-2021 (9).

Mononychellus planki (McGregor, 1950)

Tetranychus planki McGregor, 1950: 300.

Antônio Prado: EVA – *Sida rhombifolia* – I-2021 (1).

Panonychus ulmi (Koch, 1836)

Tetranychus ulmi Koch, 1836: 11.

Antônio Prado: EVA – *Malus domestica* – I-2021 (1). FUJI – *Malus domestica* – XI-2020 (2), II-2021 (1), III-2021 (8), IV-2021 (4), V-2021 (3), VI-2021 (1). GALA – *Malus domestica* – III-2021 (8), IV-2021 (11), VI-2021 (2). Muitos Capões: FUJI – *Malus domestica* – XI-2020 (2), XII-2020 (13), I-2021 (33), II-2021 (10), III-2021 (36), IV-2021 (227), V-2021 (143), VI-2021 (42). GALA – *Malus domestica* – IX-2020 (2), X-2020 (1), XI-2020 (5), XII-2020 (11), I-2021 (40), II-2021 (58), III-2021 (11), IV-2021 (30), V-2021 (26), VI-2021 (11), *Trifolium repens* – V-2021 (1). São Joaquim: FUJI – *Malus domestica* – IX-2020 (1), XI-2020 (4), XII-2020 (5), I-2021 (326), II-2021 (2), III-2021 (1), V-2021 (1), VIII-2021 (5). GALA – *Acaena eupatoria* – I-2021 (1), *Malus domestica* – XI-2020 (2), XII-2020 (17), I-2021 (105), II-2021 (2), III-2021 (5), IV-2021 (1), V-2021 (1), VIII-2021 (2).

Tetranychus sp.1

Antônio Prado: EVA – *Chromolaena laevigata* – II-2021 (6), *Elephantopus mollis* – IV-2021 (1). GALA – *Trifolium pratense* – VI-2021 (1). Muitos Capões: FUJI – *Bidens pilosa* – IV-2021 (2).

Tetranychus urticae Koch, 1836

Tetranychus urticae Koch, 1836.

Antônio Prado: EVA – *Malus domestica* – XII-2020 (4), I-2021 (1), III-2021 (1). FUJI – *Malus domestica* – X-2020 (3), XII-2020 (6), I-2021 (3), II-2021 (1). GALA – *Malus domestica* – XII-2020 (1). Muitos Capões: GALA – *Malus domestica* – XII-2020 (1).

Triophtydeidae

Triophtydeus sp.

Antônio Prado: EVA – *Malus domestica* – I-2021 (1). GALA – *Malus domestica* – VIII-2021 (1).

Trombidiidae

Antônio Prado: FUJI – *Lolium multiflorum* – VI-2021 (1).

Tydeidae

Lorryia aberrans (Oudemans, 1932)

Tydeus aberrans Oudemans, 1932: 350.

São Joaquim: FUJI – *Malus domestica* – IX-2020 (2).

Lorrya parvireticuli Mondin, Nuvoloni & Feres, 2016

Lorrya parvireticuli Mondin, Nuvoloni & Feres, 2016: 475.

São Joaquim: FUJI – *Plantago australis* – I-2021 (1).

Pretydeus henriandrei Kaźmierski, 1996

Pretydeus henriandrei Kaźmierski, 1996: 173.

Antônio Prado: FUJI – *Malus domestica* – VIII-2021 (1).

Quasitydeus sp.

Antônio Prado: FUJI – *Malus domestica* – II-2021 (1), III-2021 (1).

Tydeus californicus (Banks, 1904)

Tetranychoides californicus Banks, 1904: 54.

Antônio Prado: EVA – *Baccharis anomala* – I-2021 (2), *Chromolaena laevigata* – II-2021 (1), III-2021 (17), *Malus domestica* – X-2020 (1), XI-2020 (1), I-2021 (23), II-2021 (12), III-2021 (31), IV-2021 (31), V-2021 (5), VII-2021 (1), *Plantago australis* – IV-2021 (2), *Sida rhombifolia* – I-2021 (1), *Vernonanthura tweediana* – X-2020 (1), III-2021 (4). FUJI – *Malus domestica* – IV-2021 (2), V-2021 (1), VI-2021 (2). GALA – *Malus domestica* – II-2021 (1), III-2021 (1), V-2021 (3), VI-2021 (2), VIII-2021 (2).

São Joaquim: FUJI – *Malus domestica* - III-2021 (1), IV-2021 (2), *Plantago australis* – V-2021 (1). GALA – *Malus domestica* – IV-2021 (1).

Tydeus manoi Silva, Rocha & Ferla, 2014

Tydeus manoi Silva et al. 2014: 504–06.

São Joaquim: FUJI – *Acaena eupatoria* – IX-2020 (1), V-2021 (5), VIII-2021 (2), *Plantago australis* – VI-2021 (8). GALA – *Acaena eupatoria* – VI-2021 (5), *Plantago australis* – VI-2021 (4).

Sarcoptiformes

Acaridae

Tyrophagus putrescentiae (Schrank, 1781)

Acarus putrescentiae Schrank, 1781: 552.

Antônio Prado: EVA – *Malus domestica* – IX-2020 (1), X-2020 (1), VII-2021 (5). FUJI – *Lolium multiflorum* – VI-2021 (1), *Malus domestica* – IX-2020 (1). Muitos Capões: FUJI – *Bidens pilosa* - IV-2021 (1), *Lolium multiflorum* – IX-2020 (1), *Malus domestica* – IX-2020 (4), XI-2020 (1), *Plantago australis* – VIII-2021 (1), *Trifolium repens* – X-2020 (2), IV-2021 (3). GALA – *Lolium multiflorum* – X-2020 (2), XII-2020 (3), *Malus domestica* – XI -2020 (1), *Vernonanthura tweediana* – XII -2020 (1). São Joaquim: FUJI – *Lolium multiflorum* – III-2021 (6), *Plantago australis* – I-2021 (1). GALA – *Holcus lanatus* – X-2020 (1), *Lolium multiflorum* – III-2021 (2), *Malus domestica* – VIII-2021 (2), *Plantago australis* – XI-2020 (1).

Histiostomatidae

Histiostoma sp.

São Joaquim: FUJI – *Plantago australis* – V-2021 (2).

Oribatida

Antônio Prado: EVA – *Adiantopsis chlorophylla* – VII-2021 (16), *Baccharis anomala* – I-2021 (2), *Elephantopus mollis* – I-2021 (5), II-2021 (2), III-2021 (17), IV-2021 (10), *Plantago australis* – IV-2021 (8), VIII-2021 (8), *Solanum pseudocapsicum* – IX-2020 (1), *Sida rhombifolia* – I-2021 (2), *Taraxacum officinale* – IX-2020 (2), *Vernonanthura tweediana* – X-2020 (1), XII-2020 (5). FUJI – *Cantinoa mutabilis* – VII-2021 (4), *Elephantopus mollis* – II-2021 (1), III-2021 (18), *Lolium multiflorum* – X-2020 (4), XI-2020 (1), XII-2020 (10), VI-2021 (14), *Plantago australis* – III-2021 (7), IV-2021 (6), VI-2021 (2), *Paspalum dilatatum* – XI-2020 (2), I-2021 (2), *Richardia brasiliensis* – IV-2021 (3), *Steinchisma hians* – V-2021 (3), *Talinum paniculatum* – VI-2021 (43), *Urochloa plantaginea* – V-2021 (1), *Veronica persica* – VIII-2021 (1). GALA – *Adiantopsis chlorophylla* – V-2021 (13), *Euphorbia heterophylla* – III-2021 (1), *Elephantopus mollis* – V-2021 (18), *Hypochaeris* sp. – IX-2020 (1), XII-2020 (1), *Lolium multiflorum* – IX-2020 (1), X-2020 (10), *Plantago australis* – VII-2021 (18), VIII-2021 (3), *Paspalum dilatatum* – III-2021 (2), *Trifolium repens* – I-2021 (3), *Richardia brasiliensis* – IV-2021 (3), *Urochloa plantaginea* – I-2021 (28), *Veronica persica* – VIII-2021 (2). Muitos Capões: FUJI – *Bidens pilosa* – V-2021 (1), *Euphorbia heterophylla* – V-2021 (3), *Lolium multiflorum* – X-2020 (16), *Plantago australis* – IX-2020 (2), XII-2020 (1), II-2021 (2), V-2021 (10), VIII-2021 (1), *Sonchus oleraceus* – I-2021 (1), *Trifolium repens* – X-2020 (1), IV-2021 (12), VI-2021 (1), VII-2021 (5), *Veronica persica* – IX-2020 (2), *Vernonanthura tweediana* – V-2021 (1), IV-2021 (8). GALA – *Euphorbia heterophylla* – I-2021 (2), IV-2021 (1), V-2021 (1), *Lolium multiflorum* – X-2020 (3), *Plantago australis* – X-2020 (2), XII-2020 (1), V-2021 (26), VII-2021 (3), VIII-2021 (3), *Paspalum dilatatum* – IX-2020 (6), II-2021 (3), *V. cracca* – VI-2021 (1), *Vernonanthura tweediana* – II-2021 (1), V-2021 (25). São Joaquim: FUJI – *Acaena eupatoria* – V-2021 (7), VI-2021 (2), *Bromus unioloides* – X-2020 (10), *Holcus lanatus* – X-2020 (9), XII-2020 (1), II-2021 (19), *Lolium multiflorum* – XI-2020 (1), III-2021 (8), *Malus domestica* – IX-2020 (9), X-2020 (1), III-2021 (1), IV-2021 (2), VII-2021 (2), *Plantago australis* – XII-2020 (2), I-2021 (4), II-2021 (10), III-2021 (12), IV-2021 (1), V-2021 (20), VIII-2021 (2), *Raphanus sativus* – IX-2020 (1). GALA – *Acaena eupatoria* – IX-2020 (1), XI-2020 (1), IV-2021 (1), V-2021 (2), *Holcus lanatus* – X-2020 (7), XII-2020 (7), II-2021 (19), *Lolium multiflorum* – IX-2020 (1), X-2020 (5), III-2021 (9), *Malus domestica* – IX-2020 (1), VI-2021 (3), VII-2021 (5), VIII-2021 (1), *Plantago australis* – XI-2020 (9), XII-2020 (1), II-2021 (12), III-2021 (11), IV-2021 (3), V-2021 (5), VII-2021 (3), VIII-2021 (1), *Trifolium repens* – X-2020 (1), XII-2020 (1).

Winterschmitiidae

Czenskinspia transversostriata (Oudemans, 1931)

Donndorffia transversostriata Oudemans, 1931: 203.

Antônio Prado: EVA – *Chromolaena laevigata* – III-2021 (1), *Malus domestica* – IV-2021 (3), *Vernonanthura tweediana* – III-2021 (4), IV-2021 (3). GALA – *Malus domestica* – VI-2021 (1). Muitos Capões: FUJI – *Plantago australis* – II-2021 (1). GALA – *Vernonanthura tweediana* – V-2021 (1). São Joaquim: FUJI – *Malus domestica* – III-2021 (6), V-2021 (2). GALA – *Malus domestica* – IV-2021 (1), V-2021 (3).

Dichotomous key for the identification of the mite fauna associated with apple plants in Brazil

1. Chelicerae stylet shaped, curved blades or toothed chelae. Palp with a thumb-claw complex or simple and with 1-5 segments; Stigma, when present, at the base or between bases of chelicerae, at base of gnathosoma, on the anterior margin of the propodosoma or laterally to coxal region between legs III and IV……2
– Chelicerae ending in toothed chelae; Simple palpus; Opening of the tracheas absent or indistinct……54
2. With stigma laterally, between legs III and IV region.……Order Mesostigmata……3
– Stigma, when present, at the base or between bases of chelicerae, at the base of gnathosoma, on the anterior margin of the propodosoma……Order Trombidiforme……26
3. Adults with more than 20 pairs of dorsal shield setae……Ascidae……*Asca*
Adults with less than 20 pairs of dorsal shield setae……Phytoseiidae……4
4. Podonotal region of dorsal shield with 5 or 6 pairs of lateral setae……5
– Podonotal region of dorsal shield with 4 pairs of lateral setae……Amblyseiinae……9
5. Setae *Z1*, *S2*, *S4* and *S5* absent; Setae *r3* usually inserted into the dorsal shield……
Phytoseiinae……*Phytoseius guianensis* De Leon
– At least one of the following setae present: *Z1*, *S2*, *S4* or *S5*; Setae *r3* usually inserted into the body cuticle……
Subfamily Typhlodrominae……6
6. Setae *R1* absent and *S2* present……*Galendromus* (*G.*) *annectens* (De Leon)
– Setae *R1* present and *S2* usually absent……7
7. Setae long on the margin of dorsal shield; Setae *R1* much smaller than *s6*……*Typhlodromina tropica* (Chant)
– Setae short on the margin of the dorsal shield; Setae *R1* and *s6* with similar length……8
8. Sternal shield with 2 pairs of setae……*Metaseiulus* (*M.*) *camelliae* (Chant & Yoshida-Shaul)
– Sternal shield with 3 pairs of setae……*Metaseiulus* (*M.*) *eiko* (El-Banhawy)
9. Sternal shield with median posterior projection……10
– Sternal shield without median posterior projection……17
10. Chelicerae of normal size and shape, with prominent teeth distributed evenly along the fixed digit; peritreme usually extending to *j1* level……*Typhlodromalus*……11
– Chelicerae reduced in size, with small teeth at the distal tip of the fixed digit; peritreme usually not extending to *j3* level ……*Euseius*……13
11 Spermatheca with visible ductus major, swollen bifid atrium and thick cervix……
……*T. marmoreus* (El-Banhawy)
– Spermatheca not as above……12
12 Setae *z4* at most 20% longer than *z2*…… *T. peregrinus* (Muma)
– Setae *z4* about twice longer than *z2*……*T. aripo* De Leon
13. Dorsal shield smooth……14
Dorsal shield reticulated……15
14. Setae *z4* as long or longer than the distance between their bases and bases of setae *z2* ……
……*E. concordis* (Chant)
– Setae *z4* approximately half the distance between their bases and the bases of setae *z2* ……
……*E. mesembrinus* (Dean)
15. Genu III without macroseta……*E. sibelius* (De Leon)
– Genu III with macroseta……16
16. Setae *r3* inserted on unsclerotised cuticle and *R1* on dorsal shield……*E. alatus* De Leon
– Setae *r3* and *R1* inserted on unsclerotised cuticle ……*E. inouei* (Ehara & Moraes)
17. Setae *S4* absent……*Phytoseiulus macropilis* (Banks)
– Setae *S4* present……18
18. Proportion of setae size *s4*:*Z1*>3.1……19
– Proportion of setae size *s4*:*Z1*<3.1……23
19. Setae *J2* present or if absent then *j5* also absent……20
Setae *J2* absent and setae *j5* present……*Proprioseiopsis ovatus* (Garman)
20. Sternal shield usually as long as wide; all shields lightly sclerotized ……
……*Amblyseius chiapensis* De Leon
– Sternal shield usually wider than long; all shield heavily sclerotinized……21
21. Leg I with macrosseta…… *Iphiseiodes* ……22
– Leg I without macrosseta……*Arrenoseius*

22 Ventri-anal shield with 4 pairs of preanal setae……..…….. *I. metapodalis* (El-Banhawy)
– Ventri-anal shield with 3 pairs of preanal setae…….…….....*I. zuluagai* Denmark & Muma
23. Genus of leg II without and of leg III rarely with macrosseta……..…...*Neoseiulus*……..…...24
– Genus of leg II and III rarely without macrosseta……*Typhlodromips mangleae* De Leon
24. Spermathecal calyx about truncate near atrium……*N. tunus* (De Leon)
– Spermathecal calyx with rounded end near atrium……..25
25 Most dorsal setae long, frequently exceeding the bases of nearby setae…….....
……*N. californicus* (McGregor)
– Most dorsal setae short, not reaching the bases of nearby setae……..... *N. fallacis* (Garman)
26. Adults with two pairs of legs; body vermiform…….
Eriophyidae……..……...*Aculus schlechtendali* (Nalepa)
– Adults with four pairs of legs; body oval to rounded……..…….....27
27. Palpus with thumb-claw complex ……..…….28
– Palpus without thumb-claw complex……..36
28. Palp tarsus with comb-like setae……..……...Cheyletidae……*Cheletomorpha*
– Palp tarsus without comb like setae……..……...29
29. With long recurved whip like chelicera……Tetranychidae……...……30
– With short needle like chelicerae…..……..……Stigmaeidae……...……*Agistemus*…….……...…34
30. Empodium with tenent hairs. With prominent projections over rostrum……
……*Bryobia praetiosa* Koch
– Empodium without tenent hairs. Without prominent projections over rostrum……..…31
31. Empodium clawlike. With three pairs of para-anal setae……....*Panonychus ulmi* (Koch)
– Empodium split distally. With two pairs of para-anal setae……*Tetranychus*…...……...……32
32. Empodia I - II with spur……..……...……..……33
– Empodia I - II without spur……..…..*T. urticae* Koch
33. Aedeagus with large knob, posterior and anterior projections pointed, dorsal margin convex……
……*T. mexicanus* (McGregor)
– Aedeagus head curved hook, with pointed tip……....*T. ludeni* Zacher
34. Length of setae *c1* between 45–60µm……..……..……*A. floridanus* Gonzalez
– Length of setae *c1* between 60–80µm……..……..…...35
35. Ratios of setae ve/ve-ve 2.5, e1/e1-e1 1.9, and h1/h1-h1 2.4 ……..……...……...…
A. brasiliensis Matioli, Ueckermann & Oliveira
– Ratios of setae ve/ve-ve 3.7, e1/e1-e1: 2.3, and h1/h1-h1: 2.0…..…….…… ……
……*A. riograndensis* Johann & Ferla
36. Gnatosoma with quadrangular or circular contour; Leg IV slender without pretarsus and claws in females, but, usually with a sessile single claw in males, leg IV with three-segmented in females with femurgenu and tibiotarsus fused, in male with three or four segments with tibia and tarsus usually separate……..……...Tarsonemidae …….…….... 37
– Gnatosoma with variable contour; Leg IV not like this ……..…….. 45
37. Metapodosomal venter with 3 or 4 pairs of setae; leg I without pulvillus……..……..
……*Polyphagotarsonemus latus* (Banks)
– Metapodosomal venter with 2 pairs of setae; Leg I with pulvillus…….…….....……38
38. Some of the dorsal idiossomal setae enlarged……..……....…*Daidalotarsonemus*…….…….……39
– Dorsal idiossomal setae not enlarged…….……40
39 Setae *e* thin (± 3 µm); palp long (± 18 µm).....*D. esalqi* Rezende, Lofego & Ochoa
– Setae *e* broad (± 17 µm); palp short (± 10 µm).....*D. savanicus* Rezende, Lofego & Ochoa
40 Gnathosornal palpi markedly elongated……*Rhynchotarsonemus*
– Gnathosornal palpi not markedly elongated……..……..……..41
41 Tegula enlogated……..……*Xenotarsonemus*
– Tegula not elongated……..……42
42 Tarsi I-III relatively long……*Fungitarsonemus*
– Tarsi I-III normal……...*Tarsonemus*……..……...……..43
43. Setae *sc2* at least 1.5 times longer than the distance between their bases……....…...*T. waitei* Banks
Setae *sc2* about as long as or shorter than distance between their bases……..……...…44
44. Poststernal apodeme not bifurcated anteriorly at the level of setae *3a* ……...……
……*T. merus* Lin & Zhang
Poststernal apodeme bifurcated anteriorly at the level of setae *3a*……..…….....*T. confusus* Ewing

45. Posterior part of opistho dorsum with setae *f1* as a trichobothrium……...
Eupodidae……..*Benoinyssus*
– Setae *f1* not like this……..46
46. Chelicerae fused at base and with movable digit further modified into an elongate stylet……..…….. 47
– Chelicerae not fused at base and capable of moving scissor-like over gnathosoma……...
Cunaxidae……....*Cunaxoides*
47. Prodorsum without trichobothria……...Tenuipalpidae…….…… 48
Prodorsum with trichobothria…….49
48. Setae *h2* elongate, much longer than other dorsal setae……...……...*Tenuipalpus*
– Setae *h2* not elongate, similar in shape and length of other dorsal setae……...*Brevipalpus*
49. Adults with 1 pair of genital papillae or papillae absent…….……Iolinidae……*Pseudopronematulus*
– Adults with 2 pairs of genital papillae…….……..50
50. Leg I with vestigial or no apotele…….……...Triophtydeidae……...……*Triophtydeu*s
– Leg I with apotele …….……..…..Tydeidae…….…….51
51. Up to three seta on genu II…..…….52
– No setae on genu II……...……....*Pretydeus henriandrei* Kaźmierski
52. Femur III with two setae…….…….…….…...*Lorryia aberrans* (Oudemans)
– Femur III with no setae…….…….…….……53
53. Femur II with three setae…….…….…….…….…*Quasitydeus*
– Femur II with two setae ……..……..*Tydeus californicus* (Banks)
54. Prodorsum without specialized sensory organs other than setiform setae; adult idiosoma weakly sclerotized……....
Suborder Oribatida, Cohort Astigmatina…….……...…….55
– Prodorsum usually with a pair of specialized setae arising from sensory pits or bothridia (pseudostigmatic organs); adult idiosoma usually well sclerotized……...…….. ……..……...……
Suborder Oribatida (excluding Astigmatina)
55. One pair of short and strong condilophores…….…….Acaridae……*Tyrophagus putrescentiae* (Schrank)
– Condilophores fused into v-shaped sclerites.……Winterschmidtiidae ……
Czenspinskia transversostriata (Oud.)

Discussion

After a long period of absence of studies on mites in apple cultivation (Lorenzato et al. 1986, Ferla & Moraes 1998, Monteiro 2002, Monteiro et al. 2006, 2008), this study presents relevant results on the mite fauna, especially after the recent record of *A. schlechtendali* in culture (Ferla et al. 2018, Nascimento et al. 2020). Understanding the predators and prey species associated with this crop would facilitate management practices, aiming to improve the apple production. In addition, this is also the first study that evaluates the mite fauna in producing organic apple orchards in Brazil.

The data presented here show the mite fauna associated with apple orchards in southern Brazil. The greatest acarine abundance was observed in the municipality of Antônio Prado, possibly because one more orchard was sampled than in the other municipalities. However, it is worth noting that greater diversity was presented in organic orchards, in addition to low populations of phytophagous mites, suggesting that native predatory mites have the capacity to control *P. ulmi* and *A. schlechtendali*, two exotic phytophagous species.

Aculus schlechtendali was the most abundant phytophagous species, suggesting that it is a species with the potential to cause economic damage to the crop. Recent records of the species in the country (Ferla et al. 2018, Nascimento et al. 2020), together with the findings of this study, warn about the possibility of this species reaching the status of a pest in culture. According to a study predicting the potential distribution of *A. schlechtendali*, in addition to the states in the southern region of the country, other areas in the state of São Paulo and possibly in Minas Gerais were shown to be potentially suitable for its occurrence (Corrêa et al. 2021). This species is considered an important pest of apple trees in several countries (Duso et al. 2010), mainly in nurseries and orchards, where it can be found feeding on flowers, fruits and leaves, affecting the plants physiological activity, quality and aesthetics of plants (Easterbrook & Palmer 1996, Walde et al. 1997, Spieser et al. 1998, Duso et al. 2010).

Spontaneous vegetation present in the orchards showed high acarine diversity, with emphasis on predatory species. Thus, it can be stated that the maintenance of spontaneous vegetation in orchards favors the permanence of predators, acting as a refuge and reservoir for these natural enemies (Altieri 1999, 2002, Prischmann & James 2003). Certain plants associated with orchards play an important ecological role as they are hosts of species that help in the biological control of agricultural pests, as they naturally migrate from this spontaneous vegetation to the main crop of the orchard (Tixier et al. 2000, Lykouressis et al. 2008, Ji et al. 2022). These plants can provide shelter and food, such as pollen, for predatory mites, keeping them in these areas even in periods with unfavorable abiotic conditions or when there is a shortage of prey (Landis et al. 2000, Tixier et al. 2000, Demite & Feres 2005), assisting in the colonization of these areas through aerial dispersal (Tixier et al. 2000, Jung & Croft 2001). *Plantago australis* and *V. tweediana* harbored a greater abundance of mites and presented a higher proportion of predators, demonstrating that they are species with the potential to be maintained in orchards. Faoro (2022) cites *Plantago major* L. (Plantaginaceae), plantain, a

species of the same genus as the main species found in the orchards of this study, as a plant with the potential to harbor predatory mites and recommends its maintenance in orchards. However, further studies on the potential of these plants as reservoirs of natural enemies of phytophagous mites must be carried out.

Phytoseiidae is an important family for apple cultivation (Monteiro et al. 2008, Silva et al. 2022), this study presented the greatest diversity, with species that may be migrating from spontaneous vegetation to apple trees. This mite family can feed on phytophagous mites and have other alternative food sources, such as pollen, fungi, plant exudate and insects (McMurtry et al. 1970, McMurtry & Rodriguez 1987). The most abundant predator species observed in the orchards evaluated was *N. californicus*, a species that occasionally uses pollen as food (Pascua et al. 2020). In Antônio Prado orchards, maintained under organic management, *N. californicus* was found only on apple plants, however in these orchards there was a greater diversity of predatory mite species. In orchards in the municipalities of Muitos Capões and São Joaquim, under conventional and regenerative management, *N. californicus* was present both in apple trees and in spontaneous vegetation, however, these orchards showed lower diversity of Phytoseiidae. While 13 species of Phytoseiidae were found in Antônio Prado, in São Joaquim there were only five and in Muitos Capões three. As the last two areas use pesticide spraying to control pests, more frequently in conventional than in regenerative areas, it is likely that the low acarine diversity in these areas compared to organic management areas is related to the use of pesticides. According to Maeyer et al. (1992), less intensive agricultural management allows greater conservation of the diversity of natural enemies. The spraying of pesticides is one of the main factors responsible for reducing the diversity of arthropods, especially natural enemies (Kropczyn & Tuovinen 1988, Meyer et al. 2009).

The findings of this study indicate that the different management systems used in orchards influence the occurrence of predatory species, mainly Phytoseiidae, with greater diversity being found in organic orchards. Therefore, to maintain a greater diversity of phytoseiid mites in apple orchards, organic management appears to be the most appropriate to be used. Furthermore, the high acarine diversity, mainly predators, found in the spontaneous vegetation, demonstrated the importance of maintaining these plants in orchards serving as a refuge and reservoir, favoring the permanence of natural enemies in these environments.

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Authors Contributions

Priscila de Andrade Rode: substantial contribution in the concept and design of the study, contribution to data collection, contribution to data analysis and interpretation, and contribution to manuscript preparation.

Júlia Jantsch Ferla: contribution to dichotomous key confection, to critical revision, and adding intellectual content.

Gabriel Lima Bizarro: contribution to data collection, mite identification, to critical revision, and adding intellectual content.

Matheus Schussler: contribution to data collection, and to mite identification.

Noeli Juarez Ferla: substantial contribution in the concept and design of the study, contribution to critical revision, and to adding intellectual content.

Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Data Availability

Supporting data are available at <https://doi.org/10.48331/scielodata.JBIZS9>.

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CAPITULO 3

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Article

Biodiversity and mite population fluctuation in different apple orchards in southern Brazil

PRISCILA DE ANDRADE RODE[1,2*], GABRIEL LIMA BIZARRO[1], MATHEUS SCHUSSLER[1], DANIELE MALMANN[1], GUILHERME ANDRÉ SPOHR[1], TAIRIS DA-COSTA[1,3] & NOELI JUAREZ FERLA[1, 2, 4]

[1]*Laboratório de Acarologia, Tecnovates, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.*

[2]*Programa de Pós-graduação em Biotecnologia, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.*

[3]*Laboratório de Evolução, Ecologia Química e Quimiotaxonomia, Universidade Federal do Rio Grande do Sul, 91501-970, Porto Alegre, Rio Grande do Sul, Brazil.*

[4]*CNPq researcher.*

[*]*Corresponding author: pdrode@universo.univates.br*

Abstract

The aim of this work was to know the population fluctuation of the mites in apple (*Malus domestica* Borkh: Rosaceae) orchards with different crop management strategies, with emphasis on *Aculus schlechtendali* Nalepa (Eriophyidae) and *Panonychus ulmi* (Koch) (Tetranychidae) and their natural enemies. The studies were carried out in 2020-21, in three organic orchards (Eva, Fuji and Gala), from Antônio Prado, two conventional (Fuji and Gala), from Muitos Capões, RS, Brazil, and two of regenerative agriculture (Fuji and Gala), in São Joaquim, SC, Brazil. Forty plants/orchard were sampled, from which three leaves/plant from the apical, median and basal offshoot were detached. The material was screened and identified in the laboratory. A total of 7.193 specimens, belonging to 14 families, 29 genera, and 40 species, were collected. The most common phytophagous mites were *A. schlechtendali* (46.2%), *P. ulmi* (16.9%) and *Polyphagotarsonemus latus* Banks (Tarsonemidae) (10.9%). *Panonychus ulmi* was observed in all orchards, being abundant in conventional and regenerative orchards. The most common predatory mites were *Neoseiulus californicus* (McGregor) (Phytoseiidae), *Agistemus riograndensis* Johann and Ferla (Stigmaeidae) and *Agistemus brasiliensis* Matioli, Ueckermann and Oliveira (Stigmaeidae). Among predators, greater diversity was observed in organic orchards, while in conventional and regenerative orchards *N. californicus* was the most common. Greater acarine abundance was observed when there was an increase in temperatures, and the predatory mites increased their populations in response to the presence of phytophagous mites. The results suggest that the mite populations were influenced by the cultivar and mainly by the management used.

Key words: *Aculus schlechtendali,* diversity, *Malus domestica,* mite fauna, organic management, predatory mite

Introduction

Nowadays, Brazil is among the largest apple (*Malus domestica* Borkh: Rosaceae) producers in the world, with approximately one million tons per year. The quality of the fruits in the country has been increasing gradually year after year (Kist *et al.* 2019). The production is located mainly in the highest regions of the three southern states, in places where the environment is more favorable, with the state of Santa Catarina and Rio Grande do Sul being the largest producer, followed by Paraná (Kist *et al.* 2019). There is a significant number of apple cultivars, Gala and Fuji are the most important, but more recent cultivars, such as Eva, have a relevant national production (Kist *et al*. 2019).

Conventional agriculture is widely used in several crops due to the high productivity, however, it presents risks that include loss of biodiversity, environmental pollution and risk to human health (Gomiero *et al*. 2011; Campbell *et al.* 2017). Aiming at sustainable development and better use of natural resources (Walker *et al.* 2017; Zhu *et al.* 2018) 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). Pesticide spraying has been the main criterion used to differentiate organic from conventional managements (Sumberg & Giller 2022). Another alternative to conventional agriculture is regenerative agriculture, which seeks to improve soil conservation, without weeding and maintaining spontaneous plants covering (The soil association 2021), however, if necessary, this system allows the use of pesticides for pest control.

The indiscriminate use of pesticides in orchards can lead to a reduction in natural enemies, and consequently, an increase in the population of phytophagous mites, causing economic damage (Van Leeuwen & Dermauw 2016; Walker *et al.* 2017; Schmidt-Jeffris & Beers 2018). Eriophyidae and Tetranychidae are phytophagous mites found associated with apple orchards (Duso *et al.* 2010; Ferla *et al.* 2018; Nascimento *et al.* 2020). Among these stand out *Panonychus ulmi* (Koch), *Tetranychus urticae* Koch (Tetranychidae) and *Aculus schlechtendali* Nalepa (Eriophyidae) (Duso *et al.* 2010; Ferla *et al.* 2018; Nascimento *et al.* 2020; Kasap & Atlihan 2021; Corrêa *et al.* 2021; Silva *et al.* 2022). *Aculus schlechtendali* represents a threat to apple production and it is a quarantine importance for Brazil (Ferla *et al.* 2018; Nascimento *et al.* 2020; Corrêa *et al.* 2021; Silva *et al.* 2022).

Even though apple matters for Brazil, little is known about the mites associated. Therefore, it is necessary to know the diversity and population fluctuation of mites associated with this culture, especially after the detection of *A. schlechtendali* in the region. It also aims to evaluate different crop management strategies, emphasizing the occurrence of *A. schlechtendali* and *P. ulmi* and their natural enemies.

Materials and Methods

Study area. The studies were carried out between 2020-21 in seven orchards of the cultivars Eva, Fuji and Gala located in the municipalities of Muitos Capões (28°23'23"S 51°15'12"W) and Antônio Prado (28°22'44"S 49°56'12"W), state of Rio Grande do Sul and São Joaquim (28°53'23"S 51°23'06"W), state of Santa Catarina (Figure 1).

Antônio Prado: Three organic orchards of cultivars Eva (APE), Fuji (APF) and Gala (APG) were assessed. To control mites and insects, Bordeaux mixture, lime sulfur, neem oil and Cera Trap® attractant were used. Spontaneous vegetation was maintained, and mowing was only carried out randomly. Two hectares of APE orchards were sampled, with 15-year-old trees and APF and APG orchards of one hectare each and 20-year-old trees. The spacing between rows was 4 m and 1.80 m between plants. In these orchards, the soil cover was preserved, with the presence of spontaneous plants, such as grasses and weeds, in association with the litter kept in the area.

Muitos Capões: Two conventional orchards, one Fuji (MCF) and another Gala (MCG) were assessed. The total area of the orchards was 240 hectares and approximately 12 years old. The spacing was 4.2 m between rows x 1 m between trees. In both orchards, the soil was kept unprotected with the use of herbicides and weeding to control the pests in orchards, as well as the spraying of pesticides to control pests.

São Joaquim: Two orchards with regenerative agriculture, one Fuji (SJF) and another Gala (SJG), were assessed. The area was 5.5 hectares, and the trees were approximately 30 years old and spacing between trees was 3 m and 7 m between corridors. In these orchards, the soil was kept covered by spontaneous plants, in association with litter. Weeding was not carried out. Pigs, sheep

and chickens were kept grazing throughout the area, feeding on spontaneous plants and fruits aborted from apple trees. In these areas, when necessary, producers spray pesticides for pest control.

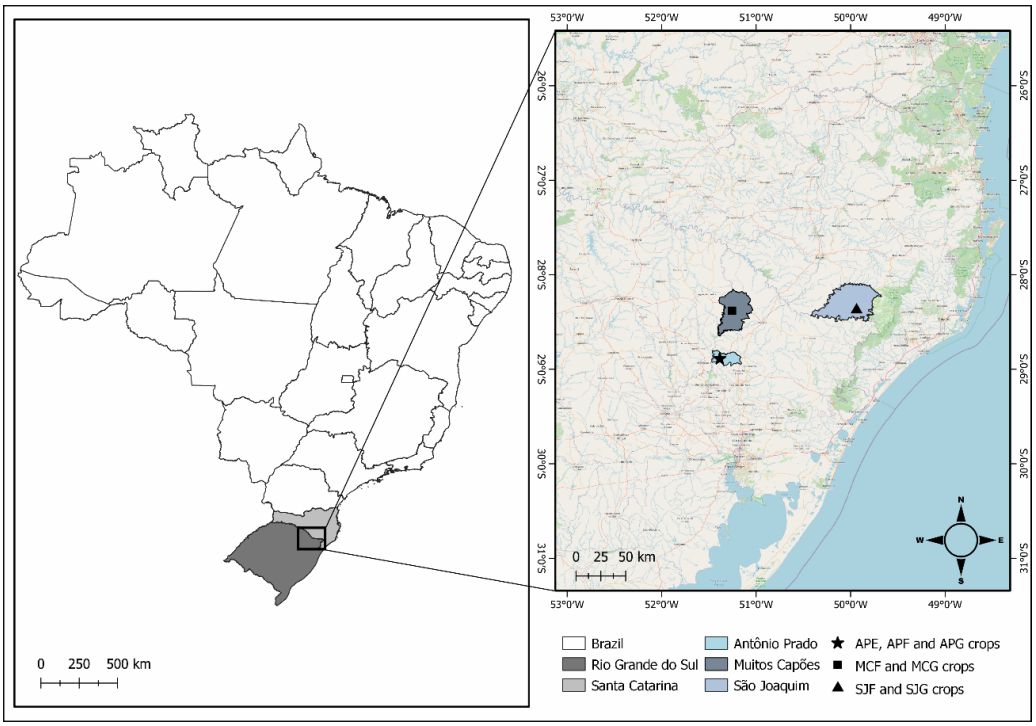

FIGURE 1. Collection points in apple-producing regions in the municipalities of Antônio Prado and Muitos Capões, Rio Grande do Sul, and São Joaquim, Santa Catarina, Brazil.

Sampling procedures. Sampling was carried out monthly from September 2020 to August 2021. The orchards were divided into quadrants and the sampled trees were marked to identify the origin of the sampled leaves. In each orchard, 40 trees were sampled, selected from the fifth row, counting from the edge, from which three leaves of a median branch of each tree from the apical, median and basal regions of the branch were chosen, totaling 120 leaves/orchard. In the senescence period, branches were collected from the middle part of the tree and three buds were sorted from the apical, median and basal regions, totaling 120 buds/orchard. The material was individually packed in previously identified transparent plastic bags, kept at low temperature and taken to the Acarology Laboratory (Labacari), University of Vale do Taquari - Univates, Lajeado, state of Rio Grande do Sul. Screening was performed under a Leica S6E stereoscopic microscope, with the aid of a fine paint brush. Adult female and male mites were mounted on microscope slides using Hoyer's medium (Jeppson *et al.* 1975) and kept in an oven at 50-60 °C for approximately eight days, for drying, fixation and clearing of the specimens. Mites were identified using Zeiss Axio Scope A1 phase-contrast optical microscope and specific bibliography (Baker & Tuttle 1994; Chant & McMurtry 1994; Amrine & Stasny 1994; Amrine *et al.* 2003; Fan & Zhang 2005; Chant & McMurtry 2007; Johann *et al.* 2013; Skvarla *et al.* 2014; Silva *et al.* 2016). The species found in the study were deposited in the Mite Reference Collection of the Museum of Natural Sciences of the University of Vale do Taquari - Univates (Sisgen: A8302CB).

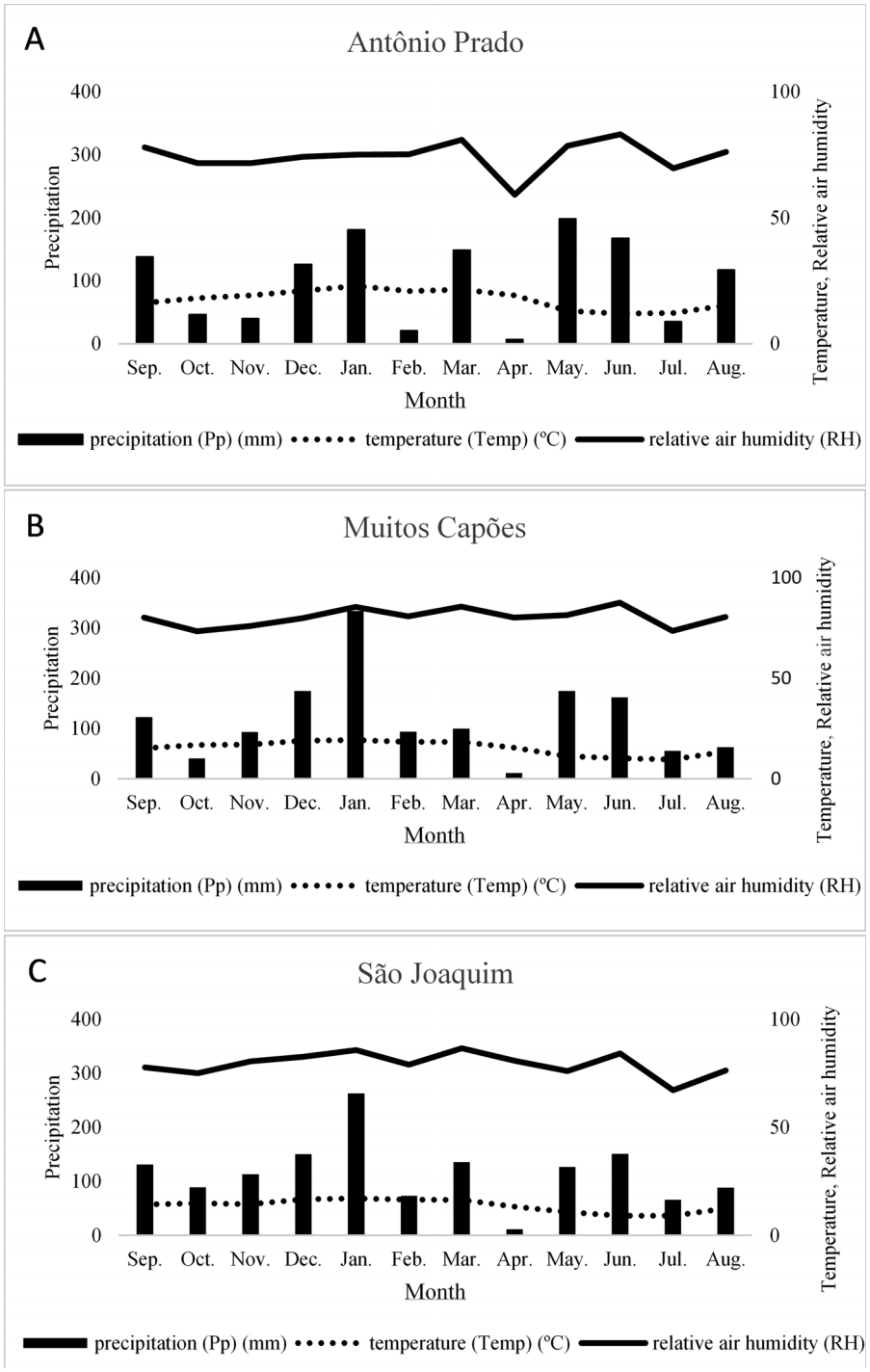

FIGURE 2. Meteorological data for Antônio Prado (A), Muitos Capões (B) and São Joaquim (C) municipalities, from September 2020 to August 2021, provided by Embrapa.

The information on the climatological variables was obtained monthly from meteorological stations close to the collection points, as follows: Antônio Prado information from the INMET meteorological station, municipality of Bento Gonçalves (A840); Municipality of Muitos Capões,

data from the INMET meteorological station, Vacaria (A880); São Joaquim, information from the Morro da Igreja Automatic Weather Station (A845) (EMAMI) (Figure 2).

Statistical analysis

Constancy (C) was calculated according to Silveira-Neto *et al.* (1976), through the formula: C = (P x 100)/N, where P = number of collections containing the species and N = total number of collections performed and classified as: constant (C> 50%), accessory (25 % <C <50%) and accidental (C < 25%). Dominance (D) was defined using the formula: D% = (i/t) x100, where I = total number of individuals of a species and t = total individuals collected and grouped according to the categories established by Friebe (1983): Eudominant (> 10%), Dominant (5 ≥ 10%), Subdominant (2 ≥ 5%), Eventual (1 ≥ 2%), and rare (D < 1%). Constant, Dominant and Eudominant species were highlighted in each orchard to carry out population fluctuation studies. The total number of unobserved mite species was estimated from the Chao equation (Chao *et al.* 2014) using the 'spec pol' function of the vegan package (R Core Team 2019). It was evaluated whether the sampling effort carried out was sufficient to sample the richness of mites present in the orchards of each municipality. A rarefaction curve of the mite species was performed, calculating the interpolation/extrapolation according to the number of individuals sampled. A diversity of profile was also carried out using the diversity of order of the Hill series (Hill 1973) that allows comparing the diversity of mites in a dynamic way along the parameters in the scale (Rényi diversity) between different communities (Chao *et al.* 2014). To generate these estimates, we used a matrix of mites associated with the orchards of the three municipalities studied, the diversity of profile was constructed using the 'renyi' function of the vegan package (Oksanen *et al.* 2018). All analyzes were performed in R (R Core Team 2019). The relationships between all species were determined by the Pearson correlation coefficient (Zar 1999) was also calculated using the BIOESTAT 5.3 software (Ayres *et al.* 2007).

Results

Species diversity. A total of 7.193 specimens were collected, belonging to 14 families, 29 genera, and 40 species/morphospecies (Table 1). The most abundant phytophagous species were *A. schlechtendali* (46.2%), *P. ulmi* (16.9%) and *Polyphagotarsonemus latus* Banks (Tarsonemidae) (10.9%). *Panonychus ulmi* was present in all orchards and throughout the evaluation period of this study, being constant in all CA orchards and in APF. Among the predatory mites, *Neoseiulus californicus* (McGregor) (Phytoseiidae) (Type II predator—associated to dense web producing tetranychid mites) (7.5%), *Agistemus riograndensis* Johann and Ferla (Stigmaeidae) (4.4%) and *Agistemus brasiliensis* Matioli, Ueckermann and Oliveira (Stigmaeidae) (3.3%) stood out.

Organic orchards. In APE, the constant species were *Pseudopronematulus* sp. (Iolinidae), *Euseius mesembrinus* Dean, *Euseius inouei* Ehara and Moraes (Phytoseiidae)*, A. brasiliensis* and *Tydeus californicus* Banks (Tydeidae). In this orchard, *A. schlechtendali* and *A. riograndensis* were Eudominants; *A. brasiliensis* and *T. californicus*, Dominants. In APF, only *P. ulmi* was Constant and Dominant; *Aculus schlechtendali* and *P. latus* were Eudominants. In APG, *Pseudopronematulus sp.* and *Tarsonemus waitei* Banks (Tarsonemidae) were Constants; *A. schlechtendali* and *P. latus*, Eudominants.

Conventional orchards. In both cultivars, *N. californicus*, *P. ulmi* and *T. waitei* were Constants. In MCF, *A. schlechtendali* was also Constant. As for dominance, *A. schlechtendali*, *N. californicus* and *P. ulmi* were Eudominant in both cultivars. With respect to natural enemies, only *N. californicus* and *Proprioseiopsis cannaensis* Muma (Phytoseiidae) were present in MCF and MCG.

TABLE 1. Mites associated with apple cultivars in the municipalities of Muitos Capões, Antônio Prado, Rio Grande do Sul and São Joaquim, Santa Catarina, Brazil, collected between August 2020 and September 2021.

Species	Antônio Prado							Muitos Capões							São Joaquim								
	Eva			Fuji			**Gala**			Fuji			**Gala**			Fuji			**Gala**				
	T	**C**	**D**	T	C	D	**T**	**C**	**D**	T	C	D	**T**	**C**	**D**	T	C	D	**T**	**C**	**D**	S	%
Aculus schlechtendali – F	**1371**	**A**	**E**	86	A	E	**379**	**A**	**E**	224	C	E	**1207**	**A**	**E**	5	I	Ev	**58**	**A**	**E**	**3330**	**46,2**
Agistemus brasiliensis – P	**175**	**C**	**D**	10	A	S	**15**	**A**	**Ev**	13	A	Ev	**24**	**A**	**Ev**	-			**1**	**I**	**R**	**238**	**3,3**
Agistemus floridanus – P	**-**			3	I	Ev	**4**	**I**	**R**	-			**-**			1	I	R	**1**	**I**	**R**	**9**	**0,1**
Agistemus riograndensis – P	**210**	**A**	**E**	7	A	S	**27**	**A**	**S**	5	I	Ev	**11**	**I**	**Ev**	16	A	S	**42**	**A**	**D**	**318**	**4,4**
Agistemus sp. – P	**-**			1	I	R	**-**			-			**-**			-			**-**			**1**	**0,01**
Amblyseius chiapensis – P	**1**	**I**	**R**	-			**-**			-			**-**			-			**-**			**1**	**0,01**
Arrenoseius sp. – P	**1**	**I**	**R**	-			**-**			-			**-**			-			**-**			**1**	**0,01**
Asca sp. – P	**-**			1	I	R	**-**			-			**-**			-			**-**			**1**	**0,01**
Benoinyssus sp. – G	**-**			-			**2**	**I**	**R**	-			**-**			-			**-**			**2**	**0,02**
Brevipalpus sp. – F	**4**	**A**	**R**	9	I	S	**8**	**A**	**Ev**	1	I	R	**1**	**I**	**R**	-			**-**			**23**	**0,3**
Czenskinspia transversostriata - G	**3**	**I**	**R**	-			**1**	**I**	**R**	-			**-**			8	I	S	**4**	**I**	**Ev**	**16**	**0,2**
Daidalotarsonemus esalqi - F	**1**	**I**	**R**	-			**-**			-			**1**	**I**	**R**	-			**-**			**2**	**0,02**
Daidalotarsonemus savanicus - F	**9**	**A**	**R**	-			**-**			-			**-**			-			**-**			**9**	**0,1**
Euseius inouei – P	**37**	**C**	**S**	1	I	R	**1**	**I**	**R**	-			**-**			-			**-**			**39**	**0,5**
Euseius mesembrinus – P	**49**	**C**	**S**	2	I	Ev	**-**			-			**-**			-			**-**			**51**	**0,7**
Fungitarsonemus sp. – F	**-**			-			**-**			-			**-**			1	I	R	**-**			**1**	**0,01**
Galendromus annectens – P	**1**	**I**	**R**	-			**9**	**A**	**Ev**	-			**-**			-			**-**			**10**	**0,1**
Lorryia aberrans - G	**-**			-			**-**			-			**-**			2	I	R	**-**			**2**	**0,02**
Neoseiulus californicus – P	**5**	**A**	**R**	5	A	Ev	**11**	**A**	**Ev**	161	C	E	**193**	**C**	**E**	63	A	E	**106**	**A**	**E**	**544**	**7,5**
Metaseiulus eiko – P	**11**	**A**	**Ev**	6	A	S	**18**	**A**	**S**	-			**-**			-			**-**			**35**	**0,4**
Neoseiulus fallacis – P	**-**			1	I	R	**-**			-			**-**			-			**-**			**1**	**0,01**
Neoseiulus tunus – P	**10**	**A**	**R**	1	I	R	**-**			-			**-**			-			**-**			**11**	**0,1**
Suborder Oribatida – G	**-**			-			**-**			-			**-**			15	A	S	**10**	**A**	**S**	**25**	**0,3**
Panonychus ulmi – F	**1**	**I**	**R**	19	C	D	**21**	**A**	**S**	506	C	E	**195**	**C**	**E**	345	C	E	**135**	**C**	**E**	**1222**	**16,9**
Polyphagotarsonemus latus – F	**17**	**I**	**Ev**	188	A	E	**582**	**A**	**E**	-			**-**			-			**-**			**787**	**10,9**

.....continued on the next page

TABLE 1. (Continued)

Species	Antônio Prado						Muitos Capões						São Joaquim							
Pretydeus henriandrei – G	**-**			1	I	R	**-**			-			**-**			-			**1**	**0,01**
Proprioseiopsis cannaensis – P	**-**			-			**-**			1	I	R	**1**	**I**	**R**	-			**-**		**2**	**0,02**
Pseudoprone matulus sp. - G	**40**	**C**	**S**	4	I	Ev	**9**	**C**	**Ev**	1	I	R	**1**	**I**	**R**	-			**-**		**55**	**0,76**
Quasitydeus sp. - G	**-**			2	I	Ev	**-**			-			**-**			-			**-**		**2**	**0,02**
Rhynchotarsonemus sp. – F	**1**	**I**	**R**	-			**-**			-			**-**			-			**-**		**1**	**0,01**
Tarsonemus confusus – F	**5**	**I**	**R**	-			**-**			-			**-**			2	I	R	**-**		**7**	**0,09**
Tarsonemus merus – F	**16**	**A**	**Ev**	9	I	S	**17**	**A**	**S**	1	I	R	**7**	**A**	**R**	44	C	D	**49**	**C**	**E**	**143**	**1,9**
Tarsonemus waitei – F	**38**	**A**	**S**	13	A	S	**16**	**C**	**Ev**	13	C	Ev	**25**	**C**	**Ev**	6	A	Ev	**16**	**A**	**S**	**127**	**1,7**
Tenuipalpus sp. – F	**1**	**I**	**R**	-			**-**			-			**-**			-			**-**		**1**	**0,01**
Tetranychus sp. – F	**2**	**I**	**R**	6	I	S	**-**			-			**-**			-			**-**		**8**	**0,1**
Tetranychus urticae – F	**4**	**A**	**R**	7	A	S	**1**	**I**	**R**	-			**1**	**I**	**R**	-			**-**		**13**	**0,1**
Triophtydeus sp. - G	**1**	**I**	**R**	-			**1**	**I**	**R**	-			**-**			-			**-**		**2**	**0,02**
Tydeus californicus – G	**105**	**C**	**D**	5	A	Ev	**9**	**A**	**Ev**	-			**-**			3	I	Ev	**1**	**I**	**R**	**123**	**1,7**
Tyrophagus putrescentiae – G	**7**	**A**	**R**	1	I	R	**-**			5	I	Ev	**1**	**I**	**R**	-			**2**	**I**	**R**	**16**	**0,2**
Xenotarsonemus sp. – F	**-**			-			**-**			13	I	Ev	**-**			-			**-**		**13**	**0,1**
Total	**2126**			388			**1131**			944			**1668**			511			**425**		**7.193**	
%	**29,5**			5,3			**15,7**			13,1			**23,1**			7,1			**5,9**		**7.193**	
Richness	**28**			24			**19**			12			**13**			13			**12**			

T = Total mites; C = Constance; D = Dominance; S = Sum; C = Constant; A = Accessory; I = Accidental; E = Eudominant; D = Dominant; S = Subdominant; Ev = Eventual; R = Rare; F = Phytophagous; P = Predator; G = Generalist/mycophagous.

Regenerative orchards. *Tarsonemus merus* Lin and Zhang (Tarsonemidae) and *P. ulmi* were Constants in SJF and SJG. In SJF, *N. californicus* and *P. ulmi* were Eudominants, while in SJG, in addition to these two species, *A. schlechtendali* e *T. merus* were Eudominants. *Agistemus riograndensis* was Dominant in SJG. With respect to natural enemies, only *N. californicus* were present in SJF and SJG.

The Chao estimator indicate that if more apple orchards were evaluated, more mite species would be found (Chao = 46.75). The rarefaction curves show that the mite richness of organic and conventional orchards is greater than that found in this study (Figure 3). The mite richness of regenerative management was sufficiently sampled.

Hill's diversity profile demonstrates greater acarine richness in organic orchards, as well as the values of Shannon-Wiener and Simpson indices. These results indicate that the organic management presents greater diversity, followed by regenerative and conventional (Figure 4). In GCM, there was lower richness (13) and high abundance (1668), thus finding lower values in the Shannon's diversity index (H = 0.9413) and Equitability (J = 0.3670) and high values of the Simpson index. (0.4488),

suggesting this orchard as the least diverse (Table 1). Greater richness was obtained in APE (28) and APF (24). However, in APF, there was lower abundance (388) and, therefore, high values of Shannon's diversity index (H = 1.8480) and Equitability (J = 0.5815). The data obtained in this study indicate that APF and SJG areas were the most diverse in terms of rare species, even with low richness (12) and low abundance (425).

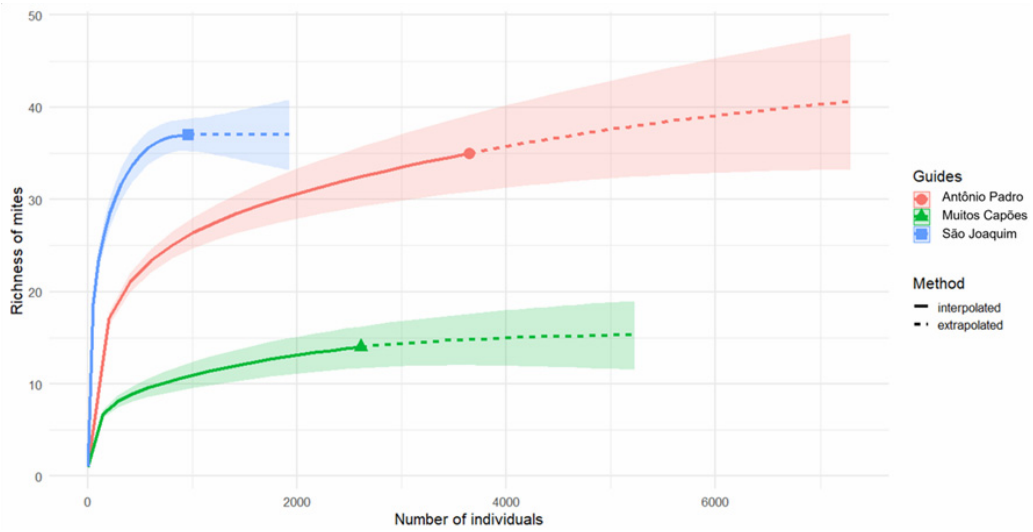

FIGURE 3. Rarefaction curves of mite species: x axis, number of individuals per sampling unit; -y-axis, interpolation (before value) and extrapolation (after the value) of the Hill number with order q = 0 displaying the species richness found and the number of expected species in relation to the mean. The shadow indicates the confidence intervals (95%).

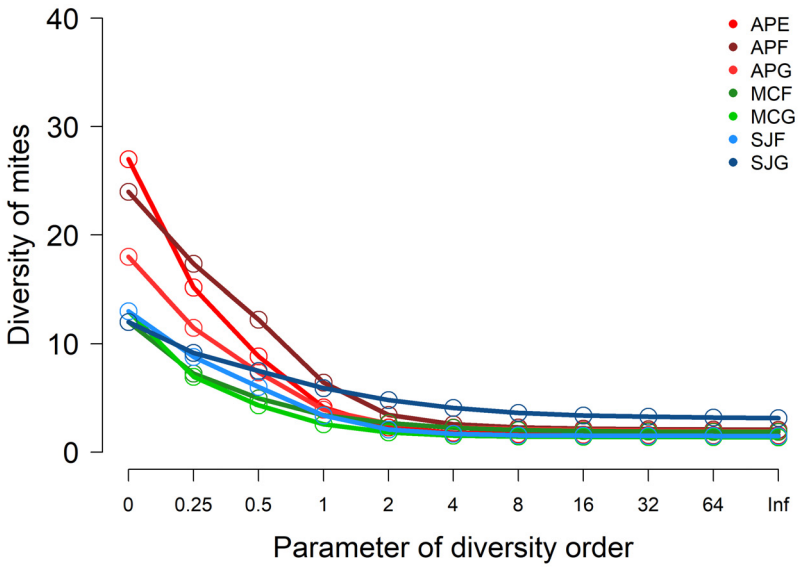

FIGURE 4. Hill numbers diversity profile. The x-axis shows the change in diversity indices over Hill numbers; the y-axis displays the level of diversity for x-axis measurements. The left side of the x-axis is more sensitive to rare species, while the right side is more sensitive to the abundance of mite taxa. This continuum of values allows inferring the contributions of rare versus abundant species in a community. Some diversity indices on the x axis can be inferred: 0 species richness; 1, Shannon-Wiener index; 2, Simpson's index; inf, BergerParker index.

Population fluctuation. *Aculus schlechtendali*, *P. latus* and *P. ulmi* were the most common and abundant phytophagous mites, proving to be key species in apple cultivation in southern Brazil. *Panonychus ulmi* was observed in all orchards, being frequent and abundant in the organic and regenerative orchards. It was present in almost the entire study period and was more abundant in the period from December to February, in regenerative and conventional. *Aculus schlechtendali* reached high populations in December and January, mainly in APE and MCG. *Polyphagotarsonemus latus* had significant populations in organic orchards between December and January.

Among the predatory mites, *A. brasiliensis*, *A. riograndensis*, *E. inouei*, *E. mesembrinus* and *N. californicus*, common in organic orchards, stood out. *Neoseiulus californicus* was the most common species in conventional orchards. High populations of *A. brasiliensis* and *A. riograndensis* were observed only in APE.

Tarsonemus waitei, *T. merus* and *T. californicus* were the most common generalist mites. *Tarsonemus waitei* was common in the organic and conventional orchards, *T. merus*, in regenerative and *T. californicus* only in APE. *Pseudopronematulus* sp. was present in high populations only in organic orchards.

Organic orchards. In APE, *A. schlechtendali* had a population peak in December (22.45 mites/plant) and *A. brasiliensis* in January (1.73 mites/plant) (Figure 5). Tarsonemid and tydeidd mites showed high populations from December to March, along with *E. inouei, E. mesembrinus* and *A. brasiliensis*, whose populations were highest in March (3.08 mites/plant). *Agistemus brasiliensis* showed positive correlation with *P. ulmi* ($r=0.70$; $p=0.009$).

In APF, the population peak of *P. latus* occurred in January (1.18 mites/plant), maintaining high populations from December to February, while *A. schlechtendali* had a peak in December (1.15 mites/plants). *Neoseiulus tunus* (De Leon) (Phytoseiidae) showed correlation with *T. californicus* ($r=0.62$; $p=0.02$); *Agistemus brasiliensis* with *P. latus* ($r=0.6$; $p=0.01$); *Metaseiulus eiko* El-Banhawy (Phytoseiidae) with *P. ulmi* ($r=0.68$; $p=0.01$); *Neoseiulus fallacis* Garman (Phytoseiidae) with *T. urticae* ($r=0.65$; $p=0.02$); *Agistemus riograndensis* with *T. californicus* ($r=0.6$; $p=0.02$).

In APG, the population peaks of *P. latus* (7.55 mites/plant) and *A. schlechtendali* (5.15 mites/plant) were observed in January. The largest population of *P. ulmi* was in April (0.28 mites/plant). Between December and June, there was a population increase of phytoseiid and stigmaeid mites. The populations of *M. eiko* ($r=0.67$; $p=0.01$) and *N. californicus* ($r= 0.96$; $p<0.0001$) had a correlation with *A. schlechtendali; M. eiko* ($r=0.85$; $p=0.0004$), *N. californicus* ($r=0.92$; $p<0.0001$) and *Agistemus floridanus* Gonzalez (Stigmaeidae) ($r=0.64$; $p= 0.02$) had a correlation with *P. latus*.

Conventional orchards. In MCF, *A. schlechtendali* had a population peak in December (3.85 mites/plant) and population increase of *N. californicus*, with a peak in March (1.65 mites/plant) (Figure 6). In April, the population of *N. californicus* decreased considerably and in May there was a peak of *P. ulmi* (5.68 mites/plant). *Pseudopronematulus* sp. had positive correlation with *N. californicus* ($r=0.84$; $p=0.0006$), *T. merus* ($r=1.0$; $p<0.0001$) and *Brevipalpus sp*. (Tenuipalpidae) ($r=1.0$; $p<0.0001$). *Neoseiulus californicus* had a correlation with *T. merus* ($r= 0.84$; $p=0.0006$) and *Brevipalpus* sp. ($r=0.84$; $p=0.0006$).

In MCG, the peak population of *A. schlechtendali* (16.40 mites/plant) was in December, followed by *N. californicus*, in January (2.13 mites/plant). *Panonychus ulmi* had a population peak in February (1.45 mites/plant). *Pseudopronematulus* sp. showed a positive correlation with *N. californicus* ($r=0.85$; $p=0.0004$) and *P. cannaensis* ($r=1.0$; $p<0.0001$) and these two species were also correlated with each other ($r=1.0$; $p<0.0001$). *Neoseiulus californicus* with *P. ulmi* ($r= 0.67$; $p=0.01$) and with *P. cannaensis* ($r= 0.85$; $p= 0.0004$).

Regenerative orchards. In SJF, the population peak of *P. ulmi* occurred in January (8.15 mites/leaf) and in March *N. californicus* (0.80 mites/leaf) and *T. merus* (0.30 mites/leaf) (Figure 7). *Aculus schlechtendali* was correlated with *N. californicus* ($r=0.94$; $p<0.0001$) and *Czenspinskia*

transversostriata Oudemans (Winterschmidtiidae) (r=0.90; p<0.0001). *Neoseiulus californicus* was correlated with *C. transversostriata* (r=0.91; p<0.0001) and *T. waitei* (r= 0.65; p= 0.01). *A. floridanus* with *P. ulmi* (r=0.99; p<0.0001).

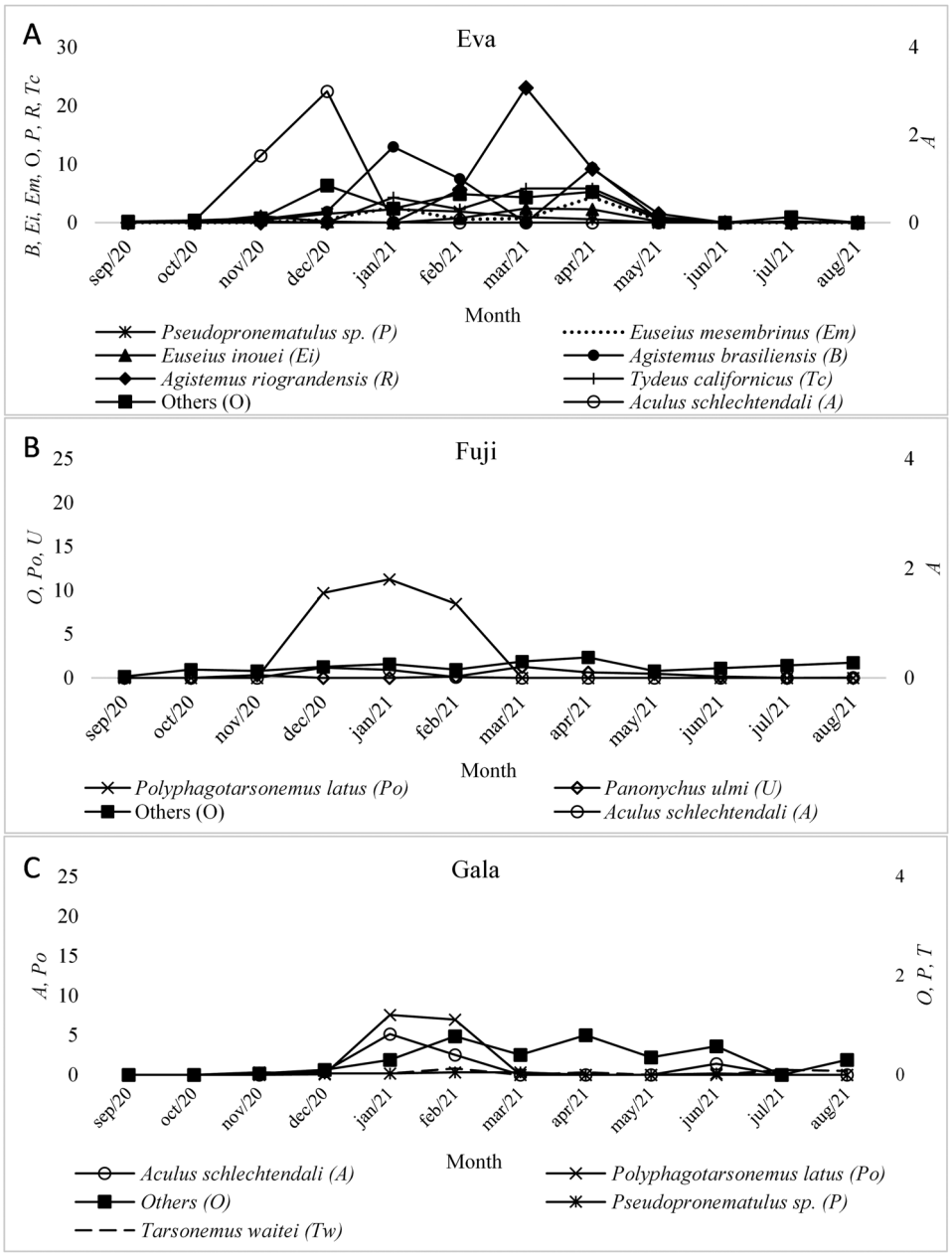

FIGURE 5. Population fluctuation of mites associated with orchards of apple trees of the cultivars Eva (A), Fuji (B) and Gala (C) in the municipality of Antônio Prado, state of Rio Grande do Sul, Brazil.

In SJG, *A. schlechtendali* (1.40 mites/plant) and *P. ulmi* (2.63 mites/plant) peaked in January. In March there was a peak of *T. merus* (0.43 mites/plant) and in May of *A. riograndensis* (0.58 mites/plant). *Neoseiulus californicus* was correlated with *A. brasiliensis* (r=0.80; p=0.001). *Agistemus*

floridanus correlated with *T. waitei* (r=0.76; p=0.003) and *A. riograndensis* with *C. transversostriata* (r=0.95; p<0.0001).

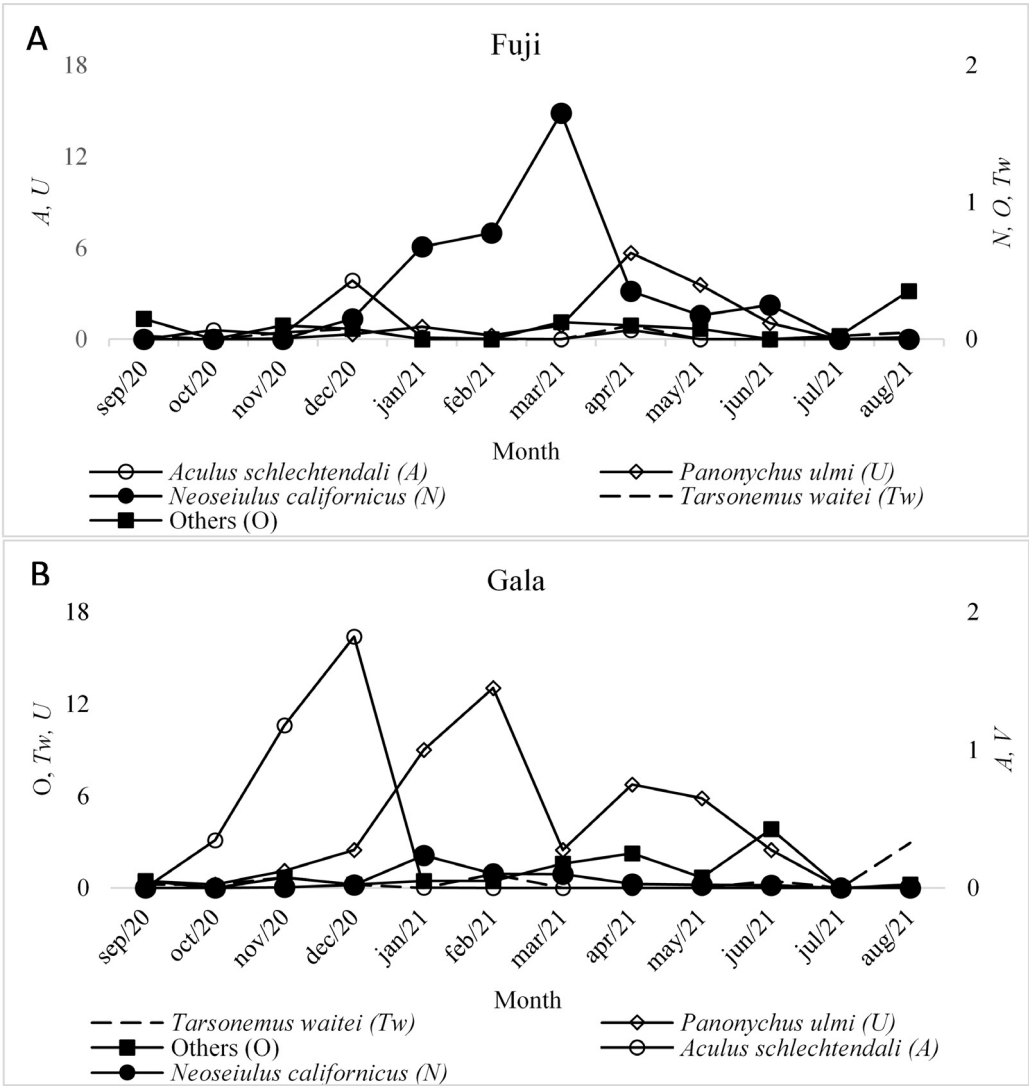

FIGURE 6. Population fluctuation of mites associated with orchards of apple trees of the cultivars Fuji (A) and Gala (B) in the municipality of Muitos Capões, state of Rio Grande do Sul, Brazil.

Discussion

Our study showed the population fluctuation of mites associated with apple orchards in southern Brazil. It was demonstrated that the management used in the orchards impacts on the abundance and diversity of the mites present. Cultivars and plant stratum also indicate to be an influential factor on the mite fauna in apple orchards. In addition, population peaks of predatory mites occurred after the peaks of phytophagous species, suggesting an ecological association between predators and prey.

The fact that *A. schlechtendali* was the main phytophagous mite collected and present in all orchards evaluated, which serves as a warning to researchers and producers, since it is a species of

Brazilian quarantine importance (Ferla *et al.* 2018; Nascimento *et al.* 2020) and already has high populations in different cultivars and producing regions of the country (Silva *et al.* 2022). It was considered an important pest in several countries (Duso *et al.* 2010), especially in nurseries and orchards, where it can be found feeding on flowers, fruits and leaves, affecting the physiological activity of plants, the quality and aesthetics of plants (Easterbrook & Palmer 1996; Walde *et al*. 1997; Spieser *et al.* 1998; Duso *et al.* 2010). To date, in Brazil, *A. schlechtendali* was not observed causing significant economic damage in apple orchards in the south of the country (Ferla *et al.* 2018; Nascimento *et al.* 2020; Silva *et al.* 2022). It is possible that the species is not causing significant damage to the crop in organic orchards due to the natural control carried out by natural enemies present (Maula & Khan 2015; Solomon *et al.* 2000). In conventional and regenerative orchards, this control may be occurring due to the use of pesticides or even the presence of *N. californicus*, which is the prevalent predator species, and which is already reported to be resistant to certain agrochemicals (Meyer *et al.* 2009). Although the control can be carried out with the use of acaricides, they are not selective, harming populations of natural enemies, and being able to select populations of resistant *A. schlechtendali* (Mota-Sanchez *et al.* 2023).

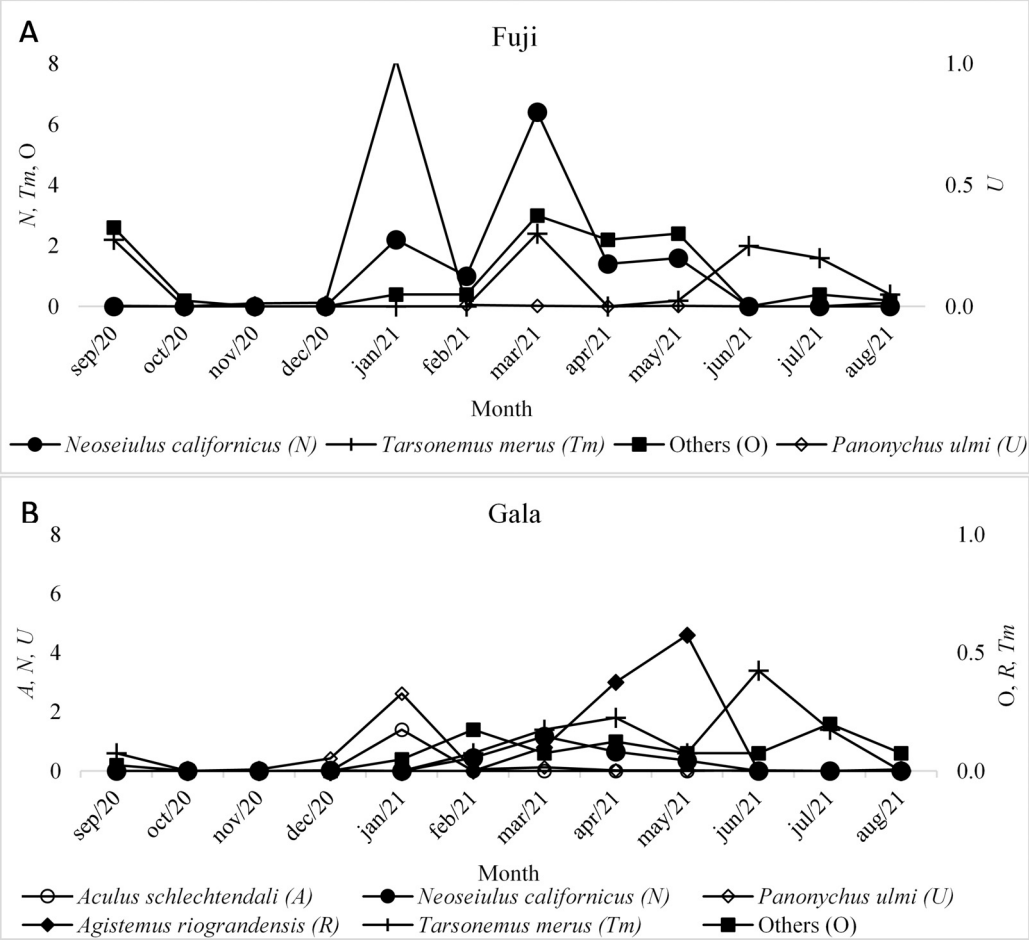

FIGURE 7. Population fluctuation of mites associated with orchards of apple trees of the cultivars Fuji (A) and Gala (B) in the municipality of São Joaquim, state of Santa Catarina, Brazil.

Eva is a new cultivar originating from the crossing of Anna and Gala (Hauagge & Tsuneta 1999). Therefore, our results indicate that Gala may be a susceptible cultivar for the establishment of *A. schlechtendali* populations. Thus, some characteristics of Gala transferred to Eva may have made it susceptible to infestations of this phytophagous mite. Other authors observed greater abundance of *A. schlechtendali* in Fuji, followed by Gala and Eva (Nascimento *et al.* 2020; Silva *et al.* 2022). The difference between those studies (Nascimento *et al.* 2020; Silva *et al.* 2022) and the present one may be related to the collection time, sampling frequency, number of orchards sampled and location. In addition, 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* in low populations. The population peak occurred from December to January, and in some orchards the mite had been present since October and in February there had already been a considerable decrease and in March it was already absent. In evaluations carried out in apple orchards with different cultivars, there was a significant difference in the establishment of natural enemies in the crop (Duso & Pasini 2003; Duso *et al.* 2003; Ahmad *et al.* 2013).

In this study *P. ulmi* was one of the main phytophagous mites present in the crop, similarly, to observed in previous studies carried out on apple trees (Lorenzato *et al.* 1986; Silva *et al.* 2022). This phytophagous mite, in addition to the apple tree, is one of the most frequent species on vines, in southern Brazil (Johann *et al.* 2009). It commonly occurs in both cultures, however, in recent years it has been highlighted for its presence on vines (Johann *et al.* 2009; Johann & Ferla 2012; Da Silva *et al.* 2020; Silva *et al.* 2020, 2021). *Panonychus ulmi* demonstrates to be adapted to both cultures and can be considered of economic importance for both (Ferla & Moraes 1998; Johann *et al.* 2009; Johann & Ferla 2012; Nascimento *et al.* 2020; Da Silva *et al.* 2020; Silva *et al.* 2020, 2021). Even though the two cultures are quite close, and with mite species in common, both the behavior and development of some mites such as *P. ulmi* differ (Navia *et al.* 1998; Johann *et al.* 2019). This may suggest that the species may adapt to host, or the existence of different biotypes in both cultures (Johann *et al.* 2019). The greater abundance of *P. ulmi* observed in conventional and regenerative orchards suggests that the use of pesticides may have affected the populations of natural enemies, since less richness of phytoseiids was observed in these orchards. In addition, high populations of *P. ulmi* in these orchards may be indicative of resistance to acaricides (Khajehali *et al.* 2021). This species is among the mites with the highest number of reports of resistance to pesticides (Mota-Sanchez *et al.* 2023). The results show the effect of acaricides on richness.

Tetranychus urticae was present in low populations in this study, but in other parts of the world, this mite was reported causing damage to apple trees, with the economic importance varying according to the region where the orchards are located (Helle & Sabelis 1985; Lorenzato 1987; Lorenzato 1988). In a recent survey carried out in orchards in the main producing regions of southern Brazil, this species was not present (Silva *et al.* 2022). Low populations in conventional orchards may have been due to the high populations of *N. californicus* controlling this phytophagous mite. This predatory mite is reported nearly always associated with tetranychids producing heavy webbing, showing adaptations for living in spider mite colonies with heavy webbing and with the ability to cut strands of webbing with the chelicerae (Shimoda *et al.* 2009; McMurtry *et al.* 2013). This is evident when compared with populations observed in organic orchards, where low populations of *N. californicus* were observed and there was not such an effective control of *T. urticae* populations.

Polyphagotarsonemus latus occurred with high populations in organic orchards, representing 10.9% of the total mites collected. Studies on the presence of *P. latus* in apple trees are rare and it is not considered to be of economic importance for the crop (Lorenzato 1987, 1988). However, in the Serra Gaúcha region, *P. latus* is considered a species of economic importance in vines, being one of the main phytophagous mites of the crop (Haji *et al.* 2001; Da Silva *et al.* 2020). Possibly,

populations of the species are migrating from vineyards to apple orchards because they are crops grown nearby (Pommer & Barbosa 2009), since there are common acarine species in both cultures, such as *P. ulmi* (Ferla & Moraes 1998; Johann *et al.* 2009; Johann & Ferla 2012; Nascimento *et al.* 2020; Silva *et al.* 2020; 2021; Da Silva *et al.* 2020).

In all orchards evaluated, the principal phytophagous mites *A. schlechtendali*, *P. latus* and *P. ulmi*, had population peaks in the months of high temperatures. In countries where *A. schlechtendali* is considered a pest, the population peak of the species also occurs in the summer period (Simoni *et al.* 2018). *Panonychus ulmi* occurs between November and April, reaching its population peak between the end of January and the beginning of March (Lorenzato *et al.* 1986; 1987).

The main species of predatory mites found in this study associated with populations of phytophagous mites belonged to the families Phytoseiidae and Stigmaeidae, standing out *Neoseiulus californicus*, *A. riograndensis* and *A. brasiliensis*. These results agree with Ferla & Moraes (2002) and Lorenzato *et al.* (1986), who highlighted the Stigmaeidae as the second important group of predators, after the Phytoseiidae. However, for Ferla and Moraes (1998), the most common predatory species were *Euseius* spp. and *N. tunus*, and for Lorenzato *et al.* (1987), *A. chiapensis, N. tunus* and *Amblyseius* sp. Possibly the predatory species currently present in conventional and regenerative orchards are resistant to the use of pesticides, as in the case of *N. californicus*, which was present in high populations in this study (Meyer *et al.* 2009). Phytoseiidae and Stigmaeidae are important enemies used in biological control of phytophagous mites in agroecosystems (Duso & de Lillo, 1996; Tixier, 2018), with phytoseiids being essential in the control of Eriophyidae and Tetranychidae in apple orchards in Europe (Solomon *et al.* 2000). The fact that in all orchards evaluated the populations of predatory species followed those of phytophagous mites, more specifically *A. schlechtendali* and *P. ulmi*, indicate an association between them. For Lorenzato (1987), the highest population levels of *N. californicus* occurred soon after the emergence of *P. ulmi* populations in the culture. Thus, the presence of high populations of Stigmaeidae and the greater diversity of Phytoseiidae found in organic orchards may be related, in addition to the arrival of *A. schlechtendali* in Brazilian management methods. Thus, the management strategy of organic agriculture helps to preserve higher biodiversity and maintain natural enemies. Therefore, the populations of Stigmaeidae and Phytoseiidae coinciding with the arrival of phytophagous to the orchards, the highest populations also occur during the months with high temperatures. In general, this work shows that populations of phytoseiids are abundant until February, when they are replaced by stigmeids. In organic orchards, the highest populations occurred between January and May and in conventional and regenerative orchards the Stigmaeidae had their population peaks between March and June, a period in which phytoseiids were already reducing in the orchards. In a study carried out by Ferla and Moraes (1998), phytoseiids were present in high populations from early December to March. In addition, the highest population peaks of Stigmaeidae occurred from late February to mid-May, after the phytoseiids decline, like what was observed in this study. Thus, the richness of predators naturally established in the orchards would be related to the abundance and diversity of phytophagous mites present, being directly related to the environmental balance (Kazmierczak & Lewandowski 2006; Mailloux *et al.* 2010). Furthermore, the establishment of natural enemies can be favored by management, with species being negatively affected by the presence of pesticides in orchards (Ahmad *et al.* 2013). Several factors can affect the success of predatory mites as biological control agents in different crops, including the application of pesticides, climatic conditions, food availability, cultivar characteristics and intraguild competition (Zhang & Croft 1995; Solomon *et al.* 2000; Bonafos *et al.* 2007; Duso *et al.* 2012)

This study made it possible to better understand the distribution and population fluctuation of *A. schlechtendali* in apples, providing important information that can support future studies of ecology in this important production chain. The results of this study suggest lower diversity of predatory

mites in conventional and regenerative orchards when compared to organic orchards. The importance of management for predatory mite populations in apple trees in southern Brazil is observed, as predatory mites were associated with the main phytophagous mites, indicating a predator-prey relationship between the species. Environmental factors such as temperature increase may have affected the plant and consequently the population fluctuation of mites. In the months of higher temperatures, there was an increase in mite populations, mainly *A. schlechtendali*. Even though *P. ulmi* was present during the whole period mainly in conventional and regenerative orchards, during the months of high temperature its populations increased.

Final considerations

Organically managed apple orchards in southern Brazil harbor a high diversity of mites compared to conventional and regenerative orchards. The phytophagous mites *A. schlechtendali*, *P. latus* and *P. ulmi* were the most common, while *N. californicus*, *A. brasiliensis* and *A. riograndensis* were the most important predatory mites in this chain. The results suggest that the mite populations are influenced by the cultivar used, abiotic factors, and mainly by the management used in the production. Additional studies are suggested to monitor *A. schlechtendaliand*, its damage and evaluate *N. californicus, A. brasiliensis and A. riograndensis* as control agents for phytophagous mites in the apple crop chain.

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CAPITULO 4

Rode, P.A., Bizarro, G.L., Rodighero, L.F., Ferla, N.J. Mite community response to different apple orchards. Artigo submetido no periódico “International Journal of Tropical Insect Science”. (Situação: Em revisão).

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Mite community response to different apple orchards

--Manuscript Draft--

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Abstract:	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 acarina 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 acarine 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.
Corresponding Author:	Priscila de Andrade Rode Universidade do Vale do Taquari BRAZIL
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universidade do Vale do Taquari
Corresponding Author's Secondary Institution:	
First Author:	Priscila de Andrade Rode
First Author Secondary Information:	
Order of Authors:	Priscila de Andrade Rode
	Gabriel Lima Bizarro
	Luana Fabrina Rodighero
	Noeli Juarez Ferla
Order of Authors Secondary Information:	
Author Comments:	January, 2024 Dear Editor, International Journal of Tropical Insect Science, We are submitting the manuscript entitled “Mite community response to different apple orchards” to be analyzed by referees and published in your important journal. The manuscript has 19 pages (61 kB), five figures and three tables. The study evaluated the response of the mite community to cultivars, plant stratum and the management of apple orchards. The results obtained demonstrate that the cultivars influenced the acarina community, the apical stratum had the highest acarine abundance, and that the 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. The authors inform:

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Mite community response to different apple orchards

Priscila de Andrade Rode[1,2*], https://orcid.org/0000-0001-9172-8483
Gabriel Lima Bizarro[1], https://orcid.org/0000-0001-6142-872X
Luana Fabrina Rodighero[1]
Noeli Juarez Ferla[1, 2, 3], https://orcid.org/0000-0003-0771-6864
[1]*Laboratório de Acarologia, Tecnovates, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.*
[2]*Programa de Pós-Graduação em Biotecnologia, Universidade do Vale do Taquari -Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.*
[3]*CNPq researcher*.
[*]Corresponding author: pdrode@universo.univates.br

Abstract. 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 acarina 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 acarine 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*.

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INTRODUCTION

Brazil is among the largest apple producers (*Malus domestica* Borkh: Rosaceae) 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 three southern states 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). Already the regenerative agriculture is considered an alternative to conventional agriculture, as it has the characteristic of improving soil protection, not using machinery and maintaining soil cover by plants, spontaneous or not (The soil association 2021), however, if it is necessary, this system allows the use of pesticides to control pests.

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

Probably, resistant individuals of *P. ulmi* and *T. urticae* might be selected by over use of pesticides (Mota-Sanchez and Wise 2023). *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). *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). 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).

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). 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* is the most common species (Moraes et al. 2004) and has a high survival rate when exposed to agrochemicals used in pest management (Albayrak et al. 2022). *Amblyseius chiapensis* DeLeon, *Euseius mesembrinus* (Dean), *Galendromus annectens* (De Leon), *Metaseiulus mexicanus* (Muma), *N. fallacis*, *Typhlodromalus marmoreus* El-Banhawy, *Typhlodromalus peregrinus* (Muma), *Metaseiulus camelliae* (Chant & Yoshida-Shaul), *Neoseiulus neotunus* (De Leon), *Neoseiulus tunus* (De Leon) and *P. macropilis* (Lorenzato et al. 1986; Lorenzato and Secchi 1993; Ferla and Moraes 1998).

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. Understanding the ecological pattern of the mite community, mainly of *A. schlechtendali* in the country's largest production region, helps in monitoring and planning future crop management actions, as well as in understanding the pattern of distribution and dispersion of these mites in the plant, in the cultivars and at production sites. 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 (Figure 1).

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 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. Despite the care taken to protect the soil in these areas, whenever necessary, producers spray pesticides to control pests. We consider the areas of this locality as being conventional with regenerative agriculture.

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; Amrine and Stasny 1994; Amrine et al. 2003; Fan and Zhang 2005; Chant and McMurtry 2007; 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. 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

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) (Figure 2A). 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 (5.38±1.30) (Figure 2B). 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; Figure 2A), 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.

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 (Figure S1). The panel suggests that *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae)

had greater relative abundance in the conventional system, while the other predators, especially *Agistemus brasiliensis* Matioli, Ueckermann & Oliveira (Stigmaeidae), *Agistemus riograndensis* Johann & Ferla (Stigmaeidae), *Euseius inouei* Ehara & 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 & 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 (Figure 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 (Figure 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*) (Figure 3). 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 having homogeneous

variances between them (Permutest, F(1,19) = 2.69, P-value = 0.12) (Figure 4A). 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) (Figure 4B). 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) (Figure 4C).

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 (Figure 5). 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 Figure 3, 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 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), 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* and, in high populations, remaining as the most representative species, 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 significant 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* (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 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 acarine 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 acarine 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 hours (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. In contrast, 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 acarine 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 acarines, 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 acarine 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.

The different apple cultivars evaluated showed influence in the acarine community, as Eva presented greater richness in relation to the others, and Fuji and Gala had a greater number of overlapping taxa in the orchards. Eva and Gala showed greater abundance of the main phytophage found, *A. schlechtendali*, demonstrating that possibly these cultivars are more susceptible to the presence of the species. Further studies are suggested on the preference of *A. schlechtendali* for the Eva cultivar and its potential to cause injuries in different apple cultivars. Finally, apical leaves showed a higher abundance of mites, mainly populations of *A. schlechtendali*. Greater attention should be given to this region of the plant in order to carry out a management plan for phytophagous mites in these orchards.

AUTHOR'S CONTRIBUTION

PAR, GLB and LFR with the sample collections, sample sorting on plants and slide mounting; GLB with morphological analysis; PAR with the data analysis and the concept of the manuscript; NJF with major revisions.

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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.

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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

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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			**Apple cultivars**			
(62%)			Eva-Fuji (65%)			
Conventional	**Organic**	**Mite species**	**Eva**	**Fuji**	**Gala**	**Mite species**
1180	41	*Panonychus ulmi* [0.14]	1	869	N/A	*Panonychus ulmi* [0.17]
0	770	*Polyphagotarsonemus latus* [0.26]	1370	318	N/A	*Aculus schlechtendali* [0.30]
1497	1835	*Aculus schlechtendali* [0.37]	5	228	N/A	*Neoseiulus californicus* [0.37]
522	21	*Neoseiulus californicus* [0.46]	177	20	N/A	*Agistemus brasiliensis* [0.43]
75	244	*Agistemus riograndensis* [0.51]	209	27	N/A	*Agistemus riograndensis* [0.49]
36	199	*Agistemus brasiliensis* [0.56]	105	8	N/A	*Tydeus californicus* [0.55]
4	119	*Tydeus californicus* [0.60]	49	2	N/A	*Euseius mesembrinus* [0.59]
106	38	*Tarsonemus (T.) merus* [0.65]	0	188	N/A	*Polyphagotarsonemus latus* [0.63]
0	35	*Metaseiulus eiko* [0.68]	37	1	N/A	*Euseius inouei* [0.67]
2	53	*Pseudopronematulus sp* [0.71]	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]

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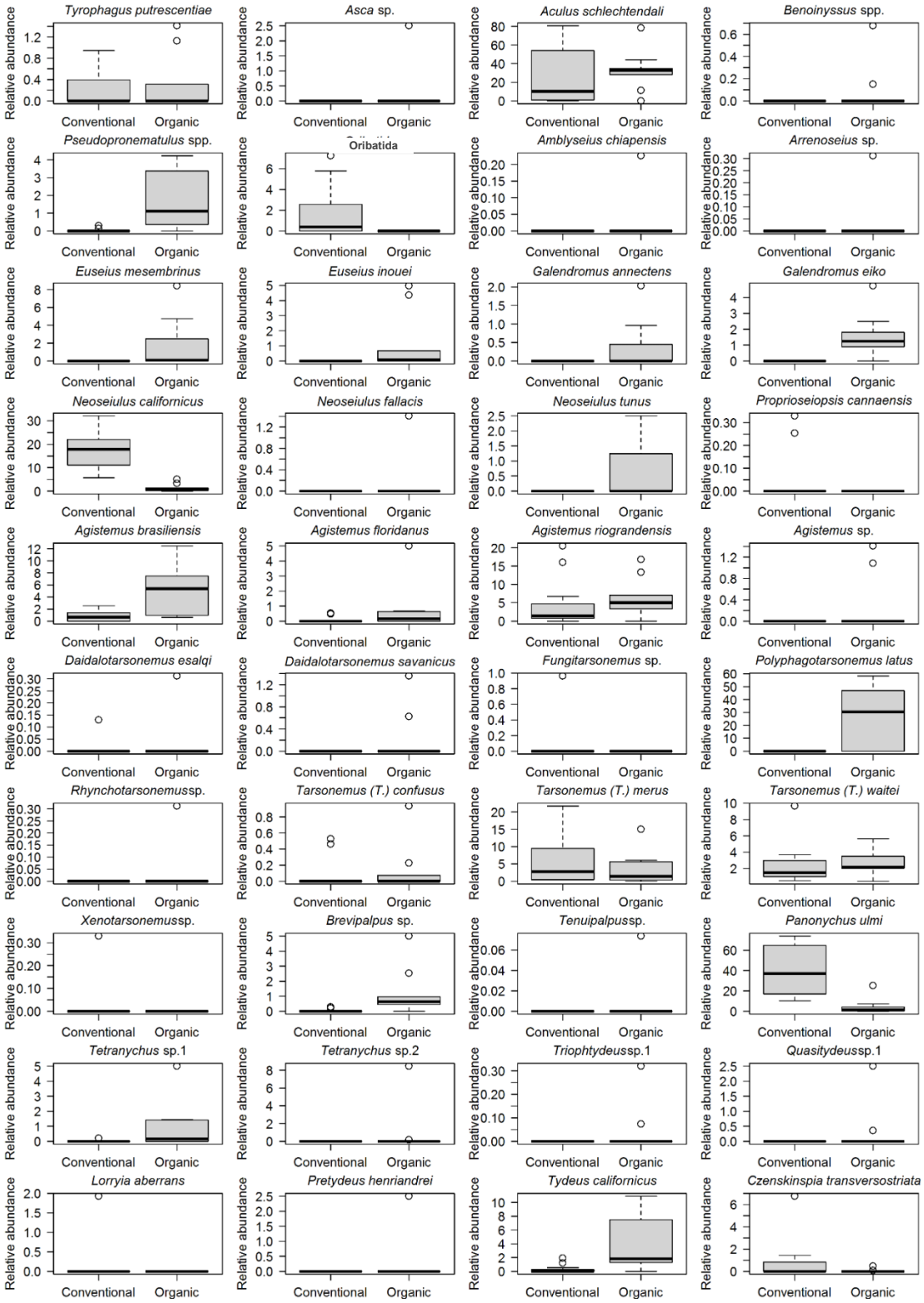

Figure S1. Paired analysis of the combination of conventional and organic apple growing systems for the main species present in apple orchards.

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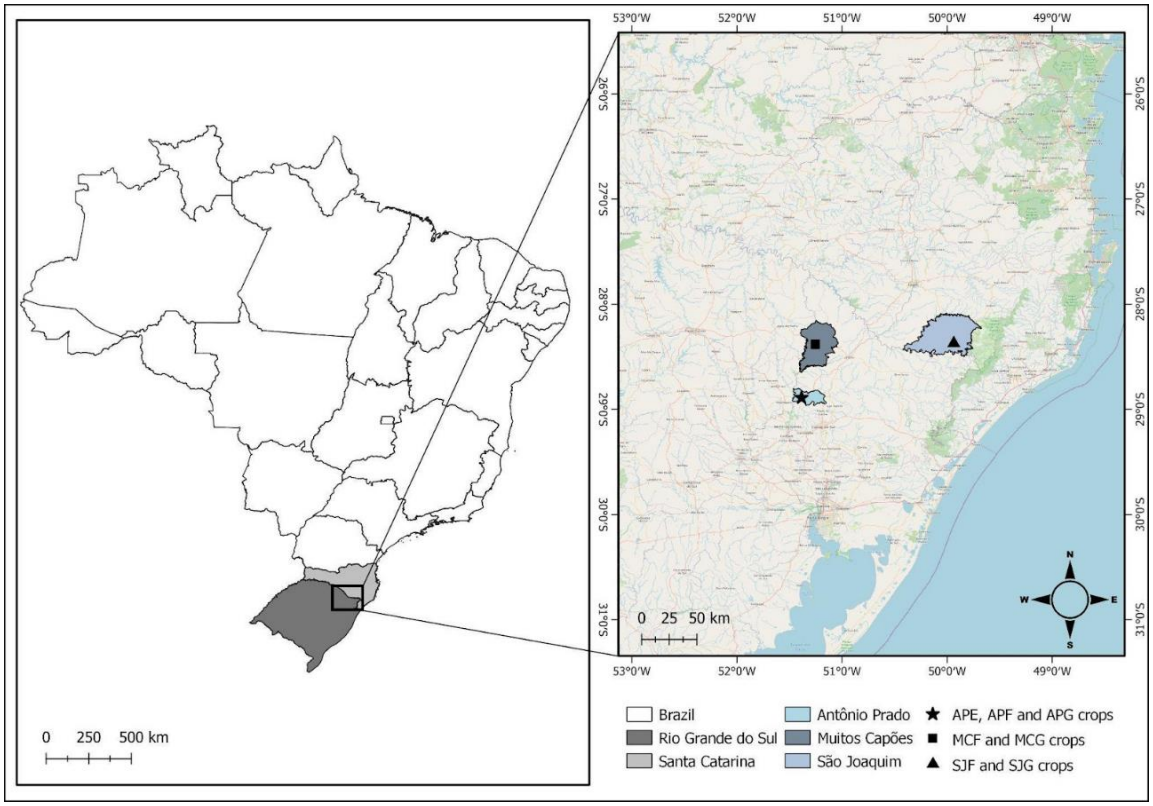

Figure 1. Collection points in the apple-producing regions in the municipalities of Antônio Prado and Muitos Capões, state of Rio Grande do Sul, and São Joaquim, state of Santa Catarina, Brazil.

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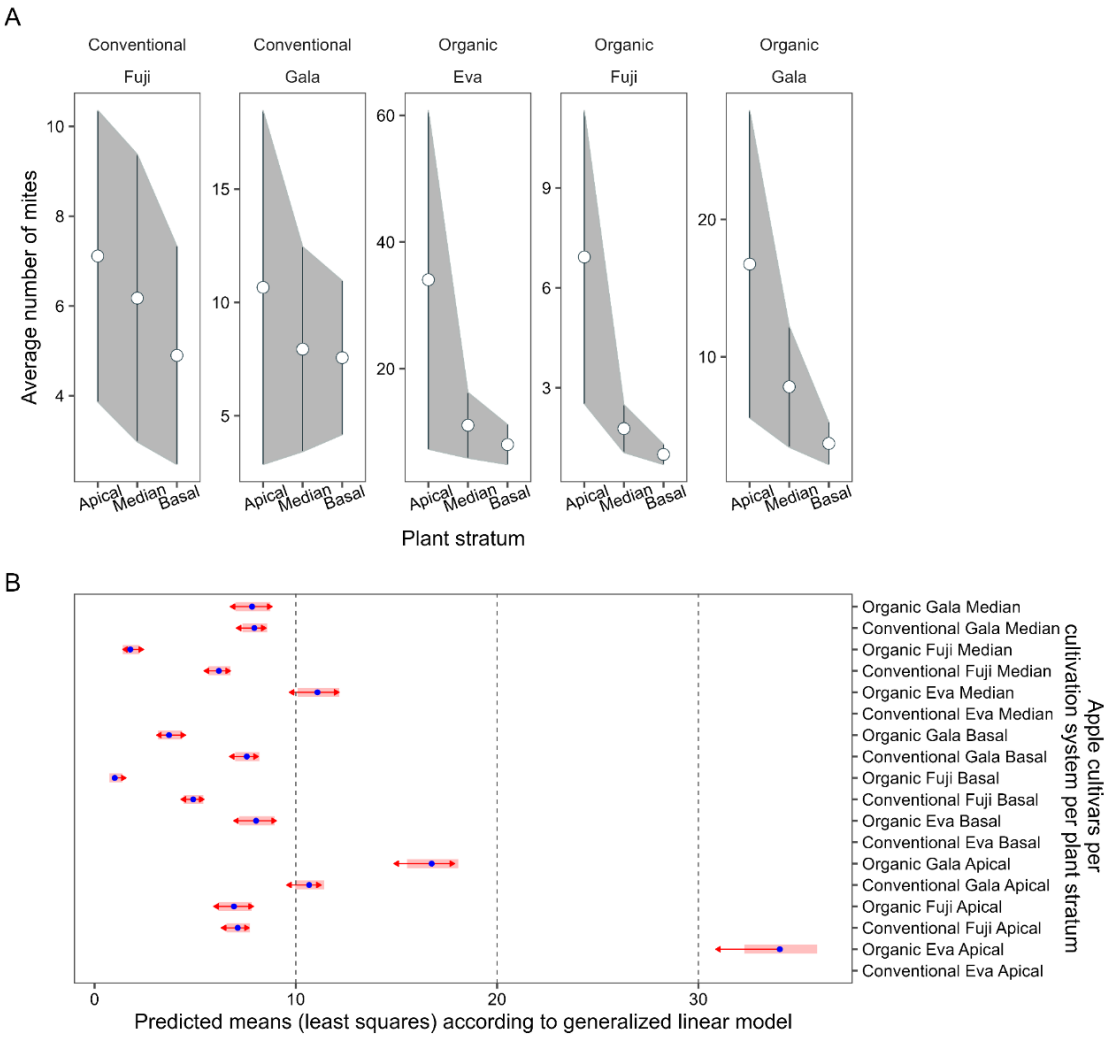

Figure 2. (A) Mean quantity (points) and standard error (vertical bars) of mites in different cropping systems per apple cultivar per plant layer. The scale on the y-axis was adjusted according to the values of each variable. The grayish shadow connecting the vertical bars has been added to make the 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).

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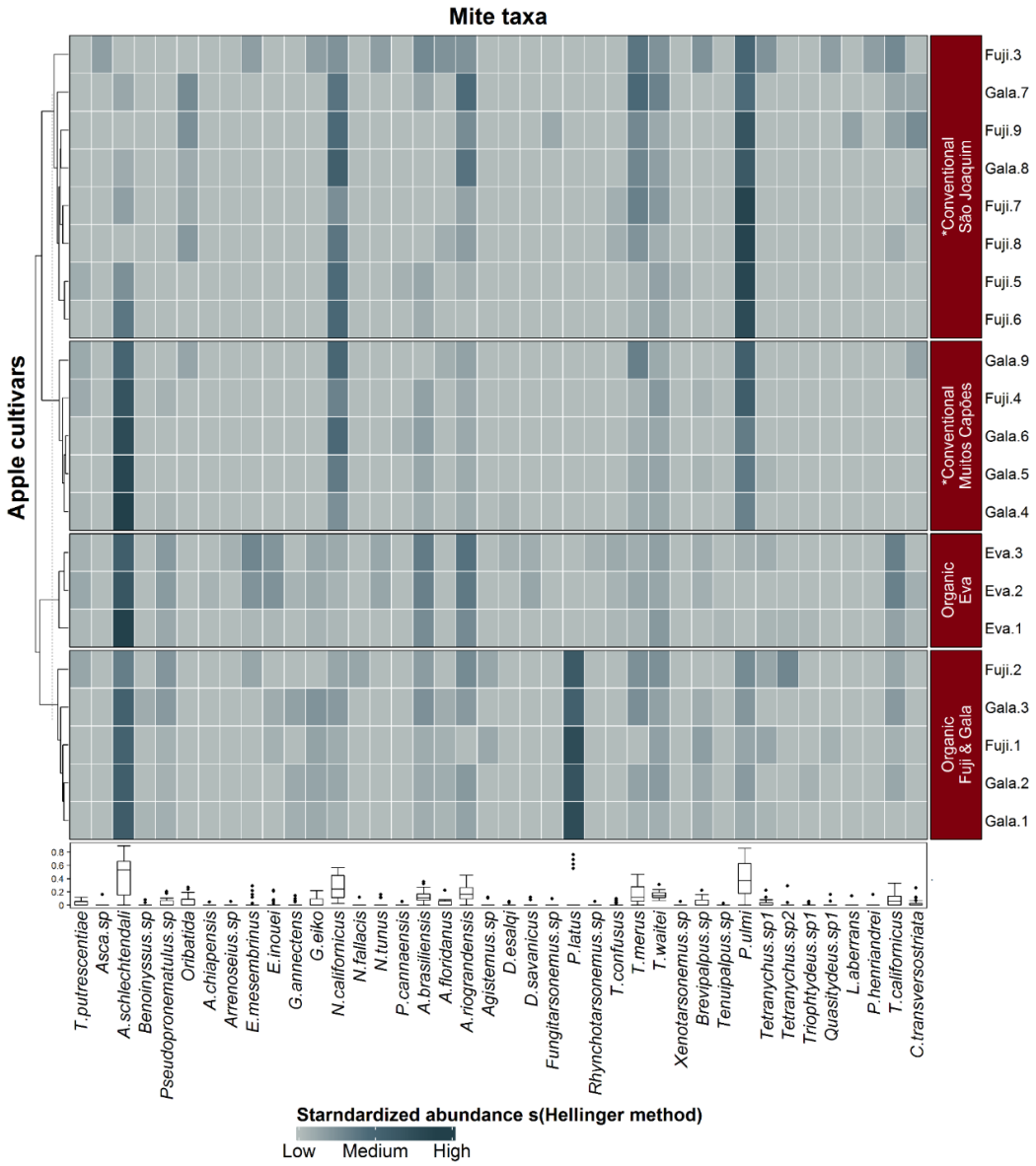

Figure

Figure 3. 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.

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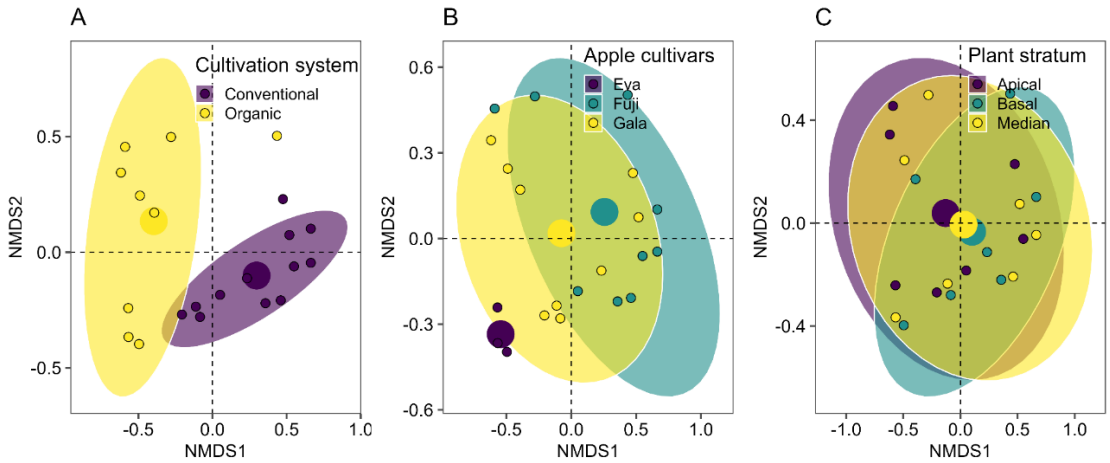

Figure 4. Non-metric multidimensional scaling (NMDS, stress = 0.09) showing mite community composition in three different contexts: (A) two cropping systems (organic, conventional), (B) three apple cultivars (Eva, Fuji, Gala), (C) three plant stratum (apical, median, basal). Shaded ellipses surround each group at a 95% confidence level.

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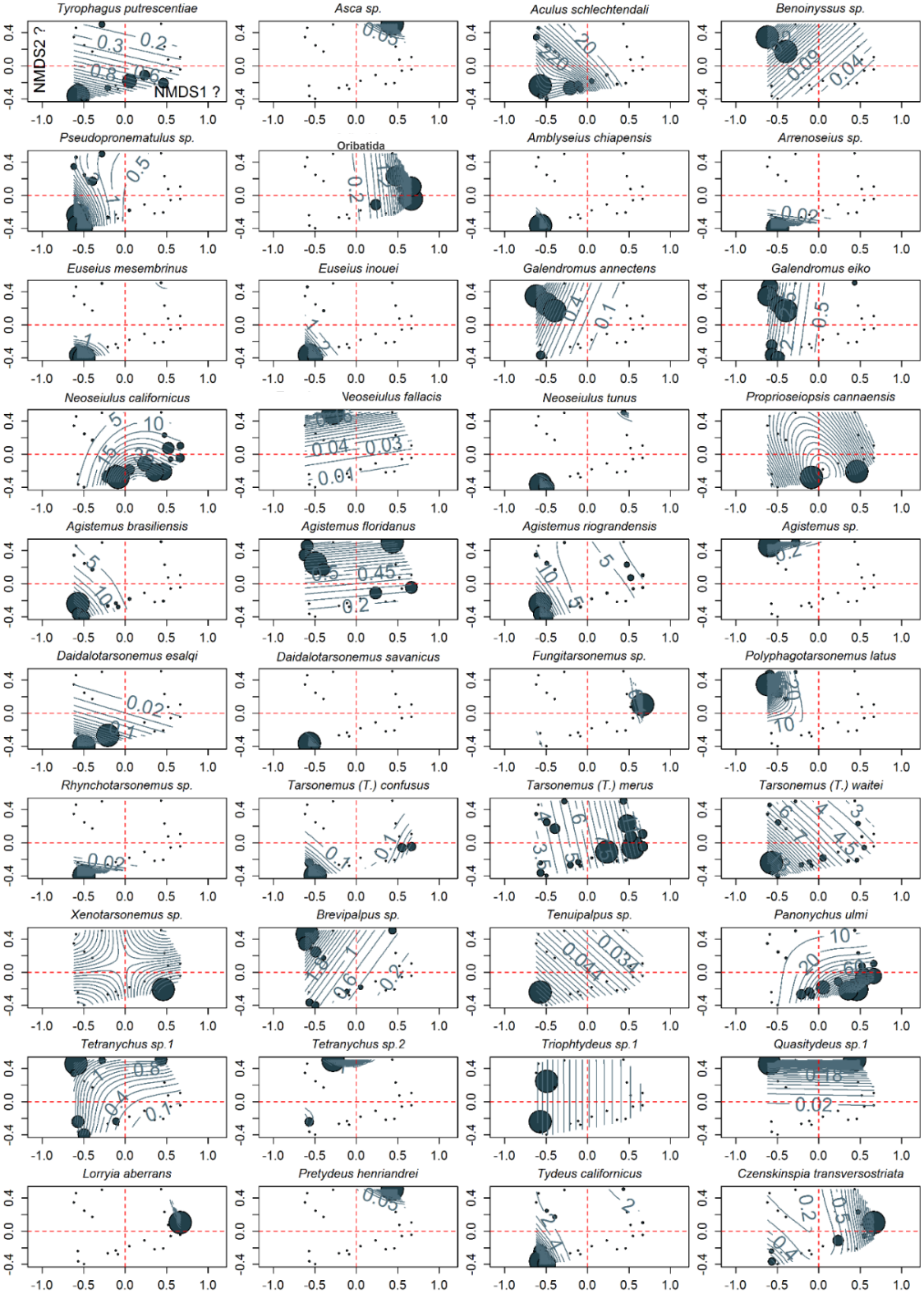

Figure 5. Non-parametric multidimensional (NMDS) sizing of the mite community. The points (*scatter plots*) were plotted as *bubble points*, that is, the standardized abundance (Hellinger's method) of mites was added to the function so that the size of the points indicates the proportional number of individuals sampled according to each of the three conditions of possible interpretations (Figure 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.

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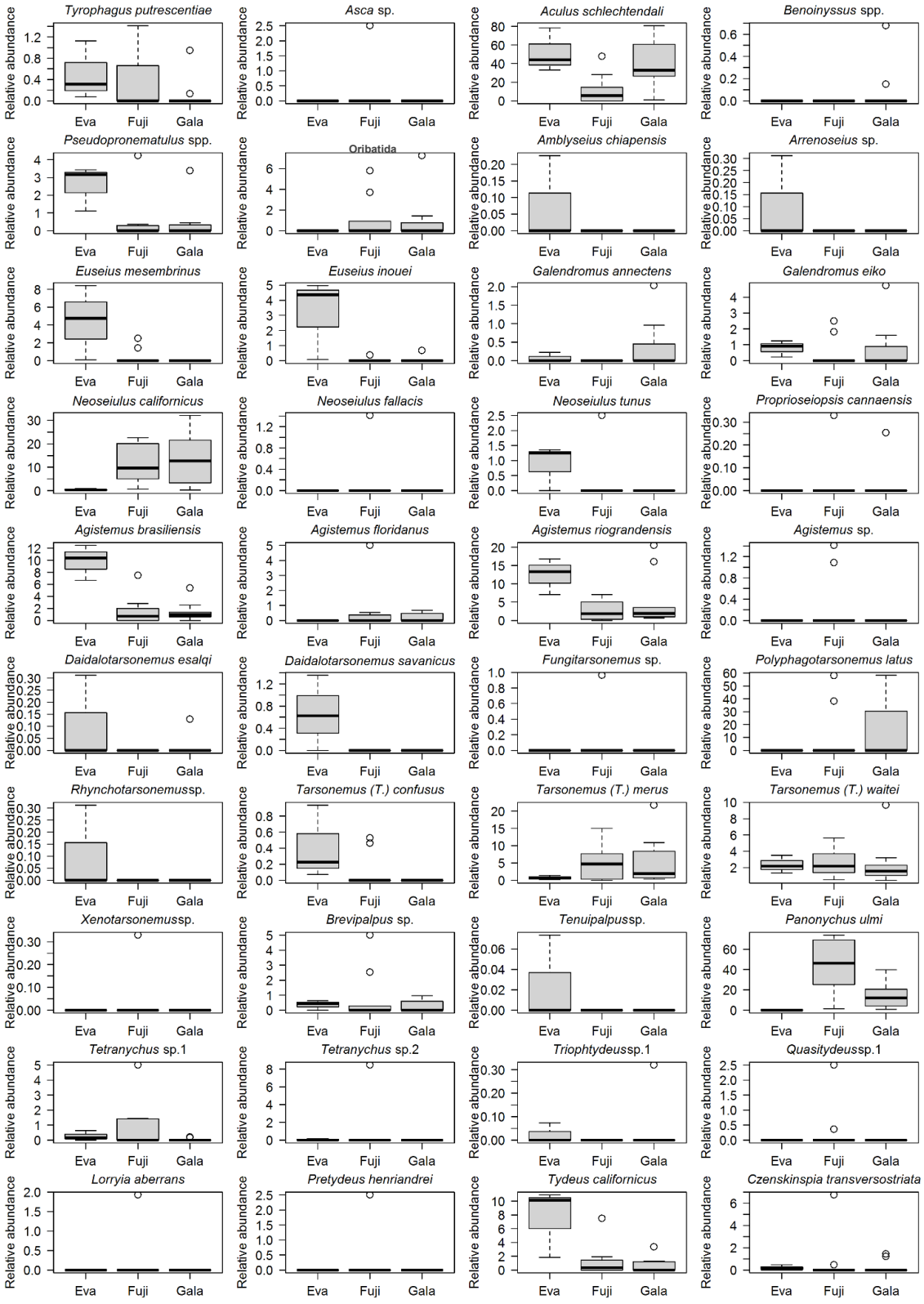

Figure S2. Paired analysis of the combination of Eva, Fuji and Gala apple cultivars for the main species present in apple orchards.

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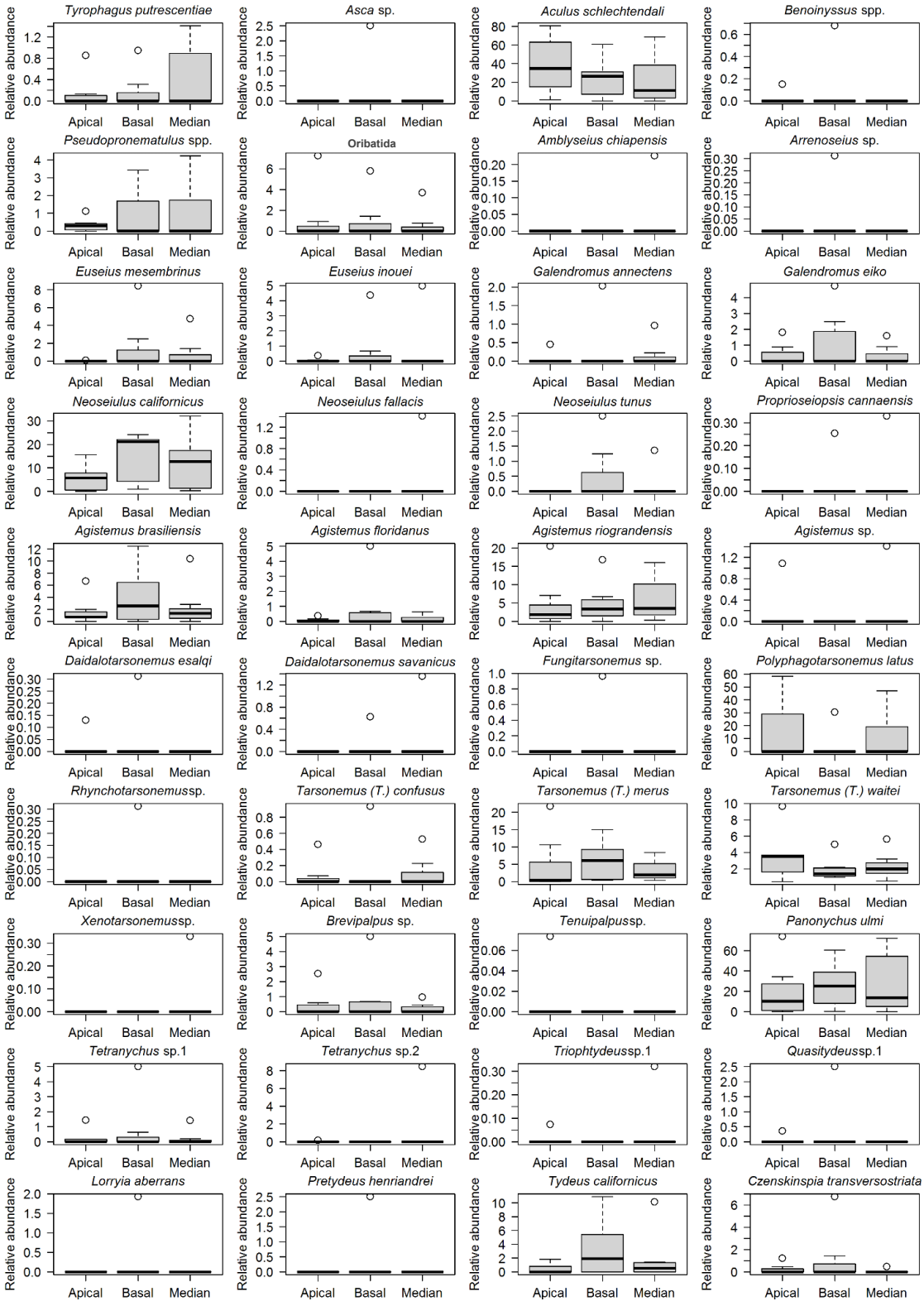

Figure S3. Paired analysis of the combination of apical, median and basal strata for the main species present in apple orchards.

CAPITULO 5

Rode, P.A., Schussler, M., Bizarro, G.L., Ferla, N.J. How do different agricultural managements interfere with the Phytoseiidae mite (Acari: Phytoseiidae) community in apple trees? Artigo submetido no periódico “Acarologia”. (Situação: Publicado).

Acarologia
Open Science in Acarology

How do different agricultural managements interfere with the Phytoseiidae mite (Acari: Phytoseiidae) community in apple trees?

Priscila de Andrade Rode[a,b], Matheus Schussler[a], Gabriel Lima Bizarro[a], Noeli Juarez Ferla[a,b,c]

[a] Laboratório de Acarologia, Tecnovates, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.
[b] Programa de Pós-Graduação em Biotecnologia, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.
[c] CNPq researcher

Original research

ABSTRACT

In this study we performed the sampling of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites. Collections were carried out in apple orchards in three different production areas: 1- organic agriculture (Antônio Prado, RS); 2- conventional agriculture (Muitos Capões, RS); 3- regenerative agriculture (São Joaquim, SC). In total, seven orchards were evaluated, in Muitos Capões and São Joaquim, two orchards of the Fuji and Gala, whereas in Antônio Prado, three cultivars (Eva, Fuji and Gala) were considered. In each orchard, 40 plants were evaluated, and from each plant a median branch was randomly chosen from which a leaf was removed from the apical, median and basal thirds. The collected leaves were taken to the laboratory, they were observed and the mites found mounted in Hoyer's medium and identified. A total of 695 phytoseiid specimens were collected. Greater abundance was noted in the apical stratum of plants of the Gala cultivar, demonstrating the effect of cultivar and stratum on phytoseiid richness, abundance and distribution. *Neoseiulus californicus* (McGregor) (Phytoseiidae) was the main species in areas of conventional and regenerative cultivation, being present in all evaluated orchards, but with low occurrence in areas of organic management. In organic orchards, species of the genus *Euseius* [*Euseius mesembrinus* (Dean) and *Euseius inouei* (Ehara & Moraes)] (Phytoseiidae) were more abundant. The results suggest that producers consider less intensive use of pesticides and herbicides in orchards in order to maintain populations of predatory mites due to their potential for biological control.

Keywords *Euseius inouei*; *Euseius mesembrinus*; *Malus domestica*; *Neoseiulus californicus*; predatory mite

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Corresponding author
Priscila de Andrade Rode:
pdrode@universo.univates.br

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Introduction

Conventional agriculture is applied in several crops due to being highly productive, but it has substantial negative externalities, including loss of biodiversity, soil erosion, environmental pollution and risk to human health (Gomiero *et al.* 2011; Campbell *et al.* 2017). There is thus 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 resource conservation (Willer *et al.* 2021). As an alternative to conventional management, the organic agriculture production has been developed in several countries (Gomiero *et al.* 2011; Smith *et al.* 2012; Caprio *et al.* 2015; Gomiero 2018; Sumberg and Giller 2022). Another alternative is regenerative agriculture: it aims at improving soil protection, not using machinery and maintaining soil covered by plants, spontaneous or not, but, if it is necessary, pesticides can be used to control pests (The soil association 2021).

Pesticide spraying modifies the environment, directly or indirectly affecting the interactions between species along the trophic and non-trophic chain (Dalkvist *et al.* 2009; Guedes *et al.* 2016; Zhao *et al.* 2020). Direct effects include mortality and various sublethal effects, while indirect effects include habitat changes, through contamination of food and shelter, and modification in species communities with associated interaction (Sánchez-Bayo 2021). Disruption of natural control is a key factor in pest outbreaks, where pesticides can reduce populations of predators, parasitoids and pathogenic organisms that naturally occur (Geiger *et al.* 2010; Janssen and Rijn 2021). Furthermore, the relationship between biodiversity and pest control is of great interest for sustainable agricultural production (Letourneau *et al.* 2011; Veres *et al.* 2013; Crowder and Jabbour 2014; Liere *et al.* 2017; Möth *et al.* 2021).

The conventional system prevails in apple production areas (*Malus domestica* Borkh: Rosaceae) in Brazil (Lorenzato and Secchi 1993; Monteiro 1994; Hardmann *et al.* 2003). However, more and more producers are interested in implementing a farming system less dependent on pesticides, especially in the state of Rio Grande do Sul (Kist *et al.* 2015). The Gala and Fuji cultivars are the most used and account for approximately 90% of the national production, while the Eva cultivar, associated with other recent ones, account for about 5% of the production (Fioravanço *et al.* 2010).

Phytophagous mites of the Eriophyidae and Tetranychidae families are considered as important apple pests (Ferla *et al.* 2018; Nascimento *et al.* 2020), particularly *Panonychus ulmi* (Koch) (Tetranychidae), *Tetranychus urticae* Koch (Tetranychidae) and *Aculus schlechtendali* (Nalepa) (Eriophyidae) (Nascimento *et al.* 2020; Kasap and Atlihan 2021). Recently, the quarantine species *A. schlechtendali* was recorded in Southern Brazil (Ferla *et al.* 2018; Nascimento *et al.* 2020). Phytoseiid mites are effective predators of phytophagous mites (McMurtry *et al.* 2013; Demite *et al.* 2014; Knapp *et al.* 2018). In apple growing areas in South America, *Neoseiulus californicus* (McGregor) is the most common species (Croft and McGroarty 1977; Monetti and Fernandez 1996; Khajuria 2009; Toyoshima *et al.* 2011). However, the effect of landscape management on the diversity and distribution of these predatory mites in apple production areas in southern Brazil is unknown.

The knowledge of abundance and diversity of natural enemies in apple plantations is expected to better understand their distribution and dispersion pattern, for the implementation of future pest management actions. We thus performed surveys of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites.

Material and methods

Study areas

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 (Figure 1).

Antônio Prado: In this locality, three cultivars were considered (Eva, Fuji and Gala). The surface of Eva's orchard was 2 hectares, and that of Fuji and Gala, 1 hectare/area. In all areas, the plantation density was 4 x 1.80 m (rows x trees). Soil was covered, with spontaneous plants

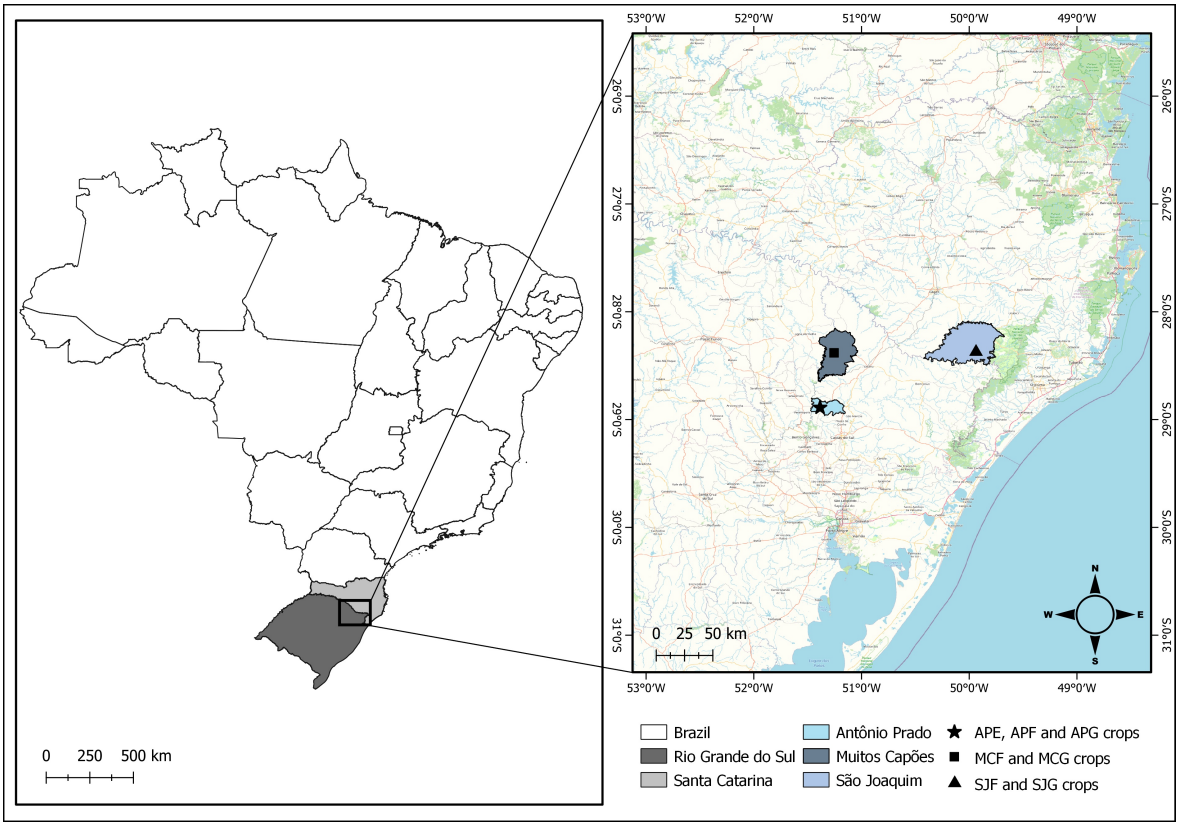

Figure 1 Collection points in apple-producing regions in the municipalities of Antônio Prado (organic management) and Muitos Capões (conventional management), Rio Grande do Sul, and São Joaquim (regenerative management), Santa Catarina, Brazil. Authorship: Castro, I. S.

and grasses, in association with soil litter. In these orchards, the spontaneously growing plants were maintained and when necessary, some were removed weeding. There was no spraying of synthetic pesticides, such as insecticides/acaricides and herbicides, in the sampled areas. However, the producers used Copper sulfate and lime (0,3%) mixed with Bordeaux mixture (0,5%) after the vegetative period, every 15 days, neem oil in the same period every 30 days for pest control, lime sulfur (8%) once in winter and Cera Trap® attractive trap for capturing fruit flies from thinning to harvest. In this way, the orchards of this locality were conducted under organic management.

São Joaquim: Two orchards were evaluated, one planted with the Fuji cultivar and the other planted with the Gala cultivar. The area was 5.5 hectares for each orchard, and the density plantation was 7 x 3 m (rows x trees). In both orchards, the soil was kept covered by weeds, grasses and weeds, in association with soil litter. Pigs, sheeps and chickens were kept grazing throughout the area, feeding on the weeds and fruit of the apple trees that fell. Whenever necessary, producers sprayed pesticides (Bordeaux mixture, Fenitrothion emulsifiable concentrate, Dodina concentrated suspension and Indoxacarb + Fipronil) to pest control. In this way, the orchards of this locality were conducted under regenerative agriculture.

Muitos Capões: Collections were carried out in two conventional orchards, one planted with Fuji and the other with Gala cultivars. The total area of the orchards was 240 hectares each, with a plantation density of 4.2 x 1 m (rows x trees). In both orchards, weeds were destroyed using herbicides (Glifosato, Cletodim concentrated suspension and saflufenacil) and weeding, and spraying of pesticides (Fosmete formulation, Dimetoato emulsifiable concentrate, Fenitrothion emulsifiable concentrate and Clorpirifós emulsifiable concentrate) to control pests was carried out frequently.

Sampling

In all the orchards, the evaluated trees were identified with ribbons. From the fifth row, counting from the edge, we selected 40 trees/orchard, and from each one, a median branch was collected from which three leaves were detached, one from each stratum of the plant: basal, median and apical. Collections were carried out monthly, totaling 120 leaves/orchard/month. In winter, when apple trees lose their leaves, buds from a median branch of each stratum were evaluated, totalizing 120 buds/orchard/month and 40 for each stratum/orchard/month. The leaves or buds were individualized in plastic bags, and then packed in styrofoam boxes containing artificial ice (Gelo-x®) to keep them at a low temperature.

Climatological information on temperature (°C), relative humidity (%) and precipitation (mm) were obtained from meteorological stations close to the collection points, namely: Antônio Prado, information from the INMET meteorological station, municipality of Bento Gonçalves (A840); Muitos Capões, data from the INMET meteorological station, Vacaria (A880); São Joaquim, information from the Automatic Meteorological Station of Morro da Igreja (A845) (EMAMI).

Mite identification

The collected material was examined with the aid of a stereoscopic microscope (40×) and a fine-tipped brush. Mites removed from each leaf were mounted on slides with Hoyer's medium (Jeppson *et al.* 1975). After mounting, the slides were kept in ovens at 50-60 °C for an average period of 7 days. Identification was performed at the Acarology Laboratory of University of Vale do Taquari - Univates, Lajeado municipality. The Zeiss Axio Scope A1 phase contrast light microscope was used to observe the structures of the specimens (Sisgen: A8302CB). Adult mites were initially separated in families using the key provided by Walter and Krantz (2009). Subsequently, the genera were identified using the world literature about the groups collected (De Leon 1961; Chant and McMurtry 1994; 2007; Ferla *et al.* 2007; Camargo Barbosa and Demite 2023). Whenever possible, identification to species level was done by comparisons with original descriptions and redescriptions.

Statistical analyses

Constancy (C) was calculated according to Silveira-Neto *et al.* (1976), using the formula:

$$C = \frac{(P * 100)}{N}$$

where:

P = number of collections containing the species;

N = total number of collections carried out.

The result was classified as: Constant (Co) (C > 50%), Accessory (A) (25% < C <50%) and Accidental (I) (C < 25%). Dominance (D) was defined using the formula:

$$D(\%) = \left(\frac{i}{t}\right) * 100$$

where:

i = total number of individuals of a species;

t = total number of individuals collected.

The result was grouped according to the categories established by Friebe (1983): Eudominant (Eu) (> 10%), Dominant (Do) (5% > 10%), Subdominant (S) (2% > 5%), Eventual (Ev) (1% > 2%) and Rare (R) (D < 1%) (Rodrigues 2017).

We observed whether the sampling effort was sufficient to represent all the richness of mites present in the orchards of each management system, where a rarefaction curve of Phytoseiidae species was calculated through interpolation/extrapolation according to the

number of individuals found in the areas. Rarefaction was calculated using the iNEXT package using the endpoint abundance data of 1200 species. The ggiNEXT function of the ggplot2 package was used to construct the rarefaction curve graph, using the R software (R Core Team 2023).

The total number of mite species was estimated from the Chao equation (Chao *et al.* 2014) using the 'specpool' function from the vegan package. We compared Phytoseiidae diversity dynamically using the Hill diversity profile curve (Hill 1973). The diversity of the seven orchards was compared using the Rényi exponential series ($\exp(H\alpha) = \exp[(1/1-\alpha)\ln\sum pi\alpha]$). This series includes the main diversity indices, from the most sensitive for rare species (low α value) to those that give greater weight to abundant species (high α values) (Tóthmérész 1995). In this series, $\alpha = 0$ corresponds to the total number of species, $\alpha = 1$ to the Shannon index, $\alpha = 2$ to the Simpson index and $\alpha \rightarrow \infty$ to the Berger-Parker index. To generate these estimates, we used a matrix of mites associated with the studied orchards, the diversity of profile was constructed using the 'renyi' function from the vegan package (Oksanen *et al.* 2018). The analyses were performed in the *R* software (R Core Team 2023).

We analysed the similarity in Phytoseiidae communities between the orchards. A Euclidean distance matrix was determined and using the factor extra package of the R software (R Core Team 2023) a dendrogram was constructed using the ward. D2 method. The dendrogram was used to separate the clusters according to the similarity of the orchards based on the abundance and diversity of species found in each area and then a cluster graph was constructed using the fviz_cluster function from the factoextra package, where abundance and richness information was plotted on the x and y axes, respectively. A multivariate analysis using the principal components method was performed to determine the main species responsible for the formation of orchard clusters. For this purpose, the FactoMineR (Lê *et al.* 2008) and factoextra (Kassambara and Mundt 2020) packages were used.

Regarding data on Phytoseiidae abundance, we initially compared data from areas that used different agricultural management systems (regardless of cultivar). Thus, Eva data were removed from this analysis, as this cultivar was not found in São Joaquim and Muitos Capões. We evaluated the abundance of Phytoseiidae among different management practices, cultivars, branch stratum and the interaction between these variables. Then, we evaluated the abundance in relation to areas with different cultivars, where the evaluated variables were: cultivars, branch stratum and the interaction of variables.

All abundance data were analyzed using a generalized linear model (GLM with Poisson distribution), and the Tukey test ($P < 0.05$) was used to determine differences between modalities. We used the SAS software (SAS Institute 2002) to perform the statistical analyses. Graphs were constructed using SigmaPlot® 11.0 software (Systat software, Inc.).

We used Phytoseiidae abundance data from the areas of each agricultural production system to analyse the relationship between the abundance of mites and abiotic parameters (monthly average temperature, relative humidity and precipitation). Then the data were subjected to multivariate regression analysis (Stepwise) using the SAS software (SAS Institute 2002). Curves were constructed using SigmaPlot® 11.0 software (Systat software, Inc.).

Results

A total of 695 phytoseiid specimens were collected, belonging to 10 species and seven genera. A greater number of species was found in the orchards of the Antônio Prado (organic management), with eight species collected on Eva, six on Fuji and four on Gala. In these orchards, the species of the genus *Euseius* (*Euseius mesembrinus* (Dean) and *Euseius inouei* (Ehara & Moraes)) were dominant in Eva, while *Metaseiulus eiko* (El-Banhawy) showed greater abundance in Fuji and Gala. A low number of species was observed in the orchards of Muitos Capões (conventional management) and São Joaquim (regenerative management). In São Joaquim, only *N. californicus* was observed on both Fuji and Gala. *Neoseiulus californicus*

was present in all the orchards considered, however, many more individuals were observed in the area of Muitos Capões, both on Fuji and Gala cultivars (Table 1).

The species rarefaction curve in orchards under organic management did not stabilize, indicating that more species might be present if more collections were carried out. However, in orchards using conventional and regenerative management systems, the species rarefaction curve stabilized, showing that sampling in these locations was sufficient to determine the number of species. The curve's confidence interval reveals a difference in the Phytoseiidae richness between the evaluated areas, where the areas with organic management, presented greater richness than the others (Figure 2).

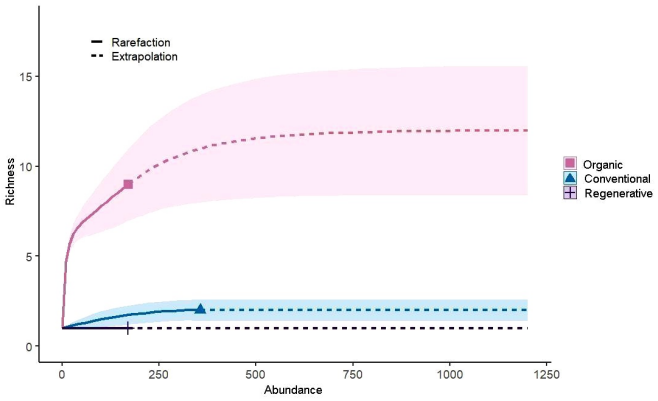

Figure 2 Mite species rarefaction curves: x-axis shows the abundance of Phytoseiidae mites; y-axis shows the richness of Phytoseiidae mites. The solid line indicates the interpolation (before the value) and the strikethrough line indicates the extrapolation (after the value) of the Hill number with order q = 0 showing the observed and expected richness in relation to the mean, respectively. The shadow indicates the 95% confidence intervals.

The diversity curves in the area conducted under organic management (Antônio Prado - Eva, Fuji or Gala) do not overlap the curves of the orchards conducted under conventional (Muitos Capões - Fuji or Gala) and regenerative management systems (São Joaquim - Fuji or Gala). However, the curves of the conventional and regenerative management systems overlap when the α value is equal to or greater than 1. Regarding the cultivars, considering only orchards with an organic management system, the cultivar Gala showed less diversity compared to the other apple cultivars. The cultivar Eva showed greater diversity than the cultivar Fuji when the

Table 1 Phytoseiidae associated with apple orchards in the municipalities of Muitos Capões, Antônio Prado, Rio Grande do Sul and São Joaquim, Santa Catarina, Brazil, collected between August 2020 and September 2021.

Species	Antônio Prado									Muitos Capões						São Joaquim						Total
	Eva			Fuji			Gala			Fuji			Gala			Fuji			Gala			
	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	
Amblyseus chiapensis	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Arrenoseius sp.	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Euseius mesembrinus	49	Co	Eu	2	I	Eu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51
Euseius inouei	37	Co	Eu	1	I	Do	1	I	S	-	-	-	-	-	-	-	-	-	-	-	-	39
Galendromus annectens	1	I	Ev	-	-	-	9	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	10
Metaseiulus eiko	11	A	Do	6	A	Eu	18	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	35
Neoseiulus californicus	5	A	S	5	A	Eu	11	A	Eu	161	Co	Eu	193	Co	Eu	63	A	Eu	106	A	Eu	544
Neoseiulus tunus	10	A	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Neoseiulus fallacis	-	-	-	1	I	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Proprioseiopsis cannaensis	-	-	-	1	I	Do	-	-	-	1	I	Ev	1	I	Ev	-	-	-	-	-	-	3
Total	115			16			39			162			194			63			106			695
%	16.55			2.30			5.61			23.31			27.91			9.06			15.25			
Richness	8			6			4			2			2			1			1			

T = Total of mites; C = Constance; D = Dominance; Co = Constant; A = Accessory; I = Accidental; Eu = Eudominant; Do = Dominant; S = Subdominant; Ev = Eventual; R = Rare

α value was low, indicating greater diversity for species considered rare, while the cultivar Fuji showed greater diversity as the α value increased, indicating greater diversity in relation to taxa (Figure 3).

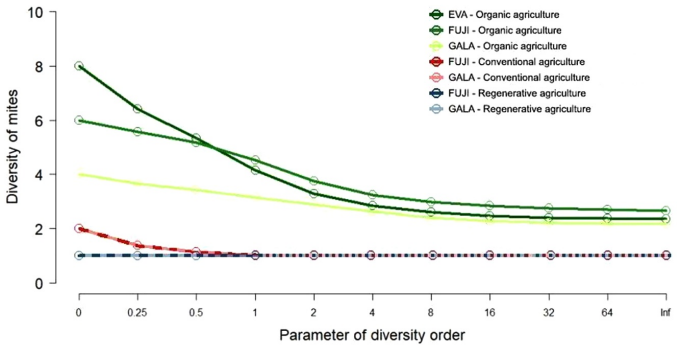

Figure 3 Hill number diversity profile. The x-axis shows the change in diversity indices over the Hill numbers; the y-axis displays the diversity level for measures on the x-axis. The left side of the x-axis is more sensitive to rare species, while the right side is more sensitive to the abundance of mite taxa. This continuum of values allows inferring the contributions of rare versus abundant species in a community. Some diversity indices on the x-axis can be inferred: 0 species richness; 1, Shannon-Wiener index; 2, Simpson index; inf, index Berger Parker.

The similarity analysis revealed differences both between different areas and different cultivars. The dendrogram and the cluster analyses (Figure 4A, B) show that the cultivar Eva is well separated from the other orchards, regardless of the management used. The orchards conducted under organic management (Fuji and Gala) formed a second cluster, distinct from orchards conducted under conventional and regenerative management and using the same cultivars (Figure 4A). Regarding the organic systems, the cultivar Eva is well separated from the other varieties, due to greater Phytoseiidae abundance and richness (Figure 4B).

The total variance explained by the two main axes was 80.7% (axes 1 and 2 explaining 56.3% 24.4%, respectively) (Figure 5). Orchards with conventional (Muitos Capões) and regenerative management (São Joaquim), which use pesticides, were grouped, related to *N. californicus*, and *Proprioseiopsis cannaensis* (Muma). The organic cultivation (Antônio Prado) areas were grouped into two clusters, one being Fuji and Gala, and the other Eva. These areas were related to the greatest diversity of species, being *Arrenoseius* sp., *A. chiapensis*, *E. inouei, E. mesembrinus* and *Neoseiulus tunus* (De Leon), the main species related to the Eva organic orchard, and *M. eiko* and *Galendromus annectens* (De Leon) with the Fuji and Gala organic orchards (Figure 5; Figure S1).

Significant differences in abundance of Phytoseiidae were observed when comparing the three types of management (Figure 6A; GLM: $F_{2,702} = 74.92$, $P < 0.001$). The highest abundance was observed in orchards with conventional management (Figure 6A). The lowest abundance was observed at the apical leaf level. However, there was no difference in the Phytoseiidae number between the median and basal levels (Figure 6A; GLM: $F_{2,702} = 13.05$, $P < 0.0001$). The cultivar Gala showed greater abundance than the cultivar Fuji (Figure 6B; GLM: $F_{1,702} = 10.40$, $P = 0.0013$). The variables management and stratum of the branch interacted (Figure 6C; GLM: $F_{4,702} = 3.76$, $P = 0.0049$), where greater abundance was observed in the apical, median and basal regions of the conventional management area. No difference was observed in the apical stratum of apple trees under organic and regenerative management, however, for the median and basal strata, the abundance differs between areas (Figure 6C).

Within the orchards of organic cultivation, a higher Phytoseiidae number was observed on the cultivar Eva, while no difference was observed between Fuji and Gala varieties (Figure 7A; GLM: $F_{2,350} = 29.60$, $P < 0.0001$). In these same orchards, we observed a higher mite abundance at the median and basal levels than at apical one (Figure 7A; GLM: $F_{2,350} = 8.25$,

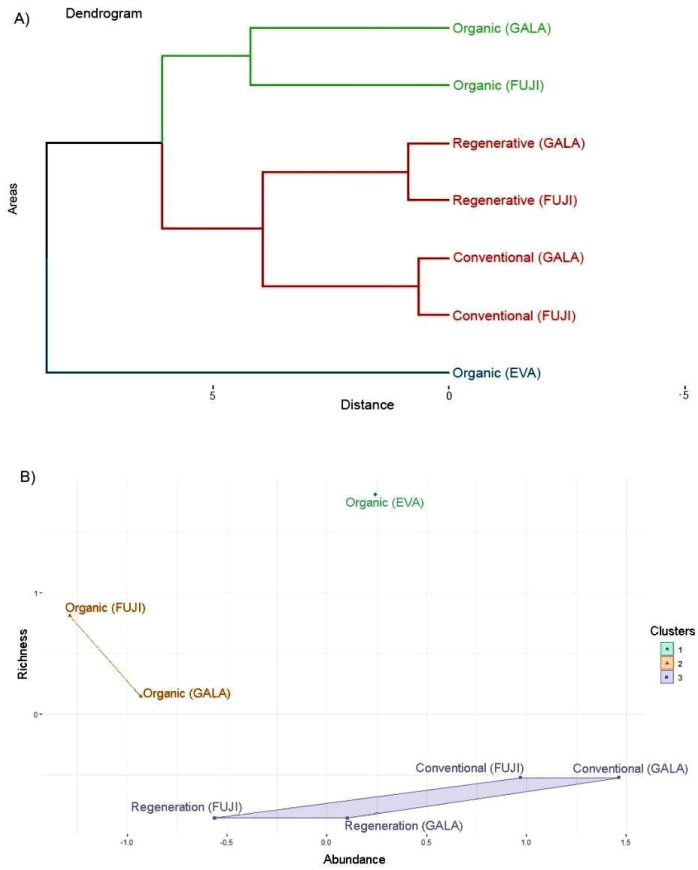

Figure 4 Similarity between areas with different agricultural management systems, considering the number and diversity of species. **A** – Dendrogram; **B** – Cluster Graph.

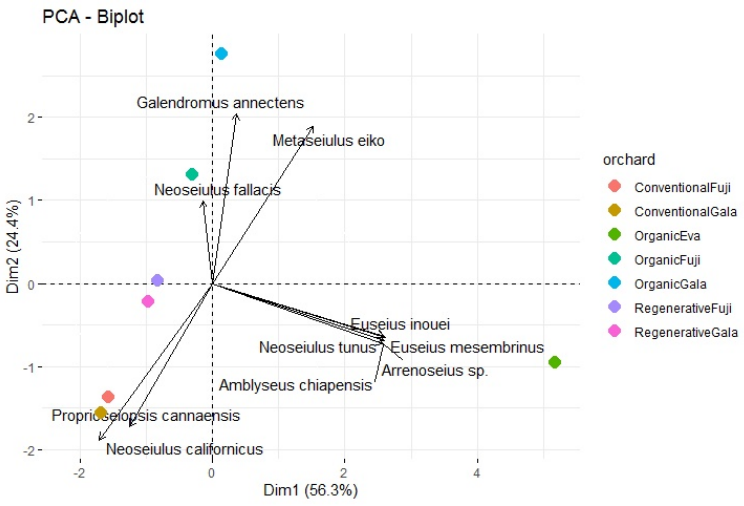

Figure 5 Biplot with the projection of variations in the factorial plane to determine the main species responsible for the variations between the orchards evaluated.

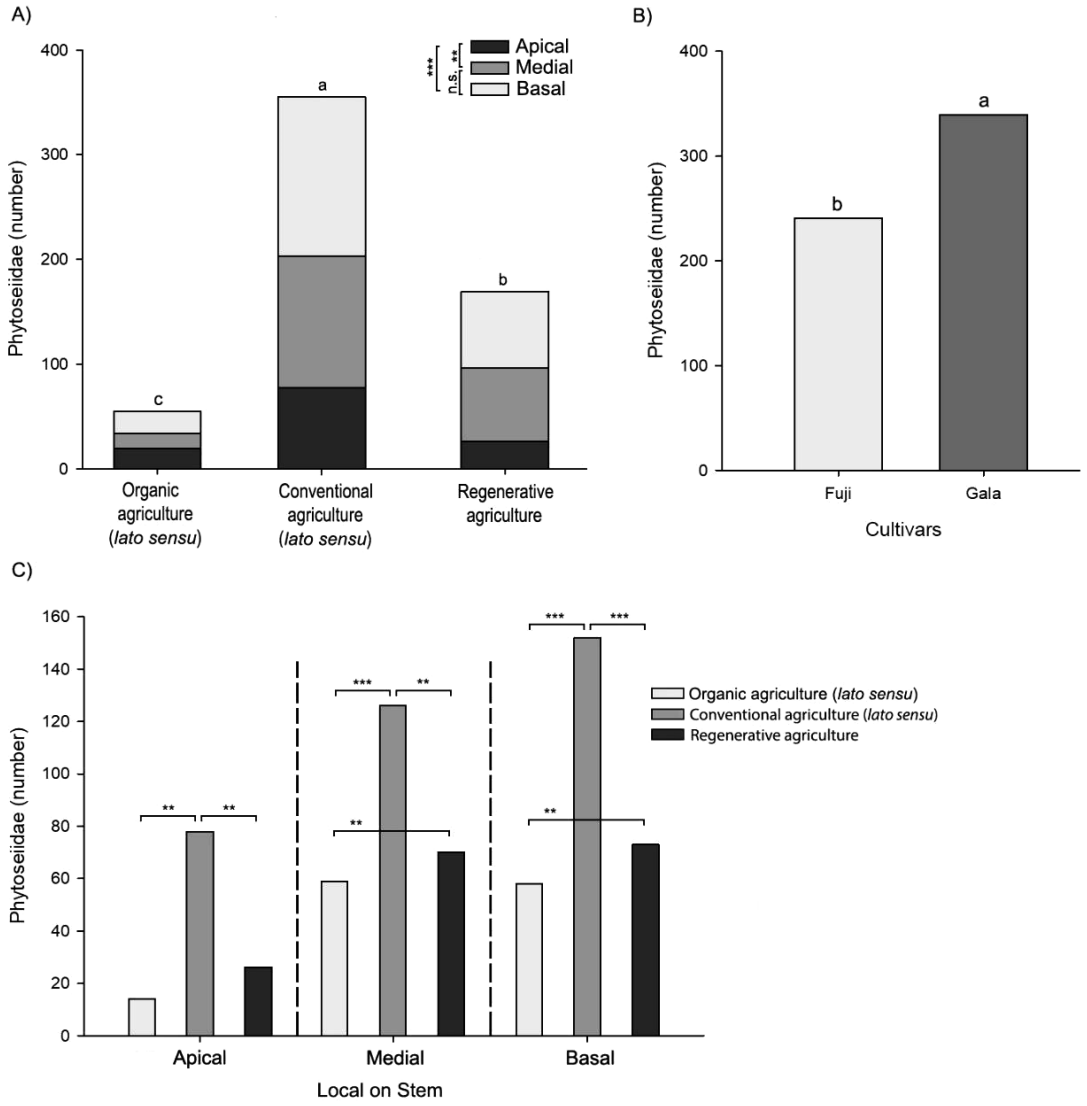

Figure 6 Abundance of Phytoseiidae in apple tree production areas with organic, conventional and regenerative management. **A** – number of Phytoseiidae in different areas and in different strata of the apple tree branch; **B** – number of Phytoseiidae in different apple tree cultivars; **C** – number of Phytoseiidae in relation to the interaction between different areas and leaf location on the branch. (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

$P = 0.0003$), whereas no difference in relation to the stratum of the branch was noted for the Fuji and Gala cultivars (Figure 7B; GLM: $F_{2,117} = 12.01$, $P < 0.0001$). Within orchards under conventional management, the density Phytoseiidae was not significantly different between the varieties Fuji and Gala, but their abundance was lower at the apical level than on basal part, median level showing intermediate densities (Figure 7C; GLM: $F_{2,234} = 7.66$, $P = 0.0006$). Within orchards under regenerative management, the abundance of Phytoseiidae was significantly different between the Fuji and Gala varieties (Figure 7E; GLM: $F_{1,233} = 6.22$, $P = 0.0133$). The density was significantly lower at the apical level than at basal and median ones (Figure 7F; GLM: $F_{2,233} = 6.76$, $P = 0.0014$).

The annual average precipitation, temperature and relative humidity in Antônio Prado were 102.075 mm, 17.64 °C and 74.40%; in Muitos Capões 118.975 mm, 15.41 °C and 80.43% and in São Joaquim 116.56 mm, 13.75 °C and 79.33%, respectively (EMBRAPA 2021). The stepwise analysis showed that the relative humidity variable affected the dynamics of the

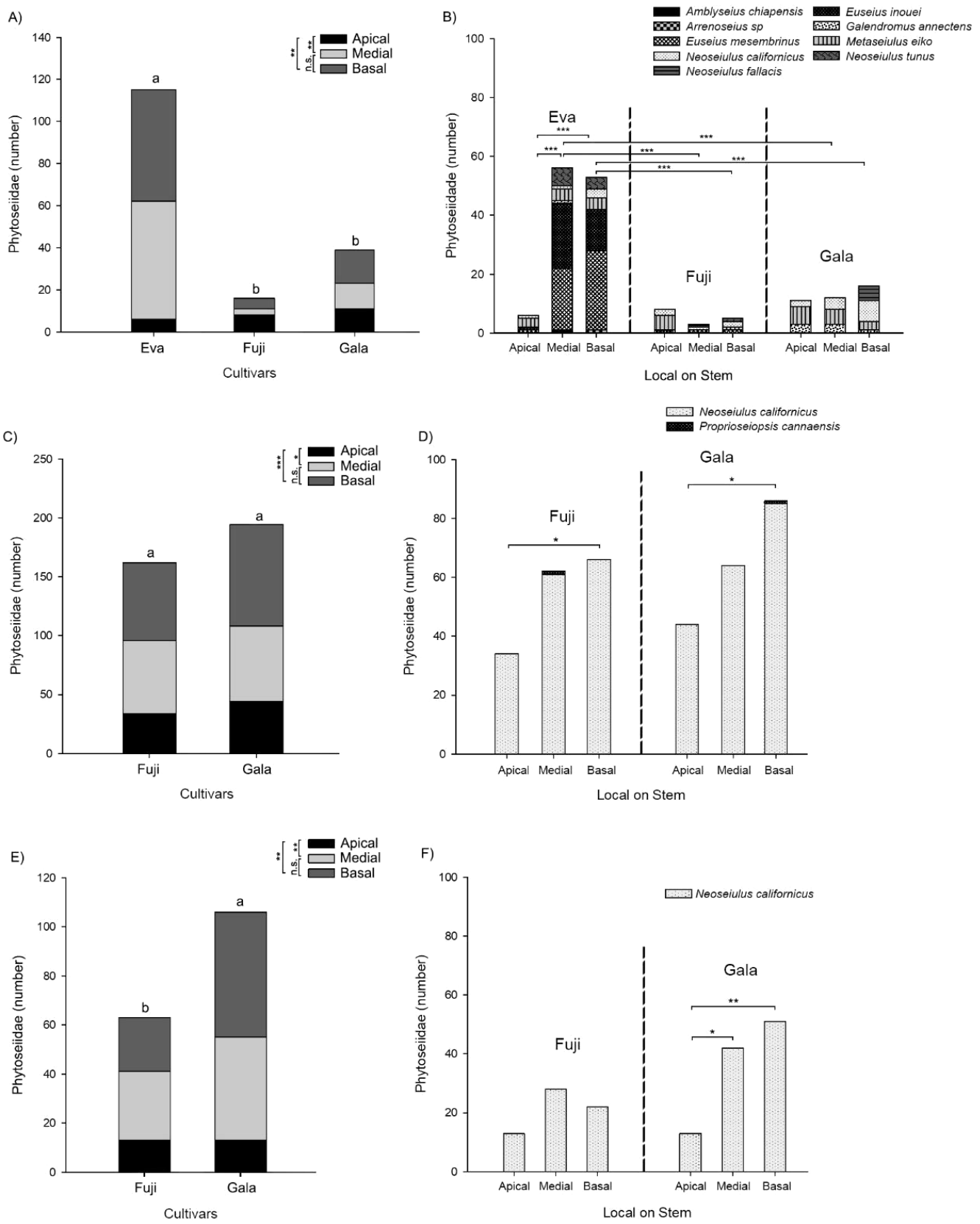

Figure 7 Phytoseiidae abundance in apple production areas **A** – Phytoseiidae abundance among cultivars in the organic management area; **B** – abundance of Phytoseiidae between the variety-leaf stratum interaction in the organic management area; **C** – abundance of Phytoseiidae among the cultivars in the conventional management area; **D** – abundance of Phytoseiidae among the leaf strata in the conventional management area; **E** – abundance of Phytoseiidae among cultivars in the regenerative management area; **F** – abundance of Phytoseiidae among the leaf strata in the regenerative management area. (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

Phytoseiidae population in the area with conventional management ($F_{3,8}$ = 4.39; P = 0.0419). This variable explained 37.21% (R2 = 0.3721) of the variation in abundance. In the area of organic and regenerative management, climatic variables did not interfere with the abundance of these predatory mites ($F_{3,8}$ = 2.85; P = 0.1051; $F_{3,8}$ = 1.37; P = 0.3197), respectively (Figure 8).

Discussion

In this study we performed the sampling of phytoseiid mites in different apple production orchards, and we evaluated the richness and abundance of these mites, as well as their distribution in the different strata of the plants. Furthermore, we studied how the different apple tree cultivars affect the diversity and distribution of these predatory mites. We observed that the diversity of Phytoseiidae mites was higher in apple orchards from the municipality of Antônio Prado (organic management) than from the municipalities of Muitos Capões (conventional management) and São Joaquim (regenerative management). Furthermore, the apple tree cultivar also had an important effect on the richness, abundance and distribution of these predatory mites. *Neoseiulus californicus* was found in all orchards, but with low occurrence in Antônio Prado orchards. In all areas, we did not observe such a significant effect of the abiotic variables of temperature, relative humidity and precipitation on the density of phytoseiid mites throughout the year. There was only a small effect of relative humidity in the conventional management area.

In this study, the apical stratum presented a lower density of predatory mites, being able to indicate that the median and basal regions of the branch could had greater availability of phytophagous mites or some alternative food, such as pollen (Monteiro 1994; Pascua *et al.* 2020). Furthermore, the apical region may be affected by solar incidence, which causes an increase in temperature on the leaf surface, influencing mite populations. Therefore, the mites could be looking for leaves in the middle and basal regions to settle, where the temperature and humidity would be ideal for their survival (Coombs and Bale 2013).

According to Maeyer *et al.* (1993), less intensive agricultural management allows for greater conservation of the diversity of natural enemies. Pesticide spraying is one of the main factors responsible for reducing arthropod diversity, especially natural enemies (Kropczynska and Tuovinen 1988; Meyer *et al.* 2009), while to spontaneous vegetation allows the conservation of the diversity of these biological control agents in agricultural production areas (Altieri 1999, 2002). These plants can provide shelter and food for predatory mites, even in periods with unfavourable abiotic conditions or when prey is scarce (Landis *et al.* 2000; Tixier *et al.* 2000; Demite and Feres 2005). Even if spontaneous plants were present in the inter-rows of the regenerative management systems (São Joaquim), this area did not show greater diversity than the conventional management area (Muitos Capões) (where spontaneous plants were removed). As in both areas, pesticides were used (conventional area more frequently than the regenerative area), it could be assumed that the low Phytoseiidae in these orchards compared to the orchards under organic management (Antônio Prado) is related to the use of pesticides. However, the abundance of Phytoseiidae mites was higher in the conventional orchards than in the others. This result was due to the large number of individuals of *N. californicus*, a species that occasionally uses pollen as food (Pascua *et al.* 2020). The ability of a predatory mite to feed on alternative diets, particularly pollen, may limit the sublethal effects of pesticides (Pozzebon *et al.* 2014). However, the most probable hypothesis is that *N. californicus* might be resistant to pesticides, as already mentioned in other studies (Moraes *et al.* 2004; Meyer *et al.* 2009; Van Lenteren 2012; Yorulmaz-Salman and Ay 2013; Tixier et al 2013, 2018; Ghazy *et al.* 2016; Knapp *et al.* 2018; Inak and Yorulmaz-Salman 2022).

The multivariate analysis grouped the orchards that use pesticides (Muitos Capões and São Joaquim) into one cluster and the organic cultivation areas (Antônio Prado) into two other clusters, one being Fuji and Gala, and the other with Eva. These groupings demonstrated the

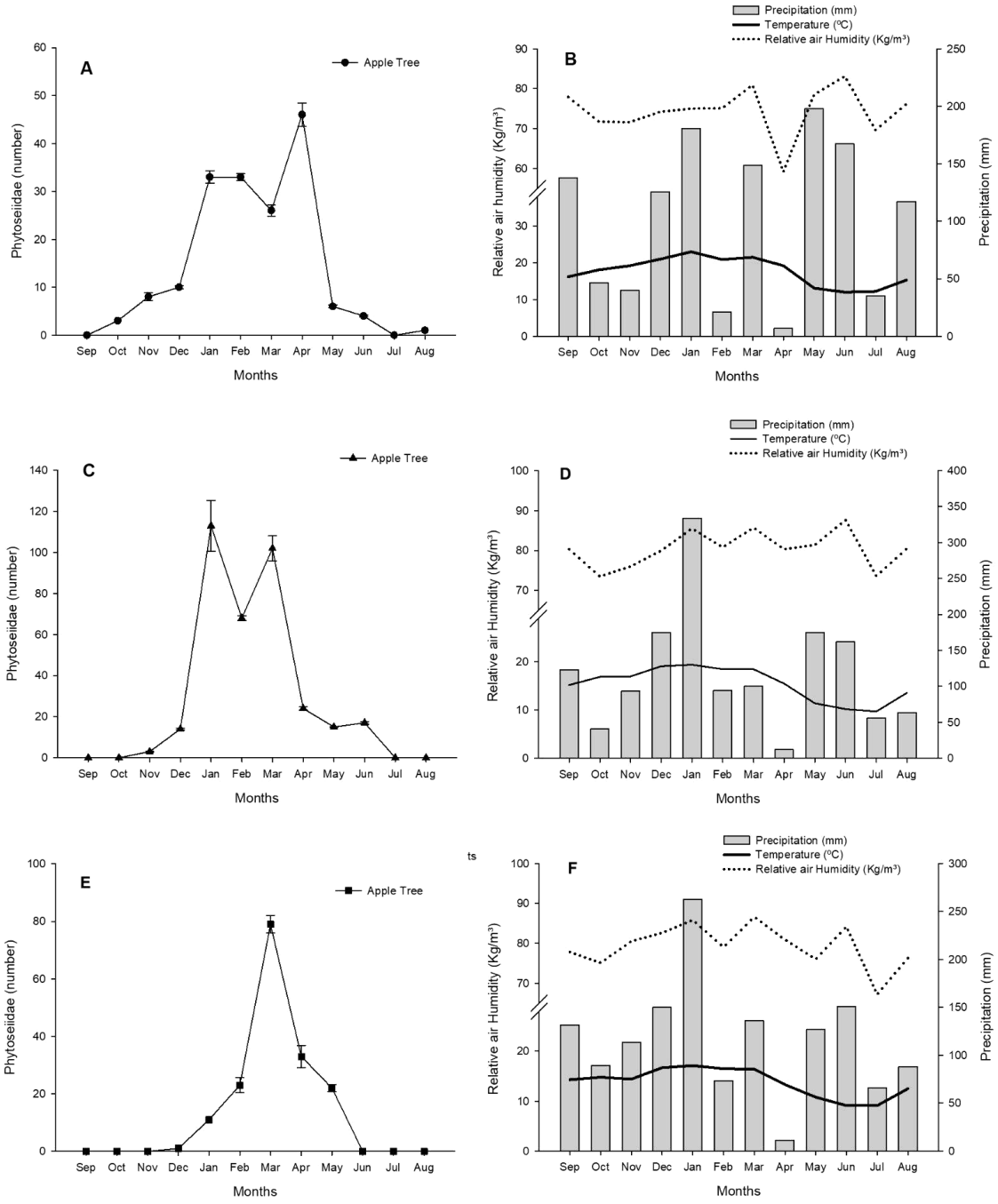

Figure 8 Phytoseiidae mite population dynamics and monthly averages of abiotic variables (temperature, precipitation and relative humidity) from September 2020 to August 2021. **A** – Phytoseiidae mite population dynamics in the organic management area (Antônio Prado); **B** – monthly averages of the abiotic variables in the organic management areas; **C** – Phytoseiidae mite population dynamics in the conventional management area (Muitos Capões); **D** – abiotic variables in areas under conventional management; **E** – Phytoseiidae mite population dynamics in the regenerative management area (São Joaquim); **F** – abiotic variables in regenerative management area.

different composition of acarine species in these areas, with *N. californicus*, one of the main species present in orchards that use pesticides. Even if densities of *N. californicus* were higher

in areas using pesticides, this species was also observed in all orchards evaluated in this study. In areas where these products were not used, the number of individuals of *N. californicus* was lower than in areas that use pesticides. A possible explanation is that without interference from pesticides, *N. californicus* is not able to thrive due to greater interaction with other predators. A study of lethal and non-lethal intraguild interactions between *Euseius stipulatus* (Athias-Henriot) and *N. californicus* showed that the first species negatively affected the population of the second, while the abundance of *E. stipulatus* was not affected by the introduction of a second predator (Abad-Moyano *et al.* 2010). A more in-depth study on the impact of *N. californicus* dominance is necessary, following pest populations in a long-term effect in areas with pesticide use, as well as studying the intraguild interaction between predators in areas without use of these chemicals.

In the organic management areas (Antônio Prado), we observed differences between the composition of the Phytoseiidae mite community between the different cultivars, where Eva had the highest number of species. Furthermore, Phytoseiidae abundance differs between Fuji and Gala cultivars. The plant architecture can affect mites in several ways: (i) species interactions (increase or reducing predation, cannibalism or competition) and (ii) pollen quantity (Kreiter *et al.* 2002; Schmidt 2014). The three cultivars considered have different leaf hairiness, which can have affected the density of Phytoseiidae mites.

Considering only the cultivar Eva, we observed that *E. mesembrinus* and *E. inouei* were constant and eudominant. Some species use fungal spores or pollen as a food source, in the absence of the prey mites (Gambaro 1998; Croft *et al.* 2004). This is the case of predatory mites of the genus *Euseius*, classified as generalist types IV, meaning that these predators develop well when feeding on pollen (McMurtry *et al.* 2013). The structural complexity of the leaf favors populations of Phytoseiidae type IV, by increasing pollen retention (Kreiter *et al.* 2002) on the surface, providing an alternative source of food in times of scarcity of prey (Schmidt 2014). There is a positive correlation between pollen retention and trichome density (Kreiter *et al.* 2002). However, it is necessary to carry out controlled studies to more accurately assess the effects of these structures on the behavior of these predators in apple plants.

This study shows the importance of producers considering the less intensive use of pesticides and herbicides in orchards in order to maintain populations of predatory mites due to their potential as agents acting in ecological services. Furthermore, the results suggest that the native fauna is able to maintain *A. schlechtendali* populations at acceptable levels for the cultivars studied.

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Author's contribution

PAR, MS and GLB with the sample collections, sample sorting on plants, slide mounting and identification; GLB and MS with morphological analysis; PAR with the analysis and concept of the manuscript; NJF with revisions.

ORCID

Priscila de Andrade Rode https://orcid.org/0000-0001-9172-8483
Matheus Schussler https://orcid.org/0000-0001-5669-3633
Gabriel Lima Bizarro https://orcid.org/0000-0001-6142-872X
Noeli Juarez Ferla https://orcid.org/0000-0003-0771-6864

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CAPITULO 6

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Spontaneous vegetation as a strategy for the conservation of predatory mites in apple orchards

Priscila de Andrade Rode[1, 2*], https://orcid.org/0000-0001-9172-8483

Gabriel Lima Bizarro[1], https://orcid.org/0000-0001-6142-872X

Matheus Schussler[1], https://orcid.org/0000-0001-5669-3633

Guilherme André Spohr[1], https://orcid.org/0000-0002-0813-7939

Daniele Mallmann[1], https://orcid.org/0000-0002-2212-1044

Elisete Maria de Freitas[2], https://orcid.org/0000-0002-9292-1557

Noeli Juarez Ferla[1, 2, 3] https://orcid.org/0000-0003-0771-6864

[1] Laboratory of Acarology, Tecnovates, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.

[2] Postgraduate program in Biotechnology, Universidade do Vale do Taquari - Univates, 95914-014, Lajeado, Rio Grande do Sul, Brazil.

[3] CNPq researcher.

[*] Corresponding author: pdrode@universo.univates.br

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Abstract. This study aims to recognize the mitefauna present in the spontaneous vegetation associated with apple orchards, defining the species with the greatest potential as a reservoir of predatory mites. The studies were carried out in the 2020-21, in three organic orchards (Eva, Fuji and Gala), in Antônio Prado, two conventional (Fuji and Gala), in Muitos Capões, state of Rio Grande do Sul and two of regenerative agriculture (Fuji and Gala), in São Joaquim, Santa Catarina. Monthly collections were made of the five spontaneous plants present in the apple orchards. Sixty-seven species/morphospecies belonging to 26 botanical

families associated with apple orchards did sample, with plants from eight families hosting mites. The families that presented the greatest abundance were Asteraceae (33%), followed by Plantaginaceae (33%), Poaceae (19%) and the other families (15%). *Plantago australis* Lam. (Plantaginaceae) showed greater mite abundance (32.7%), with 41.7% being predators. The second plant was *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) (16.9%), with 51.9% predators. The greatest richness was found associated with the spontaneous vegetation of organic orchards, with greater diversity presented by phytoseiid mites. *Plantago australis* and *V. tweediana* prove to be the most suitable plant species for maintaining native natural enemies in apple orchards.

Keywords: *Agistemus brasiliensis*, *Arrenoseius gaucho*, Natural enemies, *Plantago australis*, *Vernonanthura tweediana.*

Introduction. Brazil is among the largest apple producers in the world, with the South region being the most productive in the country (Kist *et al*., 2019). The most produced cultivars are Gala and Fuji, however, some more recent ones, such as Eva, have gained relevance in national production (Kist *et al*., 2019).

The production of apples in the conventional system is carried out through the intensive application of fertilizers and chemical products (DA PIM, 2020). In Brazil, production still largely depends on a high quantity of pesticides to combat pest organisms that attack orchards (Meyer *et al*., 2009). Agricultural intensification, characterized by habitat loss, reduced landscape heterogeneity and increased use of pesticides, represents the main driver of biodiversity decline, environmental imbalance and health risks (Gomiero *et al*., 2011; Meehan *et al*., 2011; Jonsson *et al*., 2012; Campbell *et al*., 2017; Silva *et al*., 2019; de Pedro *et al*., 2020). There is an urgent need for change in agricultural production systems, aimed at sustainable development (Raudonis *et al*., 2007; Walker *et al*., 2017; Zhu *et al*., 2018; Willet

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et al., 2021). In this context, organic production emerges as an alternative to the conventional system. This type of management uses only products permitted by the national production standard, minimizing risks to worker health, reducing the use of chemical products, thus obtaining cleaner, ecologically correct production, free of waste and, consequently, increasing benefit to the final product (Gomiero *et al*., 2011; Smith *et al*., 2012; Caprio *et al*., 2015; Gomiero, 2018; Sumberg & Giller, 2022). One of the main criteria used to differentiate organic agriculture from others is the non-use of pesticides (Sumberg & Giller, 2022). Regenerative agriculture is considered an alternative to conventional agriculture, as its characteristic is to improve soil protection, not use machinery and maintain soil cover with plants, whether spontaneous or not (The soil association, 2021), however, if necessary, this system allows the use of pesticides to control pests.

Inadequate management of orchards favors the emergence of phytosanitary problems and results in economic losses associated with the reduction of natural enemies and an increase in phytophagous populations that can reach pest *status* (Meehan *et al*., 2011; Jonsson *et al*., 2012; Van Leeuwen & Dermauw, 2016; Walker *et al*., 2017; Schmidt-Jeffris & Beers, 2018). *Panonychus ulmi* (Koch) and *Tetranychus urticae* Koch (Tetranychidae) are important phytophagous mites present in Brazilian apple orchards (Ferla *et al*., 2018; Nascimento *et al*., 2020; Silva *et al*., 2022; Rode *et al*., 2023). Recently, the presence of *Aculus schlechtendali* Nalepa (Eriophyidae) was recorded in Brazil, serving as a warning for the apple production chain, as it is a species of quarantine importance present in the country (Ferla *et al*., 2018; Nascimento *et al*., 2020; Corrêa *et al*., 2021; Silva *et al*., 2022; Rode *et al*., 2023).

Among the natural enemies commonly associated with apple trees and spontaneous vegetation in this crop's orchards are species of Phytoseiidae and Stigmaeidae, with different eating habits (Lorenzato *et al*., 1986; Ferla & Moraes, 1998; Klock *et al*., 2011; Johann & Ferla, 2012; Rode *et al*., 2024b). Phytoseiidae can feed on phytophagous mites and have

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alternative food sources, such as pollen, fungi, plant exudate and insects (McMurtry *et al*., 2013; Tixier, 2018). These characteristics mean that the family is intensely studied and several species are important agents of applied biological control of tetranychid mites in agroecosystems (Moraes *et al*., 2004).

Landscape management can contribute to the sustainable control of pest species, as the composition of the environment can directly affect the abundance of an herbivore, affecting its dispersal, mortality or reproduction, or indirectly, affecting its natural enemies (Veres *et al*., 2013). Spontaneous vegetation, also known as invasive plants or weeds, occurs associated with orchards, generally between tree rows and can be native or exotic, with natural germination and rapid growth (Lykouressis *et al*., 2008; Diehl *et al*., 2012). Generally, mowing or herbicide applications remove these plants, and these practices leave the soil without vegetation, harming the establishment of predatory species in agricultural crops (Altieri & Liebman, 1986; Carvalho, 2013).

Some associated plants have trichomes, domatia and nectaries, beneficial structures for the plant that offer refuge, a safe place for oviposition and supply of alternative food such as pollen and nectar to different mite species (Agrawal *et al*., 2000; Ferla & Moraes, 2002; Prischmann & James, 2003; Matos *et al*., 2006; Duso *et al*., 2010). Certain plants associated with orchards play an important ecological role as they host species that help in the biological control of agricultural pests, as they naturally migrate from these associated plants to the main crop of the orchard (Tixier *et al*., 2000; Altieri *et al*., 2002; Kreiter *et al*., 2002; Lykouressis *et al*., 2008; Ji *et al*., 2022). Increased vegetation diversity is positively related to natural enemy diversity (Letourneau *et al*., 2011). The adequate maintenance of this vegetation in agroecosystems helps to conserve the diversity of natural enemies and significantly reduce the populations of phytophagous species with the potential to reach the level of economic damage (Altieri *et al*., 2002; Monteiro *et al*., 2002 a; b; Isbell *et al*., 2017; Pedro *et al*., 2020; Faoro,

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2022; Ji *et al*., 2022). Strategically increasing plant diversity improves crop yields, yield stability, benefits pollinators, and suppresses harmful weeds and pests, while the effects of diversification on soil nutrients and carbon remain poorly understood (Isbell *et al*., 2017). Studies show the importance of natural vegetation associated with cultivation areas for reducing populations of phytophagous mites and developing ecological pest management in rural areas (Altieri *et al*., 2002; Demite & Feres, 2005; Isbell *et al*., 2017). However, little is known about the role of these plants as reservoirs of natural enemies in apple orchards in Brazil.

Therefore, the objective of this study was to recognize the mitefauna present in the spontaneous vegetation associated with apple orchards, defining the plant species with the greatest potential to be a reservoir of predatory mites of economic importance in southern Brazilian apple cultivation.

Materials and Methods

Study area. The study was carried out in the 2020-21 harvest in three 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), Rio Grande do Sul, and São Joaquim (28°53'23"S 51°23'06"W), Santa Catarina, Brazil (Figure 1).

Antônio Prado: In this location, collections were carried out in three organic orchards of Eva, Fuji and Gala cultivars. In Eva's orchard, the area was two hectares, while in Fuji and Gala orchards, the areas were one hectare for each cultivar. In all areas, the spacing between plants was 4 x 1.80 m (rows x trees). The soil cover in all orchards in this location was preserved, with the presence of spontaneous plants, such as grasses and weeds, in association with litter. There was no spraying of pesticides or herbicides in these areas.

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São Joaquim: In this location, two orchards were evaluated, one with the Fuji cultivar and the other Gala. The total area of each orchard was 5.5 hectares, and the spacing was 7 x 3 m (rows x trees). In both areas, spontaneous plants, grasses and weeds, in association with litter, covered the soil. Weeding was not carried out. Pigs, sheep and chickens were kept grazing throughout the area, and these animals feed on both spontaneous plants and aborted fruits. Despite the care taken to protect the soil in these areas, whenever necessary, producers sprayed pesticides to control pests. In this way, the areas in this location were considered regenerative agriculture.

Muitos Capões: In this location, collections were carried out in two conventional orchards, one with the Fuji cultivar and the other with Gala. The total area of the orchards was 240 hectares, with a spacing of 4.2 x 1 m (rows x trees). In both areas of the locality, the soil was kept unprotected, with the use of herbicides and weeding, and the spraying of chemical products to control pests is frequent.

Collects. Sampling was carried out monthly from September 2020 to August 2021, totaling 12 samples/cultivar. The orchards divided into quadrants consisting of four rows. The five most frequent species of spontaneous plants were collected monthly in sufficient quantity for a sampling effort of one hour of sorting (Diehl *et al*., 2012). The material was packaged separately in plastic bags, identified, and stored in a Styrofoam box with Gelox® and transported to the Acarology Laboratory of the University of Vale do Taquari, Univates. In the laboratory, the leaves were screened under a stereoscopic microscope (40×) and the mites were mounted on microscope slides in Hoyer's medium (Jeppson *et al*., 1975). The slides were kept in an oven at a temperature of 50-60 °C for a period of 10 days to promote distension, clarification of the specimens and drying of the medium.

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Mite identification. The identification of mites was made with the aid of an optical microscope with phase contrast (Zeiss Axio Scope A1) and dichotomous keys (Lindquist, 1986; Amrine & Stasny, 1994; Baker & Tuttle, 1994; Chant & Mcmurtry, 1994; Matioli *et al*., 2002; Amrine *et al*., 2003; Fan & Zhang, 2005; Chant & Mcmurtry, 2007; Ferla *et al*., 2011; Johann *et al*., 2013; Demite *et al*., 2014; Skvarla *et al*., 2014; Silva *et al*., 2016; Johann *et al*., 2017). The representative specimens of each of the species found were labeled, kept in slide boxes, stored in a room with humidity control and deposited in the Collection of Reference Mites of the Museum of Natural Sciences of the University of Vale do Taquari – Univates (SisGen A05CB2A).

Identification of spontaneous plants. A sample of each plant collected was mounted on exsiccate for subsequent identification, which took place with the help of specific bibliography (Lorenzi, 1994; Moreira & Bragança, 2011). The determination of families was based on the Angiosperm Phylogeny Group IV systems (APG IV 2016).

Statistical analysis. Constancy (C) was calculated according to Silveira-Neto *et al.* (1976), through the formula: C = (P x 100)/N, where P = number of collections performed and classified as constant (C > 50%), accessory (25% < C < 50%) and accidental (C < 25%). Dominance (D) was defined using the formula: D% = (i/t) x100, where I= total number of individuals of a species and t = total individuals collected and grouped according to the categories established by Friebe (1983): Eudominant (> 10%), Dominant (5 ≥ 10%), Subdominant (2 ≥ 5%), Eventual (1 ≥ 2%), and rare (D < 1%). Constant, Dominant and Eudominant species were highlighted in each orchard to carry out population fluctuation studies. Para as análises de interações entre os ácaros e as plantas foi utilizado o pacote Bipartite do programa R (R Development Core Team, 2023).

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176 **Results**

177 The results presented here are complementary to those of Rode et al. (2024a).

178 Spontaneous plants and mite fauna. Sixty-seven species belonging to 26 botanical families
179 associated with apple orchards were sampled. Among the plant families collected, eight had
180 mites, being most abundant in Asteraceae and Plantaginaceae (33% each), followed by
181 Poaceae (19%) and other families (15%) (Table 1). The majority of plants sampled had mites
182 (57.8%), while 42.2% of the plants did not have mites in any of the orchards evaluated.
183 Asteraceae was more diverse with 17 species and, among these, 10 had mites. *Plantago*
184 *australis* Lam. (Plantaginaceae) was the species with the highest mite abundance (32.7%),
185 with 56.9% generalists and 41.7% predators. The second species was *Vernonanthura*
186 *tweediana* (Baker) H. Rob. (Asteraceae) (16.9%). Among the mites recorded, the highest
187 abundance of predatory mites was on *V. tweediana* (51.9%) (Figure 2).

188 In total, 1.908 mites belonging to 76 species/morphospecies were collected, with
189 emphasis on generalists (53.1%), predators (43.8%) and phytophagous (3.1%) (Table 2).
190 Phytoseiidae was the most diverse predator family, with 13 species/morphospecies (25% of
191 the total predators) associated with the spontaneous vegetation evaluated. This family
192 presented 362 specimens, 47% of which were present in organic orchards, 42% in regenerative
193 agriculture and 11% in conventional ones. The greatest richness of predators did find
194 associated with the spontaneous vegetation of organic orchards, followed by regenerative and
195 conventional agriculture orchards.

196 Organic orchards. In Eva, there was greater richness (39 species/morphospecies) and greater
197 abundance (21.8%) when compared to the others (Table 2). In this orchard, the predatory
198 species, *Agistemus brasiliensis* Matioli, Ueckermann & Oliveira (Stigmaeidae) and
199 *Arrenoseius gaucho* Ferla, Silva & Moraes (Phytoseiidae) were eudominant, *Euseius*

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200 *mesembrinus* (Dean) (Phytoseiidae) dominant and *A. gaucho* constant. *Arrenoseius gaucho*
201 was also constant and eudominant in Fuji. In Gala, *Armascirus* sp. was constant and
202 eudominant and *Ologamasus margaridae* Bizarro & Rode (Ologamasidae), constant and
203 dominant, and *Ologamasus tuberculatus* Bizarro & Rode (Ologamasidae) and *Orolaelaps* sp.1
204 (Melicharidae) dominants. Furthermore, *N. californicus* was absent in these orchards.

205 The main host plants for predatory mites were *P. australis*, *V. tweediana* and
206 *Elephantopus mollis* Kunth (Asteraceae). In Eva, greater mite abundance found in *V.*
207 *tweediana*, with greater abundance of predators, especially *A. brasiliensis* (Figure 3). The
208 second plant was *P. australis*, with *A. gaucho* as the main predator species. In Fuji, *E. molis*
209 was more abundant, with predator species being more abundant and *A. gaucho* also being
210 more abundant (Figure 4). *Xenotarsonemus* sp.1 (Tarsonemidae) was the second most
211 abundant species in this orchard and was present in *Talinum paniculatum* (Jacq.) Gaertn.
212 (Talinaceae), one of the main plants in the orchard. No phytophagous mites were found
213 associated with spontaneous vegetation in this orchard. In Gala, *P. australis* had greater
214 abundance, mainly from predators, especially *A. gaucho* and *O. tuberculatus* (Figure 5). Other
215 plant species such as *E. molis* and *Paspalum pumilum* Nees. (Poaceae) also stood out in the
216 orchard due to the abundance of mites present and mainly because they are hosts for several
217 predator species.

218 Regenerative orchards. In Fuji, *A. gaucho* was constant and eudominant, and *Amblyseius*
219 *nicola* Chant & Hansell (Phytoseiidae), *Asca* sp.1 (Ascidae), *N. californicus* and
220 *Proprioseiopsis ovatus* (Garman) (Phytoseiidae) were dominant. In Gala, *N. californicus* and
221 *A. nicola* were eudominant, *Asca* sp.1, dominant and *A. gaucho*, constant and dominant.

222 Greater mite abundance was present in *P. australis*, followed by *L. multiflorum*. In
223 Fuji, the proportion of predatory and generalist mites was similar, with the main predatory
224 species in this orchard being *A. gaucho*, associated mainly with *P. australis* (Figure 6). No

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phytophagous mites were found in the spontaneous vegetation of this orchard. However, the orchard presented the greatest richness of generalist mites on associated plants. In Gala, less richness in spontaneous vegetation was noted, only four species (Figure 7). The main predatory mite in this orchard was *N. californicus*, host to the four plants species and most abundant in *L. multiflorum*.

Conventional orchards. In Fuji, *A. brasiliensis* was eudominant and *N. californicus* dominant. In Gala, *N. californicus* was also dominant.

The plant species that presented the highest predator richness were *P. australis*, *Lolium multiflorum* L. (Poaceae) and *V. tweediana*. In Fuji, *V. tweediana* had the highest abundance, among the four species present in this plant, one predator, *N. californicus* and three generalists, *Tarsonemus merus* Lin & Zhang, *Tarsonemus confusus* Ewing and *Xenotarsonemus* sp.1 (Tarsonemidae) (Figure 8). *Neoseiulus californicus* was the second most abundant predator. The second main plant species was *P. australis*, with *A. brasiliensis* as the main mite species on the plant and in the orchard. In Gala, the most abundant plant species were *V. tweediana* and *P. australis*. The highest abundance of *Xenotarsonemus* sp.1 and *Xenotarsonemus* sp.2 (Tarsonemidae) was in *P. australis* (Figure 9). In this orchard, the third main species was the phytophagous mite *Brevipalpus* sp. (Tenuipalpidae).

Discussion

The botanical families that showed the greatest mite abundance in spontaneous vegetation were Asteraceae, Plantaginaceae and Poaceae, both for generalist and predatory mites. In general, *P. australis* and *V. tweediana* were the species with the greatest abundance, in addition to being those with the highest proportion of predatory mites. The greatest richness of predatory mites was found associated with the spontaneous vegetation of organic orchards, highlighting the Phytoseiidae, the most diverse family associated with the plants evaluated.

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The spontaneous vegetation mainly housed populations of mites with generalist and predatory food habits, with phytophagous present, but in a smaller proportion. The presence of this vegetation, between the rows and around the orchards, may be conserving the diversity and abundance of predators and, consequently, keeping the populations of phytophagous mites below the level of economic damage (Landis *et al*., 2000; Bellini *et al*., 2005; Mailloux *et al*., 2010; Isbell *et al*., 2017). The composition of the landscape can, directly, affect the abundance of a pest, its dispersal, mortality or reproduction (Veres *et al*., 2013), or indirectly, affecting its natural enemies, ensuring their permanence in the orchards, even in the absence of the main prey (Ferla & Moraes, 2002; Duso *et al*., 2010; Veres *et al*., 2013; Demite *et al*., 2015), assisting in applied biological control and reducing the use of agrochemicals in crops (Isaacs *et al*., 2009). The increase in resource availability, associated with the presence of spontaneous vegetation, helps natural enemies and reduces the pest's ability to move and access the host plant (Finch & Collier, 2000). In this way, greater plant diversity (Letourneau *et al*., 2011) provides alternative resources such as nectar, pollen, prey and more host options (Carrié *et al*., 2012; Balzan *et al*., 2014) increasing the presence and establishment of enemies natural in the environment. Therefore, it is important to associate natural management strategies with the maintenance of spontaneous plants around and between the orchards in order to maintain populations of predatory mites, controlling phytophagous species (Letourneau *et al*., 2009; Letourneau *et al*., 2011; Isbell *et al*., 2017).

The greater acarine richness and diversity observed in organically managed orchards, where plant diversity was also greater, demonstrate that the presence of this vegetation is helping to conserve these communities in a natural environment (Letourneau *et al*., 2011; Isbell *et al*., 2017). The diversity of organisms present in spontaneous plants determines the ecological interactions that will exist between them (Pires & Guimarães, 2013; Balzan *et al*., 2016). The abundance of natural enemies presents in a given environment largely depends on

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the amount of existing non-agricultural habitats (Langellotto & Denno, 2004; Tscharntke *et al*., 2007; Tylianakis *et al*., 2007; Attwood *et al*., 2008). Furthermore, the functionality of vegetation covers varies according to the intensity of input use, mainly pesticides and fertilizers (Herzog *et al*., 2006; Ricci *et al*., 2009; Geiger *et al*., 2010). Thus, the management used in orchards may influence in maintaining the mite diversity present in different orchards (Letourneau *et al*., 2011; Veres *et al*., 2013; Isbell *et al*., 2017) as observed in this study.

Four species stood out for harboring the majority of predators, however, *P. australis* and *V. tweediana* proved to be species with the potential to be kept in orchards. In addition to harboring greater mite abundance, these two species were those with the highest proportion of predators, both in organic orchards and in orchards that used pesticides. Faoro (2022) cites *Plantago major* L. (Plantaginaceae), a species of the same genus as the main species found in the orchards of this study, as a plant with the potential to harbor predatory mites and recommends its maintenance in orchards. The trichomes observed in *P. australis* are short, hyaline and membranous (Hefler, 2011). In *V. tweediana*, trichomes are glandular and tectorial and hyaline (Darte & Chella, 2014). In addition to the similarity of trichomes, the leaves of both species are membranous. These structures are possibly favoring the presence of predators who can find alternative resources to feed on and, due to the spacing between the trichomes, are able to move freely in search of prey. Furthermore, leaf trichomes may be contributing to the retention of resources, such as pollen from other plants, which can serve as food for generalist predatory mites (Flechtmann & McMurtry, 1992; Roda *et al*., 2003; Tixier, 2018).

The high populations of predators found in this study indicate that in addition to feeding on phytophagous species, these mites may be finding alternative food sources (Wäckers & Van Rijn, 2012). Pollen is reported by McMurtry and Croft (1997) as a food accepted by natural enemies because it is nutritionally adequate, favoring the permanence of

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these organisms in agroecosystems. In studies carried out in spontaneous vegetation associated with vines, populations of Phytoseiidae and Stigmaeidae were found in these plants (Johann *et al*., 2009; Diehl *et al*., 2012). Of the species collected by Moura *et al.* (2013) also in vines, 50% were predators. Based on these works, it is possible to verify that the associated spontaneous vegetation has the potential as reservoirs of natural enemies to control phytophagous mites also in apple cultivation.

In this work, Phytoseiidae was the most diverse family associated with the plants evaluated. The family is widely known and studied for its potential as natural enemies of several species of phytophagous mites (Letourneau *et al*., 2011; Isbell *et al*., 2017; Tixier, 2018). Most species are generalists (McMurtry *et al*., 2013; 2015), which allows them to remain in the environment even in the absence of their main prey. However, some structures such as Solanaceae trichomes hinder the movement of these organisms and are not favorable to the presence of predators (Tixier, 2018). Our results showing that of the two species sampled from this family, only one had a predatory mite. However, the presence of pollen can increase the density of predatory mites, as some of them grow better on pollen than on prey (Flechtmann & McMurtry, 1992). A study developed by Roda *et al.* (2003) demonstrated that the hairier the apple leaves are, the greater the densities of *Typhlodromus* (*Typhlodromus*) *pyri* Scheuten, in this case, due to the greater quantity of pollen and spores of the fungus captured by the structures, and serve as an alternative food for predators.

Based on these findings, we advocate the maintenance of spontaneous vegetation in apple orchards as a favorable path towards optimized ecological intensification measures. Because they act as a physical barrier for herbivores and as a reservoir for predators that control species with the potential to reach pest status, it is suggesting that these plants should be maintained as a conservative biological control strategy, being a viable and efficient strategy (Dihel *et al*., 2012; Isbell *et al*., 2017). Among the species found associated with apple

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trees, *P. australis* and *V. tweediana* proved to be the most suitable species for maintenance in apple orchards to provide shelter from native predatory mites.

In conclusion, ecological intensification through the establishment of living vegetation cover can benefit apple orchard management programs by reducing environmental degradation, increasing populations of phytophagous mites that cause economic damage, and maintaining crop yield. This study recognizes the spontaneously growing vegetation associated with apple orchards, the mitefauna present there and the plant species that have potential as a reservoir of natural enemies. However, it is important that more studies should be carried out to determine the levels of interaction between vegetation and apple trees, aiming to evaluate the movement of mite populations between the two environments.

Author's contribution. PAR, GAS, MS, GLB and DM with the sample collections, sample sorting on plants, slide mounting and identification; GLB and MS with morphological analysis; EMF, PAR and GAS with the vegetation identification; PAR with the statistical analysis and concept of the manuscript; NJF with major revisions.

Conflict of Interest. The authors declare that they have no conflict of interest related to the publication of this manuscript.

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646

647 **Figure Captions**

648 Figure 1. Collection points in apple producing regions in the municipalities of Antônio Prado
649 and Muitos Capões, state of Rio Grande do Sul, and São Joaquim, state of Santa Catarina,
650 Brazil. Authorship: Castro, I. S.

651

652 Figure 2. (A) *Plantago australis,* (B) Abaxial leaf surface of *Plantago australis*,
653 (C)*Vernonanthura tweediana* and (D) Abaxial leaf surface of *Vernonanthura tweediana*.

654

655 Figure 3. Bipartite network of mitefauna and the spontaneous vegetation of the apple orchard
656 of the Eva cultivar in the municipality of Antônio Prado, state of Rio Grande do Sul. The bars
657 on the left side represent species of host plants and the bars on the right represent species of
658 mites. Plant species (black), phytophagous mites (green), generalist mites (yellow) and
659 predatory mites (brown).

660

661 Figure 4. Bipartite network of mitefauna and spontaneous vegetation of the apple orchard of
662 the Fuji cultivar in the municipality of Antônio Prado, state of Rio Grande do Sul. The bars
663 on the left side represent host plant species and the bars on the right represent species of mites.
664 Plant species (black), generalist mites (yellow) and predatory mites (brown).

665

666 Figure 5. Bipartite network of acarofauna and spontaneous vegetation of the apple orchard of
667 the Gala cultivar in the municipality of Antônio Prado, state of Rio Grande do Sul. The bars

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668 on the left represent host plant species and the bars on the right represent mite species. Plant
669 species (black), phytophagous mites (green), generalist mites (yellow) and predatory mites
670 (brown).
671
672 Figure 6. Bipartite network of acarofauna and spontaneous vegetation of the apple orchard of
673 the Fuji cultivar in the municipality of São Joaquim, state of Santa Catarina. The bars on the
674 left represent host plant species and the bars on the right represent mite species. Plant species
675 (black), generalist mites (yellow) and predatory mites (brown).
676
677 Figure 7. Bipartite network of acarofauna and spontaneous vegetation of the apple orchard of
678 the Gala cultivar in the municipality of São Joaquim, state of Santa Catarina. The bars on the
679 left represent host plant species and the bars on the right represent mite species. Plant species
680 (black), phytophagous mites (green), generalist mites (yellow) and predatory mites (brown).
681
682 Figure 8. Bipartite network of acarofauna and spontaneous vegetation of the apple orchard of
683 the Fuji cultivar in the municipality of Muitos Capões, state of Rio Grande do Sul. The bars
684 on the left side represent species of host plants and the bars on the right side represent species
685 of mites. Plant species (black), phytophagous mites (green), generalist mites (yellow),
686 predatory mites (brown).
687
688 Figure 9. Bipartite network of acarofauna and the spontaneous vegetation of the apple orchard
689 of the Gala cultivar in the municipality of Muitos Capões, state of Rio Grande do Sul. The
690 bars on the left side represent host plant species and the bars on the right represent species of
691 mites. Plant species (black), phytophagous mites (green), generalist mites (yellow) and
692 predatory mites (brown).

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693 **Table Captions**

694 Table 1. Spontaneous vegetation in apple orchards in the municipalities of Muitos Capões,
695 Antônio Prado, state of Rio Grande do Sul and São Joaquim, state of Santa Catarina, Brazil,
696 evaluated between August 2020 and September 2021. Food habit: P = Predator, G =
697 Generalist and F = Phytophagous.

698

699 Table 2. Mite fauna associated with spontaneous vegetation in apple orchards in the
700 municipalities of Muitos Capões, Antônio Prado, state of Rio Grande do Sul and São Joaquim,
701 state of Santa Catarina, Brazil, collected between August 2020 and September 2021

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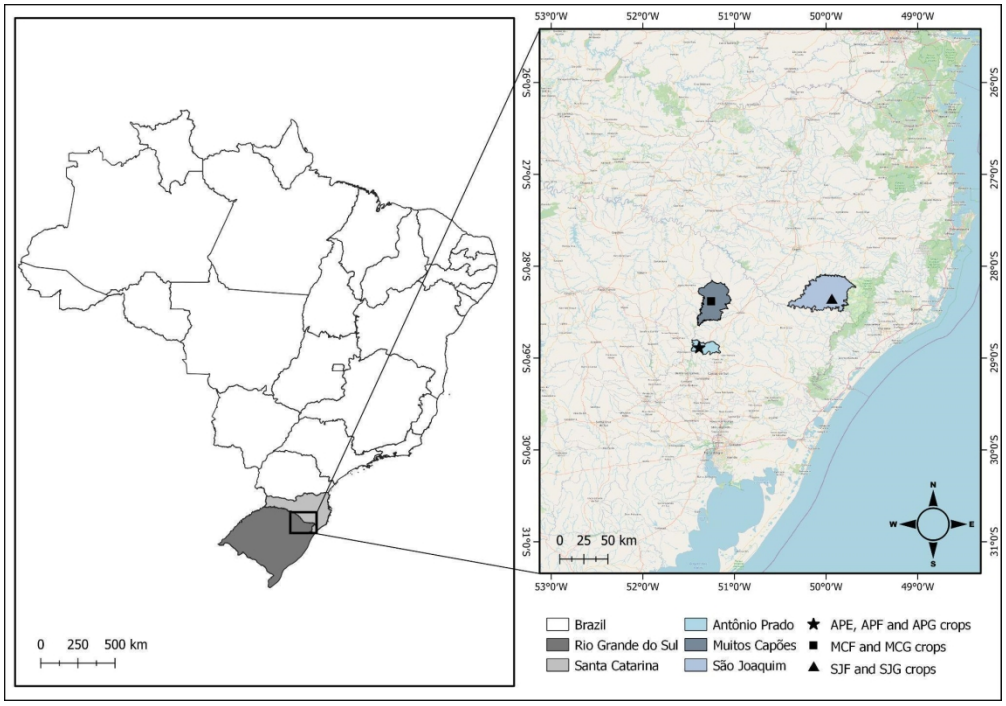

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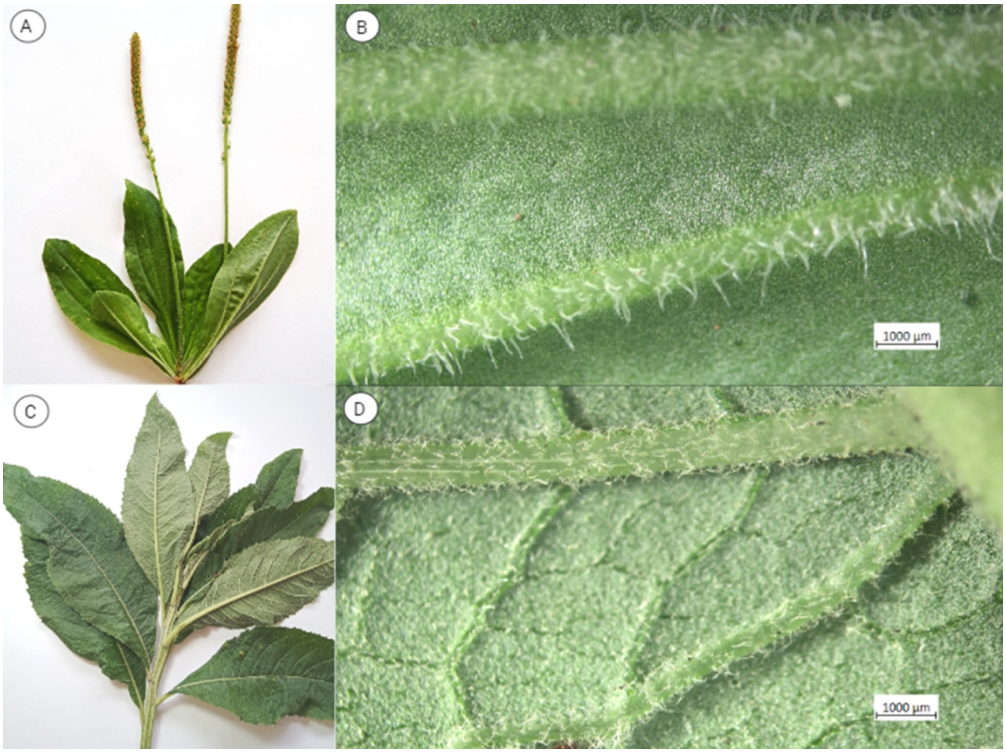

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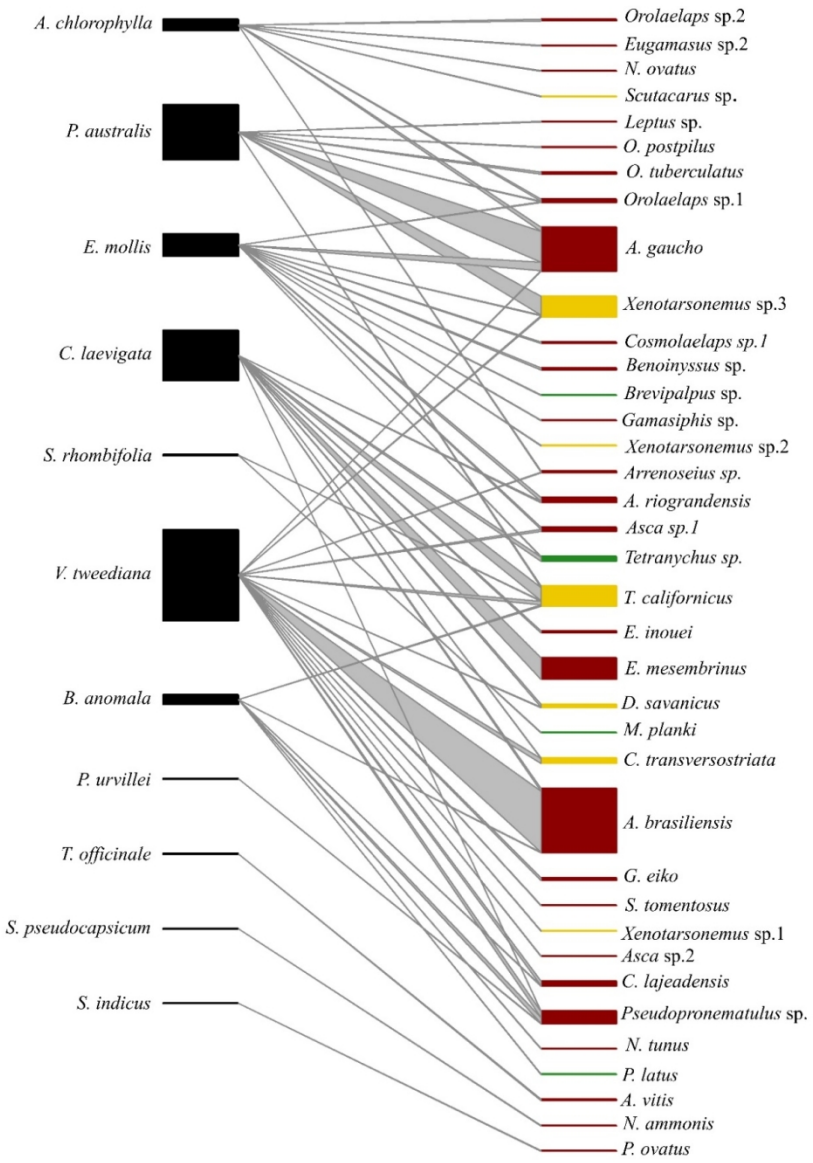

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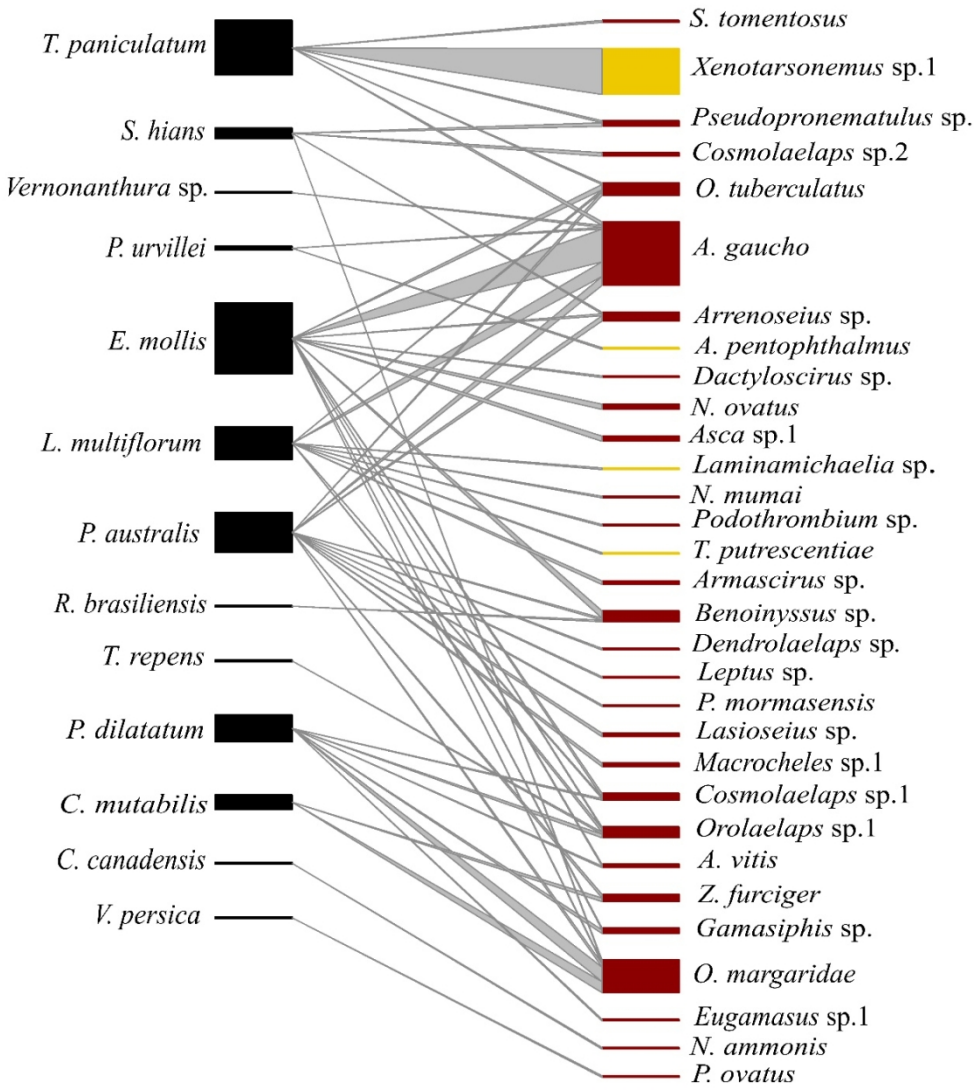

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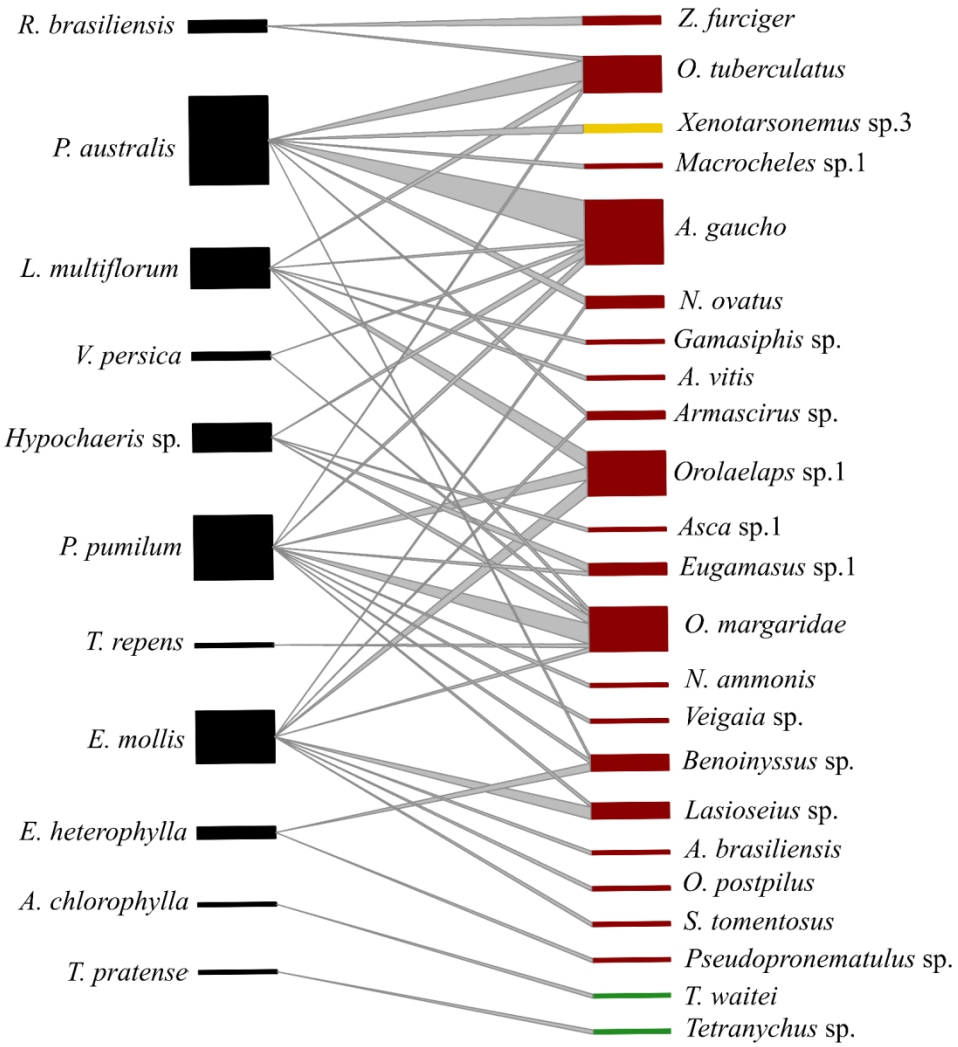

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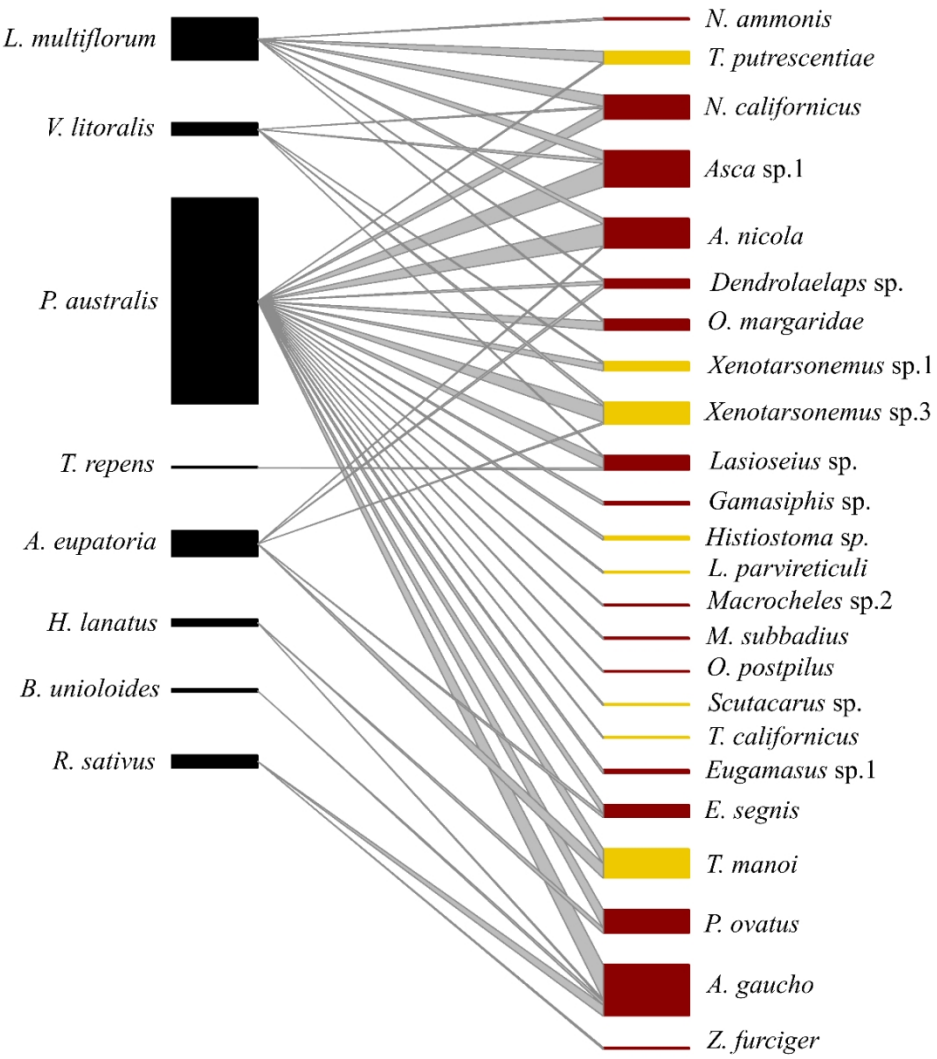

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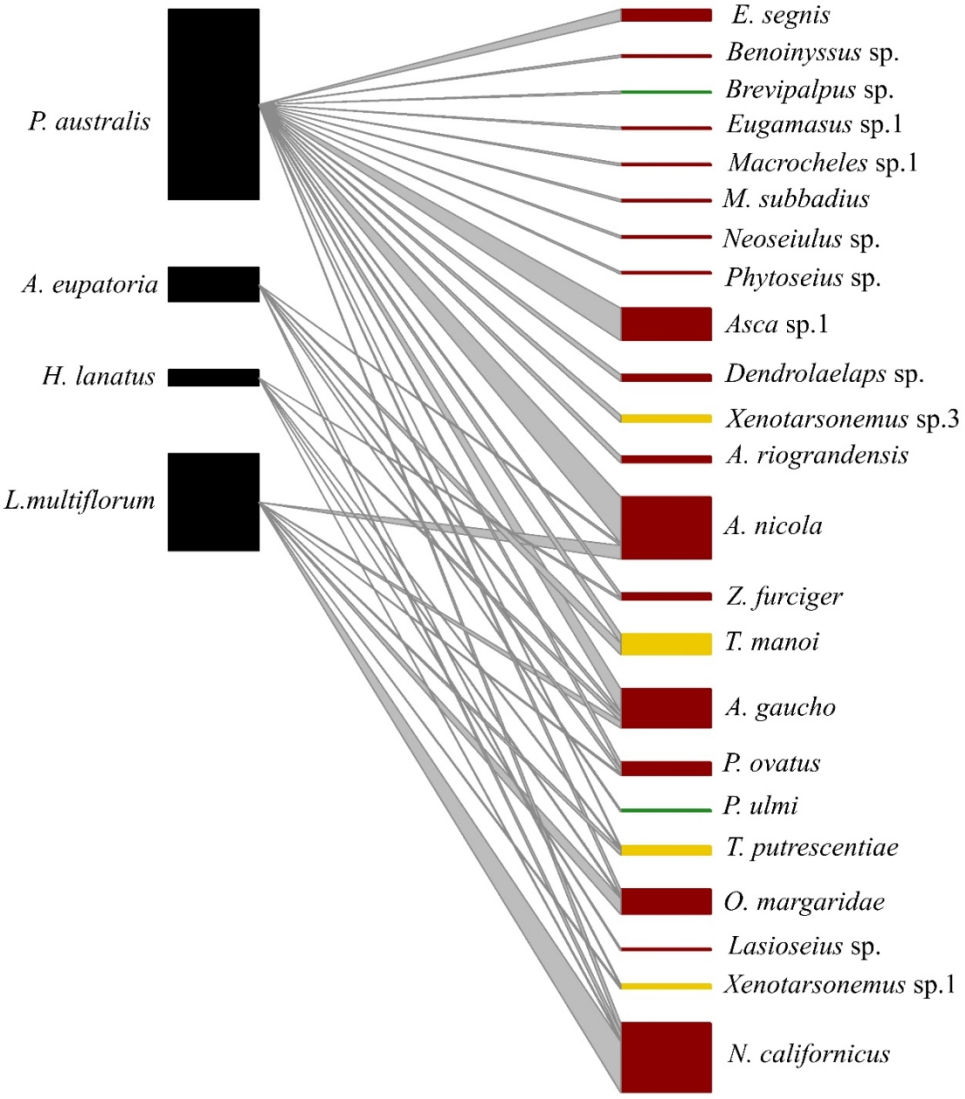

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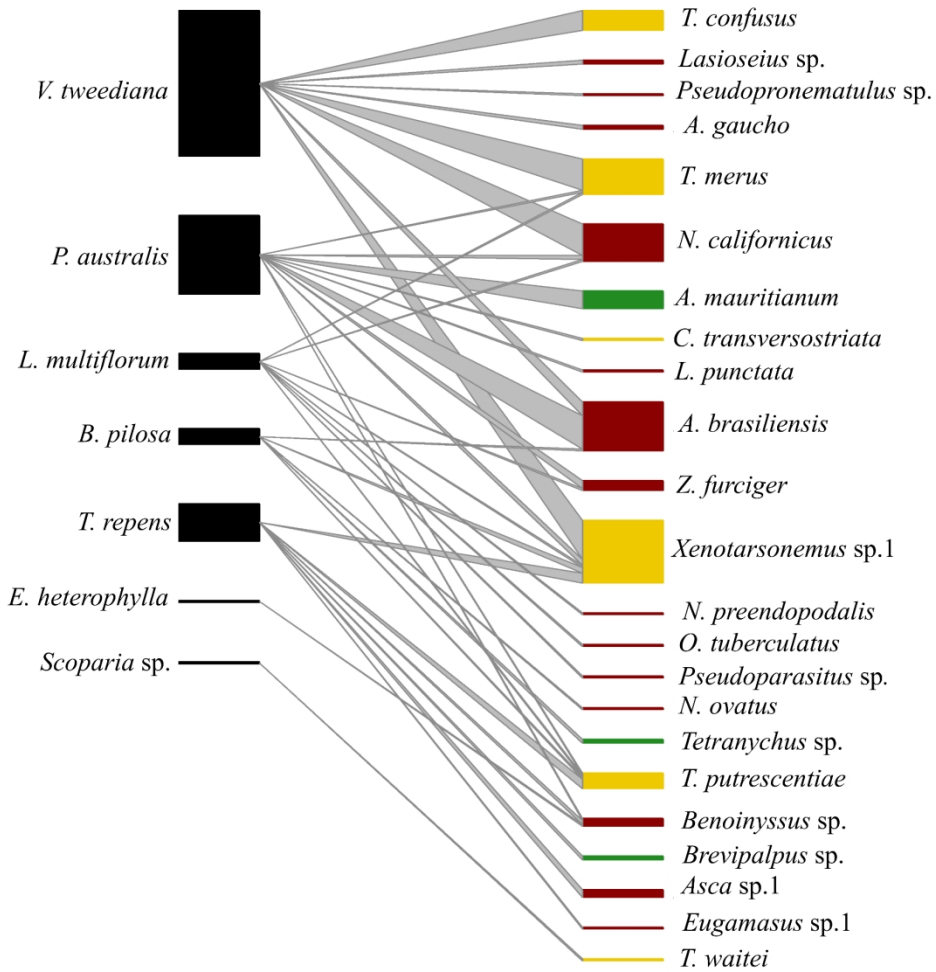

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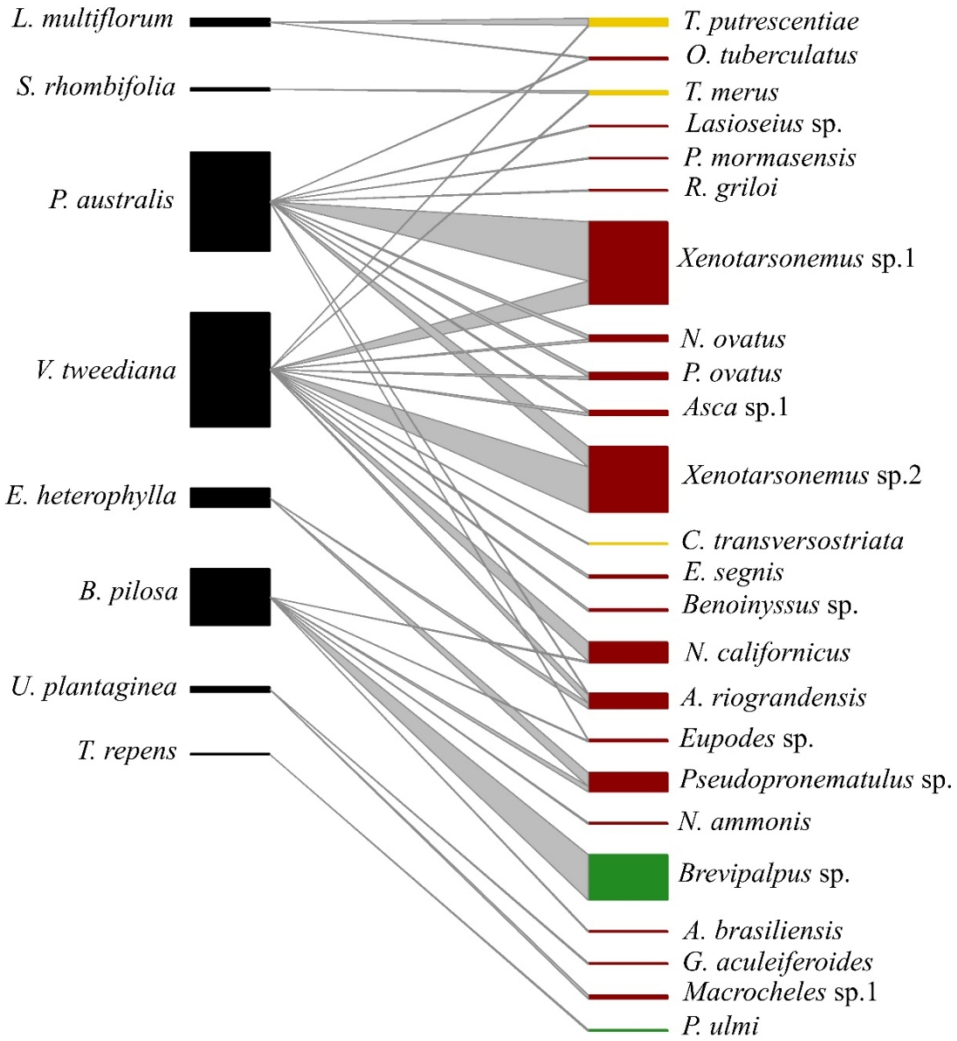

148x163mm (220 x 220 DPI)

Botanic family	Botanic species	Mite abundance	P (%)	G (%)	F (%)
AMARANTHACEAE	*Amaranthus deflexus*	-	-	-	-
	Iresine diffusa	-	-	-	-
APIACEAE	*Centella asiatica*	-	-	-	-
	Conium maculatum	-	-	-	-
	Daucus pusillus	-	-	-	-
APOCYNACEAE	*Oxypetalum* sp.	-	-	-	-
ARALIACEAE	*Hydrocotyle leucocephala*	-	-	-	-
ASTERACEAE	*Baccharis anomala*	17	70.6	23.5	5.9
	Baccharis dracunculifolia	-	-	-	-
	Baccharis sp.	-	-	-	-
	Baccharis trimera	-	-	-	-
	Bidens pilosa	50	20	10	70
	Chromolaena laevigata	69	58	33.3	8.7
	Conyza bonariensis	-	-	-	-
	Conyza canadensis	1	100	-	-
	Elephantopus mollis	154	57.8	40.9	1.3
	Gamochaeta americana	-	-	-	-
	Hypochaeris sp.	9	77.8	22.2	-
	Koanophyllon sp.	-	-	-	-
	Senecio brasiliensis	-	-	-	-
	Sonchus oleraceus	1	-	100	-
	Taraxacum officinale	4	50	50	-
	Vernonanthura sp.	1	100	-	-
	Vernonanthura tweediana	322	51.9	48.1	-
BRASSICACEAE	*Raphanus sativus*	8	87.5	12.5	-
CARYOPHYLLACEAE	*Stellaria media*	-	-	-	-

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COMMELINACEAE	*Commelina erecta*	-	-	-	-
CONVOLVULACEAE	*Ipomoea alba*	-	-	-	-
	Ipomoea indivisa	-	-	-	-
	Ipomoea sp.	-	-	-	-
CUCURBITACEAE	*Sicyos* sp.	-	-	-	-
EUPHORBIACEAE	*Euphorbia heterophylla*	26	69.2	30.8	-
FABACEAE	*Trifolium pratense*	6	-	83.3	16.7
	Trifolium repens	42	23.8	69	7.1
	Vicia cracca	1	-	100	-
HYPERICACEAE	*Hypericum caprifoliatum*	-	-	-	-
LAMIACEAE	*Cantinoa mutabilis*	12	66.7	33.3	-
	Leonurus japonicus	-	-	-	-
MALVACEAE	*Sida sp.*	-	-	-	-
	Sida rhombifolia	6			
OXALIDACEAE	*Oxalis* sp.	-	-	-	-
PLANTAGINACEAE	*Plantago australis*	624	41.7	56.9	1.4
POACEAE	*Axonopus affinis*	-	-	-	-
	Bromus catharticus	-	-	-	-
	Bromus unioloides	12	9.1	90.9	-
	Eragrostis plana	-	-	-	-
	Holcus lanatus	73	13.7	86.3	-
	Lolium multiflorum	190	47.9	52.1	-
	Paspalum dilatatum	17	88.2	11.8	-
	Paspalum pumilum	12	50	50	-
	Paspalum urvillei	20	60	40	-
	Sporobolus indicus	1	100	-	-
	Steinchisma hians	8	62.5	37.5	-

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	Urochloa plantaginea	34	14.7	85.3	-
POLYGONACEAE	*Rumex obtusifolius*	-	-	-	-
PTERIDACEAE	*Adiantopsis chlorophylla*	45	31.1	68.9	-
ROSACEAE	*Acaena eupatoria*	42	32.6	65.2	2.2
RUBIACEAE	*Richardia brasiliensis*	10	40	60	-
	Richardia sp. 1	-	-	-	-
	Richardia sp. 2	-	-	-	-
SCROPHULARIACEAE	*Scoparia* sp.	1	-	100	-
	Veronica persica	8	37.5	62.5	-
SOLANACEAE	*Solanum americanum*	-	-	-	-
	Solanum pseudocapsicum	2	50	50	-
TALINACEAE	*Talinum paniculatum*	73	6.8	93.2	-
VERBENACEAE	*Lantana camara*	-	-	-	-
	Verbena litoralis	7	57.1	42.9	-
		1.908			

For Review Only

Species	Food habit	Antônio Prado									Muitos Capões						São Joaquim						Total	%
		Eva			Fuji			Gala			Fuji			Gala			Fuji			Gala				
		T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D		
Agistemus brasiliensis	P	**89**	**A**	**E**	**0**	**-**	**-**	**1**	**I**	**Ev**	25	I	E	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	116	6,1
Agistemus riograndensis	P	**7**	**I**	**S**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	11	I	S	**0**	**-**	**-**	**3**	**I**	**Ev**	21	1,1
Amblyseius nicola	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**16**	**I**	**D**	**27**	**A**	**E**	43	2,3
Amblyseius vitis	P	**2**	**I**	**R**	**2**	**I**	**Ev**	**1**	**I**	**Ev**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	5	0,3
Amphialycus pentophthalmus	G	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Aponychus mauritianum	F	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	9	I	S	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	9	0,5
Armascirus sp.	P	**0**	**-**	**-**	**0**	**-**	**-**	**2**	**C**	**E**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Arrenoseius gaucho	P	**61**	**C**	**E**	**35**	**C**	**E**	**17**	**I**	**Ev**	2	I	Ev	0	-	-	**28**	**C**	**E**	**17**	**C**	**D**	160	8,4
Arrenoseius sp.	P	**3**	**I**	**Ev**	**7**	**A**	**S**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	10	0,5
Asca sp.1	P	**6**	**I**	**Ev**	**3**	**I**	**Ev**	**1**	**I**	**Ev**	4	I	S	4	I	Ev	**20**	**A**	**D**	**14**	**A**	**D**	52	2,7
Asca sp.2	P	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Benoinyssus sp.	P	**3**	**I**	**Ev**	**6**	**I**	**S**	**4**	**I**	**S**	4	A	S	2	I	Ev	**0**	**-**	**-**	**2**	**I**	**Ev**	21	1,1
Brevipalpus sp.	F	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	2	I	Ev	33	I	E	**0**	**-**	**-**	**0**	**-**	**-**	36	1,9
Cosmolaelaps sp.1	P	**1**	**I**	**R**	**4**	**I**	**S**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	5	0,3
Cosmolaelaps sp.2	P	**1**	**I**	**R**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Cunaxoides lajeadensis	P	**7**	**A**	**S**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	7	0,4
Czenspinskia transversostriata	G	**8**	**I**	**S**	**0**	**-**	**-**	**0**	**-**	**-**	1	I	R	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	10	0,5
Dactyloscirus sp.	P	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Daidalotarsonemus savanicus	G	**5**	**I**	**Ev**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	5	0,3
Dendrolaelaps sp.	P	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**5**	**A**	**S**	**3**	**I**	**Ev**	9	0,5
Eugamasus sp.1	P	**0**	**-**	**-**	**1**	**I**	**R**	**3**	**I**	**S**	1	I	R	0	-	-	**2**	**I**	**Ev**	**1**	**I**	**R**	8	0,4
Eugamasus sp.2	P	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Eupodes sp.	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	2	I	Ev	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Euseius inouei	P	**3**	**I**	**Ev**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	3	0,2

Euseius mesembrinus	P	**30**	**A**	**D**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	30	1,6
Eustigmaeus segnis	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	2	I	Ev	**7**	**I**	**S**	**5**	**I**	**S**	14	0,7
Gaeolaelaps aculeiferoides	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Gamasiphis sp.	P	**1**	**I**	**R**	**3**	**I**	**Ev**	**1**	**I**	**Ev**	0	-	-	0	-	-	**2**	**I**	**Ev**	**0**	**-**	**-**	7	0,4
Histiostoma sp.	G	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**2**	**I**	**Ev**	**0**	**-**	**-**	2	0,1
Laminamichaelia sp.	G	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Lasioseius sp.	P	**0**	**-**	**-**	**2**	**I**	**Ev**	**4**	**I**	**S**	2	I	Ev	1	I	R	**7**	**A**	**S**	**1**	**I**	**R**	17	0,9
Ledermuelleriopsis punctata	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	1	I	R	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Leptus sp.	P	**1**	**I**	**R**	**1**	**I**	**R**	**-**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Lorrya parvireticuli	G	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**1**	**I**	**R**	**0**	**-**	**-**	1	0,1
Macrocheles sp.1	P	**0**	**-**	**-**	**2**	**I**	**Ev**	**1**	**I**	**Ev**	0	-	-	3	I	Ev	**0**	**-**	**-**	**1**	**I**	**R**	7	0,4
Macrocheles sp.2	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**1**	**I**	**R**	**0**	**-**	**-**	1	0,1
Macrocheles subbadius	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**1**	**I**	**R**	**1**	**I**	**R**	2	0,1
Metaseiulus eiko	P	**4**	**I**	**Ev**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	4	0,2
Mononychellus planki	F	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Neocunaxoides ovatus	P	**1**	**I**	**R**	**3**	**I**	**Ev**	**3**	**I**	**S**	1	I	R	5	I	S	**0**	**-**	**-**	**0**	**-**	**-**	13	0,7
Neogamasellevans ammonis	P	**1**	**I**	**R**	**1**	**I**	**R**	**1**	**I**	**Ev**	0	-	-	5	I	R	**1**	**I**	**R**	**0**	**-**	**-**	9	0,5
Neogamasellevans preendopodalis	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	1	I	R	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Neoseiulus californicus	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	19	A	D	15	A	D	**13**	**A**	**D**	**30**	**A**	**E**	77	4,0
Neoseiulus mumai	P	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Neoseiulus sp.	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**1**	**I**	**R**	1	0,1
Neoseiulus tunus	P	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Ologamasus postpilus	P	**1**	**I**	**R**	**0**	**-**	**-**	**1**	**I**	**Ev**	0	-	-	0	-	-	**1**	**I**	**R**	**0**	**-**	**-**	3	0,2
Ologamasus margaridae	P	**0**	**-**	**-**	**18**	**A**	**R**	**11**	**C**	**D**	0	-	-	0	-	-	**6**	**A**	**S**	**11**	**A**	**S**	46	2,4
Ologamasus tuberculatus	P	**3**	**I**	**Ev**	**7**	**I**	**S**	**9**	**A**	**D**	1	I	R	2	I	Ev	**0**	**-**	**-**	**0**	**-**	**-**	22	1,2
Oribatida	G	**78**	**C**	**E**	**118**	**C**	**E**	**82**	**C**	**E**	67	C	E	100	C	E	**109**	**C**	**E**	**100**	**C**	**E**	654	34,3
Orolaelaps sp.1	P	**5**	**A**	**Ev**	**6**	**A**	**S**	**11**	**A**	**D**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	22	1,2
Orolaelaps sp.2	P	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Panonychus ulmi	F	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	1	I	R	**0**	**-**	**-**	**1**	**I**	**R**	2	0,1
Phytoseius grupo plumifer	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**1**	**I**	**R**	1	0,1
Podothrombium sp.	P	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1

Polyphagotarsonemus latus	F	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Proprioseiopsis ovatus	P	**1**	**I**	**R**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	5	A	S	**13**	**I**	**D**	**6**	**A**	**S**	26	1,4
Pseudoparasitus sp.	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	1	I	R	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Pseudopronematulus sp.	P	**18**	**A**	**S**	**3**	**I**	**Ev**	**1**	**I**	**Ev**	1	I	R	10	I	S	**0**	**-**	**-**	**0**	**-**	**-**	33	1,7
Puleus mormasensis	P	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	0	-	-	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Rubroscirus griloi	P	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Scutacarus sp.	G	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**1**	**I**	**R**	**0**	**-**	**-**	2	0,1
Scutopalus tomentosus	P	**1**	**I**	**R**	**1**	**I**	**R**	**1**	**I**	**Ev**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	3	0,2
Tarsonemus merus	G	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	18	A	D	3	I	Ev	**0**	**-**	**-**	**0**	**-**	**-**	21	1,1
Tarsonemus waitei	G	**0**	**-**	**-**	**0**	**-**	**-**	**1**	**I**	**Ev**	1	I	R	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Tarsonemus confusus	G	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	10	I	D	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	10	0,5
Tetranychus sp.	F	**7**	**I**	**S**	**0**	**-**	**-**	**1**	**I**	**Ev**	2	I	Ev	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	10	0,5
Tydeus californicus	G	**28**	**A**	**D**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**1**	**I**	**R**	**0**	**-**	**-**	29	1,5
Tydeus manoi	G	**0**	**-**	**-**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	0	-	-	**16**	**A**	**D**	**9**	**I**	**S**	25	1,3
Tyrophagus putrescentiae	G	**0**	**-**	**-**	**1**	**I**	**R**	**0**	**-**	**-**	8	A	S	6	I	S	**7**	**I**	**S**	**4**	**A**	**S**	26	1,4
Uropodina	G	**0**	**-**	**-**	**0**	**-**	**-**	**1**	**I**	**Ev**	0	-	-	1	I	R	**0**	**-**	**-**	**0**	**-**	**-**	2	0,1
Veigaia sp.	P	**0**	**-**	**-**	**0**	**-**	**-**	**1**	**I**	**Ev**	0	-	-	0	-	-	**0**	**-**	**-**	**0**	**-**	**-**	1	0,1
Xenotarsonemus sp.1	G	**1**	**I**	**R**	**25**	**I**	**E**	**0**	**-**	**-**	34	C	E	60	I	E	**5**	**I**	**S**	**2**	**I**	**Ev**	127	6,6
Xenotarsonemus sp.2	G	**1**	**I**	**R**	**0**	**-**	**-**	**0**	**-**	**-**	0	-	-	48	I	E	**0**	**-**	**-**	**0**	**-**	**-**	49	2,6
Xenotarsonemus sp.3	G	**29**	**I**	**D**	**0**	**-**	**-**	**2**	**I**	**Ev**	0	-	-	0	-	-	**12**	**A**	**S**	**3**	**I**	**Ev**	46	2,4
Zygoseius furciger	P	**0**	**-**	**-**	**4**	**I**	**S**	**2**	**I**	**Ev**	5	I	S	0	-	-	**1**	**I**	**R**	**3**	**A**	**Ev**	15	0,8
		41						**16**			22						**27**			**24**			190	
	Abundance	**5**			**262**			**3**			0			324			**8**			**6**			8	
	Richness	**39**			**31**			**25**			24			26			**25**			**23**				
%		**21,8**			**13,7**			**8,5**			11,5			17,0			**14,6**			**12,9**				

T = Total of mites. C = Constance: C = Constant, A = Accessory, I = Accidental. D = Dominance: Eu = Eudominant, Do = Dominant, S = Subdominant, Ev = Eventual. Food habit: P = Predator, G = Generalist, F = Phytophagous.

CAPITULO 7

Rode, P.A., Wurlitzer, W.B., Ferla, N.J. *Tetranychus ludeni* Zacher, 1913 (Tetranychidae) and *Phytoseiulus macropilis* (Banks, 1904) (Phytoseiidae) in apple trees grown in a greenhouse in southern Brazil: injuries and control. Artigo submetido no periódico "Entomological Communication". (Situação: Publicado).

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Scientific Note

Tetranychus ludeni Zacher, 1913 (Tetranychidae) and *Phytoseiulus macropilis* (Banks, 1904) (Phytoseiidae) in apple trees grown in a greenhouse in southern Brazil: injuries and control

Priscila A. Rode, Wesley B. Wurlitzer, Noeli J. Ferla

Universidade do Vale do Taquari - Univates, Lajeado, RS, Brazil.
Corresponding author: wesleeywurlitzer@gmail.com

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Abstract. This study reports the presence and injuries caused by *Tetranychus ludeni* Zacher, 1913 (Acari: Tetranychidae) on apple tree seedlings (*Malus domestica* Borkh: Rosaceae) in nurseries in southern Brazil. The ability of the predatory mite of *Phytoseiulus macropilis* (Banks, 1904) (Acari: Phytoseiidae) to control *T. ludeni* infestations in this environment was also evaluated. *Tetranychus ludeni* infestation was observed during routine monitoring at the Acarology Laboratory of the University of Vale do Taquari - Univates, Lajeado, Rio Grande do Sul. Injuries were observed on the leaves, with gradual growth linked to the population increase of *T. ludeni*. In the control seedlings, there was defoliation and weakening of the plant. *Phytoseiulus macropilis* released on infested plants controlled the populations of this phytophagous mite. Fifty specimens of *P. macropilis* were released in each seedling. *Tetranychus ludeni* caused injuries to apple seedlings, while *P. macropilis* proved to be efficient in controlling this phytophagous mite.

Keywords: Agroecology, Biological control, Plant health, *Malus domestica.*

Brazil is among the largest apple producers in the world and has been growing in the foreign market through the advancement of exports to several countries (Kist 2019). Brazilian apple production is mainly concentrated in the southern region of the country, due to the favorable environment for culture (Kist 2019). Among the main problems of this crop in Brazil are mite infestations, such as those of *Panonychus ulmi* (Koch, 1836) (Acari: Tetranychidae) that reach high populations, causing injuries and damage (Ferla & Moraes 1998; Monteiro 2002; Silva et al. 2022). In addition, the occurrence of *Aculus schlechtendali* (Nalepa, 1890) (Acari: Eriophyidae) and *Tetranychus ludeni* Zacher, 1913 (Acari: Tetranychidae) has been reported, however, with no record of economic damage (Flechtmann 1996; Ferla et al. 2018; Nascimento et al. 2020). Changes in agroecosystems and the indiscriminate use of chemicals in apple crops favor the population increase of phytophagous mites, as they reduce the presence of natural enemies (Lorenzato & Secchi 1993; Schmidt-Jeffris & Beers 2018).

Tetranychus ludeni is associated with more than 300 species of plants, some of which are of economic importance, such as carrots, beans, eggplant, pumpkin and papaya (Zhang 2003; Gotoh et al. 2015). It preferentially attacks the apical and median leaves of the plants, using their stylets to pierce the epidermis and suck the cellular contents (Moraes & Flechtmann 2008). In Brazil, *T. ludeni* can occur in high populations in several crops, such as cotton, soybeans and beans, causing injuries and damages (Moraes & Flechtmann 2008; Mendonça et al. 2011; Reichert et al. 2014; Reichert et al. 2016). At temperatures close to 30 °C, there is an increase in reproduction and fecundity, raising populations to the level of injuries (Silva 2002; Gotoh et al. 2015). Gotoh et al. (2015) suggested that because *T. ludeni* is well adapted to warmer climates, it could displace *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) in some crops, and become one of the main agricultural pests in the world. In apple trees, so far, there is only one occurrence reported by Flechtmann (1996) in the Country of Porto Alegre, state of Rio Grande do Sul.

Phytoseiidae are widely distributed worldwide, and some species are recognized as important natural enemies used in programs of applied biological control of phytophagous mites (Sato et al. 2007; McMurtry et al. 2013). Species of the genus *Phytoseiulus* Evans, 1952, are specialist predators (Group Ia) that feed specifically on spider mites of the genus *Tetranychus* (McMurtry & Croft 1997; McMurtry et al. 2013). Studies demonstrated the potential of *Phytoseiulus macropilis* (Banks, 1904) (Acari: Phytoseiidae) to control *T. urticae* in strawberries (Ferla et al. 2007), tomato (Sato et al. 2011) and soybean (Reichert et al. 2014; Rezende et al. 2014). Lorenzato & Secchi (1993) reported the presence of *P. macropilis* in apple trees.

There are few studies about *T. ludeni* associated with apples and no reference to injuries caused by this mite species in adult plants or apple tree seedlings. Thus, this study aims to record the presence and injuries caused by *T. ludeni* in apple tree seedlings in nurseries in southern Brazil, as well as to evaluate the ability of the predatory mite *P. macropilis* to control infestations in this environment.

Apple tree seedlings were acquired from a commercial nursery in the municipality of Lajeado, state of Rio Grande do Sul, Brazil. The plants were kept in a greenhouse in black plastic pots (11 L) containing organic compost and soil, irrigated every three days and kept isolated to be used in a laboratory experiment. Natural infestations of *T. ludeni* were observed on 20 apple plants of the Gala cultivar, seedlings, during routine monitoring. Infested leaves were collected and triaged for specimen identification at the Acarology Laboratory of the University of Vale do Taquari - Univates (Labacari), Lajeado, Rio Grande do Sul. The collected mites were mounted on microscope slides with Hoyer's medium and taken to a drying kiln at a temperature between 50-60 °C and kept for seven days. The identification was carried out at Labacari using an Optical Microscope with phases contrast - (Zeiss Imager Z2) and dichotomous key (Baker & Turtle 1994). Specimens were deposited in the reference collection of the Laboratory of Acarology at Univates (ZAUMCN).

The stock rearing of *P. macropilis* was established in bean trays (*Phaseoulus vulgaris* L.: Fabaceae) and the mites fed with *T. urticae* under laboratory conditions (25±1 °C temperature, 12 hours of photophase and 70±5% of relative humidity) during the evaluation

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period.

Fifty stock rearing predatory mites were released per plant, with the aid of a fine-tipped brush, one month after recording the presence of *T. ludeni* on the seedlings. Two seedlings were kept isolated and without the presence of the predator. The seedlings were kept isolated in a greenhouse during the evaluation period of *P. macropilis* populations feeding on *T. ludeni*. Every week, two leaves were taken from each plant to evaluate the populations of phytophagous and predatory mites under a stereoscopic microscope (40×). The experiment finished in one month, when no phytophagous mites were observed.

This is the first record of *T. ludeni* causing injuries to apple seedlings in a commercial nursery in Rio Grande do Sul (Fig. 1). *Tetranychus ludeni* is not considered a species of economic importance in apple crops (Ferla et al. 2018; Nascimento et al. 2020), and has been reported only once before infesting apples in Brazil (Flechtmann 1996).

Tetranychus ludeni was observed for the first time in January, a period of high temperatures that favored the survival of this mite (Silva 2002; Gotoh et al. 2015). Initially the occurrence was in the oldest leaves, and soon it spread throughout the plant, including the apical leaves, as in other cultures (Silva 2002). After a week, the first signs of injuries, formation and rapid growth of the web were recorded, in addition to considerable population growth. In the first evaluation, an average of 10 mites/leaf were observed and, after three weeks, the populations reached 40 mites/leaf. The observed injuries were similar to those caused by other phytophagous species of economic importance in the crop (Lorenzato 1988; Silva 2002; Moraes & Flechtmann 2008). The adaxial surface of the leaves showed darkening and reddish spots characteristic of leaf tanning (Fig. 2). With the population increase, the entire plant was colonized, and the leaves showed injuries that increased levels gradually. The behavior of *T. ludeni* on apple seedlings was similar to that observed by Silva (2002) on cotton leaves where the species is already established.

One week after the release of *P. macropilis*, it was possible to notice the frequent presence of populations of the predator, with an average of six predatory mites/leaf. In one month, 18 mites/leaves were already observed. As well as the considerable decrease of phytophagous mites

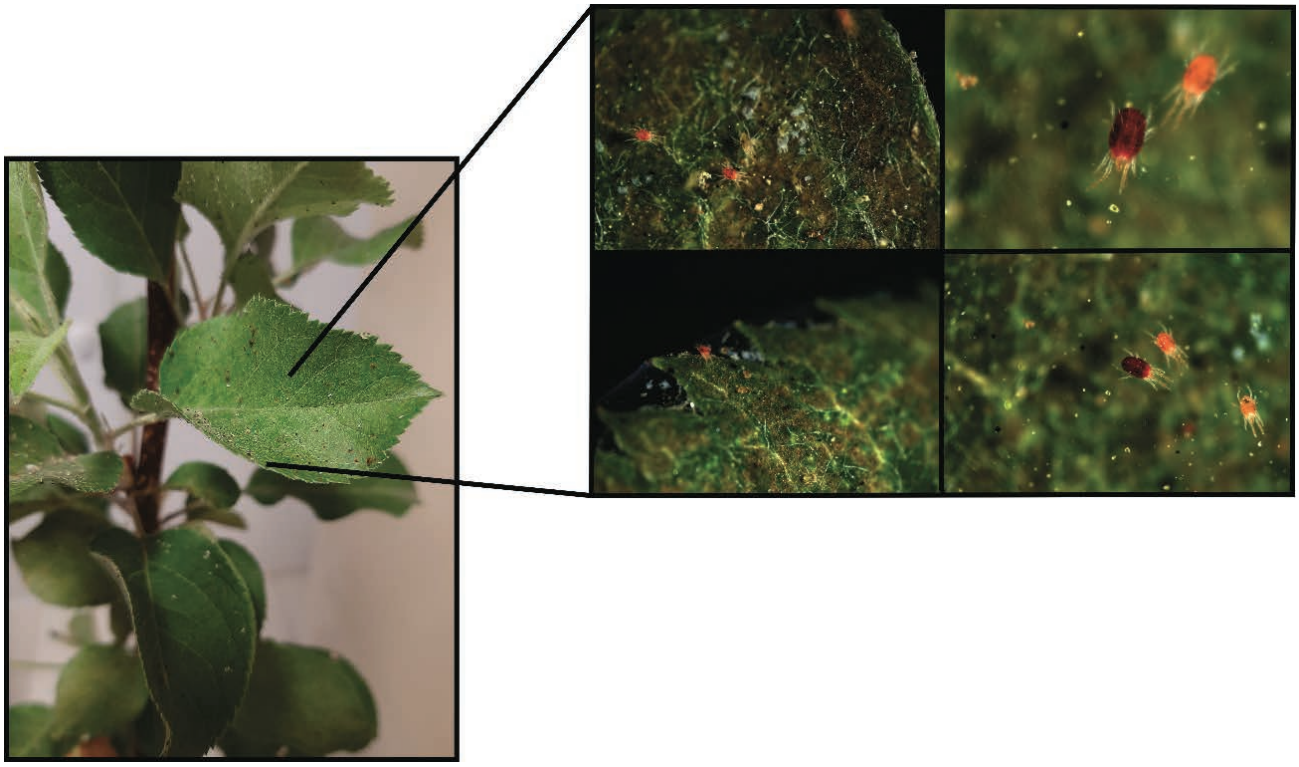

Figure 1. Apple tree leaves showing injuries caused by *Tetranychus ludeni* Zacher, 1913 (Acari: Tetranychidae).

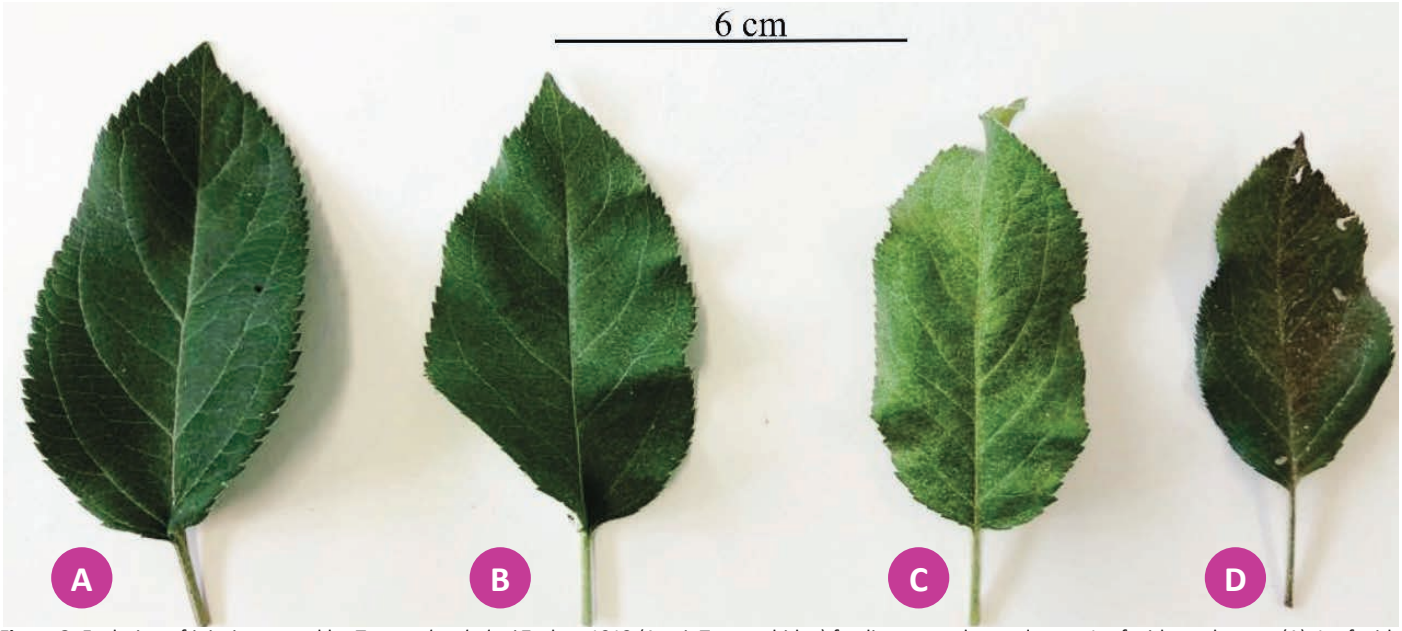

Figure 2. Evolution of injuries caused by *Tetranychus ludeni* Zacher, 1913 (Acari: Tetranychidae) feeding on apple tree leaves. Leaf without damage (A); Leaf with injuries (B); Leaf with initial damage (C); Damaged sheet (D).

that quickly had their populations controlled until the disappearance of all specimens, in the fourth week. The control plants showed a progressive increase in *T. ludeni* and injuries populations, reaching a high level of injuries. After four weeks, defoliation and weakening of the plant were observed.

The report of the occurrence of *T. ludeni* causing injuries to seedlings of apple trees serves as a warning to nurseries and growers because it is a species that in several cultures is already considered of economic importance. In addition, these results suggest *P. macropilis* as a possible controller of *T. ludeni* populations in apple trees. From the present record, it is important that further studies are carried out to investigate the occurrence of *T. ludeni* in apple trees, considering its potential as a possible cause of economic damage in situations where populations reach commercial apple orchards. In addition, it is interesting to investigate the potential of *P. macropilis* as a candidate for controlling *T. ludeni* populations in apple plants, which could serve as an alternative to prevent future problems that producers may face due to the emergence of *T. ludeni* in apple trees.

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Authors' Contributions

PAR with the cultivation and maintenance of apple tree seedlings. WBW with mite identification and photographic record. PAR and WBW with the monitoring of infestations and writing of manuscript; NJF with manuscript revisions and major revisions.

Conflict of Interest Statement

The authors declare no conflict of interest.

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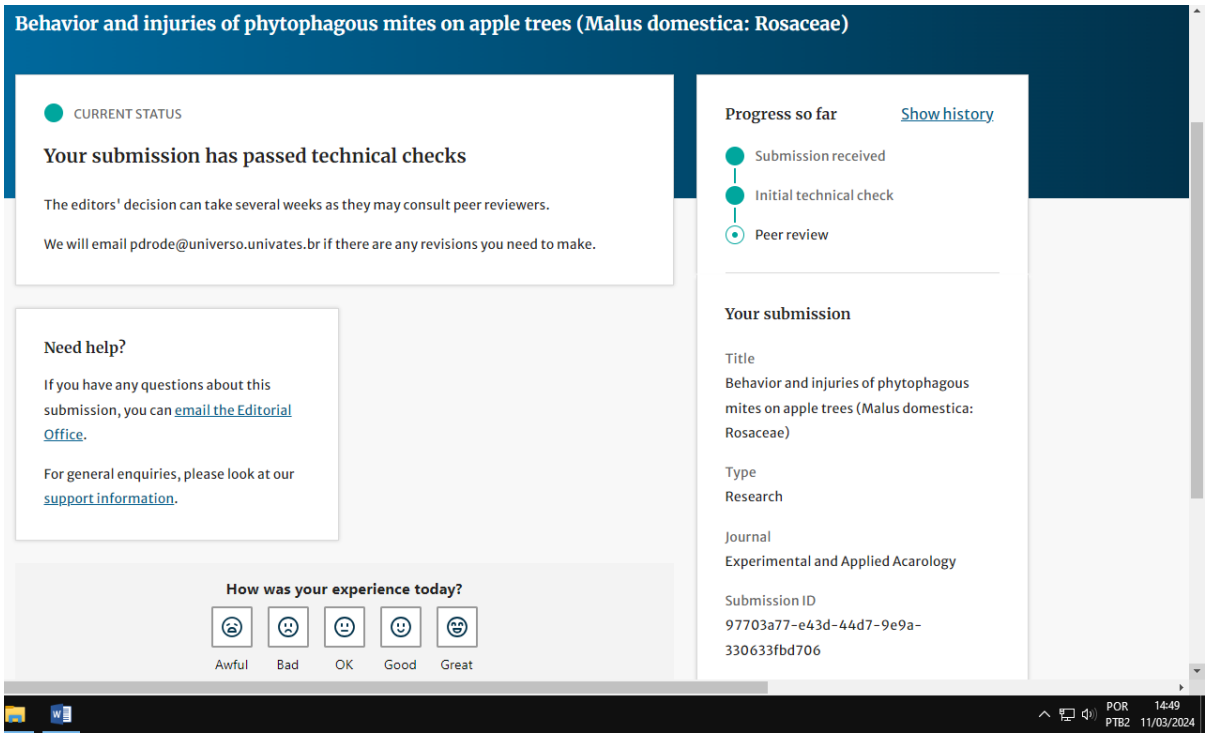
CAPITULO 8

Rode, P.A., Schneider, J.R., Mariano, C.J.C., Matthes, R.D., Castro, I.S., Ferla, N.J. Behavior and injuries of phytophagous mites on apple trees (*Malus domestica*: Rosaceae). Artigo submetido no periódico "Experimental and applied acarology". (Situação: Em revisão).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Behavior and injuries of phytophagous mites on apple trees (Malus domestica: Rosaceae)

Priscila Andrade Rode
pdrode@universo.univates.br

Universidade do Vale do Taquari - Univates

Júlia Renata Schneider
Universidade do Vale do Taquari - Univates

Cristina Jardim Cezar Mariano
Universidade do Vale do Taquari - Univates

Ronice Drebel Matthes
Universidade do Vale do Taquari - Univates

Iury Silva Castro
Universidade do Vale do Taquari - Univates

Noeli Juarez Ferla
Universidade do Vale do Taquari - Univates

Research Article

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Additional Declarations: No competing interests reported.

Abstract

This study aimed to assess the behavior of phytophagous mites, including conspecific and heterospecific effects, and the injuries caused by them at different population levels on apple tree leaves (*Malus domestica*: Rosaceae). The oviposition of *Panonychus ulmi* (Koch) was evaluated on apple tree leaves with the presence of webs, eggs, and cues of phytophagous mites (*Aculus schlechtendali* (Nalepa), *P. ulmi*, *Tetranychus urticae* Koch, and *Tetranychus ludeni* Zacher). The response to different infestation levels of *P. ulmi*, *T. urticae*, and *T. ludeni* on apple tree leaves was assessed through chlorophyll A, B, and total chlorophyll indices and membrane stability loss. The presence of conspecific webs and cues increased the oviposition of *P. ulmi*, while the presence of *A. schlechtendali* and *T. urticae* webs and eggs decreased oviposition. The presence of *A. schlechtendali* cues also led to a decline in *P. ulmi* oviposition. Leaves infested with *T. urticae* showed higher chlorophyll loss, leaves infested by *P. ulmi* and *T. ludeni* had decreased chlorophyll averages in treatments with 25 mites/leaf and above. The evaluation of membrane stability loss identified *T. ludeni* as a potential cause of injuries in apple trees. The evaluations indicated that the higher the number of mites on the leaf surface, the larger the damaged area. This work warning to the apple production chain for monitoring infestations and preventing a potential threat to culture. These results provide a foundation for further research on the potential of apple tree phytophagous mites and their interactions, both among herbivores and with predators.

Introduction

Brazil is among the largest producers of apples (*Malus domestica* Borkh: Rosaceae) in the world, and the quality of the fruits in the country has been increasing each year (Kist et al. 2019, 2022). Brazilian production is primarily located in the higher regions of the three southern states, due to the favorable climate for cultivation (Kist et al. 2019). However, the expansion of cultivation areas has contributed to the geographical distribution of agricultural pests that attack the crop (Wheeler and Hoebeke 2009). Furthermore, the continuous and indiscriminate use of pesticides in orchards has led to a reduction in natural enemies and an increase in pests, such as phytophagous mites (Lorenzato and Secchi 1993; Walker et al. 2017; Schmidt-Jeffries and Beer 2018), potentially leading to species resistance, further complicating control efforts (Bajda et al. 2015; Rameshgar et al. 2019; Mota-Sanchez and Wise 2023).

When populations reach pest status in the crop, they cause environmental, economic, and social impacts (Brown and Hovmøller 2002; Anderson et al. 2004; Navia et al. 2011). Among the main species causing damage to apple trees worldwide are *Panonychus ulmi* (Koch), *Tetranychus urticae* Koch (Tetranychidae), and *Aculus schlechtendali* (Nalepa) (Eriophyidae) (Jeppson et al. 1975; Ferla and Moraes 1998; Monteiro 2001, 2002; Nascimento et al. 2020; Kasap and Atlihan 2021).

Panonychus ulmi has been reported with populations exceeding the economic damage threshold in apple orchards worldwide, and for decades, it has been cited as the main phytophagous mite affecting the crop (Lorenzato et al. 1986, 1987; Moraes and Flechtmann 2008; Ferla and Botton 2008; Yin et al. 2013; Kasap et al. 2019; Ivanović et al. 2022). The damage caused by this species is characterized by leaf bronzing, and in severe infestations, it can lead to premature leaf drop (Moraes and Flechtmann 2008). The species has a high dispersal capability and an aptitude for colonizing new areas due to the occurrence of winter eggs, high reproductive rates, and a reproductive mode that allows a small number or even a single female to initiate a rapidly growing colony (Helle and Sabelis 1985).

Tetranychus urticae, considered economically significant in various crops, including fruit trees, vegetables, and flowers, is a major pest in greenhouses, cultivated fields, and orchards (Bolland et al. 1998; Van Leeuwen et al. 2010). It disperses through the air over long distances while migrating shorter distances among nearby trees in apple

orchards (Uesugi et al. 2009). In apple cultivation, it has been reported causing damage in various parts of the world (He et al. 2001; Liu et al. 2006; Funayama 2010; Kamusiime et al. 2023). In Brazil, it has been reported in apple orchards (Moraes and Flechtmann 2008) however, recent surveys have not found the species in the assessed orchards (Silva et al. 2022).

Aculus schlechtendali, considered of quarantine importance and recently reported in Brazil, has been observed throughout the southern region of the country, although there are no records of damage in Brazilian orchards yet (Ferla et al. 2018; Nascimento et al. 2020). In countries where the species is considered economically significant, the damage is attributed to the piercing of plant epidermal cells by its stylets, resulting in symptoms characterized by bronzing on the surface of leaves, flowers, and fruits (Duso et al. 2010). The presence of *A. schlechtendali* raises concerns about the potential for this species to reach pest status if not controlled early, becoming a problem for farmers (Nascimento et al. 2020; Corrêa et al. 2021).

Tetranychus ludeni Zacher (Tetranychidae) is associated with over 250 species of host plants, including some of economic importance (Zhang 2002; Adango et al. 2006; Moraes and Flechtmann 2008; Gent et al. 2009; Reichert et al. 2014; Gotoh et al. 2015; Fathipour and Maleknia 2016). The species tends to occur in high populations on the adaxial surface of the apical and median leaves of plants, primarily in cotton and soybean crops, causing injuries and damage (Zhang 2002; Adango et al. 2006; Moraes and Flechtmann 2008; Reichert et al. 2014; Gotoh et al. 2015; Toldi et al. 2016). In apple trees, there is a record of *T. ludeni* occurrence in an orchard (Flechtmann 1996) and another occurring and causing injuries in seedlings (Rode et al. 2023), serving as a warning to the cultivation due to the potential for future infestations in orchards and damage to plants.

Infestations of phytophagous mites pose problems as they cause injuries and result in the loss of leaf and fruit quality (Flechtmann 1975; Ochoa 1991). The damage caused by these organisms is primarily due to direct effects, involving the destruction of leaf parenchyma and an increase in transpiration from the attacked leaf (Moraes and Flechtmann 1981). Tetranychids pierce plant epidermal cells to feed, causing leakage of cytoplasmic content, air entry, increased transpiration due to water deficit, and changes in coloration due to chlorophyll removal, resulting in a decrease in the plant's photosynthetic capacity (Moraes and Flechtmann 2008; Vacante 2015). Chlorophylls are the most abundant natural pigments present in plant leaves, contributing to the absorption of photosynthetically active radiation and being crucial for oxygen and sugar production (Blackburn 2007; Jay et al. 2017). Chlorophyll content is an important indicator of the physiological state of plants and is widely used to analyze the development and growth of the plant under study (Blackburn 2007; Steele et al. 2008; Sperotto 2014). Additionally, monitoring chlorophyll loss in plant tissues is one of the indicators that allows the determination of a plant's tolerance to phytophagous pest attacks (Smith 2005), assisting in orchard management and indicating fruit quality.

To date, there is limited information about injuries caused by phytophagous mites in apple trees in Brazil, especially regarding the potential damage caused by *T. ludeni* to the crop. Additionally, little is known about the behavior of *P. ulmi* in the presence of other phytophagous species sharing the same environment. Thus, this study aimed to evaluate the behavior of phytophagous mites, including conspecific and heterospecific effects, and the injuries caused by them at different population levels on apple tree leaves.

Materials and methods

Apple trees

Seedlings of the Eva apple cultivar were obtained from a commercial nursery in the city of Lapa, state of Paraná. The plants were grown in black plastic pots (11L) filled with Carolina Soil® substrate and soil, kept in a protected area, and irrigated every two days. These plants were used for maintaining the arenas of phytophagous mite stock cultures and for the bioassays conducted during the study period.

Phytophagous mite stock cultures

Aculus schlechtendali. The stock culture was established using specimens collected from apple tree leaves in the municipality of Antônio Prado, state of Rio Grande do Sul (28°53´23”S 51°23’06”W). The arenas were maintained in rectangular trays (30 × 20 cm) containing moistened foam covered with germination paper. Two apple tree leaves with the abaxial side facing up were placed on the paper, and the edges and part of the petiole were covered with moistened hydrophilic cotton. Each arena received 30 specimens. A rectangular glass was placed over each tray to maintain humidity in the arenas. The arenas were kept in a climate-controlled room at 25 ± 1°C, with a 14-hour photoperiod and relative air humidity (RH) of 75 ± 5%. Daily, the arenas were moistened to maintain the vigor of the apple tree leaves. New arenas were constructed whenever the leaves showed a yellowish color, indicating they were unsuitable for maintaining mite populations.

Panonychus ulmi. For the establishment of cultures, collections were made in an apple orchard in the municipality of Antônio Prado. The methodology adopted for the cultures was adapted from Herbert (1981). Mites were transferred to arenas made with apple tree leaves. The arenas were constructed in rectangular trays (30 × 20 cm) containing moistened foam covered with germination paper. Two apple tree leaves with the adaxial side facing up were placed on the paper, and the edges and part of the petiole were covered with moistened hydrophilic cotton. Each arena received 20 adult females of *P. ulmi* and was kept in a germination chamber at 25 ± 1°C, with a 14-hour photoperiod and RH of 75 ± 5%, receiving daily irrigation to maintain leaf vigor.

Tetranychus ludeni. Cultures were established using specimens collected from soybean plants (*Glycine max* (L.) Merrill: Fabaceae) in the city of Muitos Capões, RS (28°21’32.4"S 51°14’46.2"W). The specimens were transferred to bean plants (*Phaseolus vulgaris* (L.): Fabaceae) cultivated in trays of 45 × 30 × 8 cm (7 L) with Carolina Soil® substrate. Infested bean trays were kept in a germination chamber at 25 ± 1°C, with a 14-hour photoperiod and RH of 75 ± 5%, receiving daily irrigation to maintain leaf vigor.

Tetranychus urticae. Cultures pre-established in the Laboratory of Acarology at Univates (Labacari) were multiplied. The specimens were transferred to bean plants cultivated in trays of 45 × 30 × 8 cm (7 L) with Carolina Soil® substrate.

Oviposition of Panonychus ulmi

Species combinations. The methodology for assessing the effect of damage, webbing, and the presence of other phytophagous mite species on the oviposition of *P. ulmi* was adapted from Sarmento et al. (2011). Forty arenas were constructed from apple tree leaves for each interaction of mite species, with 20 for testing the influence of webs and eggs on the presence of *P. ulmi* and another 20 to evaluate the influence of the presence of cues on the presence of the species. The arenas were constructed in Petri dishes with the bottom covered with a circle of cotton moistened with distilled water. On the cotton, an apple tree leaf was placed with the adaxial side facing up. The arenas for *A. schlechtendali* were constructed with the abaxial side of the leaf facing up, keeping the cotton moistened at the edges to prevent mite escape. The tested mite interactions were: *P. ulmi* × *P. ulmi*; *P. ulmi* × *T. urticae*; *P. ulmi* × *A. schlechtendali*; *P. ulmi* × *T. ludeni*; *P. ulmi* × Control (without the presence of another species in the arena). Each arena

received 10 mated females of conspecific or heterospecific mites, where they remained for two days feeding, ovipositing, and producing webs.

Effects on conspecifics and heterospecifics. After two days of infestation, mites from different species were removed from the arenas with the aid of a fine-tipped brush, taking care not to damage the web, and the web and eggs were kept for evaluation. In *A. schlechtendali* arenas, the specimens were kept as this species does not produce webs, and visualizing their eggs was not possible. A dated and mated female of *P. ulmi* was released and kept for four days in each arena. Oviposition was evaluated daily at 1:00 pm. The arenas were kept in rectangular trays at 25 ± 1°C, with a 14-hour photoperiod and RH of 75 ± 5%. The data were subjected to the Kruskal-Wallis test followed by the Dunn test, using BioEstat 5.3 software at a significance level of 5% (Ayres et al. 2007).

Effect of olfactory cues on conspecifics and heterospecifics. After two days of infestation, mites were removed from the arenas along with eggs and webs. Subsequently, a dated and mated female of *P. ulmi* was released into each arena. The *P. ulmi* female was kept in the arenas for four days, and daily oviposition assessment was conducted at 1:00 pm with the presence of conspecific and heterospecific tracks. The arenas were kept in rectangular trays at 25 ± 1°C, with a 14-hour photoperiod and RH of 75 ± 5%. The data were subjected to the Kruskal-Wallis test followed by the Dunn test, using BioEstat 5.3 software at a significance level of 5%.

Evaluation of injuries

Tests. Three apple trees were used for injury assessments caused by *P. ulmi*, three for *T. urticae*, and three for *T. ludeni*, totaling three replicates per species for each treatment. Five leaves were isolated at the base of the petiole with entomological glue, each corresponding to a treatment. Each tree received a specific quantity of mites according to the corresponding treatment: Control: 0/leaf; T1: 10 mites/leaf (T10); T2: 25 mites/leaf (T25); T3: 50 mites/leaf (T50); T4: 100 mites/leaf (T100). The mites remained on the leaves for seven days, and the apple trees were kept at 25 ± 1°C, with a 14-hour photoperiod and RH of 75 ± 5% during the experiment. After the period, the leaves were removed from the trees and sent for bioassays.

Chlorophyll index A, B, and total. To assess the total chlorophyll index, contaminated leaves were removed from the plants, and the assessment was immediately performed using an electronic chlorophyll content meter, ClorofiLOG CFL1030, Falker model. Ten random points were measured on each leaf. The measurement is made optically, based on the specific wavelengths of each chlorophyll. The means were subjected to the Kruskal-Wallis test followed by the Dunn test, using BioEstat 5.3 software at a significance level of 5%.

Membrane stability loss. For the evaluations of damage caused by *T. ludeni*, *T. urticae*, and *P. ulmi* on apple tree leaves, the histochemical analysis of plasma membrane stability loss, indicative of cell death, was performed using the method adapted from Romero-Puertas et al. (2004). For the analysis, a solution of 0.25% Evans Blue dye (0.25 g in 100 mL Milli-Q® Ultrapure water) was prepared. Subsequently, the leaves of each treatment were immersed in a Petri dish with the solution and remained at room temperature for five hours. Then, the leaves were removed from the solution and boiled in absolute alcohol, with a drop of glycerin for about an hour to remove the chlorophyll. During boiling, the Evans Blue dye penetrated the dead cells, marking the tissue with points or regions of bluish color due to damage caused by phytophagous mites. After boiling, the leaves were removed and preserved in a container with 70% alcohol for later photographic documentation.

Results

Oviposition of Panonychus ulmi. In terms of the effects of conspecifics and heterospecifics, the presence of conspecific webs and eggs and those of *T. ludeni* caused an increase in the oviposition of *P. ulmi*, with no significant difference between them (Fig. 1). The effect of the heterospecific *T. ludeni* on oviposition was similar to the control, while in the presence of webs and eggs of *A. schlechtendali* and *T. urticae*, there was a decrease in oviposition.

Regarding the effect of conspecific and heterospecific olfactory cues on the oviposition of *P. ulmi*, the previous cues of *P. ulmi* caused a significant increase in oviposition, differing from the others (Fig. 2). The presence of olfactory cues from *T. urticae* and *T. ludeni* showed a response similar to the control. On the other hand, previous cues from *A. schlechtendali* caused a significant decline in the oviposition of *P. ulmi*.

Injury assessment. Leaves with *P. ulmi* showed significantly higher chlorophyll A indices in the control (C) and T10 compared to T25, T50, and T100 (Table 1). Regarding the content of chlorophyll B and total chlorophyll, the highest indices were found in C and T10, decreasing in T25 but with the lowest indices for T50 and T100. Leaves with *T. ludeni* followed the same response observed for *P. ulmi* regarding chlorophyll A. The indices of chlorophyll A, B, and total were significantly higher in C and T10 compared to T25, T50, and T100. Leaves with *T. urticae* had higher chlorophyll A, B, and total indices in the control compared to the other treatments. The lowest chlorophyll indices were observed for T50 and T100. When comparing chlorophyll levels between species, *T. urticae* showed a greater loss of chlorophyll in apple leaves. *Panonychus ulmi* and *T. ludeni* had higher levels of chlorophyll A, B, and total when compared to *T. urticae* in both C, T10, T25, and T50. In T100, *T. ludeni* showed a higher content of chlorophyll A, B, and total, while *P. ulmi* and *T. urticae* did not differ statistically.

Table 1
Evaluation of chlorophyll A, B, and total content (Mean ± SE) in apple leaves under different infestation levels of *Panonychus ulmi*, *Tetranychus ludeni*, *Tetranychus urticae* and Control (C), with 10 mites (T10), 25 mites (T25), 50 mites (T50), and 100 mites (T100).

Treatment	Chlorophyll								
	A			B			Total		
	Panonychus ulmi	*Tetranychus ludeni*	*Tetranychus urticae*	*P. ulmi*	*T. ludeni*	*T. urticae*	*P. ulmi*	*T. ludeni*	*T. urticae*
C	42.7 ± 0.32 Aa	43.2 ± 0.30 Aa	39.8 ± 0.33 Ba	18.1 ± 0.60 Aa	18.7 ± 0.49 Aa	14.3 ± 0.32 Ba	60.8 ± 0.88 Aa	61.9 ± 0.76 Aa	54.1 ± 0.59 Ba
T10	41.1 ± 0.33 Aa	41.9 ± 0.58 Aa	34.7 ± 0.33 Bb	16.6 ± 0.65 Aa	18.1 ± 0.55 Aa	8.5 ± 0.30 Bb	57.7 ± 0.93 Aa	60.1 ± 0.99 Aa	43.1 ± 0.51 Bb
T25	38.4 ± 0.45 Ab	39.2 ± 0.52 Ab	34.1 ± 0.44 Bb	13.2 ± 0.42 Ab	13.6 ± 0.70 Ab	8.2 ± 0.23 Bb	51.6 ± 0.89 Ab	52.8 ± 1.20 Ab	42.3 ± 0.62 Bb
T50	37.6 ± 0.30 Ab	39.2 ± 0.55 Ab	29.0 ± 0.70 Bc	11.7 ± 0.27 Abc	13.1 ± 0.53 Ab	6.0 ± 0.25 Bc	49.3 ± 0.52 Abc	52.3 ± 1.03 Ab	35.0 ± 0.87 Bc
T100	31.8 ± 1.47 Bb	36.0 ± 1.24 Ab	25.4 ± 1.47 Bc	8.1 ± 0.65 Bc	12.8 ± 1.04 Ab	6.6 ± 0.40 Bc	39.9 ± 2.14 Bc	48.8 ± 2.18 Ab	32.0 ± 1.81 Bc

*Means (Mean ± SE) followed by the same lowercase letter within a column in the treatments do not differ statistically from each other by the Kruskal-Wallis test, followed by Dunn's test (α = 0.05).

**Means (Mean ± SE) followed by the same uppercase letter in the row, the species do not differ statistically in terms of chlorophyll by the Kruskal-Wallis test followed by Dunn's test (α = 0.05).

In the histochemical analysis of plasma membrane stability loss (indicative of cell death), similar levels were observed in leaves infested by *P. ulmi* in C, T10, T25, and T50, with a higher intensity of injuries in leaves with T100 (Fig. 3). In leaves infested with *T. ludeni*, C, T10, and T25 showed similar levels of membrane stability loss, while in T50 and T100, there was a higher intensity of loss. In leaves infested with *T. urticae*, injuries were less visible, with no blue coloration representing mite attacks in both C and T10, T25, and T50; some points were observed in T100.

Discussion

The results of this study suggest that the presence of conspecific eggs, webs, and olfactory cues increases the oviposition of *P. ulmi* on apple leaves, indicating that the species performs better in environments without heterospecific competitors and where conspecifics have been and demonstrated safety for the development of future generations. However, there is a decrease in oviposition of *P. ulmi* in the presence of *A. schlechtendali*, indicating a potential competitive displacement of the Tetranychid by the Eriophyid mites.

The previous presence of mites of the same species may have favored oviposition and the establishment of new populations, as the perception of conspecifics could be an indicator of safety in terms of the absence of natural enemies or other risky situations (Shiojiri et al. 2002; Rodriguez-Saona et al. 2005; Rodriguez-Saona & Thaler 2005). Given that some herbivores vary their oviposition based on interspecific competition, the pre-existence of the species at the site may indicate less competition for resources (Mayhew 1997; Gripenberg et al. 2010). Thus, new populations of *P. ulmi* may have perceived the location as a favorable environment for the establishment of their offspring as a survival strategy for the species.

The presence of *T. urticae* (web and egg) causing a decrease in the oviposition of *P. ulmi* on apple leaves may indicate competition between the species (Ferragut et al. 2013; López-Olmos and Ferragut 2023). Moreover, the decrease in oviposition of *P. ulmi* in the presence of webs and olfactory cues of *A. schlechtendali* may indicate a competitive displacement of the Tetranychid due to the presence of the Eriophyid, as observed by Croft and Hoying (1977). There are reports of competitive displacement due to the coexistence of species that use and compete for the same spaces and resources (López-Olmos and Ferragut 2023). Although competition is one of the regulators of species abundance within a community, and despite its economic importance, few studies address competition among mite species (Reitz and Trumble 2002). Therefore, specific studies on the competition between phytoseiid mite species present in apple orchards are recommended.

The differential oviposition responses, both in terms of conspecific perception and potential competition with heterospecifics, may be related to the chemical substances released by the species, such as kairomones and infochemicals, which are responsible for information transmission (Dicke and Sabelis 1988; Dicke et al. 1990). Similar to many studies demonstrating the influence of volatiles released by plants on predator-prey behavior in a tritrophic context, these kairomones can be compounds associated with the herbivores themselves present in their feces, eggs, exuviae, webs, and pheromones (Collier et al. 2000; Afsheen et al. 2008; Peñaflor 2019), mediating the behavior and interaction among organisms (Collier et al. 2000; Ayelo et al. 2021).

Regarding injuries, the infestation level of different phytophagous species influenced the chlorophyll index of the apple trees, with higher infestations of *T. urticae* causing a more significant decrease in chlorophyll levels. The loss of membrane stability was also more affected by higher infestation levels, but in this case, the species responsible for the higher cell death was *T. ludeni*. These different observed responses may be related to the distinct damages caused by each acarine species on the plant leaves and can help elucidate the damage threshold for each species in question.

Arthropods, in general, damage the physiological metabolism of plants, with piercing through stylets breaking cells, potentially reaching the photosynthetically active mesophyll tissue, leading to the destruction of chloroplasts (Bueno et al. 2009). Thus, reductions in photosynthetic pigments can be explained due to injuries caused by the mite, as it sucks cellular content, extracting cytoplasmic content from the cells (Nagara et al. 2002). The significant decrease in chlorophyll levels in apple plants caused by *T. urticae* is likely a result of the metabolically active secretions of the species, which may have interacted with the plant's photosynthetic mechanism, causing a greater decrease in chlorophyll indices (Nagara et al. 2002). Also, the aggressiveness of the species may contribute, as cells not directly damaged but adjacent to those that suffered harm may exhibit mild symptoms (Park and Lee, 2002).

The evaluations further showed that the level of phytophagous infestation on leaves influences the chlorophyll content, with infestations from 25 mites causing a decrease in chlorophyll indices. The higher the infestation, the lower the chlorophyll content. Thus, as the number of mites increased, more cells were damaged, leading to a greater reduction in chlorophyll content and the plant's photosynthetic rate. The photosynthetic rate is the plant parameter

most sensitive to the relationship between yield and pest abundance (Xu and Zhang 1991). Some plants may recover to some extent after short periods of infestation, but longer feeding periods significantly reduce the plants' recovery capacity (Nagaraj et al. 2002). In this study, high mite populations continued feeding on apple plants for seven days, which may have caused irreversible damage to the plants' photosynthetic mechanism, with significant reductions in chlorophyll levels. Additionally, it is necessary to consider that there may be indirect damage to the photosynthetic mechanism that may not necessarily manifest as chlorosis (Nabity et al. 2009).

When evaluating the leaves for membrane stability loss, the dark blue staining detected through histochemical staining using Evans Blue reagent indicates the detection of higher levels of injuries caused by phytophagous mites to apple leaves. Thus, greater loss of membrane stability was also observed in treatments with higher mite infestation for the three evaluated species. In addition to direct cellular damage, as evidenced by the loss of photosynthetic capacity, mite-induced injury to the plant leaves can lead to oxidative damage, inducing lipid peroxidation, and with redox imbalance causing membrane instability (Santamaría et al. 2018). Besides the partial destruction of cells due to the withdrawal of their cellular content, there are also various lesions from stylet piercing, and the disintegration and decomposition of organelles, likely due to the action of proteolytic enzymes secreted by mite saliva (Kielkiewicz 1985).

The evaluations demonstrate that infestations above 50 mites cause membrane stability loss, leading to cell death promoted by high mite infestation levels, similar to the findings of Blasi et al. (2017). Injuries were observed within seven days of the onset of infestation, particularly in infestations exceeding 25 mites per leaf. Moreover, visible injuries were observed in leaves that received infestations from 50 mites within the same period. Blasi et al. (2017), in studies conducted with rice leaves (*Oryza sativa* L.) infested with high population levels of *Schizotetranychus oryzae* Rossi de Simons (Tetranychidae) after 30 days, caused a significant reduction in grain productivity. Furthermore, in this study, the most pronounced signs of cell death in apple leaves were caused by *T. ludeni*, demonstrating its potential to become an economically important species in cultivation.

Studies like this are essential as they enable the understanding of the effects of different species of phytophagous mites on apple trees and their interaction with the environment and other species, assisting in decision-making regarding the most appropriate management practices for cultivation. Additionally, this work provides unprecedented information about injuries caused by *T. ludeni* in apple trees, as it is an uncommon species in this context (Rode et al. 2023). The presented results underscore the potential of this species as a possible cause of economic damage if it reaches apple orchards.

Conclusions

In conclusion, it can be inferred from this study that the previous presence of conspecifics increases the oviposition of *P. ulmi* on apple leaves, while the presence of heterospecifics (*A. schlechtendali*) decreases *P. ulmi* oviposition. Furthermore, the higher the number of mites on the leaf surface, the greater the intensity of damage and the larger the damaged area. *T. urticae* is responsible for the most significant decrease in the chlorophyll index of apple leaves, while *T. ludeni* has the highest potential for causing cell death in apple leaves. Therefore, this study serves as a warning to the apple production chain to monitor potential infestations at the field level, and it recommends that more in-depth studies be conducted to prevent a possible threat to apple cultivation. These results are promising as they provide a foundation for further research on the potential of phytophagous mite species in apple trees, especially *T. ludeni* and *A. schlechtendali* (recently recorded in cultivation), and research related to the interaction between these herbivores and their predators, as well as with apple trees.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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Author Contribution

P.A.R. with the methodology, analysis, interpretation of results and concept of the manuscript; J.R.S. with interpretation of results and revised final version; C.J.C.M. with the analysis; R.D.M. and I.S.C. with the methodology (maintenance of mites); N.J.F. with revisions.

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Figures

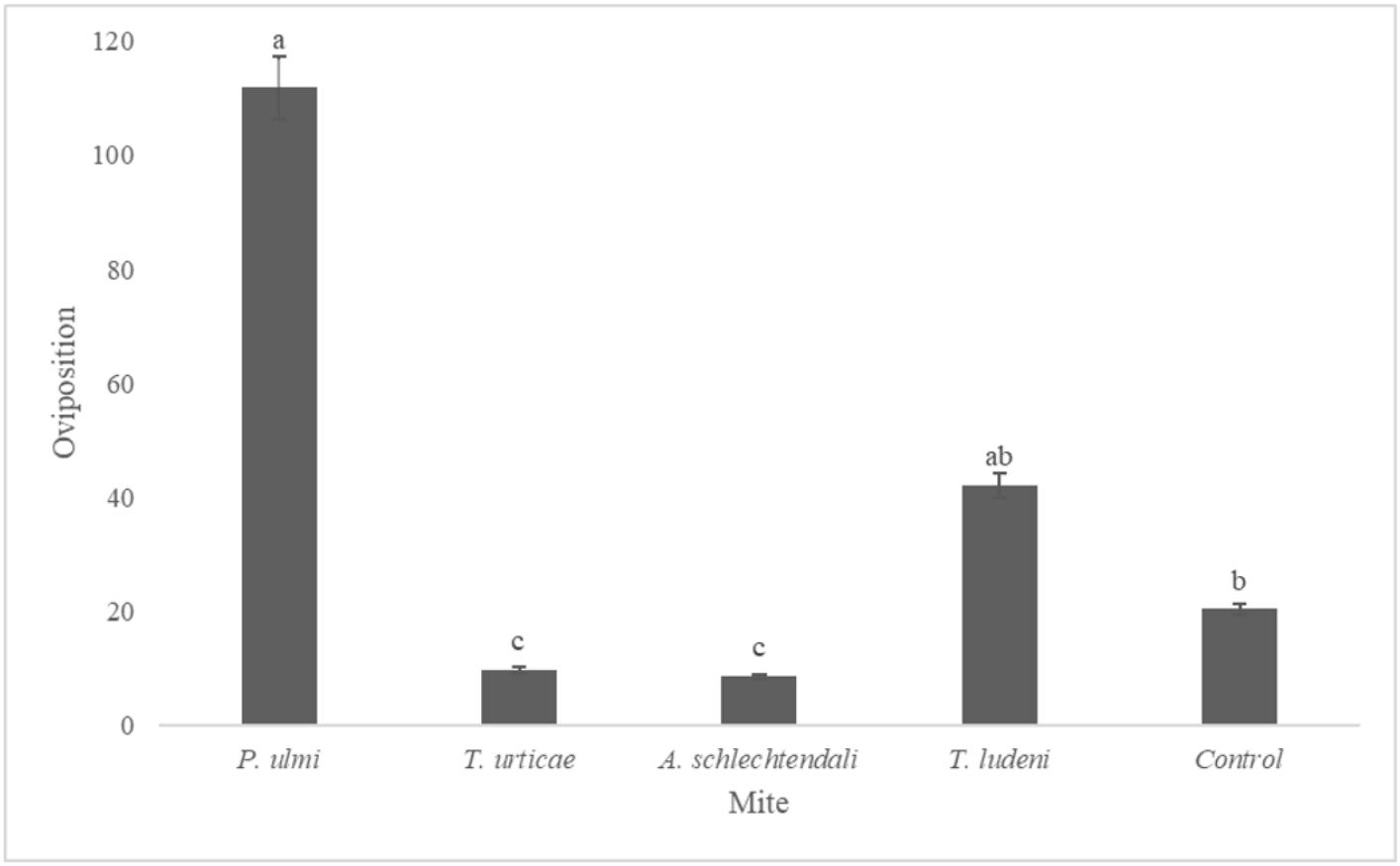


Figure 1

Mean oviposition rate of *Panonychus ulmi* on apple leaf disks with injury, webbing, and eggs of *Aculus schlechtendali*, *Panonychus ulmi*, *Tetranychus ludeni*, *Tetranychus urticae*, and control, over a seven-day period.

Different letters denote significant differences between treatments by Kruskal-Wallis test, followed by Dunn's test (α = 0.05).

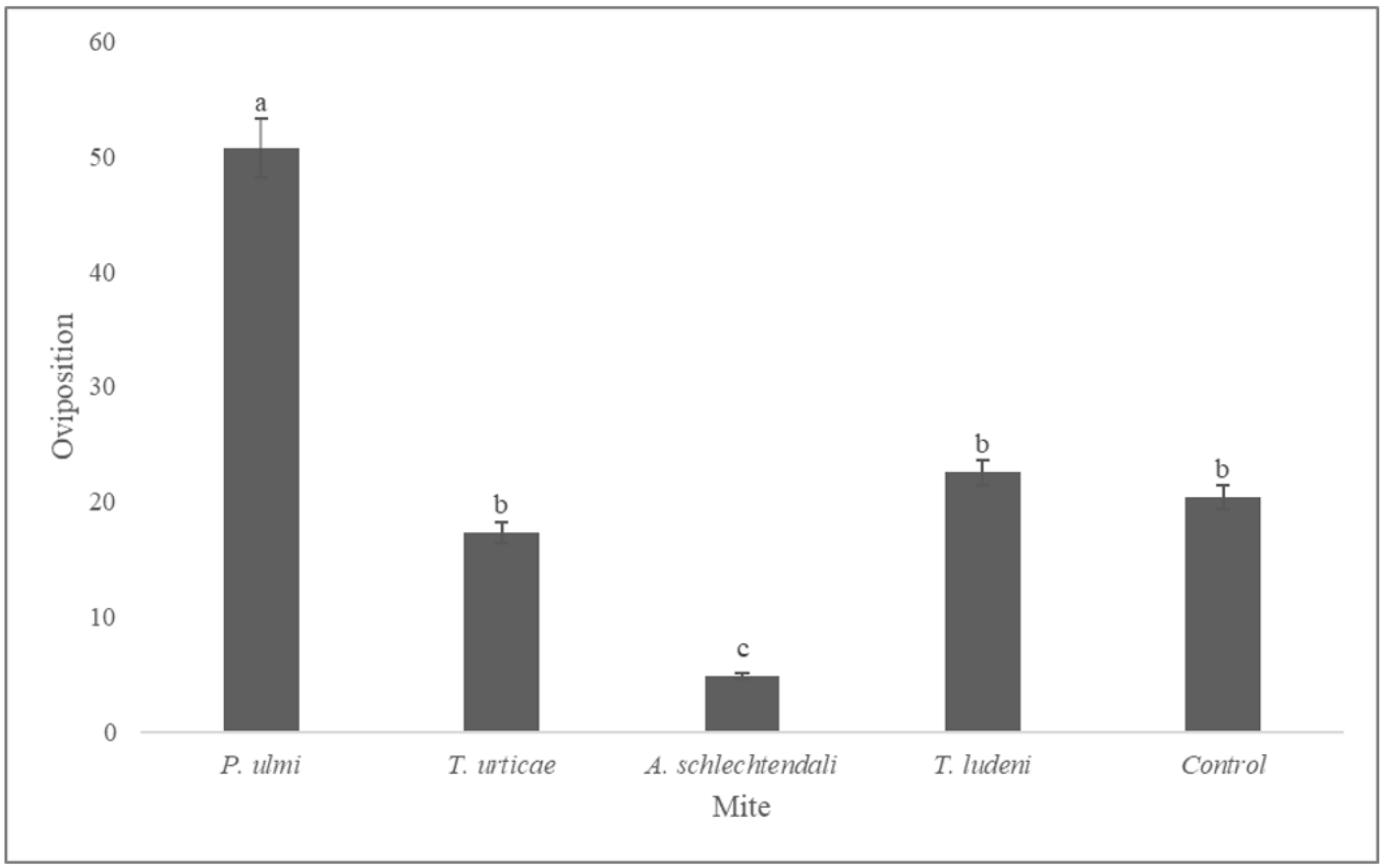


Figure 2

Mean oviposition rate of *Panonychus ulmi* on apple leaf disks with injury and cues of *Aculus schlechtendali*, *Panonychus ulmi*, *Tetranychus ludeni*, *Tetranychus urticae*, and control, over a seven-day period. Different letters denote significant differences between treatments by Kruskal-Wallis test, followed by Dunn's test (α = 0.05).

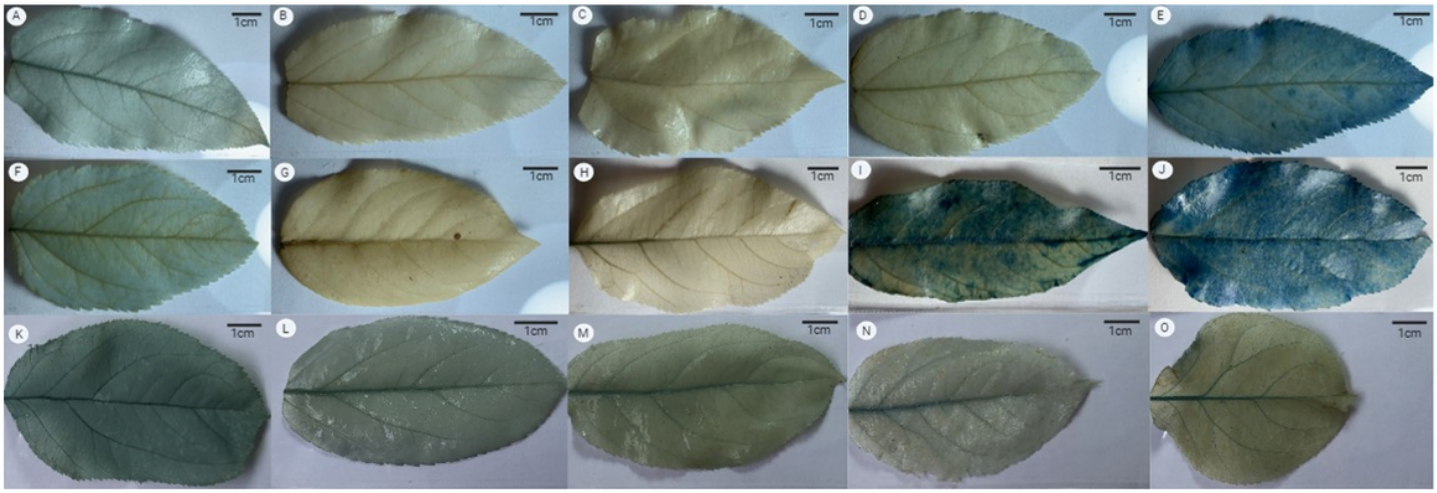


Figure 3

Injuries caused to apple leaves by *Panonychus ulmi* - A- Control, B- 10 mites, C- 25 mites, D- 50 mites, E- 100 mites; *Tetranychus ludeni* - F- Control, G- 10 mites, H- 25 mites, I- 50 mites, J- 100 mites; *Tetranychus urticae*- K- Control, L- 10 mites, M- 25 mites, N- 50 mites, O- 100 mites.

CAPÍTULO 9

Manual técnico Ácaros em macieiras no Brasil: dinâmica, injúrias, comportamento e manejo

Manual técnico
Ácaros em macieira no Brasil: dinâmica, injúrias, comportamento e manejo

PREFÁCIO

Estima-se que nos próximos vinte anos, a população mundial aumentará cerca de 30%, o que consequentemente exigirá um aumento da demanda de produção de alimentos. Atender as demandas de produção mundial de alimentos é um desafio, pois se precisa que maiores quantidades sejam produzidas em um espaço semelhante, o que muitas vezes causa impactos negativos sobre o meio ambiente. Porém, existem métodos inovadores e viáveis que podem aumentar a produtividade de forma sustentável.

O Brasil está entre os maiores produtores mundiais de maçã (*Malus domestica* Bork, Rosaceae), com produção concentrada principalmente na região sul do país. A importância social e econômica da maçã vem aumentando, porém, o desequilíbrio ambiental vem causando o aumento populacional de ácaros fitófagos que em determinados casos estão se tornando resistentes a acaricidas, o que dificulta ainda mais o seu controle. *Panonychus ulmi* (Koch) (Tetranychidae) é considerado um ácaro praga em macieiras no Brasil e, recentemente, *Aculus schlechtendali* (Nalepa) (Eriophyidae), foi relatado no país, alertando os cientistas para a possibilidade de danos nos pomares brasileiros. Neste contexto, o controle biológico é apresentado como uma técnica que utiliza organismos vivos para reduzir populações de organismos que atingem o *status* de praga nos pomares. Além da utilização destes organismos, uma série de estratégias devem ser adotadas para que o manejo se dê de forma mais natural e eficaz, mantendo ou até mesmo aumentando as taxas produtivas de forma sustentável.

Para isso, é importante que as informações disponíveis sejam avaliadas, que as espécies de ácaros presentes nos pomares sejam identificadas e que formas de manejo consciente sejam desenvolvidas. Estas ações irão possibilitar que produção brasileira de maçãs contribua para a melhora da saúde humana, animal, causando menor impacto negativo ao meio ambiente.

Este manual visa apresentar aos produtores de macieira informações sobre os ácaros associados a esta cultura macieira, possibilitar a identificação desses grupos em campo e auxiliar na tomada de decisões ecológicas no controle de pragas. As informações aqui contidas foram retiradas de artigos científicos, livros, bases de dados e resultados obtidos a partir de experimentos e observações realizadas pelos autores na tese desenvolvida pelo primeiro autor.

AGRADECIMENTOS

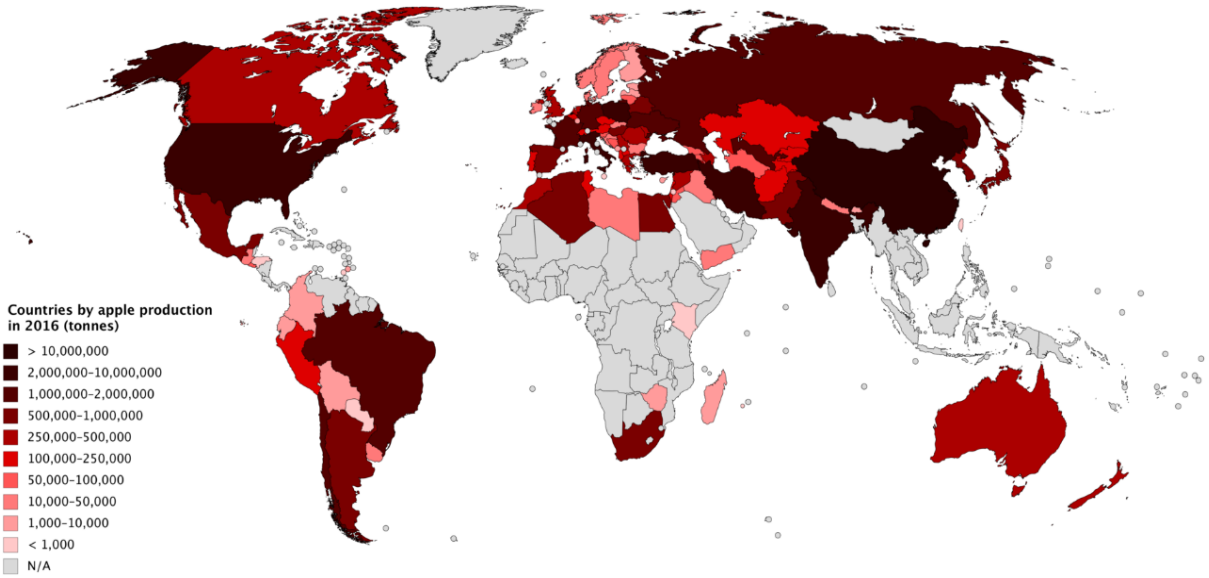
Este manual surgiu a partir do desejo dos autores em divulgar a todos os envolvidos na cadeia produtiva de forma clara e objetiva a situação atual dos ácaros associados à cultura da macieira. Além disso, a equipe que desenvolveu o projeto reconhece a importância de estarem levando seus resultados para além da comunidade acadêmica.

Os autores agradecem a todos os envolvidos na organização deste manual, em especial ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) pelo apoio financeiro e bolsas de pesquisa (processo PQ n° 313658/2020-0) e à Universidade do Vale do Taquari (Univates) pelo apoio a esta pesquisa. Aos produtores Varaschin Agro, Gilmar Bellé e Zani Luiz Fabre, pela disponibilização das áreas durante o período de colheita. Este estudo foi parcialmente financiado pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código Financeiro 001.

CULTURA DA MACIEIRA

O Brasil está entre os maiores produtores de maçã (*Malus domestica* Borkh, Rosaceae) do mundo, e vêm se destacando no mercado externo devido a sua qualidade que cresce a cada ano (Kist *et al*., 2019) (Figura 1).

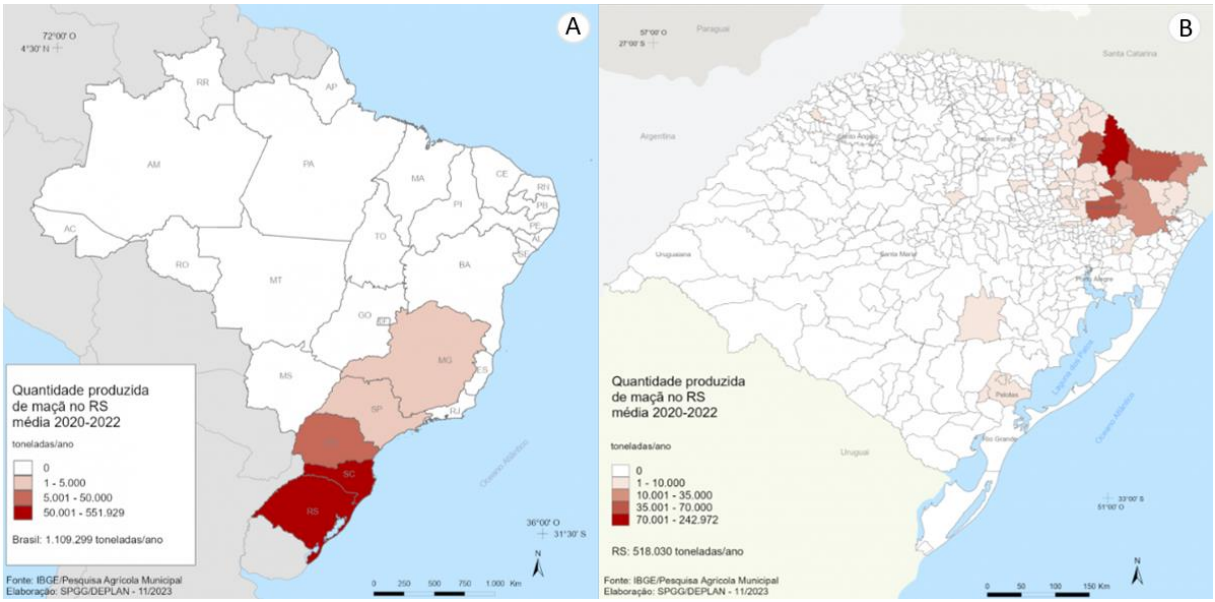
Figura 1 - Principais países produtores de maçã.



Fonte: Faostat (2016).

Os estados do Rio Grande do Sul e Santa Catarina são os maiores produtores do país, seguidos pelo estado do Paraná (Kist *et al*., 2019; IBGE 2022) (Figura 2).

Figura 2 - Quantidade produzida de maçã no Brasil, média 2020-2022 (A). Quantidade produzida de maçã no estado do Rio Grande do Sul, média 2020-2022 (B).



Fonte: IBGE/Pesquisa agrícola municipal (2023).

A produção brasileira de maçã é uma atividade de grande importância social e econômica, sendo uma alternativa de renda nas propriedades rurais, por proporcionar a fixação do homem no meio rural (Muniz Pereira; Da Silva; Agostinetto, 2018) (Figura 3).

Figura 3 - Colheita de maçãs (A, B).

Fonte: Aires, M. (2020) (A). Mandarino, D. (2018) (B).

Inúmeros cultivares de maçãs são cultivados (Way *et al*., 1990; Denardi *et al*., 2023), sendo que os mais importantes são os pertencentes aos grupos Golden delicious, Gala, Fuji e Red delicious (Fioravanço *et al*., 2010) (Figura 4). Fuji e Gala possuem qualidades que agradam o paladar do consumidor, constituindo-se como as melhores opções para os produtores (Iglesias *et al*., 2008; Fioravanço *et al*., 2010).

Figura 4 - Exemplos de cultivares de maçãs produzidos no Brasil.

Fonte: Pires, T. (2019).

Outros cultivares também são relevantes, apesar de possuírem menor importância se comparados com Fuji e Gala, correspondendo a uma média de 6% da produção brasileira de maçã (Faoro, 2022; Denardi *et al*., 2023). Estes cultivares permitem a ampliação do calendário de colheita e da região de produção, sendo uma boa opção de plantio tanto para pequenos agricultores quanto para grandes empresas. Dentre os cultivares mais recentes e menos conhecidos estão Eva, Anna e Condessa que são considerados precoces e de pouca necessidade de frio, indicados para cultivo em regiões mais quentes (Fioravanço *et al*., 2010; Denardi *et al*., 2023).

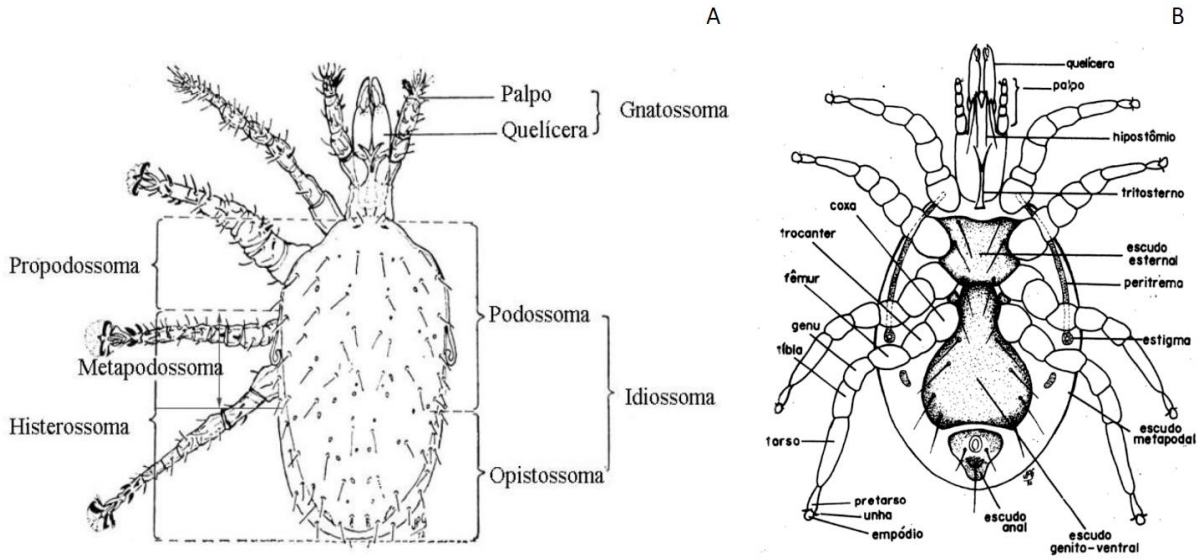
A expansão das áreas produtivas e o aumento da utilização de agrotóxicos vem causando a morte de inimigos naturais, e deixando a cultura mais suscetível ao ataque de pragas que muitas vezes criam resistência a esses insumos agrícolas (Van De Vrie, 1985; Santos *et al*., 2018; Gutiérrez-Moreno *et al*., 2019). No entanto, cientistas estão trazendo novas tecnologias que objetivam a diminuição dos danos causados pelos agrotóxicos, e a produção de alimentos mais saudáveis que auxiliam na melhora da qualidade de vida dos produtores e do consumidor final (Gliessman, 2005; Pålsson *et al*., 2022). Desta forma, o Controle Biológico surge como uma técnica que utiliza meios naturais, para controlar as populações de pragas agrícolas (Obryck; King, 1998; Pålsson *et al*., 2022).

O Controle Biológico pode utilizar parasitóides, predadores, fungos entomopatogênicos, extratos vegetais, óleos essenciais, dependendo da praga presente no ambiente e da situação em que a área agrícola se encontra (Parra *et al*., 2002; Penteado, 2006; Parra, 2014). Estas técnicas têm sido eficiente em diversas culturas, por se tratar de métodos mais seguros, sem o uso de pesticidas, sem deixar resíduos no ambiente e por causar a redução rápida das populações da praga (Parra *et al*., 2002; Oliveira; Ávila, 2010). O controle biológico, com o uso de inimigos naturais, vem sendo estudado como uma alternativa em macieiras (McMurtry; Huffaker; Vrie, 1970; Monteiro, 1994, 2002).

ÁCAROS

Os ácaros pertencem à subclasse Acari, apresentam divisão corporal diferenciada, sem segmentação aparente, e se diferenciam uns dos outros por características morfológicas marcantes (Krantz; Walter, 2009) (Figura 5). Eles correspondem ao segundo grupo mais numeroso de artrópodes, sendo superados apenas pelos insetos.

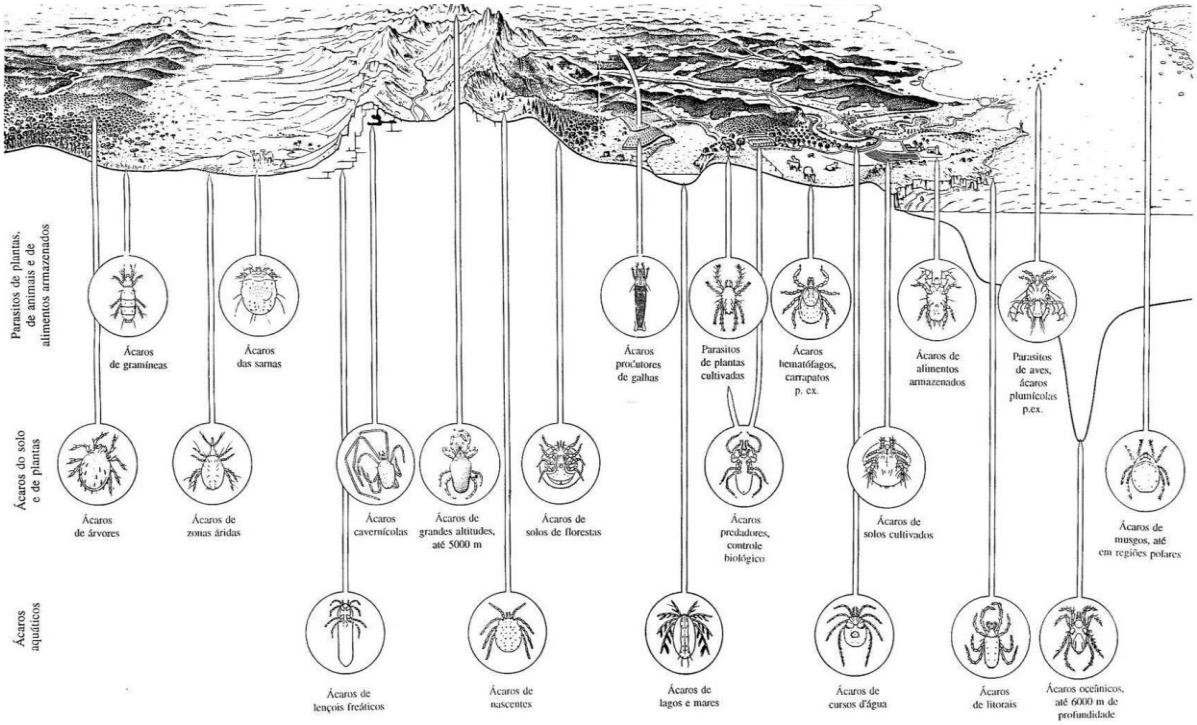
Figura 5 - Esquema de um ácaro Mesostigmata, em vista dorsal, mostrando as principais estruturas do idiossoma (A). Esquema de um ácaro Mesostigmata, em vista ventral, mostrando as principais estruturas do idiossoma (B).



Fonte: modificado de Krantz (1978). Flechtmann (1973).

Os ácaros são encontrados tanto em ecossistemas terrestres quanto aquáticos e possuem diversos hábitos alimentares (Flechtmann, 1975; Moraes; Flechtmann, 2008) (Figura 6).

Figura 6 - Ácaros em todos os biótipos.



Fonte: Flechtmann, C.H.W.

Os ácaros, dependendo do grupo que pertencem podem ingerir diferentes partes vegetais, pólen, fungos e algas, podendo ainda possuir hábitos parasitários, ser predadores ou alimentar-se de matéria orgânica em decomposição, bactérias, nematóides, entre outros (Flechtmann, 1975; Moraes; Flechtmann, 2008).

Ácaros das subordens Prostigmata e Mesostigmata apresentam maior importância econômica agrícola (Evans, 1992). Entre os Prostigmata estão os fitófagos das famílias Eriophyidae, Tarsonemidae, Tenuipalpidae e Tetranychidae e o predador Stigmaeidae (Jeppson *et al*., 1975) e entre os Mesostigmata, destacam-se os predadores, Phytoseiidae (Demite; McMurtry; Moraes, 2014).

ÁCAROS FITÓFAGOS. Os ácaros fitófagos se alimentam do fluido celular vegetal, por meio de peças bucais denominadas estiletes (Walter; Proctor, 1999), inseridos em diferentes partes da planta (folhas, flores, ramos, frutos) (Figura 7). Após as células serem perfuradas, os ácaros sugam o alimento para o interior do seu aparelho digestivo (Moraes; Flechtmann, 2008).

Figura 7 - Ácaro fitófago, *Tetranychus ludeni* Zacher (Acari: Tetranychidae) visto sob microscópio estereoscópico (A). Gnatossoma de *Tetranychus ludeni* visto sob microscópio óptico com contraste de fases - Estiletes indicados por seta (B).

Fonte: Da-Costa, T. (2024) (A). de Castro e Castro, B.M. (2015) (B).

Ao ser removido o conteúdo das células vegetais, ocorre a diminuição da capacidade da planta realizar a fotossíntese (Moraes; Flechtmann, 2008). As lesões podem alterar processos fisiológicos, prejudicando o crescimento, a floração e os rendimentos da planta (Tomczyk; Kropczynska, 1985) (Figura 8). A intensidade das injúrias causadas na planta pode ser influenciada pela espécie do ácaro, a densidade populacional do fitófago, a duração do ataque, e ainda, por fatores relacionados à planta, como o cultivar, o vigor, o tempo da colheita e as condições ambientais (Marini; Pfeifer; Sowers, 1994).

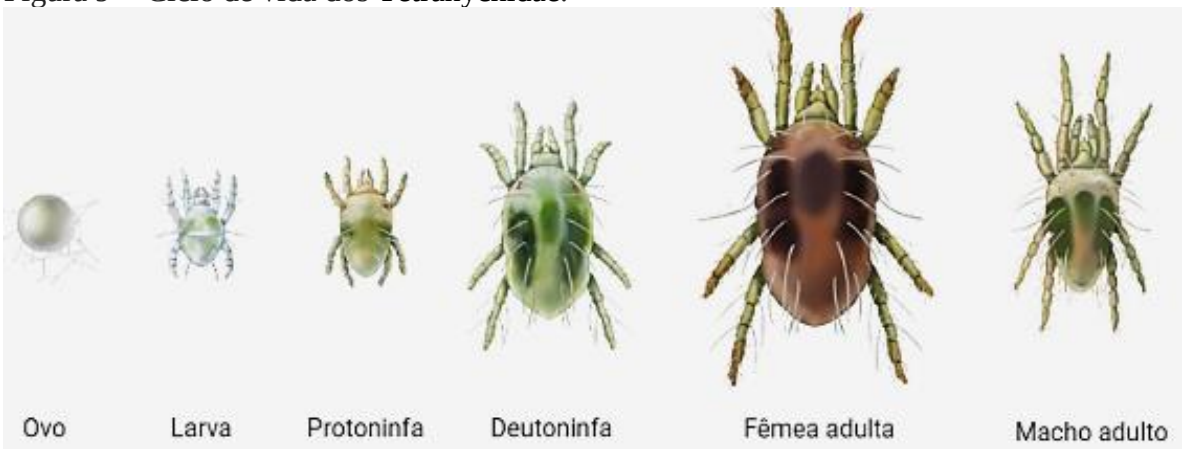
Figura 8 - Tomateiro infestado por *Tetranychus evansi* (A). Tomate infestado e apresentando danos e teias de *T. evansi* (B).

Fonte: Terra Magna (A). Agrolink (B) (2023).

Principais ácaros fitófagos da macieira. Mudanças nos agroecossistemas, aumento das áreas de cultivo, o transporte ilegal de plantas contaminadas e a inserção de espécie exótica em local diferente, causam impactos ambientais, sociais e econômicos (Morgante, 1991; Navia; Moraes; Flechtmann, 2007; Navia *et al*., 2010). Além disso, o uso de agrotóxicos em pomares pode criar populações de fitófagos resistentes aos produtos e reduzir os inimigos naturais (Meyer; Kovaleski; Valdebenito-Sanhueza, 2008, 2009). Devido à ausência de inimigos naturais, alguns ácaros fitófagos aumentam suas populações e passam a ser consideradas pragas agrícolas (Brown; Hovmoller, 2002; Anderson *et al*., 2004). A intensidade dos danos causados por esses herbívoros depende da espécie acarina, do tamanho da população, do cultivar atacado e da idade das plantas (Easterbrook; Fuller, 1986). O monitoramento das infestações de ácaros fitófagos é importante para avaliar e acompanhar os danos reais, identificar os inimigos naturais nativos associados, e verificar quais locais são atingidos com maior intensidade pelas espécies. Dentre os grupos causadores de danos na macieira estão os Tetranychidae e Eriophyoidea (Ferla; Moraes, 1998).

Tetranychidae. Uma das famílias acarinas com maior relevância em termos de impacto econômico é a Tetranychidae que compreende diversas espécies consideradas pragas agrícolas (Migeon *et al*., 2010). Estes organismos são favorecidos por altas temperaturas e clima seco, que facilitam o aumento de suas populações (Cuthbertson; Murchie, 2005). No sul do Brasil, as infestações ocorrem nos pomares principalmente durante o verão, quando há a maior proliferação desses ácaros. O ciclo de vida dos Tetranychidae é caracterizado pelas fases de ovo, larva, protoninfa, deutoninfa e adulto (Figura 9).

Figura 9 - Ciclo de vida dos Tetranychidae.



Fonte: Adaptado de Koppert (2020).

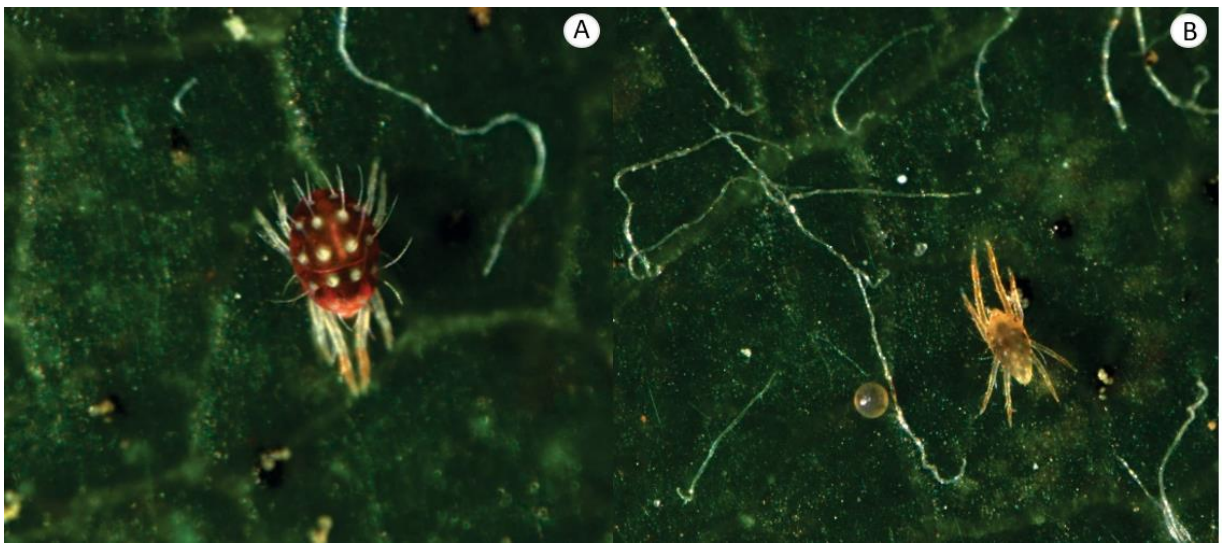
Em cada estádio, o ácaro passa por um período em que se alimenta intensamente, seguido de um período de repouso e logo após, pela muda de exoesqueleto. Durante as fases móveis, eles perfuram as células da macieira com os estiletes e nos locais onde se alimentam surgem manchas denominadas de bronzeamento foliar (Cuthbertson; Murchie, 2010).

Panonychus ulmi e *T. urticae*, espécies fitófagas, que ocorrem nos pomares de macieira brasileiros (Ferla; Moraes, 1998; Monteiro, 2001; 2002; Silva *et al*., 2022; Rode *et al*., 2023a).

***Panonychus ulmi* (Koch)**

(Ácaro-vermelho-europeu, European Red Mite, ERM) (Figura 10).

Figura 10 - Fêmea de *Panonychus ulmi* (A). Macho de *Panonychus ulmi* (B).



Fonte: Labacari (2022).

Ocorrência.

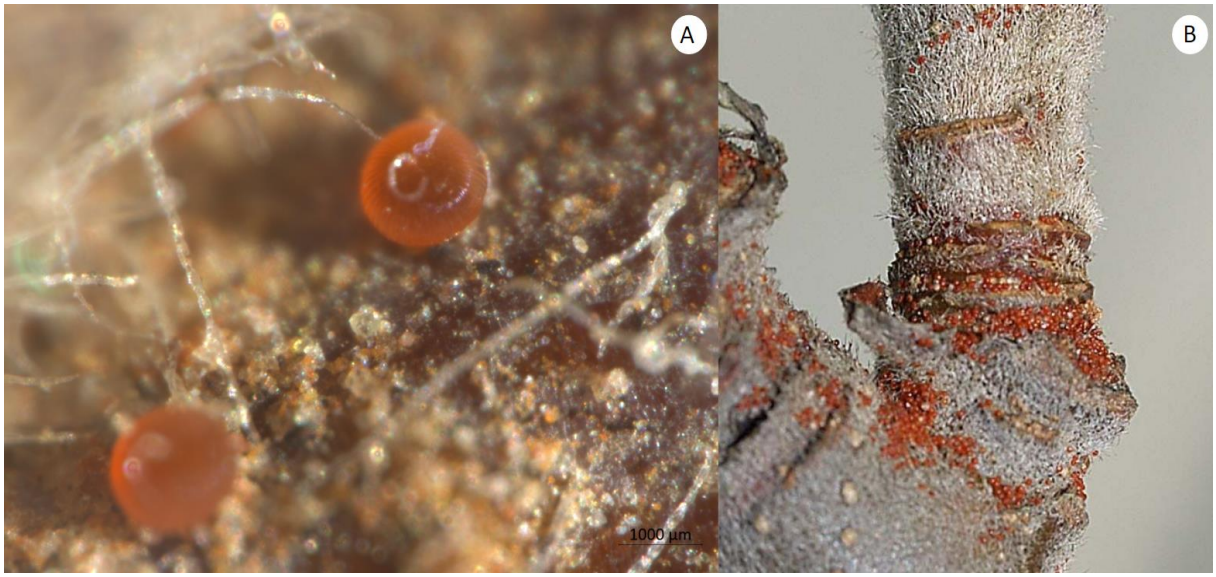
A espécie já foi reportada com populações acima do nível de dano econômico em plantas de maçã em pomares em diversas partes do mundo, inclusive no Brasil (Yin *et al*., 2013; Kasap; Athihan, 2021; Assouguem *et al*., 2024). O primeiro relato brasileiro em pomares de maçã foi feito por Flechtmann (1967) e o primeiro registro de alta infestação ocorreu em pomares de maçã de Fraiburgo (SC) (Bleicher, 1974).

A dispersão de *P. ulmi* para novas áreas é favorecida por seu pequeno tamanho, podendo ser transportado facilmente por animais ou pelo ser humano e pelo transporte de plantas infestadas com ovos de um local para outro (Helle; Sabelis, 1985). Desta forma é importante ser evitado o trânsito desnecessário dentro do pomar de uma área para outra, principalmente quando é identificada a ocorrência do ácaro em alguma planta. Além disso, deve-se evitar o transporte de material vegetal de um pomar para outro, pois mesmo que não sejam visíveis pode existir ovos de inverno nos galhos que no tempo certo eclodem e iniciam uma nova infestação. *Panonychus ulmi* possui alta taxa reprodutiva e a reprodução é por partenogênese (nascimento de fêmeas diplóides provenientes de ovos fecundados e machos haploides gerados a partir de ovos não fertilizados) possibilitando que uma pequena população ou mesmo uma única fêmea possa iniciar uma colônia com rápido crescimento (Helle; Sabelis, 1985).

Como reconhecer.

Panonychus ulmi possui o corpo globoso com coloração avermelhada e em seu dorso são observados diversos pontos brancos (tubérculos), onde se implantam as setas dorsais do idiossoma (Mineiro *et al*., 2015). Logo após a última muda (ecdise), antes de se alimentar, a fêmea apresenta coloração vermelho-amarelado ou castanha e após um período de alimentação, a coloração passa para vermelha-escura. Os ovos de *P. ulmi* são esféricos, com superfície estriada e na parte superior é observada uma haste curvada e afilada (Kovaleski; Vendramim, 1993) (Figura 11). Em campo, os ovos apresentam coloração vermelho-alaranjado, e em condições de laboratório, podem variar vermelho-alaranjados a creme-pálidos (Kovaleski; Vendramim, 1993). Durante o inverno, quando a planta passa por desfolha (período de senescência), os ovos são encontrados nos ramos, geralmente junto às bifurcações.

Figura 11 - Ovo de *Panonychus ulmi* (A). Ovos de *Panonychus ulmi* durante o período de senescência, localizados junto ao ramo da macieira (B).



Fonte: Meira, A.A. (2023) (A). Fonte: Agrolink (2023) (B).

Danos causados.

Em elevadas populações esta espécie pode ocorrer a diminuição das taxas de troca de CO_2, surgimento de manchas características de bronzeamento foliar, queda prematura das folhas, diminuição da produção, com frutos pequenos e de coloração alterada (Huffaker *et al*., 1969; Rilling; During, 1990, Ferla; Botton, 2008, Moraes; Flechtmann, 2008, Duso *et al*., 2012).

Monitoramento.

No Sul do Brasil, *P. ulmi* ocorre entre os meses de setembro a maio (Palladini; Mondardo, 2002). No período vegetativo, é importante realizar o monitoramento dos ácaros através da amostragem sequencial de presença-ausência (Ribeiro *et al*., 1990; Kovaleski; Ribeiro, 2002). Ao utilizar este sistema não é necessária a contagem do número de ácaros por folha, somente do número de folhas infestadas. Em pomares menores a amostragem deve ser realizada em talhões de 2 a 3ha, e em grandes pomares (> 50ha), a área deve ser dividida em talhões para realização da amostragem. As folhas que serão amostradas devem ser retiradas da região mediana da planta de macieira (Faoro, 2022). Semanalmente as amostragens devem ser realizadas, caminhando em ziguezague ou em forma de "V", realizando as coletas das plantas ao acaso dentro do talhão (Faoro, 2022).

Controle.

As ações de controle devem levar em conta a porcentagem de folhas infestadas e o ciclo

vegetativo da cultura (Mineiro *et al*., 2015). Sendo assim, quando 70% das folhas apresentam ácaros é realizada intervenção para controle do fitófago (Kovaleski; Ribeiro, 2002).

- Controle convencional. O controle convencional de *P. ulmi* pode ser conduzido em dois períodos: 1) controle de ovos de inverno, juntamente com a quebra de dormência - o óleo mineral, na dosagem de 3 a 5%, reduz a eclosão; 2) durante a fase vegetativa, com duas alternativas: com o uso de abamectina logo após a queda das pétalas, em mistura com óleo mineral a 0,25%, sem levar em consideração o nível populacional ou com o uso de fenpiroximato e espirodiclofeno, quando a população ultrapassa o nível de controle (Kovaleski; Ribeiro, 2002).

  Devido às regulamentações variáveis em torno do (des)registro de pesticidas, sua lista nacional de pesticidas registrados ou autoridade relevante deve ser consultada para determinar quais produtos são legalmente permitidos para uso em seu país ao considerar o controle químico. Os pesticidas devem ser sempre utilizados de forma legal, conforme o rótulo do produto.
- Controle biológico. Em 1995, o controle biológico de *P. ulmi* foi implantado em pomares comerciais de macieiras em Fraiburgo, por meio de criações do ácaro predador *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) em estufas e de liberações inoculativas em campo (Monteiro, 2002 a, b). Atualmente, o controle biológico de ácaros está implantado em mais de 90% dos pomares de Fraiburgo (Monteiro, 2002 a, b; Monteiro; Souza; Pastori, 2006).

  O sucesso do controle biológico aplicado baseia-se no uso de estratégias de manejo alternativas (Monteiro, 2002a, b; Parra, 2014; Pålsson *et al*., 2022). O monitoramento das populações de *P. ulmi* pode ser realizado com a utilização de lupas de aumento de 15X e o controle com as aplicações de inseticidas e acaricidas biológicos. Algumas espécies de ácaros Phytoseiidae vem sendo estudadas e utilizadas para o controle de infestações de *P. ulmi* em diferentes culturas no Brasil, dentre elas *N. californicus* (Monteiro, 2002 a, b; Silva *et al*., 2019). *Neoseiulus californicus* é uma espécie que tem potencial para utilização no manejo integrado em pomares de macieira e já se mostrou eficiente controlador biológico de *P. ulmi* na cultura (Monteiro, 2002 a, b). O manejo das plantas daninhas deve ser realizado sem a utilização de herbicidas por meio de roçadas. No entanto, algumas espécies de vegetação de crescimento espontâneo podem servir de abrigo a espécies de ácaros predadores, favorecendo o controle biológico do

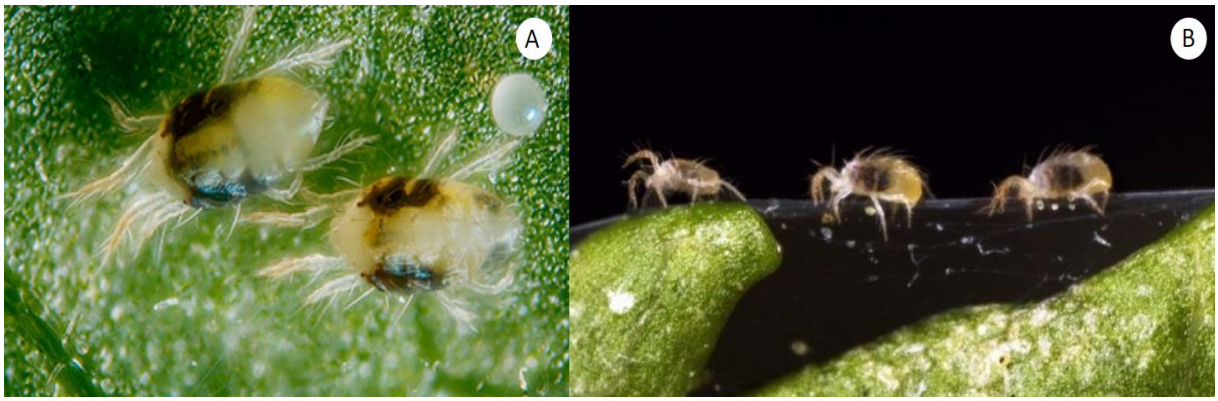
ácaro-praga (Monteiro, 2001, 2002 a, b). Monteiro (2002) mostra que durante seus estudos, *N. californicus* passou o inverno nas plantas espontâneas do pomar e migrou espontaneamente para a copa das macieiras nos anos seguintes à sua introdução.

Estudos envolvendo o uso de fungos entomopatogênicos para o controle desse ácaro na macieira também tem se mostrado eficientes, principalmente quando realizadas aplicações de *Beauveria bassiana* (Raxmanov; Sulaymoraxnova, 2023). No entanto para a utilização de fungos entomopatogênicos nos pomares, é necessário que seja realizado previamente um levantamento dos predadores presentes e avaliação do efeito desses microrganismos sobre os inimigos naturais (Wu *et al.*, 2018).

***Tetranychus urticae* Koch**

(Ácaro rajado, Two Spotted Spider Mite, TSSM) (Figura 12).

Figura 12 - Fêmeas e ovo de *Tetranychus urticae* (A). *Tetranychus urticae* andando sobre a própria teia (B).



Fonte: PROMIP (2019) (A). Agrolink (2023) (B).

Ocorrência.

Tetranychus urticae é considerado um ácaro praga em diversas culturas, incluindo árvores frutíferas, vegetais e flores, sendo considerada praga em estufas, campos de cultivo e pomares (Bolland *et al*., 1998; Van Leeuwen *et al*., 2010). Na macieira, *T. urticae* é relatado ocorrendo em diversas partes do mundo (Hardman *et al*., 2007; Funayama, 2010; Kamusiime; Nantongo; Wacal, 2023). No Brasil, já foi relatado em cultivos de macieiras (Moraes; Flechtmann, 2008), no entanto, em levantamentos recentes a espécie não foi encontrada ocorrendo nos pomares avaliados (Silva *et al*., 2022) ou em baixa abundância (Rode *et al*., 2023a).

Como reconhecer.

A produção de abundância de teia é uma característica importante desta espécie e é facilmente percebida sobre as plantas atacadas. As fêmeas de *T. urticae* apresentam coloração amarelo-esverdeada, com um par de manchas laterais escuras (Moraes; Flechtmann, 2008).

Danos causados.

O ataque deste fitófago pode causar o surgimento de manchas características de bronzeamento foliar, e em ataques severos pode causar a queda prematura das folhas ou ainda a morte da planta (Moraes; Flechtmann, 2008). Em pomares de macieira, quando as populações ultrapassam o nível de dano econômico, principalmente na época de florescimento e da formação das maçãs, pode ocorrer considerável redução em sua formação e, consequentemente, na produtividade (Moraes; Flechtmann, 2008).

Monitoramento.

Estes ácaros podem se dispersar aereamente por longas distâncias, ao mesmo tempo, em que fazem viagens mais curtas entre as árvores próximas, nos pomares de macieiras (Uesugi; Sasawaki; Osakabe, 2009). *Tetranychus urticae* tem preferência pelas folhas da região mediana e basal das plantas em que ocorre. No entanto, quando as populações estão elevadas, também podem atacar as folhas mais novas (Moraes; Flechtmann, 2008).

Controle.

- Controle convencional. O controle de *T. urticae* é frequentemente realizado de forma química com a utilização de acaricidas (Hardman *et al*., 2007; Koh *et al*., 2009), no entanto, populações dessas espécies em diversas partes do mundo estão adquirindo resistência à utilização de pesticidas (Koh *et al*., 2009). Além disso, há registro de surtos de populações da espécie ocorrendo em outros países devido a pulverizações de inseticidas de amplo espectro em pomares de macieira (Toyoshima *et al*., 2011; Funayama, 2015).

  Devido às regulamentações variáveis em torno do (des)registro de pesticidas, sua lista nacional de pesticidas registrados ou autoridade relevante deve ser consultada para determinar quais produtos são legalmente permitidos para uso em seu país ao considerar o controle químico. Os pesticidas devem ser sempre utilizados de forma legal, conforme o rótulo do produto.

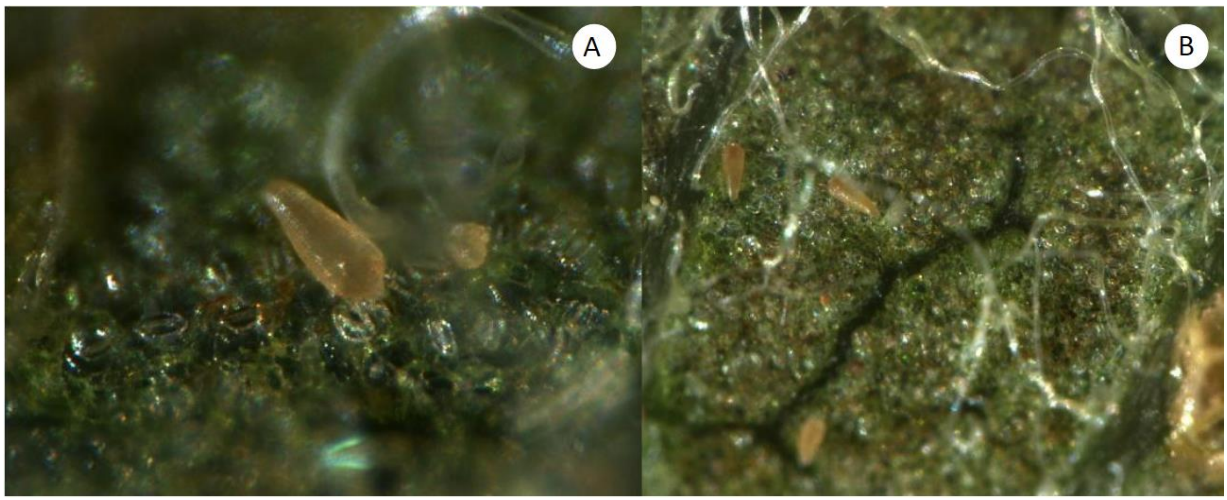
- Manejo integrado de pragas. Uma alternativa para o controle de *T. urticae* é a implantação do manejo integrado de pragas (MIP), pois esse tipo de manejo nas macieiras, busca a redução das pulverizações de pesticidas através da utilização de produtos seletivos e a seleção de fitoseídeos resistentes o suficiente para controlar a espécie. Uma espécie amplamente estudada para controle mediante manejo integrado e controle biológico de *T. urticae* em diversas culturas são *N. californicus* (De Souza-Pimentel *et al*., 2014; Iwassaki *et al*., 2015) e *P. macropilis* (Souza-Pimentel *et al*., 2016).

Eriophyidae. Essa família é considerada como o segundo principal grupo de ácaros-praga no mundo, sendo superados apenas pelos tetraniquídeos (Lindquist *et al*., 1996; Moraes; Flechtmann, 2008). Diversas espécies de eriofiídeos são consideradas ácaros praga em diferentes culturas, enquanto outras representam uma ameaça quarentenária para vários países (Moraes; Flechtmann, 2008).

***Aculus schlechtendali* (Nalepa)**

(Ácaro do caroço e da gema da maçã, Apple Rust Mite, ARM) (Figura 13).

Figura 13 - *Aculus schlechtendali* em folhas de macieira (A). Injúrias causadas por *Aculus schlechtendali* em folhas de macieira (B).



Fonte: Meira, A.A (2023).

Ocorrência.

A espécie é considerada praga da macieira em diversos países, sendo que na América

Latina já foi relatada na Argentina, Brasil e Chile (Duso *et al*., 2010; Ferla *et al*., 2018). No Brasil a espécie foi reportada pela primeira vez em macieiras na região Sul do país (Ferla *et al*., 2018), e posteriormente sua presença foi registrada em municípios dos três principais estados produtores brasileiros (Nascimento *et al*., 2020). Até o momento, não há relatos de que a espécie esteja causando danos no Brasil, tampouco o quão prejudicial o fitófago pode ser a cultura no país (Nascimento *et al*., 2020). De acordo com Corrêa et al. (2021), outras áreas, principalmente no estado de São Paulo e Minas Gerais, são potencialmente aptas para sua ocorrência por não existir até o momento um sistema de controle definido para essa espécie no Brasil (Nascimento *et al*., 2020). A presença de *A. schlechtendali* nos pomares brasileiros alerta sobre a possibilidade desta espécie atingir o *status* de praga caso não haja o controle, podendo tornar-se um problema para os agricultores (Ferla et al. 2018; Nascimento *et al*., 2020).

Como reconhecer.

Aculus schlechtendali é um ácaro de pequeno tamanho, o que não permite que sejam vistos a olho nu, dificultando que sejam identificados nas folhas sem o auxílio de um microscópio (Navia *et al*., 2010). Ovos de *A. schlechtendali* são claros quando colocados e depois tornam-se translúcidos e são invisíveis a olho nu, sendo que a visão através do microscópio também é dificultada devido ao seu pequeno tamanho.

As fêmeas adultas são as mais abundantes e frequentemente encontradas nos pomares. Apresentam corpo fusiforme e variam de 150 a 170 µm de comprimento. O escudo prodorsal varia de 45 a 50 µm de comprimento, tem um lobo anterior curto, é esculpido com um padrão diagnóstico de linhas que consistem em tubérculos semelhantes a contas e apresenta um par de cerdas dorsais divergentes, moderadamente longas, direcionadas posteriormente, próximas à região posterior. Os dois pares de pernas têm estruturas distintas em forma de garras terminalmente no tarso, denominadas garras de penas, com quatro pares de raios.

Danos causados.

Nos países onde a espécie já é considerada praga, os danos causados são caracterizados pelo bronzeamento da superfície das folhas, flores e frutos (Duso *et al*., 2010). A alimentação do ácaro durante o desenvolvimento da macieira danifica as células da camada epidérmica da planta, afetando a atividade fisiológica das plantas, sua qualidade e estética (Easterbrook, 1996; Walde; Hardman; Magagula, 1997; Spieser *et al*., 1998; Duso *et al*., 2010). Além disso, a folha de macieira pode se enrolar e em casos de grandes infestações pode ocorrer a queda prematura

das folhas e frutas (Jeppson *et al*., 1975; Easterbrook, 1996). Quando a quantidade de espécimes de *A. schlechtendali* ultrapassa os 50 ácaros por cm^2 de folha, aumenta a taxa de transpiração da folha e diminui sua taxa fotossintética (Kozlowski, 1980; Solhoy *et al*., 1991; Duso *et al*., 2010; Hoy, 2011).

Monitoramento.

Ácaros desse grupo podem se tornar invasores devido ao seu pequeno tamanho, que impossibilita que sejam vistos a olho nu e facilita a disseminação no ambiente (Navia *et al*., 2010). Este ácaro pode ser transportado sem intenção através de folhas, galhos e frutas contaminadas. Além disso, a dispersão a longa distância através do ar é uma importante estratégia de sobrevivência que pode auxiliar na rápida colonização em novos territórios (Gage; Isard; Colunga-G, 1999). O aumento das populações de *A. schlechtendali* pode ser influenciado pelo ambiente, cultivares, clima, localização do pomar e ocorrência de inimigos naturais (Denizhan, 2011; Danelski; Badowska-Czubik; Rozpara, 2015; Maula; Khan, 2015).

No início do verão, com o aumento das temperaturas, estes ácaros são encontrados na região inferior das folhas e passa a habitar a parte superior assim que ocorre o aumento das populações (Easterbrook, 1978). A densidade populacional nas folhas aumenta lentamente durante a primavera e mais rapidamente no verão, momento do seu pico populacional, tendo como temperatura ótima 23 a 28 °C (Easterbrook, 1979; Kozlowski; Boczek, 1989; Simoni *et al*., 2018), e neste período, a reprodução ocorre de forma rápida e uma fêmea é capaz de colocar 3,8 ovos por dia (Easterbrook, 1979; Kozlowski; Boczek, 1989). A densidade das populações diminui com a deterioração das folhas e com o início da hibernação dos ácaros. Em plantas jovens, *A. schlechtendali* costuma hibernar nos brotos laterais, entre as gemas e o broto principal e em árvores mais velhas, eles passam o inverno sob as fendas da casca e em gemas dormentes (Funayama; Takahashi, 1992; Easterbrook, 1996). A emergência dos ácaros após a hibernação ocorre no período da primavera, no início das brotações, atinge o pico no estágio de botão e finaliza na floração (Easterbrook, 1979; 1984; Kozlowski; Boczek, 1987). Após esse período, os ácaros passam para as escamas verdes e depois para as folhas, sépalas e receptáculos de flores e depois de um curto período de alimentação começam a ovipositar. A oviposição geralmente ocorre ao longo da nervura central e demais nervuras (Easterbrook, 1979; Kozlowski; Boczek, 1989).

Controle.

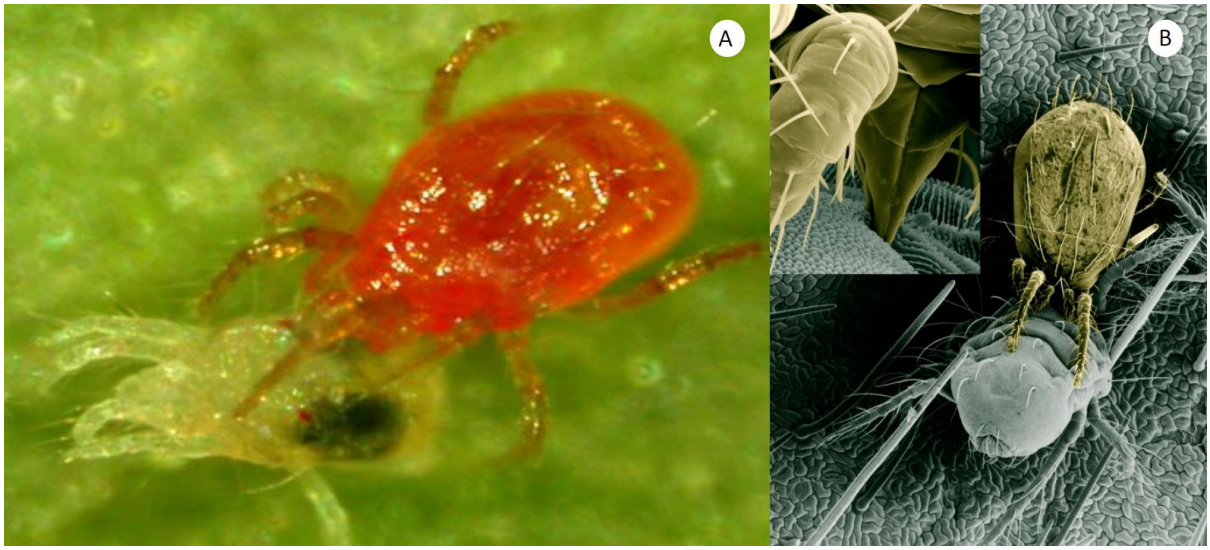
Até o momento não existem registros de danos causados por *A. schlechtendali*, o que faz com que não sejam necessárias intervenções para controle deste ácaro nos pomares brasileiros

- Controle Convencional. Alguns fungicidas são utilizados na cultura da macieira em alguns países e já foram capazes de reduzir a densidade populacional de *A. schlechtendali* sem causar prejuízos aos ácaros predadores, podendo ter o uso incentivado em programas de Manejo integrado de pragas (Maeyer *et al*., 1993). No Brasil, ainda não existem estudos relacionados ao controle químico de *A. schlechtendali*, desta forma, para utilização no país, estudos devem ser previamente realizados.

  Devido às regulamentações variáveis em torno do (des)registro de pesticidas, sua lista nacional de pesticidas registrados ou autoridade relevante deve ser consultada para determinar quais produtos são legalmente permitidos para uso em seu país ao considerar o controle químico. Os pesticidas devem ser sempre utilizados de forma legal, de acordo com o rótulo do produto.
- Controle Biológico. Estudos envolvendo espécies de ácaros predadores das famílias Stigmaeidae e Phytoseiidae estão sendo desenvolvidos para controle biológico de *A. schlechtendali* em diversos países (Clements, Harmsen, 1993; Lange; Trautmann, 1994; Lawson *et al*., 1994; Walde; Magagula; Morton, 1995). No Brasil, ainda não existem estudos relacionados ao controle biológico de *A. schlechtendali*, desta forma, para utilização no país, estudos devem ser previamente realizados.

ÁCAROS PREDADORES. Os ácaros predadores possuem quelíceras, utilizadas para agarrar e preparar seu alimento para a digestão (Figura 14).

Figura 14 - Ácaro predador se alimentando de um ácaro fitófago sob microscópio de optico de contraste de fases (A). Ácaro predador se alimentando de um ácaro fitófago sob microscópio eletrônico de varredura (B).



Fonte: FAEP (2018).

Apresentam pernas longas e que lhes permitem movimentos rápidos, sendo comumente encontrados no solo, em musgos, em restos vegetais e animais e em plantas. Nas plantas esse grupo acarino se alimenta de pequenos artrópodes como insetos e ácaros fitófagos e seus ovos e de nematóides (Vangansbeke *et al*., 2023).

Ácaros predadores de importância para a cultura da macieira. Nos pomares brasileiros de macieiras, os predadores mais abundantes são os Phytoseiidae e os Stigmaeidae (Ferla; Moraes, 1998; Meyer; Kovaleski; Valdebenito-Sanhueza, 2008; Klock *et al*., 2011, Silva *et al*., 2022). Os inimigos naturais já reportados ocorrendo nestes pomares associados aos fitófagos ou que já foram testados se alimentando deles foram *N. californicus, Agistemus riograndensis* (Johann & Ferla) (Stigmaeidae), *Agistemus brasiliensis* Matioli, Ueckermann & Oliveira (Acari: Stigmaeidae), *Agistemus floridanus* Gonzalez (Stigmaeidae) e *Zetzellia ampelae* (Johann & Ferla) (Stigmaeidae) (Ferla, Moraes, 1998; Monteiro, 2001; 2002; Meyer; Kovaleski; Valdebenito-Sanhueza, 2008; Silva *et al*., 2020, 2022).

Phytoseiidae. Alimentam-se de ácaros fitófagos e possuem outras fontes alimentares alternativas, como pólen, fungos, exsudato de plantas e insetos (McMurtry; Rodrigues, 1987; McMurtry *et al*., 2013). Diversas espécies desta família têm sido consideradas importantes agentes de controle de tetraniquídeos em diversas culturas (Moraes; Mesa; Braun, 1991; Aly, 2023). E para o melhoramento do controle biológico e do controle integrado de *P. ulmi*, já foram realizados trabalhos a nível de laboratório e com liberações de *N. californicus* em campo

(Monteiro, 1994; 2001; 2002; Huang *et al*., 2020; Göçer; Ay, 2021) (Figura 15).

Figura 15 - Fêmea de *Neoseiulus californicus* (Phytoseiidae) predando fêmea de ácaro fitófago.

Fonte: Institut Agro Montpellier (2023).

<u>Stigmaeidae</u>. Presentes em uma variedade de habitats, os representantes dessa família são ácaros de vida livre encontrados em folhas e galhos de plantas (Fan; Zhang, 2005). Os principais gêneros de Stigmaeidae encontrados na macieira são *Agistemus* e *Zetzellia* (Gerson, 1972; Lorenzato *et al*., 1986; Silva *et al*., 2022) (Figura 16). Os ácaros dessa família ocorrem no ambiente principalmente entre abril e março (Lorenzato *et al*., 1986), coincidindo com o declínio de *P. ulmi* e outras populações fitófagas nos pomares. Esses predadores são generalistas e se alimentam principalmente de espécies de Eriophyoidea, Tetranychidae, Tenuipalpidae, Tarsonemidae e outros grupos de ácaros no campo (Gerson *et al*., 2003) e em estufas (Zhang, 2003). Espécies do gênero *Agistemus* são conhecidas mundialmente por estarem associadas a estes grupos de fitófagos em diversas culturas (Ferla; Moraes, 1998; Fan; Flechtmann, 2015), incluindo macieiras (Lorenzato; Melzer, 1984). *Agistemus fleschneri* Summers foi relatado em macieiras (Strickler *et al*., 1987) associado a *A. schlechtendali* e *P. ulmi* na América do Norte.

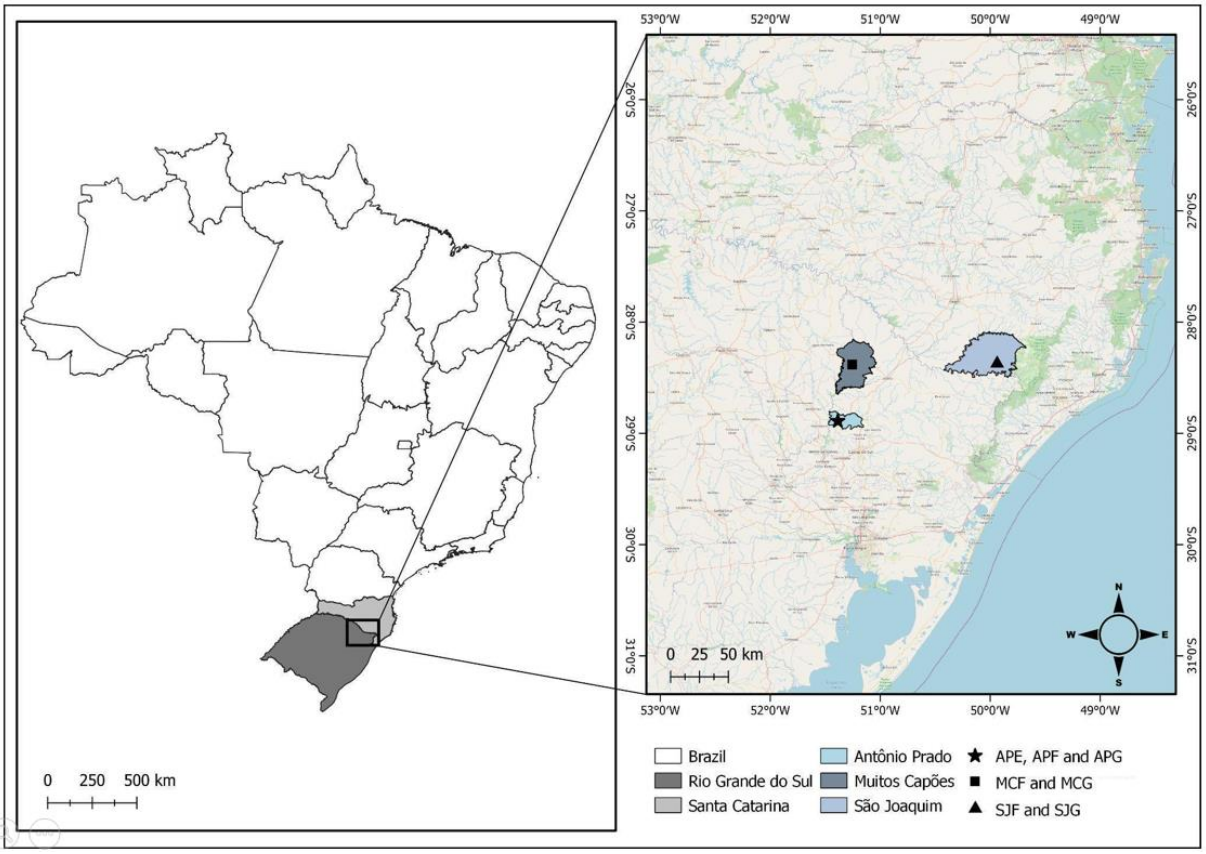
Figura 16 - Ácaro Stigmaeidae do gênero *Agistemus.*

Fonte: Ferla, N.J.; Johann, L.; Silva, G.L (2018).

MATERIAL E MÉTODOS

Área de estudo. Um estudo foi realizado na safra 2020-21 em pomares de macieiras localizados nos municípios de Antônio Prado e Muitos Capões, RS, e em São Joaquim, SC (Figura 17) (Rode *et al.,* 2023a; 2024a, b).

Figura 17 - Pontos de coletas em regiões produtoras de macieira no estado do Rio Grande do Sul, nos municípios de Antônio Prado, em pomares dos cultivares Eva (APE), Fuji (APF) e Gala (APG) e Muitos Capões, em pomares dos cultivares Fuji (MCF) e Gala (MCG), e no estado de Santa Catarina no município de São Joaquim, em pomares dos cultivares Fuji (SJF) e Gala (SJG).



Fonte: Castro, I.S (2023).

Antônio Prado: Nessa localidade foram realizadas coletas em pomares orgânicos dos cultivares Eva, Fuji e Gala. A cobertura do solo era preservada, com presença de plantas espontâneas, gramíneas e ervas daninhas, em associação com a serapilheira (Figura 18). Não ocorria pulverização de pesticidas e herbicidas nas áreas dessa localidade.

Figura 18 - Pomar de macieira no município de Antônio Prado, Rio Grande do Sul. Pomar no período de frutificação (A). Pomar no período de senescência (B). Pomar no período pós-colheita e pré-senescência (C).

Fonte: Da autora (2024).

São Joaquim: Nesta localidade foram avaliados dois pomares, um com cultivar Fuji e outro Gala. Nestas áreas, o solo era mantido coberto por plantas espontâneas, gramíneas e ervas daninhas, em associação com a serapilheira (Figura 19). A capina não era realizada. Porcos, ovelhas e galinhas eram mantidos pastoreando na área, esses animais alimentavam-se tanto das plantas espontâneas como dos frutos que abortavam das macieiras. Apesar do cuidado com a proteção do solo nessas áreas, sempre que necessário, os produtores utilizam pesticidas para o controle de pragas. Esta área foi considerada como sendo de agricultura regenerativa.

Figura 19 – Pomar de macieira no município de São Joaquim, Santa Catarina. Pomar no período de frutificação (A). Pomar no período de senescência (B). Pomar no período pós-colheita e pré-senescência (C).

Fonte: Da autora (2024).

Muitos Capões: Nessa localidade as coletas foram realizadas em dois pomares convencionais, sendo um Fuji e outro com Gala. Nas áreas da localidade o solo era mantido desprotegido, com uso de herbicidas e capina, e a pulverização de produtos químicos para controle de pragas era frequente (Figura 20).

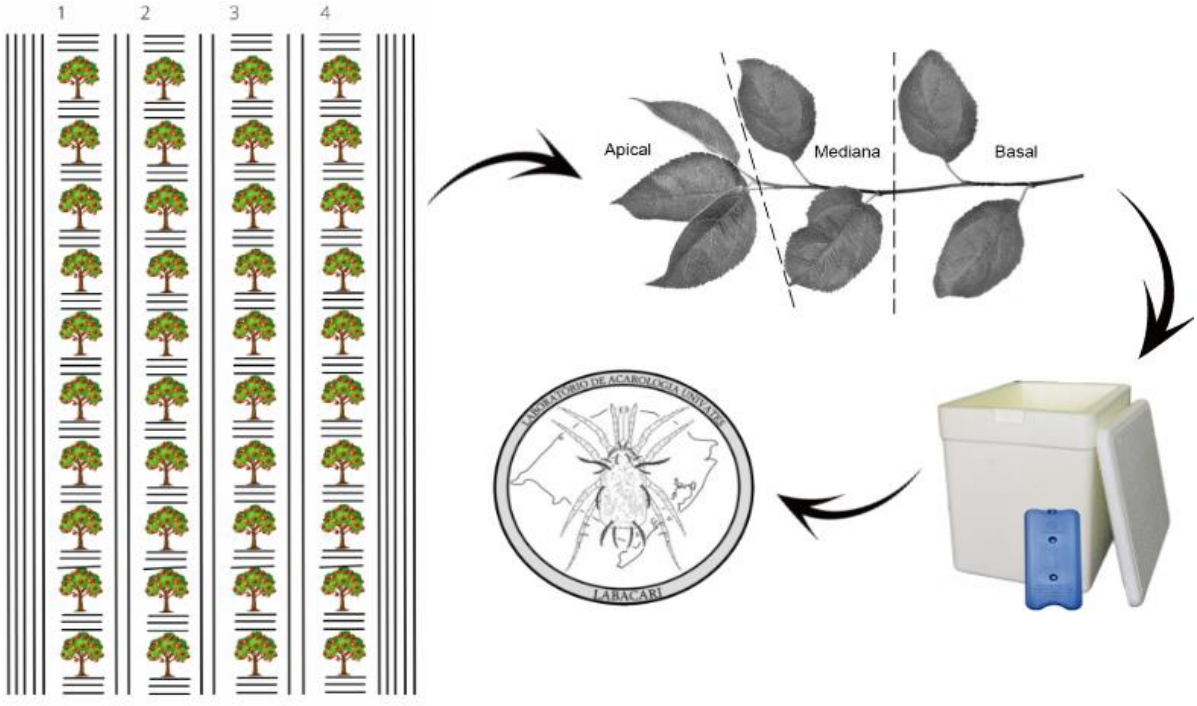
Figura 20 - Pomar de macieira no município de Muitos Capões, Rio Grande do Sul. Pomar no período de frutificação (A). Pomar no período de senescência (B). Pomar no período pós-colheita e pré-senescência (C).

Fonte: Da autora (2024).

Coleta e triagem. Os pomares foram divididos em quadrantes e 40 árvores foram marcadas com fitas para identificar a origem das folhas amostradas. As coletas foram realizadas mensalmente de setembro de 2020 a agosto de 2021.

Folhas de macieira. Para a amostragem das plantas de macieira, foram destacadas três folhas de um ramo mediano de cada planta dos estratos apical, mediano e basal do ramo (Figura 21), totalizando 120 folhas/pomar/mês. No período de senescência, as plantas estavam sem folhas e foram coletados ramos da parte central da planta e triadas três gemas dos estratos apical, mediano e basal, totalizando 120 gemas/pomar/mês.

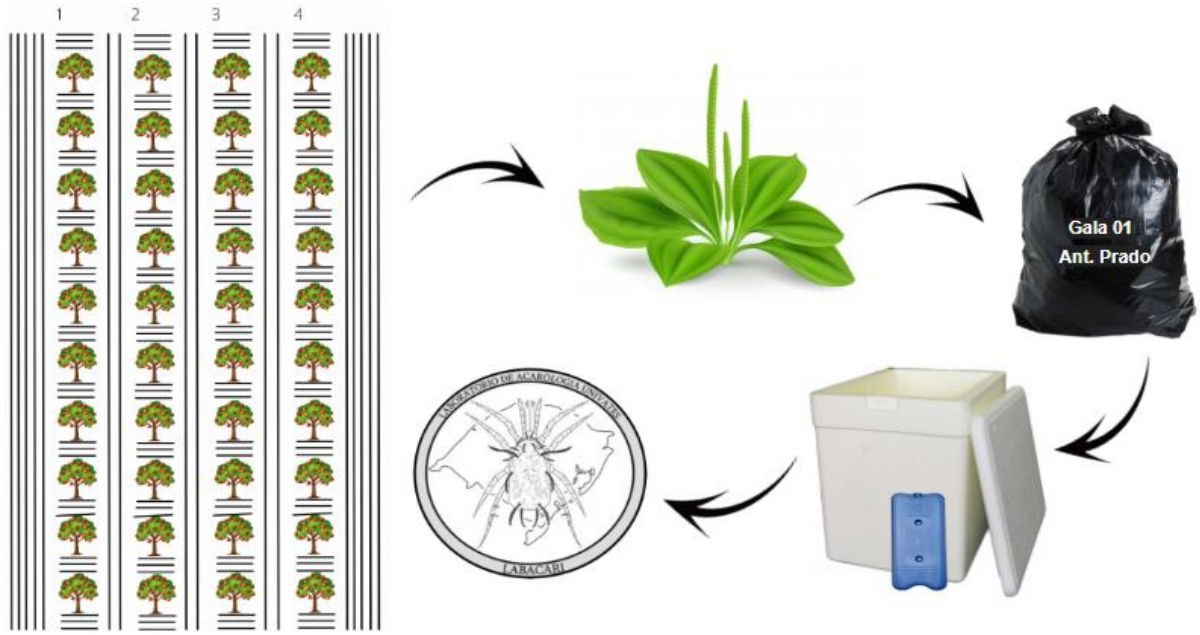
Figura 21 - Esquema representativo dos pomares de macieiras amostrados, da localização (diferentes estratos: apical, mediano e basal) das folhas coletadas ao longo do ramo de macieira, e do armazenamento e transporte do material até o laboratório de acarologia da Univates.



Fonte: Da autora (2024).

Vegetação espontânea. Para amostragem da vegetação espontânea, no mesmo período e nos mesmos pomares foram realizadas coletas das cinco plantas de ocorrência espontânea e que estavam presentes em maior quantidade no dia em questão nos pomares (Figura 22).

Figura 22 - Esquema representativo dos pomares de macieiras amostrados, da vegetação espontânea coletada, e do armazenamento e transporte do material até o laboratório de acarologia da Univates.



Fonte: Da autora (2024).

Após coletado, o material era levado imediatamente ao Laboratório de Acarologia (Labacari) da Universidade do Vale do Taquari - Univates, Lajeado, RS. A triagem era realizada sob microscópio estereoscópico, com auxílio de um pincel fino (Figura 23). Os ácaros foram montados em lâminas de microscopia (Jeppson *et al*., 1975) e mantidos em estufa a 50-60 °C por aproximadamente oito dias.

Figura 23 - Triagem dos ácaros presentes em folhas de macieiras e vegetação espontânea (A). Montagem dos ácaros em lâminas de microscopia (B). Secagem das lâminas em estufa (C).

Fonte: Da autora (2024).

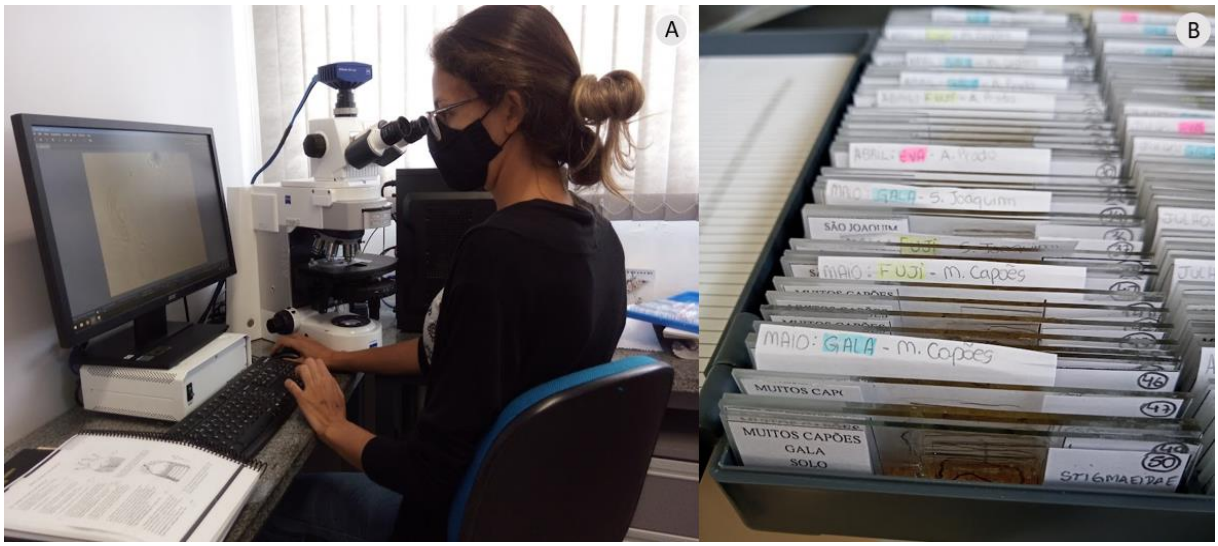
Após a triagem, uma amostra de cada planta coletada foi montada em exsicata para posterior identificação que ocorreu com o auxílio de bibliografia específica (Moreira; Bragança, 2011; Lorenzi, 2014), por comparação no Herbário do Vale do Taquari (HVAT) e consulta a especialistas (Figura 24). A determinação das famílias foi baseada nos sistemas Angiosperm Phylogeny Group IV (APG IV, 2016).

Figura 24 – Preparação do material vegetal em exsicata (A). Exsicatas prontas em prensa (B). Exsicatas em estufa para secagem do material vegetal (C).

Fonte: Da autora (2024) (A). Gomes, I.B. (2009) (B). Portalnea (C).

Identificação dos ácaros. Os ácaros eram identificados usando microscópio óptico de contraste de fase e bibliografia específica para cada grupo encontrado (Baker; Tuttle, 1994, Amrine Jr.; Stasny; Flechtmann, 2003; Chant; McMurtry, 1994, Amrine; Stasny, 1994, Amrine Jr. *et al*., 2003, Fan; Zhang, 2005, Chant; McMurtry, 2007; Johann *et al*., 2013, Skvarla *et al*., 2014, Silva *et al*., 2016, Johann *et al*., 2017) (Figura 25).

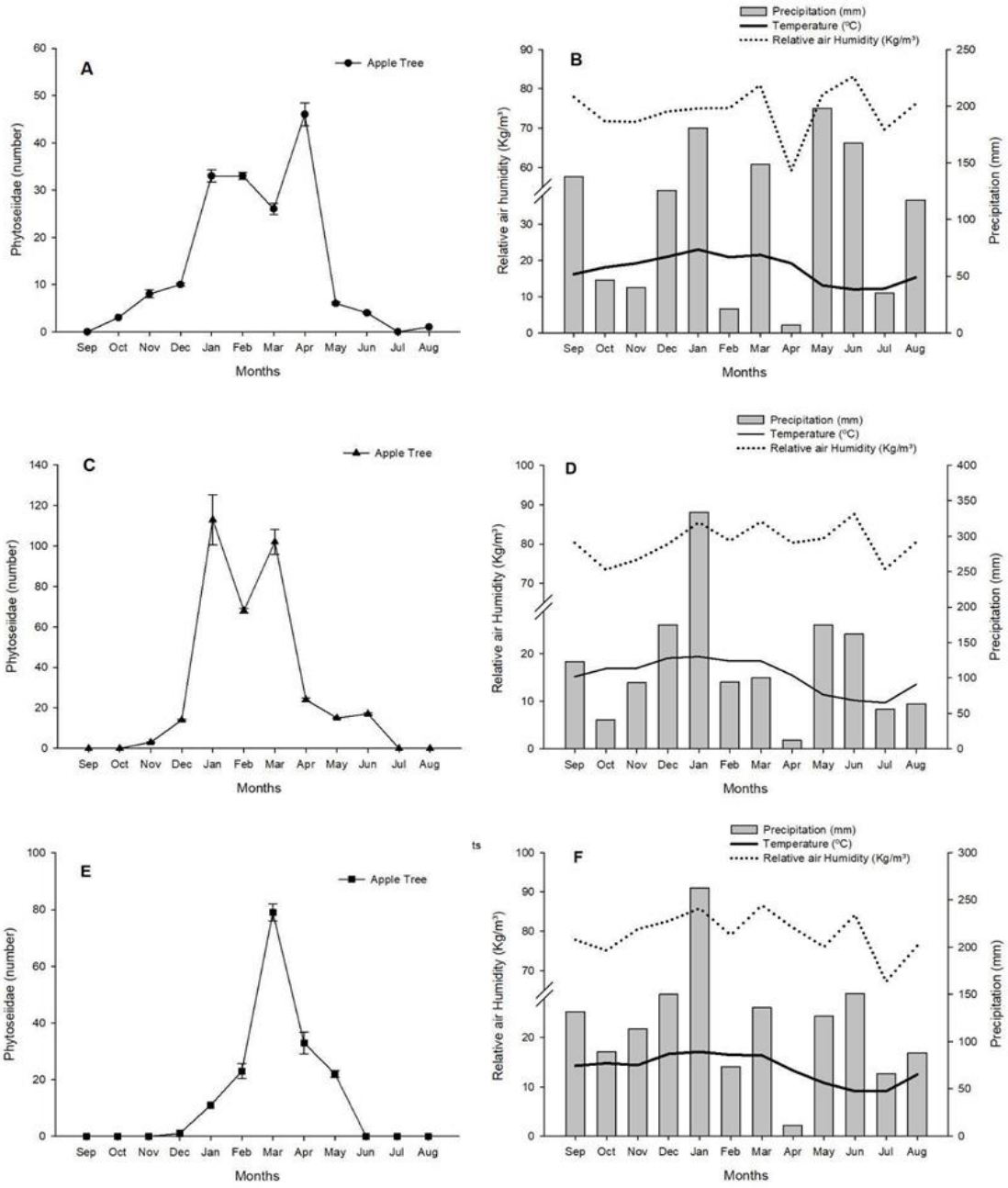
Figura 25 – Identificação dos ácaros sob microscópio óptico de contraste de fase e com o auxílio de chave dicotômica (A). Caixa porta lâminas de microscopia (B).



Fonte: Da autora (2024).

As informações climatológicas do período amostrado foram obtidas de estações meteorológicas próximas aos pontos de coleta, a saber: Antônio Prado informações da estação meteorológica do INMET, município de Bento Gonçalves (A840); Município de Muitos Capões, dados da estação meteorológica do INMET, Vacaria (A880); São Joaquim, informações da Estação Meteorológica Automática do Morro da Igreja (A845) (EMAMI) (Figura 26).

Figura 26 - Dados meteorológicos dos municípios de Antônio Prado (A), Muitos Capões (B) e São Joaquim (C), no período de setembro de 2020 a agosto de 2021, dados fornecidos pela Embrapa.


A
Apple Tree
Phytoseiidae (number)
Months
B
Precipitation (mm)
Temperature (°C)
Relative air Humidity (Kg/m³)
Relative air humidity (Kg/m³)
Precipitation (mm)
C
Apple Tree
D
Relative air Humidity (Kg/m³)
E
Apple Tree
F
Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug

RESULTADOS

DIVERSIDADE DE ÁCAROS NA MACIEIRA

Nas plantas de macieira foi coletado um total de 7.193 espécimes, pertencentes a 14 famílias, 29 gêneros e 40 espécies/morfoespécies (Tabela 1). As espécies fitófagas mais abundantes foram *A. schlechtendali* (46,2%), *P. ulmi* (16,9%) e *Polyphagotarsonemus latus* Banks (Tarsonemidae) (10,9%). *Panonychus ulmi* esteve presente em todos os pomares e durante todo o período avaliado. Entre os ácaros predadores, *N. californicus* (7,5%), *A. riograndensis* (4,4%) e *A. brasiliensis* (3,3%) se destacaram.

Pomares orgânicos. Em Antônio Prado, no pomar de Eva, as espécies constantes foram *Pseudopronematulus* sp. (Iolinidae), *Euseius mesembrinus* Dean, *Euseius inouei* Ehara e Moraes (Phytoseiidae), *A. brasiliensis* e *Tydeus californicus* Banks (Tydeidae). Neste pomar, *A. schlechtendali* e *A. riograndensis* foram Eudominantes; *A. brasiliensis* e *T. californicus*, Dominantes. No pomar de Fuji, apenas *P. ulmi* foi Constante e Dominante; *Aculus schlechtendali* e *P. latus* foram Eudominantes. No pomar de Gala, *Pseudopronematulus* sp. e *Tarsonemus waitei* Banks (Tarsonemidae) foram Constantes; *A. schlechtendali* e *P. latus*, Eudominantes. Nos pomares de Antônio Prado houve maior diversidade de predadores, quando comparados aos de Muitos Capões e São Joaquim.

Pomares convencionais. Em ambos os cultivares de Muitos Capões, *N. californicus*, *P. ulmi* e *T. waitei* foram constantes. No pomar de Fuji deste município, *A. schlechtendali* também foi constante. Quanto à dominância, *A. schlechtendali*, *N. californicus* e *P. ulmi* foram Eudominantes em ambas os cultivares. Com relação aos inimigos naturais, apenas *N. californicus* e *P. cannaensis* estavam presentes nos pomares de Fuji e Gala em Muitos Capões.

Pomares regenerativos. *Tarsonemus merus* Lin e Zhang (Tarsonemidae) e *P. ulmi* foram constantes nos pomares de Fuji e Gala em São Joaquim. No pomar de Fuji deste município, *N. californicus* e *P. ulmi* foram Eudominantes, no pomar de Gala, além dessas duas espécies, *A. schlechtendali* e *T. merus* foram Eudominantes. *Agistemus riograndensis* foi Dominante no pomar do cultivar Gala. Com relação aos inimigos naturais, apenas *N. californicus* esteve presente nos pomares de São Joaquim.

Tabela 1. Ácaros associados a cultivares de macieira nos municípios de Muitos Capões, Antônio Prado, Rio Grande do Sul e São Joaquim, Santa Catarina, Brasil, coletados entre agosto de 2020 e setembro de 2021.

Espécies	Antônio Prado									Muitos Capões						São Joaquim							
	Eva			Fuji			**Gala**			Fuji			**Gala**			Fuji			**Gala**				
	T	**Co**	**Do**	T	Co	Do	**T**	**Co**	**Do**	T	Co	Do	**T**	**Co**	**Do**	T	Co	Do	**T**	**Co**	**Do**	So	%
Aculus schlechtendali – F	**1371**	**A**	**E**	86	A	E	**379**	**A**	**E**	224	C	E	**1207**	**A**	**E**	5	I	Ev	**58**	**A**	**E**	**3330**	**46,2**
Agistemus brasiliensis – P	**175**	**C**	**D**	10	A	S	**15**	**A**	**Ev**	13	A	Ev	**24**	**A**	**Ev**	-			**1**	**I**	**R**	**238**	**3,3**
Agistemus floridanus – P	-			3	I	Ev	**4**	**I**	**R**	-			-			1	I	R	**1**	**I**	**R**	**9**	**0,1**
Agistemus riograndensis – P	**210**	**A**	**E**	7	A	S	**27**	**A**	**S**	5	I	Ev	**11**	**I**	**Ev**	16	A	S	**42**	**A**	**D**	**318**	**4,4**
Agistemus sp. – P	-			1	I	R	-			-			-			-			-			**1**	**0,01**
Amblyseius chiapensis – P	**1**	**I**	**R**	-			-			-			-			-			-			**1**	**0,01**
Arrenoseius sp. – P	**1**	**I**	**R**	-			-			-			-			-			-			**1**	**0,01**
Asca sp. – P	-			1	I	R	-			-			-			-			-			**1**	**0,01**
Benoinyssus sp. – G	-			-			**2**	**I**	**R**	-			-			-			-			**2**	**0,02**
Brevipalpus sp. – F	**4**	**A**	**R**	9	I	S	**8**	**A**	**Ev**	1	I	R	**1**	**I**	**R**	-			-			**23**	**0,3**
Czenskinspia transversostriata - G	**3**	**I**	**R**	-			**1**	**I**	**R**	-			-			8	I	S	**4**	**I**	**Ev**	**16**	**0,2**
Daidalotarsonemus esalqi - F	**1**	**I**	**R**	-			-			-			**1**	**I**	**R**	-			-			**2**	**0,02**
Daidalotarsonemus savanicus - F	**9**	**A**	**R**	-			-			-			-			-			-			**9**	**0,1**
Euseius inouei – P	**37**	**C**	**S**	1	I	R	**1**	**I**	**R**	-			-			-			-			**39**	**0,5**
Euseius mesembrinus – P	**49**	**C**	**S**	2	I	Ev	-			-			-			-			-			**51**	**0,7**
Fungitarsonemus sp. – F	-			-			-			-			-			1	I	R	-			**1**	**0,01**
Galendromus annectens – P	**1**	**I**	**R**	-			**9**	**A**	**Ev**	-			-			-			-			**10**	**0,1**
Lorryia aberrans - G	-			-			-			-			-			2	I	R	-			**2**	**0,02**
Neoseiulus californicus – P	**5**	**A**	**R**	5	A	Ev	**11**	**A**	**Ev**	161	C	E	**193**	**C**	**E**	63	A	E	**106**	**A**	**E**	**544**	**7,5**

Metaseiulus eiko – P	**11**	**A**	**Ev**	6	A	S	**18**	**A**	**S**	-			-			-			-			**35**	**0,4**
Neoseiulus fallacis – P	-			1	I	R	-			-			-			-			-			**1**	**0,01**
Neoseiulus tunus – P	**10**	**A**	**R**	1	I	R	-			-			-			-			-			**11**	**0,1**
Suborder Oribatida – G	-			-			-			-			-			15	A	S	**10**	**A**	**S**	**25**	**0,3**
Panonychus ulmi – F	**1**	**I**	**R**	19	C	D	**21**	**A**	**S**	506	C	E	**195**	**C**	**E**	345	C	E	**135**	**C**	**E**	**1222**	**16,9**
Polyphagotarsonemus latus – F	**17**	**I**	**Ev**	188	A	E	**582**	**A**	**E**	-			-			-			-			**787**	**10,9**
Pretydeus henriandrei - G	-			1	I	R	-			-			-			-			-			**1**	**0,01**
Proprioseiopsis cannaensis – P	-			-			-			1	I	R	**1**	**I**	**R**	-			-			**2**	**0,02**
Pseudopronematulus sp. - G	**40**	**C**	**S**	4	I	Ev	**9**	**C**	**Ev**	1	I	R	**1**	**I**	**R**	-			-			**55**	**0,76**
Quasitydeus sp. - G	-			2	I	Ev	-			-			-			-			-			**2**	**0,02**
Rhynchotarsonemus sp. – F	**1**	**I**	**R**	-			-			-			-			-			-			**1**	**0,01**
Tarsonemus confusus – F	**5**	**I**	**R**	-			-			-			-			2	I	R	-			**7**	**0,09**
Tarsonemus merus – F	**16**	**A**	**Ev**	9	I	S	**17**	**A**	**S**	1	I	R	**7**	**A**	**R**	44	C	D	**49**	**C**	**E**	**143**	**1,9**
Tarsonemus waitei – F	**38**	**A**	**S**	13	A	S	**16**	**C**	**Ev**	13	C	Ev	**25**	**C**	**Ev**	6	A	Ev	**16**	**A**	**S**	**127**	**1,7**
Tenuipalpus sp. – F	**1**	**I**	**R**	-			-			-			-			-			-			**1**	**0,01**
Tetranychus sp. – F	**2**	**I**	**R**	6	I	S	-			-			-			-			-			**8**	**0,1**
Tetranychus urticae – F	**4**	**A**	**R**	7	A	S	**1**	**I**	**R**	-			**1**	**I**	**R**	-			-			**13**	**0,1**
Triophtydeus sp. - G	**1**	**I**	**R**	-			**1**	**I**	**R**	-			-			-			-			**2**	**0,02**
Tydeus californicus - G	**105**	**C**	**D**	5	A	Ev	**9**	**A**	**Ev**	-			-			3	I	Ev	**1**	**I**	**R**	**123**	**1,7**
Tyrophagus putrescentiae – G	**7**	**A**	**R**	1	I	R	-			5	I	Ev	**1**	**I**	**R**	-			**2**	**I**	**R**	**16**	**0,2**
Xenotarsonemus sp. – F	-			-			-			13	I	Ev	-			-			-			**13**	**0,1**
Total	**2126**			388			**1131**			944			**1668**			511			**425**			**7.193**	
%	**29,5**			5,3			**15,7**			13,1			**23,1**			7,1			**5,9**				
Richness	**28**			24			**19**			12			**13**			13			**12**			**7.193**	

T = Total de ácaros; Co = Constância; Do = Dominância; So = Soma; C = Constante; A = Acessória; I = Acidental; E = Eudominante; D = Dominante; S = Subdominante; Ev = Eventual; R = Raro; F = Fitófago; P = Predador; G = Generalista/micófago.

Pomares de macieiras manejados organicamente no sul do Brasil abrigam uma alta diversidade de ácaros em comparação com pomares convencionais e regenerativos. Os ácaros fitófagos *A. schlechtendali*, *P. latus* e *P. ulmi* foram os mais comuns, enquanto *N. californicus*, *A. brasiliensis* e *A. riograndensis* foram os ácaros predadores mais importantes desta cadeia. Os resultados sugerem que as populações de ácaros são influenciadas pelo cultivar utilizado, por fatores abióticos e principalmente pelo manejo utilizado na produção.

FLUTUAÇÃO POPULACIONAL DE ÁCAROS EM POMARES DE MACIEIRA

Ácaros fitófagos. *Aculus schlechtendali*, *P. latus* e *P. ulmi* foram os mais comuns e abundantes, revelando-se como espécies-chave na cultura da macieira no Brasil. *Panonychus ulmi* foi observado em todos os pomares, sendo frequente e abundante nos pomares orgânicos e regenerativos. Esteve presente em quase todo o período de estudo, sendo mais abundante no período de dezembro a fevereiro, em regenerativo e convencional. *Aculus schlechtendali* atingiu altas populações em dezembro e janeiro, principalmente no pomar de Eva em Antônio Prado e no pomar de Gala em Muitos Capões. *Polyphagotarsonemus latus* teve populações significativas em pomares orgânicos entre dezembro e janeiro.

Ácaros predadores. No período avaliado, *A. brasiliensis*, *A. riograndensis*, *E. inouei*, *E. mesembrinus* e *N. californicus*, foram comuns em pomares orgânicos. *Neoseiulus californicus* foi a espécie mais comum nos pomares convencionais. Altas populações de *A. brasiliensis* e *A. riograndensis* foram observadas apenas no pomar de Eva em Antônio Prado.

Ácaros generalistas. *Tarsonemus waitei*, *T. merus* e *T. californicus* foram os ácaros generalistas mais comuns. *Tarsonemus waitei* foi comum nos pomares orgânicos e convencionais, *T. merus*, nos regenerativos e *T. californicus* apenas no pomar de Eva em Antônio Prado. *Pseudopronematulus* sp. esteve presente em altas populações apenas em pomares orgânicos.

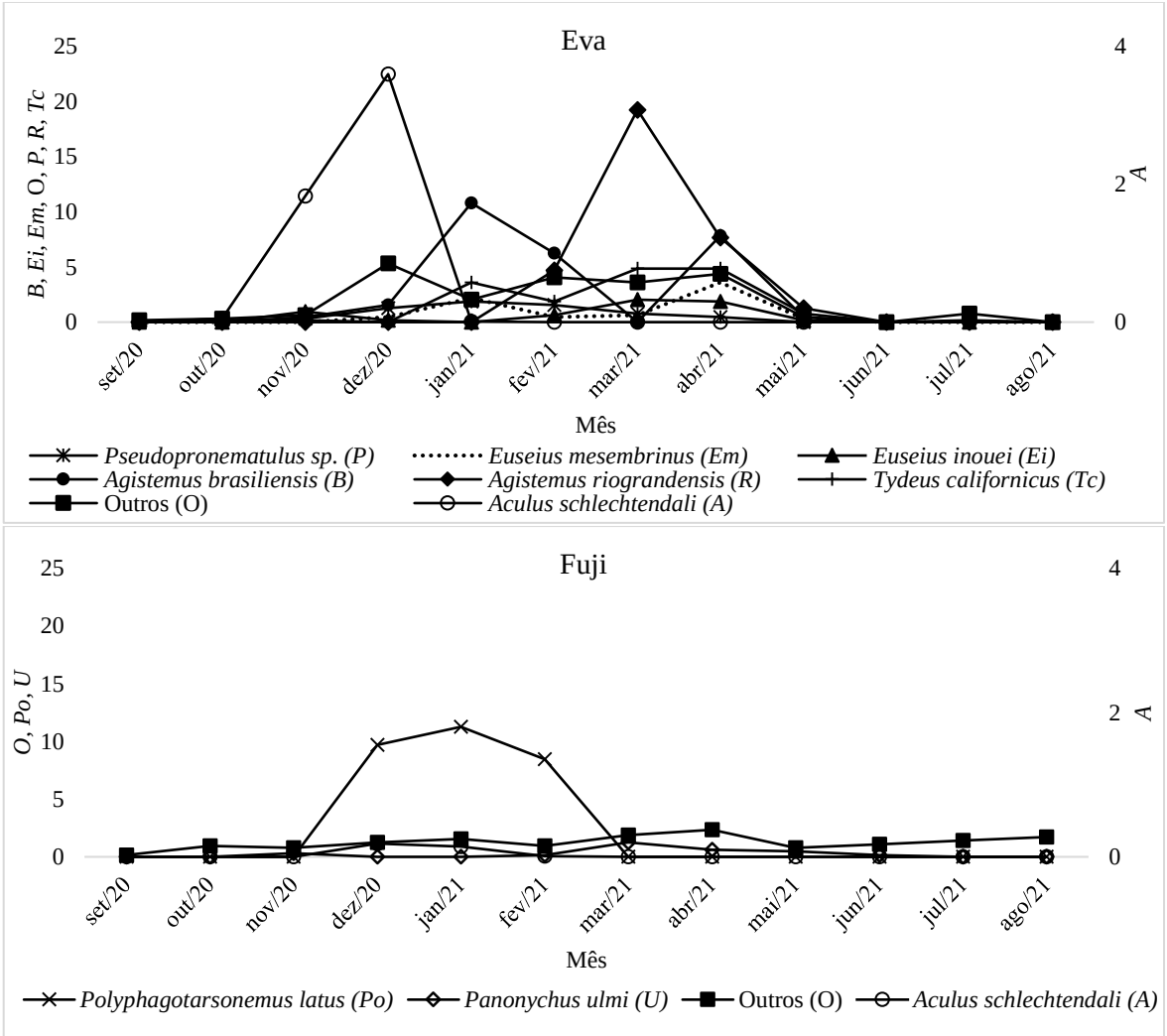
Pomares orgânicos em Antônio Prado. No pomar de Eva, *A. schlechtendali* teve pico populacional em dezembro (22,45 ácaros/planta) e *A. brasiliensis* em janeiro (1,73

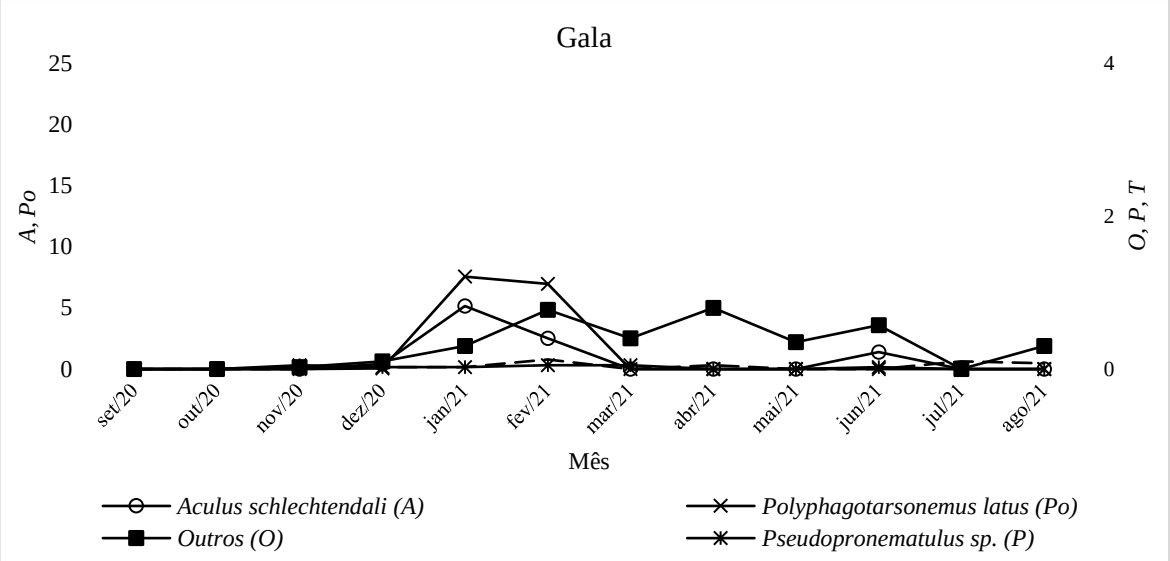
ácaros/planta) (Figura 27). Tarsonemidae e Tydeidae apresentaram altas populações de dezembro a março, acompanhando *E. inouei*, *E. mesembrinus* e *A. brasiliensis*, cujas populações foram maiores em março (3,08 ácaros/planta).

No pomar de Fuji, o pico populacional de *P. latus* ocorreu em janeiro (1,18 ácaros/planta), mantendo altas populações de dezembro a fevereiro, enquanto *A. schlechtendali* teve pico em dezembro (1,15 ácaros/planta).

No pomar de Gala, em janeiro, foi observado o pico populacional de *P. latus* (7,55 ácaros/planta) e *A. schlechtendali* (5,15 ácaros/planta). A maior população de *P. ulmi* foi em abril (0,28 ácaros/planta). Entre dezembro e junho, houve aumento populacional de ácaros fitoseiídeos e estigmeídeos.

Figura 27 - Flutuação populacional de ácaros associados a pomares de macieiras dos cultivares Eva (A), Fuji (B) e Gala (C) no município de Antônio Prado, Rio Grande do Sul, Brasil.

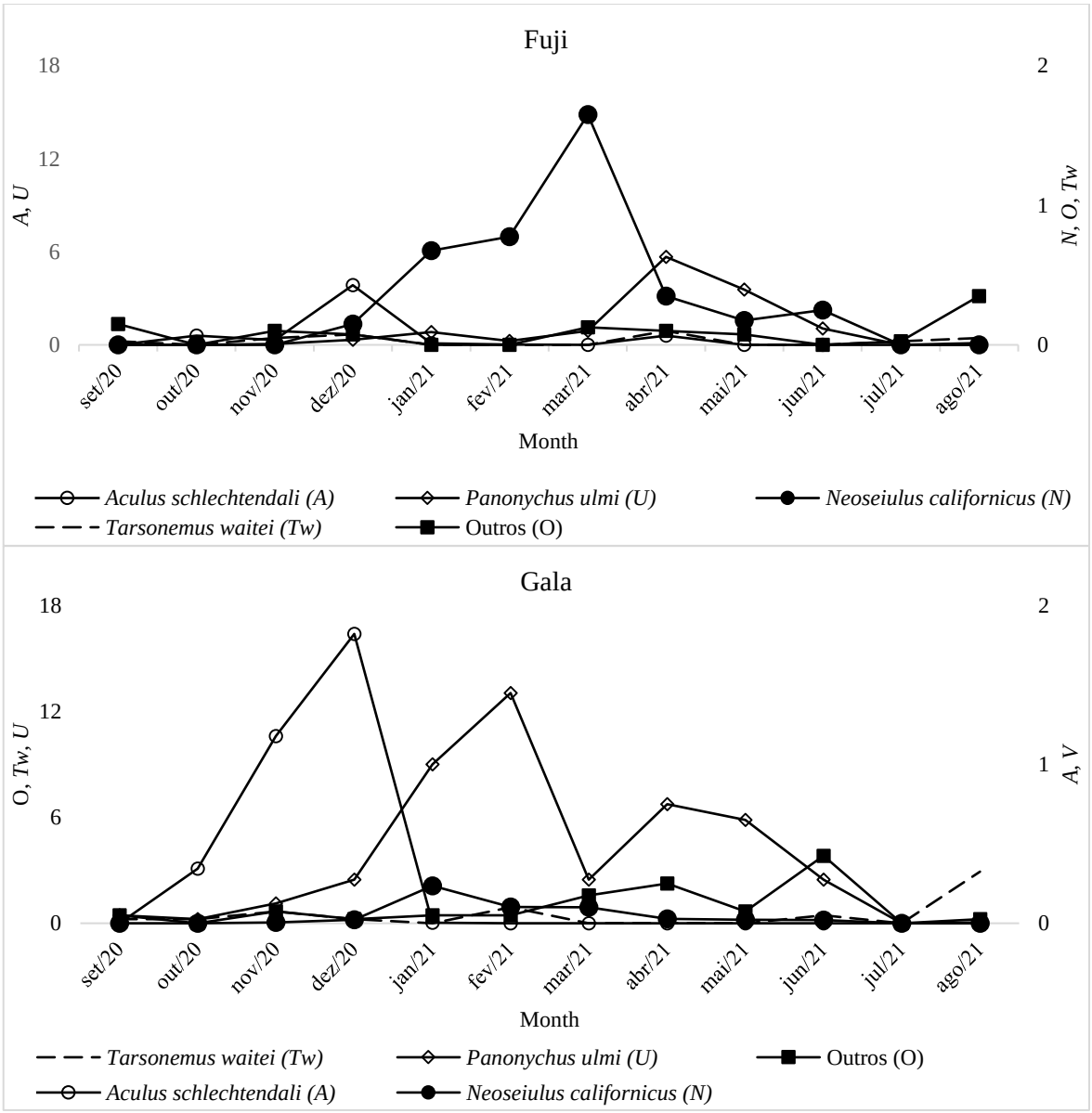




Pomares convencionais em Muitos Capões. No pomar de Fuji, *A. schlechtendali* teve pico populacional em dezembro (3,85 ácaros/planta) e aumento populacional de *N. californicus*, com pico em março (1,65 ácaros/planta) (Figura 28). Em abril, a população de *N. californicus* diminuiu consideravelmente e em maio houve um pico de *P. ulmi* (5,68 ácaros/planta).

No pomar de Gala, o pico populacional de *A. schlechtendali* (16,40 ácaros/planta) ocorreu em dezembro, seguido de *N. californicus*, em janeiro (2,13 ácaros/planta). *Panonychus ulmi* teve pico populacional em fevereiro (1,45 ácaros/planta).

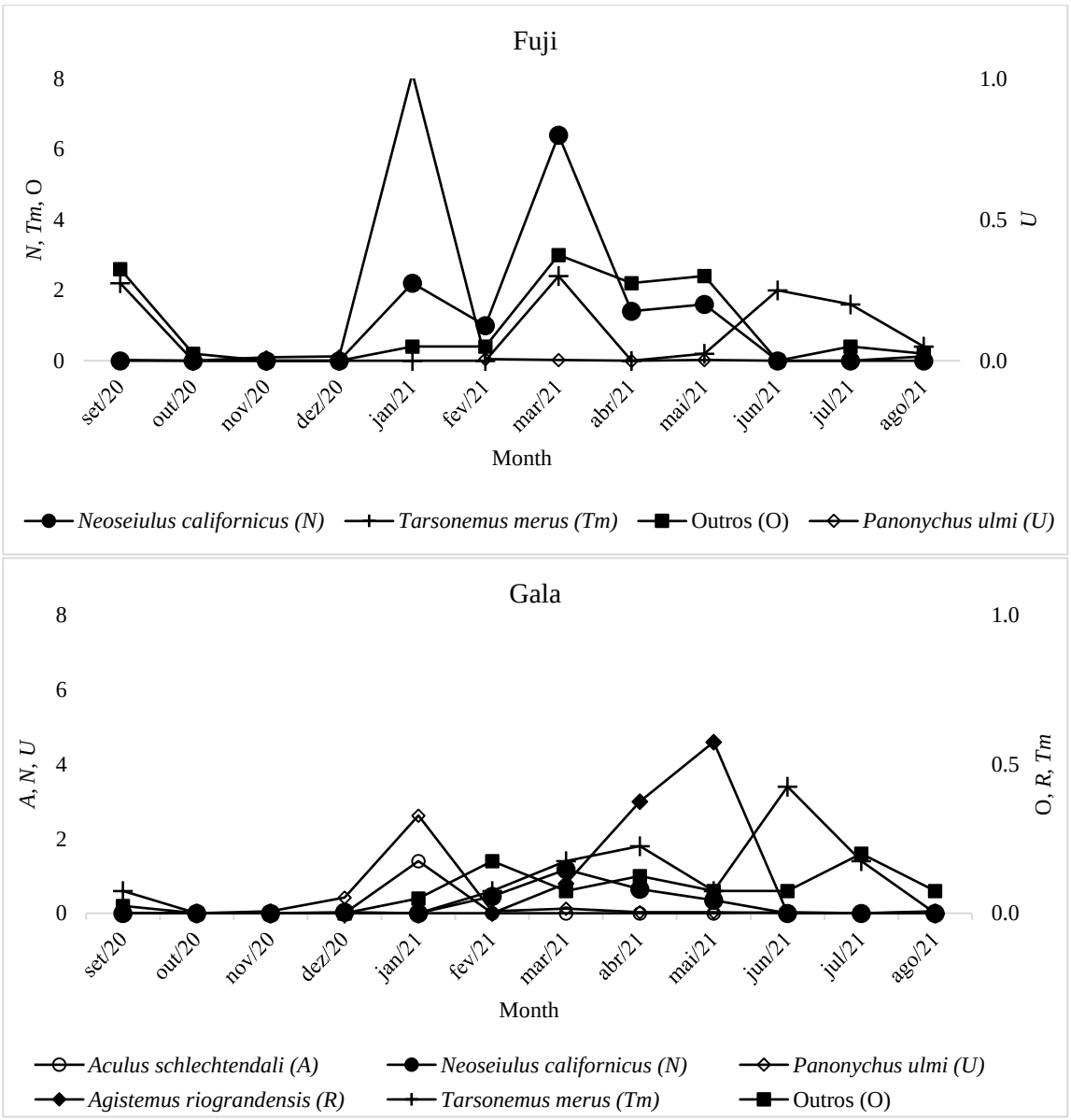
Figura 28 - Flutuação populacional de ácaros associados a pomares de macieiras dos cultivares Fuji e Gala no município de Muitos Capões, Rio Grande do Sul, Brasil.



Pomares regenerativos em São Joaquim. No pomar de Fuji, o pico populacional de *P. ulmi* ocorreu em janeiro (8,15 ácaros/folha) e em março *N. californicus* (0,80 ácaros/folha) e *T. merus* (0,30 ácaros/folha) (Figura 29).

No pomar de Gala, *A. schlechtendali* (1,40 ácaros/planta) e *P. ulmi* (2,63 ácaros/planta) atingiram o pico em janeiro. Em março houve pico de *T. merus* (0,43 ácaros/planta) e em maio de *A. riograndensis* (0,58 ácaros/planta).

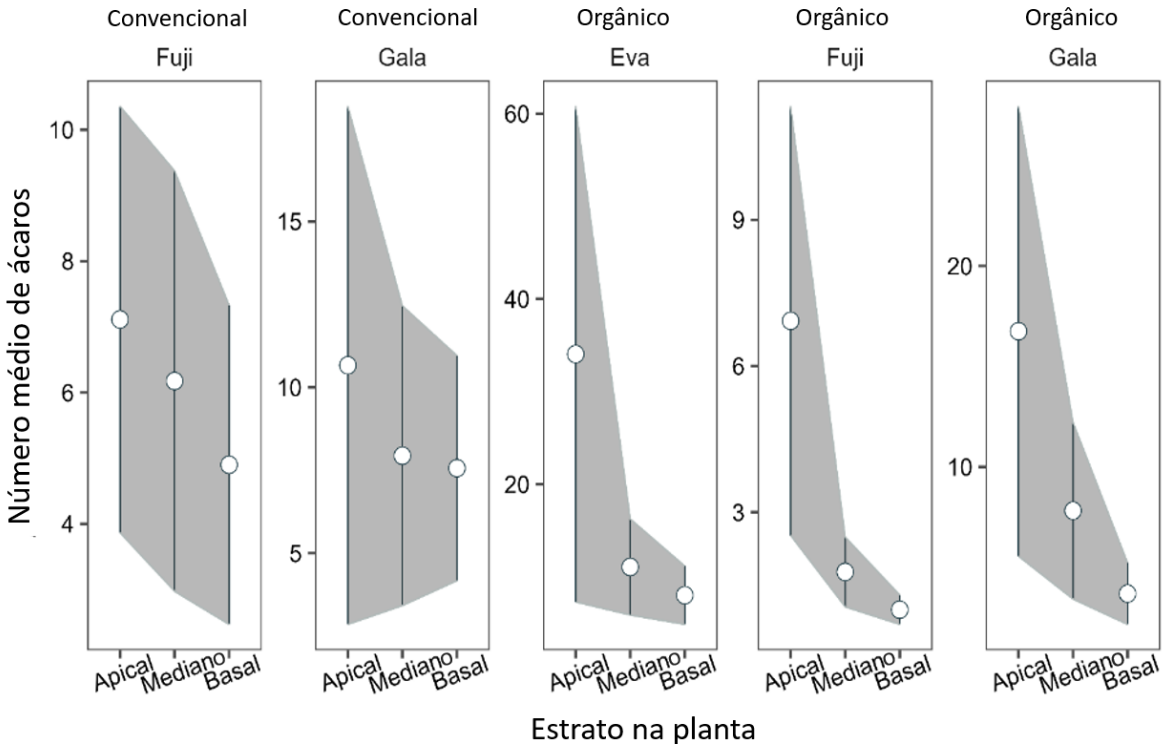
Figura 29 - Flutuação populacional de ácaros associados a pomares de macieiras dos cultivares Fuji e Gala no município de São Joaquim, RS, Brasil.



Os pomares de macieira manejados organicamente no sul do Brasil abrigam uma alta diversidade de ácaros em comparação com pomares convencionais e regenerativos. Os ácaros fitófagos *A. schlechtendali*, *P. latus* e *P. ulmi* são os mais comuns, enquanto *N. californicus*, *A. brasiliensis* e *A. riograndensis* são os ácaros predadores mais importantes dessa cadeia. Os resultados sugerem que as populações de ácaros são influenciadas pelo cultivar utilizado, fatores abióticos e principalmente pelo manejo utilizado na produção. Estudos adicionais são sugeridos para monitoramento de *A. schlechtendali*, avaliação do potencial de controle de *N. californicus*, *A. brasiliensis* e *A. riograndensis* sobre ácaros fitófagos em cultura e estudos que avaliem o potencial deste eriofiídeo como causador de danos em pomares brasileiros.

Os pomares orgânicos apresentaram maior abundância média (10,1±3,37) do que os convencionais (7,39±1,82) (Figura 30). Em relação ao cultivar, observou-se que Eva apresentou a maior média de abundância (17,7±9,13), seguida de Gala (8,96±2,52) e Fuji (5,12±1,25).

Figura 30 - Quantidade média (pontos) e erro padrão (barras verticais) de ácaros em diferentes sistemas de cultivo por cultivar de macieira por camada de planta.



Ao comparar as três variáveis de forma combinada (sistema de cultivo + cultivar + estrato) observou-se que no estrato apical de Eva Orgânica há maior abundância média de ácaros (34±26,8) (Tabela 2), seguido do estrato apical da Gala Orgânica, com menos da metade da população (16,8±11,2). Por outro lado, Fuji orgânico apresentou menor abundância média no estrato basal (1,0±0,3) e mediano (1,78 ± 0,71).

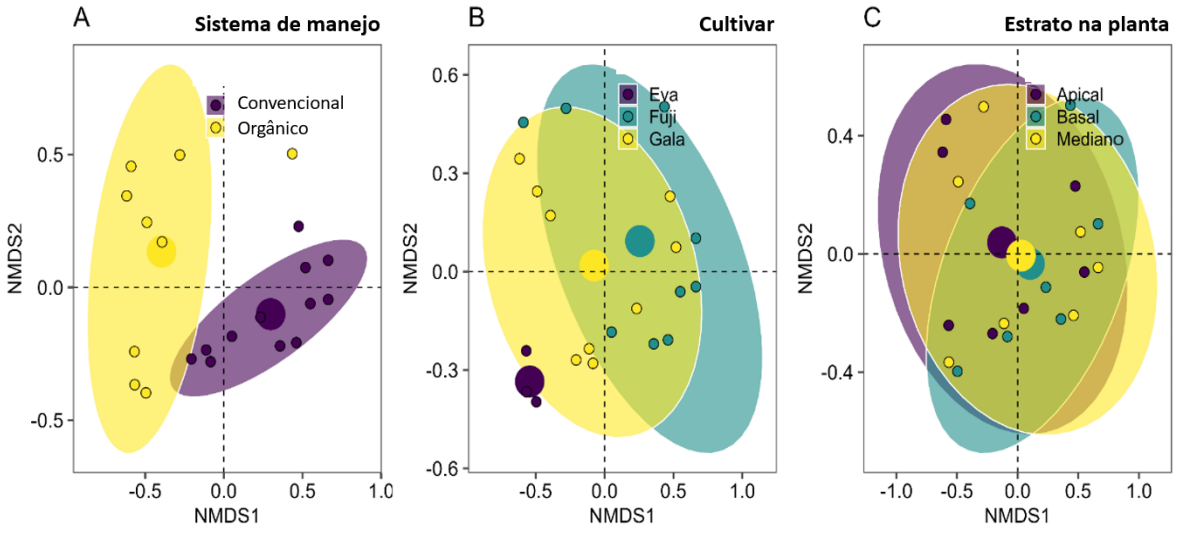
Tabela 2. Quantidade média de ácaros/sistema de cultivo/cultivar/estrato.

Sistema de cultivo	Cultivar	Estrato	Média ± SE	Ordem/infestação*
Orgânico	Eva	Apical	34,00±26,8	1º
Orgânico	Gala	Apical	16,80±11,2	2º
Orgânico	Eva	Mediano	11,10±5,19	3º
Convencional	Gala	Apical	10,70±7,82	4º
Orgânico	Eva	Basal	8,02±3,16	5º
Convencional	Gala	Mediano	7,94±4,52	6º
Orgânico	Gala	Mediano	7,82±4,4	7º
Convencional	Gala	Basal	7,56±3,4	8º
Convencional	Fuji	Apical	7,11±3,25	9º
Orgânico	Fuji	Apical	6,92±4,4	10º
Convencional	Fuji	Mediano	6,18±3,2	11º
Convencional	Fuji	Basal	4,90±2,43	12º
Orgânico	Gala	Basal	3,70±1,54	13º
Orgânico	Fuji	Mediano	1,78±0,71	14º
Orgânico	Fuji	Basal	1,00±0,30	15º

***** Posicionamento do nível mais alto de infestação para o nível mais baixo.

A estruturação da comunidade acarina, conforme o sistema de cultivo, apresentou diferentes agrupamentos. Ao analisar a comunidade segundo o sistema de cultivo, é possível verificar uma estrutura significativamente diferente na diversidade de ácaros que compõem culturas orgânicas e convencionais (Figura 31A). Quando a mesma comunidade foi avaliada com relação ao cultivar, observou-se diferença significativa entre eles (Figura 31B). No entanto, a diferença ocorreu apenas entre Eva e os outros dois cultivares, Fuji e Gala, e a maior sobreposição de espécies entre Fuji e Gala torna a diversidade de ácaros de ambas, mais semelhante entre si. Por fim, todos os estratos vegetais apresentaram grande compartilhamento de espécies de ácaros (Figura 31C).

Figura 31 - Composição da comunidade de ácaros em três contextos diferentes: (A) dois sistemas de manejo (Convencional, Orgânico), (B) três cultivares de maçã (Eva, Fuji, Gala), (C) três estratos vegetais (Apical, Mediano, Basal).



ÁCAROS PHYTOSEIIDAE EM MACIEIRAS

Foi coletado um total de 695 espécimes de fitoseídeos, pertencentes a 10 espécies e sete gêneros. O maior número de espécies foi encontrado nos pomares orgânicos, com oito espécies coletadas em Eva, seis em Fuji e quatro em Gala. Em áreas de manejo orgânico, observou-se predominância de espécies do gênero *Euseius* (*Euseius mesembrinus* (Dean) e *Euseius inouei* (Ehara & Moraes) em Eva, enquanto *Metaseiulus eiko* (El-Banhawy) apresentou maior abundância em Fuji e Gala. Observamos um baixo número de espécies nos pomares que utilizam o sistema de manejo convencional, e regenerativo. Nesta última área, apenas *N. californicus* foi coletado em pomares de Fuji e Gala. *Neoseiulus californicus* esteve presente em todos os pomares avaliados, porém muitos indivíduos dessa espécie foram amostrados na área convencional, tanto em Fuji quanto em Gala (Tabela 3).

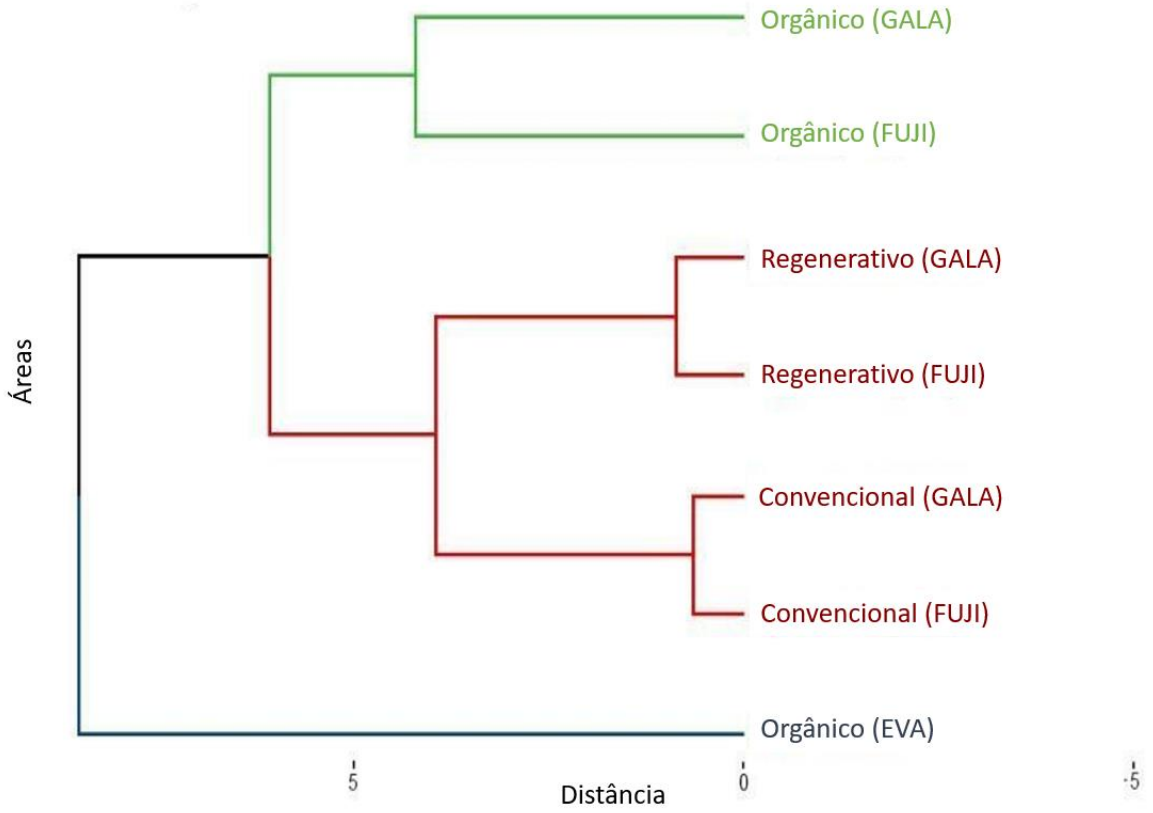
Tabela 3. Fitoseiídeos associados a pomares de macieira nos municípios de Meus Capões, Antônio Prado, Rio Grande do Sul e São Joaquim, Santa Catarina, Brasil, coletados entre agosto de 2020 e setembro de 2021.

Espécies	**Antônio Prado**									**Muitos Capões**						**São Joaquim**						Total
	Eva			Fuji			Gala			Fuji			Gala			Fuji			Gala			
	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	
Amblyseus chiapensis	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Arrenoseius sp.	1	I	Ev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Euseius mesembrinus	49	Co	Eu	2	I	Eu	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51
Euseius inouei	37	Co	Eu	1	I	Do	1	I	S	-	-	-	-	-	-	-	-	-	-	-	-	39
Galendromus annectens	1	I	Ev	-	-	-	9	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	10
Metaseiulus eiko	11	A	Do	6	A	Eu	18	A	Eu	-	-	-	-	-	-	-	-	-	-	-	-	35
Neoseiulus californicus	5	A	S	5	A	Eu	11	A	Eu	161	Co	Eu	193	Co	Eu	63	A	Eu	106	A	Eu	544
Neoseiulus tunus	10	A	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Neoseiulus fallacis	-	-	-	1	I	Do	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Proprioseiopsis cannaensis	-	-	-	1	I	Do	-	-	-	1	I	Ev	1	I	Ev	-	-	-	-	-	-	3
Total	115			16			39			162			194			63			106			695
%	16,55			2,30			5,61			23,31			27,91			9,06			15,25			
Riqueza	8			6			4			2			2			1			1			

T = Total de ácaros; C = Constância; D = Dominância; Co = Constante; A = Acessória; I = Acidental; Eu = Eudominante; Do = Dominante; S = Subdominante; Ev = Eventual

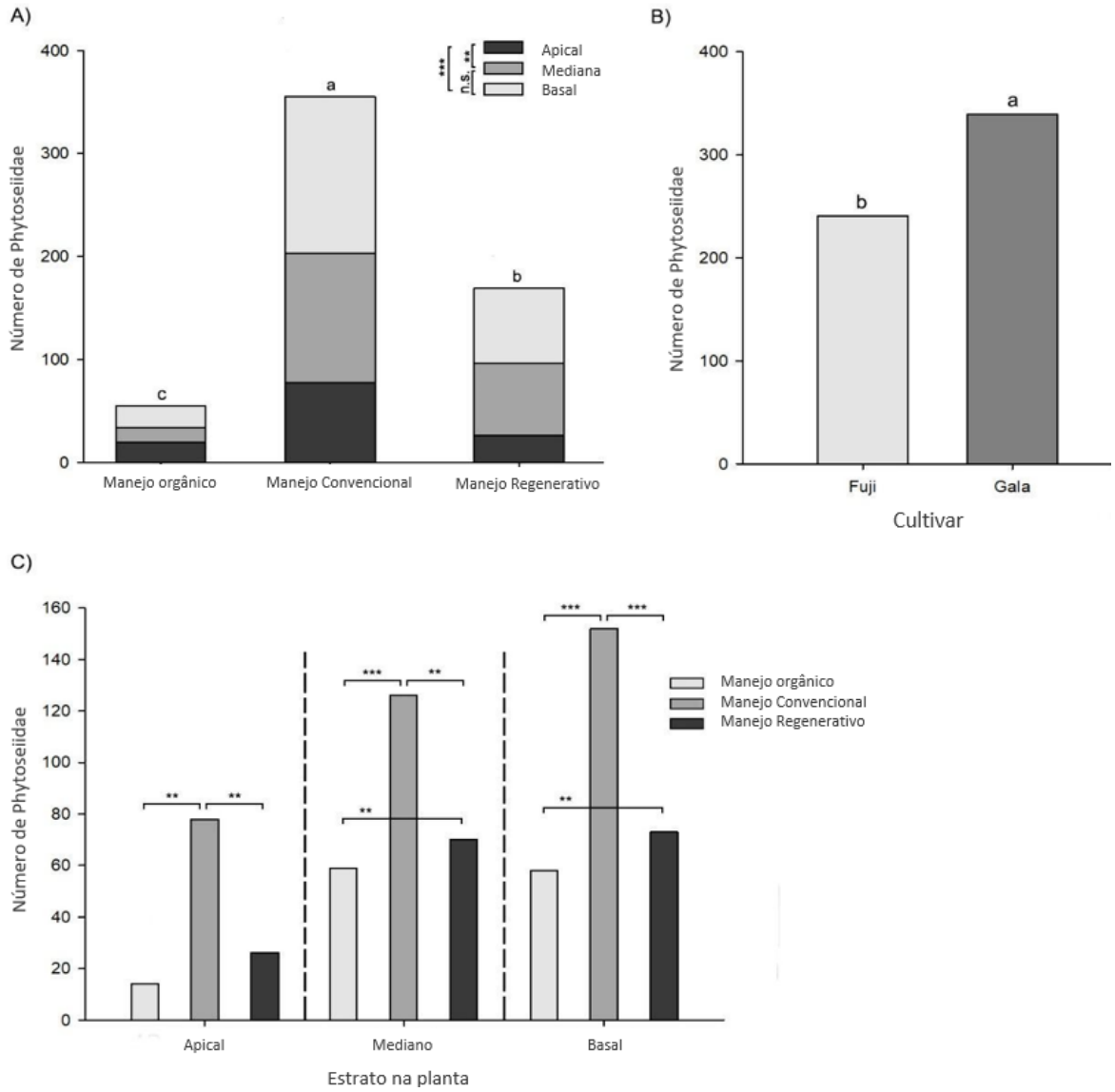
A análise de similaridade de áreas revelou diferenças tanto entre os sistemas de manejo quanto entre diferentes cultivares. Eva formou um ramo separado dos demais pomares, independente do manejo utilizado. O manejo orgânico com Fuji e Gala formou um segundo ramo distinto dos pomares com manejo convencional e regenerativo que utilizavam esses mesmos cultivares. O terceiro ramo foi formado por pomares convencionais e regenerativos tanto de Fuji quanto de Gala (Figura 32).

Figura 32 - Dendrograma da semelhança entre áreas com diferentes sistemas de manejo agrícola, considerando número e diversidade de espécies.



Foram encontradas diferenças significativas em relação à abundância de Phytoseiidae quando comparamos os diferentes tipos de manejo (Figura 33). Maior abundância foi observada no manejo convencional (Figura 33A). Foi observada menor abundância nas folhas Apicais. No entanto, não houve diferença no número desses predadores entre as folhas localizadas nas regiões mediana e basal. Gala apresentou maior abundância quando comparada a Fuji (Figura 33B). Maior abundância foi observada nas regiões apical, mediana e basal da área de manejo convencional. Não foi observada diferença no estrato apical das macieiras sob manejo orgânico e regenerativo, porém, para os estratos mediano e basal, a abundância difere entre as áreas (Figura 33C).

Figura 33 - Abundância de Phytoseiidae em pomares de macieira com manejo orgânico, convencional e regenerativo. (A) Número de Phytoseiidae em diferentes áreas e em diferentes estratos do ramo da macieira. (B) Número de Phytoseiidae em diferentes variedades de macieira. (C) Número de Phytoseiidae em relação à interação entre diferentes áreas e localização da folha no ramo.



VEGETAÇÃO ESPONTÂNEA ASSOCIADA AOS POMARES DE MACIEIRA

Foram amostradas 67 espécies pertencentes a 26 famílias botânicas associadas a pomares de macieira. Dentre as famílias de plantas coletadas, oito apresentavam ácaros, sendo mais abundantes em Asteraceae e Plantaginaceae (33% cada), seguidas por Poaceae (19%) e demais famílias (15%) (Tabela 4).

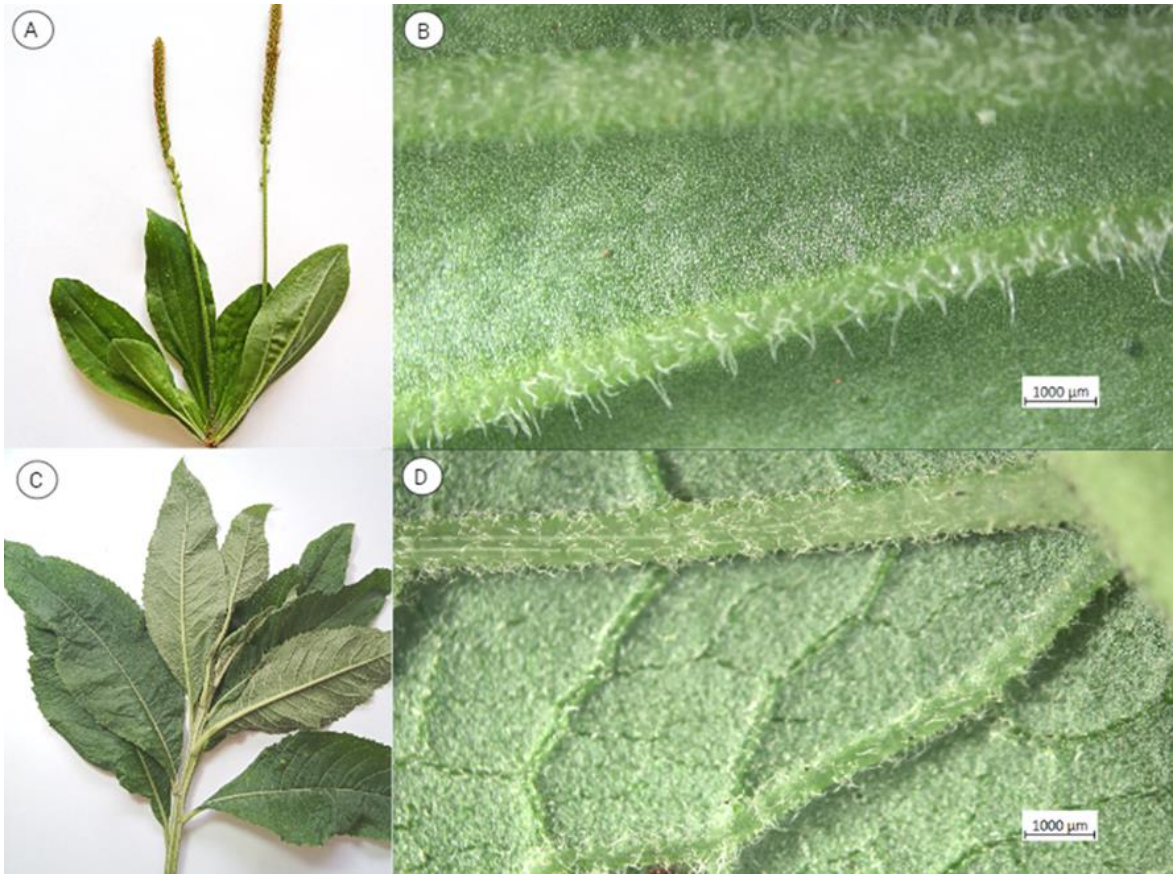
Tabela 4. Vegetação espontânea em pomares de macieira nos municípios de Muitos Capões, Antônio Prado, estado do Rio Grande do Sul e São Joaquim, estado de Santa Catarina, Brasil, coletada entre agosto de 2020 e setembro de 2021.

Família botânica	Espécie botânica	Abundância acarina	P (%)	G (%)	F (%)
AMARANTHACEAE	*Amaranthus deflexus*	-	-	-	-
	Iresine diffusa	-	-	-	-
APIACEAE	*Centella asiatica*	-	-	-	-
	Conium maculatum	-	-	-	-
	Daucus pusillus	-	-	-	-
APOCYNACEAE	*Oxypetalum* sp.	-	-	-	-
ARALIACEAE	*Hydrocotyle leucocephala*	-	-	-	-
ASTERACEAE	*Baccharis anomala*	17	70,6	23,5	5,9
	Baccharis dracunculifolia	-	-	-	-
	Baccharis sp.	-	-	-	-
	Baccharis trimera	-	-	-	-
	Bidens pilosa	50	20	10	70
	Chromolaena laevigata	69	58	33,3	8,7
	Conyza bonariensis	-	-	-	-
	Conyza canadensis	1	100	-	-
	Elephantopus mollis	154	57,8	40,9	1,3
	Gamochaeta americana	-	-	-	-
	Hypochaeris sp.	9	77,8	22,2	-
	Koanophyllon sp.	-	-	-	-
	Senecio brasiliensis	-	-	-	-
	Sonchus oleraceus	1	-	100	-
	Taraxacum officinale	4	50	50	-
	Vernonanthura sp.	1	100	-	-
	Vernonanthura tweediana	322	51,9	48,1	-
BRASSICACEAE	*Raphanus sativus*	8	87,5	12,5	-
CARYOPHILLACEAE	*Stellaria media*	-	-	-	-
COMMELINACEAE	*Commelina erecta*	-	-	-	-
CONVOLVULACEAE	*Ipomoea alba*	-	-	-	-
	Ipomoea indivisa	-	-	-	-
	Ipomoea sp.	-	-	-	-
CUCURBITACEAE	*Sicyos* sp.	-	-	-	-
EUPHORBIACEAE	*Euphorbia heterophylla*	26	69,2	30,8	-
FABACEAE	*Trifolium pratense*	6	-	83,3	16,7
	Trifolium repens	42	23,8	69	7,1
	Vicia cracca	1	-	100	-
HYPERICACEAE	*Hypericum caprifoliatum*	-	-	-	-
LAMIACEAE	*Cantinoa mutabilis*	12	66,7	33,3	-
	Leonurus japonicus	-	-	-	-
MALVACEAE					

	Sida sp.	-	-	-	-
	Sida rhombifolia	6			
OXALIDACEAE	*Oxalis* sp.	-	-	-	-
PLANTAGINACEAE	*Plantago australis*	624	41,7	56,9	1,4
POACEAE	*Axonopus affinis*	-	-	-	-
	Bromus catharticus	-	-	-	-
	Bromus unioloides	12	9,1	90,9	-
	Eragrostis plana	-	-	-	-
	Holcus lanatus	73	13,7	86,3	-
	Lolium multiflorum	190	47,9	52,1	-
	Paspalum dilatatum	17	88,2	11,8	-
	Paspalum pumilum	12	50	50	-
	Paspalum urvillei	20	60	40	-
	Sporobolus indicus	1	100	-	-
	Steinchisma hians	8	62,5	37,5	-
	Urochloa plantaginea	34	14,7	85,3	-
POLYGONACEAE	*Rumex obtusifolius*	-	-	-	-
PTERIDACEAE	*Adiantopsis chlorophylla*	45	31,1	68,9	-
ROSACEAE	*Acaena eupatoria*	42	32,6	65,2	2,2
RUBIACEAE	*Richardia brasiliensis*	10	40	60	-
	Richardia sp.1	-	-	-	-
	Richardia sp.2	-	-	-	-
SCROPHULARIACEAE	*Scoparia* sp.	1	-	100	-
	Veronica persica	8	37,5	62,5	-
SOLANACEAE	*Solanum americanum*	-	-	-	-
	Solanum pseudocapsicum	2	50	50	-
TALINACEAE	*Talinum paniculatum*	73	6,8	93,2	-
VERBENACEAE	*Lantana camara*	-	-	-	-
	Verbena litoralis	7	57,1	42,9	-
		1908			

A maioria das plantas amostradas apresentava ácaros (57,8%), enquanto 42,2% das plantas não apresentavam ácaros em nenhum dos pomares avaliados. Asteraceae foi mais diversificada com 17 espécies e, destas, 10 apresentavam ácaros. *Plantago australis* Lam. (Plantaginaceae) foi a espécie com maior abundância de ácaros (32,7%), sendo 56,9% generalistas e 41,7% predadores. A segunda espécie foi *Vernonanthura tweediana* (Baker) H. Rob. (Asteraceae) (16,9%). Entre os ácaros registrados, a maior abundância de ácaros predadores foi em *V. tweediana* (51,9%) (Figura 34).

Figure 34 - *Plantago australis* (A). Superfície abaxial da folha de *Plantago australis* (B). *Vernonanthura tweediana* (C). Superfície abaxial da folha de *Vernonanthura tweediana* (D).



Fonte: A autora (2024).

No total foram coletados 1.908 ácaros pertencentes a 76 espécies/morfoespécies, com destaque para generalistas (53,1%), predadores (43,8%) e fitófagos (3,1%) (Tabela 5). Phytoseiidae foi a família de predadores mais diversa, com 13 espécies/morfoespécies (25% do total de predadores) associadas à vegetação espontânea avaliada. Esta família apresentou 362 exemplares, sendo 47% presentes em pomares orgânicos, 42% em agricultura regenerativa e 11% em pomares convencionais. A maior riqueza de predadores foi encontrada associada à vegetação espontânea de pomares orgânicos, seguida de pomares de agricultura regenerativa e convencional.

Tabela 5. Fauna de ácaros associada à vegetação espontânea em pomares de macieira nos municípios de Muitos Capões, Antônio Prado, RS e São Joaquim, SC, coletada entre agosto de 2020 e setembro de 2021

Espécies	Hábito alimentar	Antônio Prado									Muitos Capões						São Joaquim						Soma	%
		Eva			Fuji			Gala			Fuji			Gala			Fuji			Gala				
		T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D	T	C	D		
Agistemus brasiliensis	P	**89**	**A**	**E**	0	-	-	**1**	**I**	**Ev**	25	I	E	**1**	**I**	**R**	0	-	-	**0**	-	-	116	6,1
Agistemus riograndensis	P	**7**	**I**	**S**	0	-	-	**0**	-	-	0	-	-	**11**	**I**	**S**	0	-	-	**3**	**I**	**Ev**	21	1,1
Amblyseius nicola	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	16	I	D	**27**	**A**	**E**	43	2,3
Amblyseius vitis	P	**2**	**I**	**R**	2	I	Ev	**1**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	5	0,3
Amphialycus pentophthalmus	G	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Aponychus mauritianum	F	**0**	-	-	0	-	-	**0**	-	-	9	I	S	**0**	-	-	0	-	-	**0**	-	-	9	0,5
Armascirus sp.	P	**0**	-	-	0	-	-	**2**	**C**	**E**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	2	0,1
Arrenoseius gaucho	P	**61**	**C**	**E**	35	C	E	**17**	**I**	**Ev**	2	I	Ev	**0**	-	-	28	C	E	**17**	**C**	**D**	160	8,4
Arrenoseius sp	P	**3**	**I**	**Ev**	7	A	S	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	10	0,5
Asca sp.1	P	**6**	**I**	**Ev**	3	I	Ev	**1**	**I**	**Ev**	4	I	S	**4**	**I**	**Ev**	20	A	D	**14**	**A**	**D**	52	2,7
Asca sp.2	P	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Benoinyssus sp.	P	**3**	**I**	**Ev**	6	I	S	**4**	**I**	**S**	4	A	S	**2**	**I**	**Ev**	0	-	-	**2**	**I**	**Ev**	21	1,1
Brevipalpus sp.	F	**1**	**I**	**R**	0	-	-	**0**	-	-	2	I	Ev	**33**	**I**	**E**	0	-	-	**0**	-	-	36	1,9
Cosmolaelaps sp.1	P	**1**	**I**	**R**	4	I	S	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	5	0,3
Cosmolaelaps sp.2	P	**1**	**I**	**R**	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	2	0,1
Cunaxoides lajeadensis	P	**7**	**A**	**S**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	7	0,4
Czenspinskia transversostriata	G	**8**	**I**	**S**	0	-	-	**0**	-	-	1	I	R	**1**	**I**	**R**	0	-	-	**0**	-	-	10	0,5
Dactyloscirus sp.	P	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Daidalotarsonemus savanicus	G	**5**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	5	0,3

Dendrolaelaps sp.	P	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	5	A	S	**3**	**I**	**Ev**	9	0,5
Eugamasus sp.1	P	**0**	-	-	1	I	R	**3**	**I**	**S**	1	I	R	**0**	-	-	2	I	Ev	**1**	**I**	**R**	8	0,4
Eugamasus sp.2	P	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Eupodes sp.	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**2**	**I**	**Ev**	0	-	-	**0**	-	-	2	0,1
Euseius inouei	P	**3**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	3	0,2
Euseius mesembrinus	P	**30**	**A**	**D**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	30	1,6
Eustigmaeus segnis	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**2**	**I**	**Ev**	7	I	S	**5**	**I**	**S**	14	0,7
Gaeolaelaps aculeiferoides	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**1**	**I**	**R**	0	-	-	**0**	-	-	1	0,1
Galendromus eiko	P	**4**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	4	0,2
Gamasiphis sp.	P	**1**	**I**	**R**	3	I	Ev	**1**	**I**	**Ev**	**0**	-	-	**0**	-	-	2	I	Ev	**0**	-	-	7	0,4
Histiostoma sp.	G	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	2	I	Ev	**0**	-	-	2	0,1
Laminamichaelia sp.	G	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Lasioseius sp.	P	**0**	-	-	2	I	Ev	**4**	**I**	**S**	2	I	Ev	**1**	**I**	**R**	7	A	S	**1**	**I**	**R**	17	0,9
Ledermuelleriopsis punctata	P	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Leptus sp.	P	**1**	**I**	**R**	1	I	R	**-**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	2	0,1
Lorrya parvireticuli	G	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	1	0,1
Macrocheles sp.1	P	**0**	-	-	2	I	Ev	**1**	**I**	**Ev**	0	-	-	**3**	**I**	**Ev**	0	-	-	**1**	**I**	**R**	7	0,4
Macrocheles sp.2	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	1	0,1
Macrocheles subbadius	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**1**	**I**	**R**	2	0,1
Mononychellus planki	F	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Neocunaxoides ovatus	P	**1**	**I**	**R**	3	I	Ev	**3**	**I**	**S**	1	I	R	**5**	**I**	**S**	0	-	-	**0**	-	-	13	0,7
Neogamasellevans ammonis	P	**1**	**I**	**R**	1	I	R	**1**	**I**	**Ev**	0	-	-	**5**	**I**	**R**	1	I	R	**0**	-	-	9	0,5
Neogamasellevans preendopodalis	P	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	1	0,1

Neoseiulus californicus	P	**0**	-	-	0	-	-	**0**	-	-	19	A	D	**15**	**A**	**D**	13	A	D	**30**	**A**	**E**	77	4,0
Neoseiulus mumai	P	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Neoseiulus sp.	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**1**	**I**	**R**	1	0,1
Neoseiulus tunus	P	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Ologamasus postpilus	P	**1**	**I**	**R**	0	-	-	**1**	**I**	**Ev**	0	-	-	**0**	-	-	1	I	R	**0**	-	-	3	0,2
Ologamasus sp. nov	P	**0**	-	-	18	A	R	**11**	**C**	**D**	0	-	-	**0**	-	-	6	A	S	**11**	**A**	**S**	46	2,4
Ologamasus striolatosimilis	P	**3**	**I**	**Ev**	7	I	S	**9**	**A**	**D**	1	I	R	**2**	**I**	**Ev**	0	-	-	**0**	-	-	22	1,2
Oribatida	G	**78**	**C**	**E**	118	C	E	**82**	**C**	**E**	67	C	E	**100**	**C**	**E**	109	C	E	**100**	**C**	**E**	654	34,3
Orolaelaps sp.1	P	**5**	**A**	**Ev**	6	A	S	**11**	**A**	**D**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	22	1,2
Orolaelaps sp.2	P	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Panonychus ulmi	F	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**1**	**I**	**R**	0	-	-	**1**	**I**	**R**	2	0,1
Phytoseius grupo plumifer	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**1**	**I**	**R**	1	0,1
Podothrombium sp.	P	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Polyphagotarsonemus latus	F	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Proprioseiopsis cannaensis	P	**1**	**I**	**R**	1	I	R	**0**	-	-	0	-	-	**5**	**A**	**S**	13	I	D	**6**	**A**	**S**	26	1,4
Pseudoparasitus sp.	P	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Pseudopronematulus sp.	P	**18**	**A**	**S**	3	I	Ev	**1**	**I**	**Ev**	1	I	R	**10**	**I**	**S**	0	-	-	**0**	-	-	33	1,7
Puleus mormasensis	P	**0**	-	-	1	I	R	**0**	-	-	0	-	-	**1**	**I**	**R**	0	-	-	**0**	-	-	2	0,1
Rubroscirus griloi	P	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**1**	**I**	**R**	0	-	-	**0**	-	-	1	0,1
Scutacarus sp.	G	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	2	0,1
Scutopalus tomentosus	P	**1**	**I**	**R**	1	I	R	**1**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	3	0,2
Tarsonemus merus	G	**0**	-	-	0	-	-	**0**	-	-	18	A	D	**3**	**I**	**Ev**	0	-	-	**0**	-	-	21	1,1
Tarsonemus waitei	G	**0**	-	-	0	-	-	**1**	**I**	**Ev**	1	I	R	**0**	-	-	0	-	-	**0**	-	-	2	0,1
Tarsonemus confusus	G	**0**	-	-	0	-	-	**0**	-	-	10	I	D	**0**	-	-	0	-	-	**0**	-	-	10	0,5

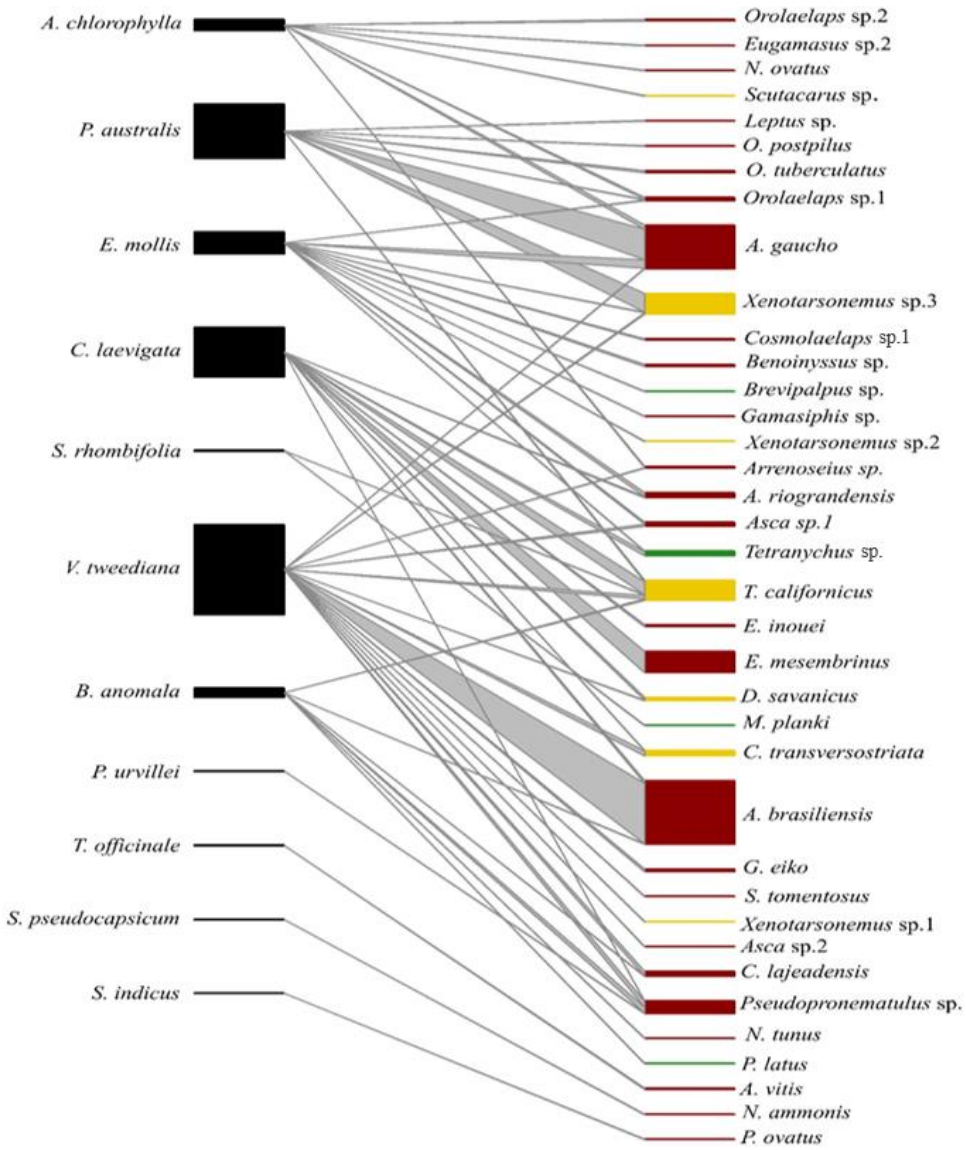
Tetranychus sp.	F	**7**	**I**	**S**	0	-	-	**1**	**I**	**Ev**	2	I	Ev	**0**	-	-	0	-	-	**0**	-	-	10	0,5
Tydeus californicus	G	**28**	**A**	**D**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	I	R	**0**	-	-	29	1,5
Tydeus manoi	G	**0**	-	-	0	-	-	**0**	-	-	0	-	-	**0**	-	-	16	A	D	**9**	**I**	**S**	25	1,3
Tyrophagus putrescentiae	G	**0**	-	-	1	I	R	**0**	-	-	8	A	S	**6**	**I**	**S**	7	I	S	**4**	**A**	**S**	26	1,4
Uropodina	G	**0**	-	-	0	-	-	**1**	**I**	**Ev**	0	-	-	**1**	**I**	**R**	0	-	-	**0**	-	-	2	0,1
Veigaia sp.	P	**0**	-	-	0	-	-	**1**	**I**	**Ev**	0	-	-	**0**	-	-	0	-	-	**0**	-	-	1	0,1
Xenotarsonemus sp.1	G	**1**	**I**	**R**	25	I	E	**0**	-	-	34	C	E	**60**	**I**	**E**	5	I	S	**2**	**I**	**Ev**	127	6,6
Xenotarsonemus sp.2	G	**1**	**I**	**R**	0	-	-	**0**	-	-	0	-	-	**48**	**I**	**E**	0	-	-	**0**	-	-	49	2,6
Xenotarsonemus sp.3	G	**29**	**I**	**D**	0	-	-	**2**	**I**	**Ev**	0	-	-	**0**	-	-	12	A	S	**3**	**I**	**Ev**	46	2,4
Zygoseius furciger	P	**0**	-	-	4	I	S	**2**	**I**	**Ev**	5	I	S	**0**	-	-	1	I	R	**3**	**A**	**Ev**	15	0,8
Abundância		415			262			163			220			324			278			246			1908	
Riqueza		39			31			25			24			26			25			23				
%		**21,8**			**13,7**			**8,5**			**11,5**			**17,0**			**14,6**			**12,9**				

T = Total de ácaros; C = Constância; D = Dominancia; Co = Constante; A = Accessoria; I = Acidental; Eu = Eudominante; Do = Dominante; S = Subdominante; Ev = Eventual.

Pomares orgânicos. Em Eva houve maior riqueza (39 espécies/morfoespécies) e maior abundância (21,8%) quando comparada às demais (Tabela 5). Neste pomar, as espécies predadoras, *Agistemus brasiliensis* Matioli, Ueckermann & Oliveira (Stigmaeidae) e *Arrenoseius gaucho* Ferla, Silva & Moraes (Phytoseiidae) foram eudominantes, *Euseius mesembrinus* (Dean) (Phytoseiidae) dominante e *A. gaucho* constante. *Arrenoseius gaucho* também foi constante e eudominante em Fuji. Em Gala, *Armascirus* sp. foi constante e eudominante e *Ologamasus margaridae* Bizarro & Rode (Ologamasidae), constante e dominante, e *Ologamasus tuberculatus* Bizarro & Rode (Ologamasidae) e *Orolaelaps* sp.1 (Melicharidae) dominantes. Além disso, *N. californicus* estava ausente nestes pomares.

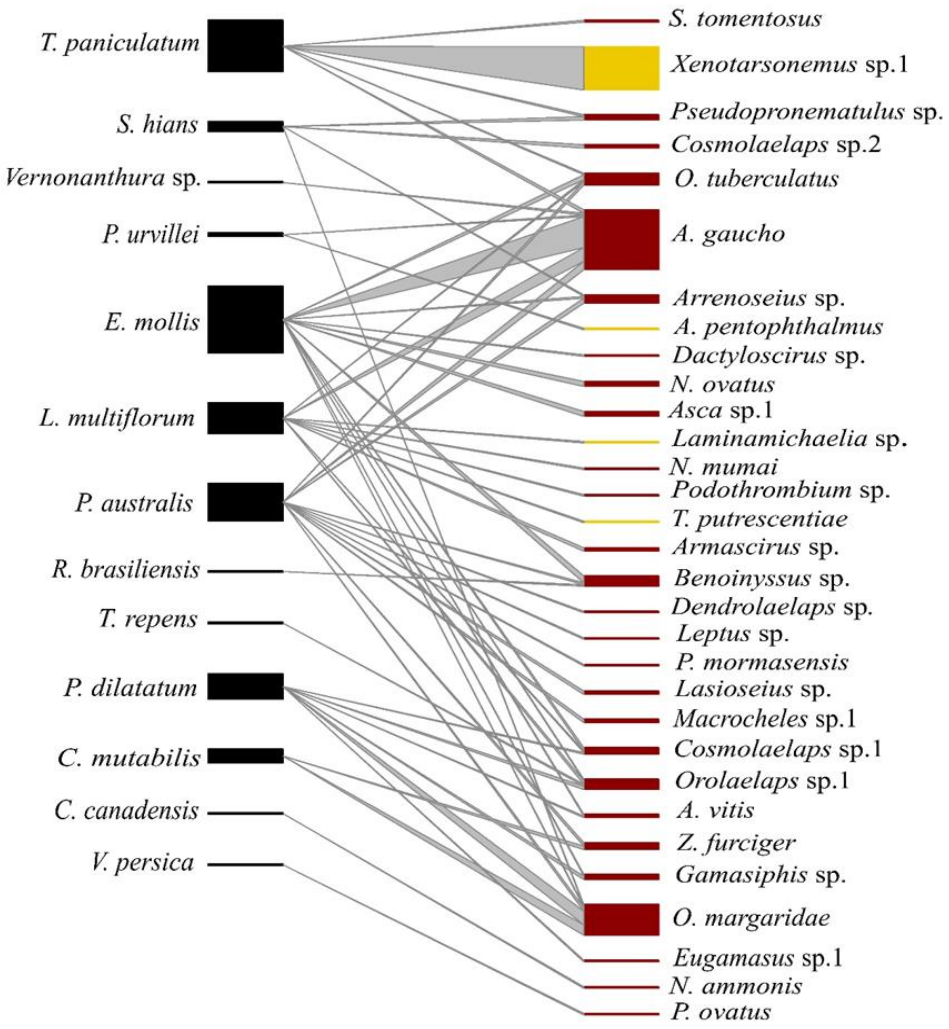
As principais plantas hospedeiras dos ácaros predadores foram *P. australis*, *V. tweediana* e *Elephantopus mollis* Kunth (Asteraceae). Em Eva, maior abundância de ácaros encontrada em *V. tweediana*, com maior abundância de predadores, especialmente *A. brasiliensis* (Figura 35). A segunda planta foi *P. australis*, tendo *A. gaucho* como principal espécie predadora.

Figura 35 - Rede bipartite da acarofauna e vegetação espontânea do pomar de macieiras do cultivar Eva no município de Antônio Prado, Rio Grande do Sul. As barras do lado esquerdo representam espécies de plantas hospedeiras e as barras da direita representam espécies de ácaros. Espécies vegetais (preto), ácaros fitófagos (verde), ácaros generalistas (amarelo) e ácaros predadores (marrom).



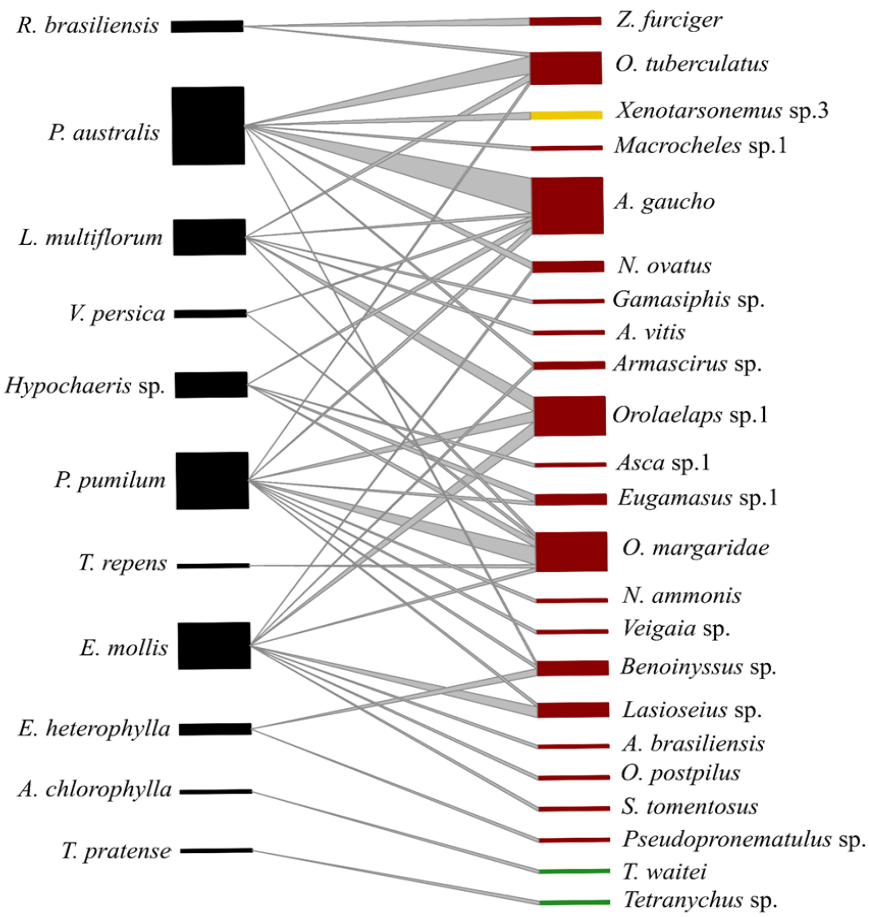
Em Fuji, *E. molis* foi mais abundante, sendo as espécies predadoras mais abundantes e *A. gaucho* também mais abundante (Figura 36). *Xenotarsonemus* sp.1 (Tarsonemidae) foi a segunda espécie mais abundante neste pomar e esteve presente em *Talinum paniculatum* (Jacq.) Gaertn. (Talinaceae), uma das principais plantas do pomar. Não foram encontrados ácaros fitófagos associados à vegetação espontânea neste pomar.

Figura 36 - Rede bipartite da acarofauna e vegetação espontânea do pomar de macieiras do cultivar Fuji no município de Antônio Prado, Rio Grande do Sul. As barras do lado esquerdo representam espécies de plantas hospedeiras e as barras da direita representam espécies de ácaros. Espécies vegetais (preto), ácaros generalistas (amarelo) e ácaros predadores (marrom).



Em Gala, *P. australis* apresentou maior abundância, principalmente de predadores, especialmente *A. gaucho* e *O. tuberculatus* (Figura 37). Outras espécies de plantas como *E. molis* e *Paspalum pumilum* Nees. (Poaceae) também se destacou no pomar pela abundância de ácaros presentes e principalmente por serem hospedeiros de diversas espécies predadoras.

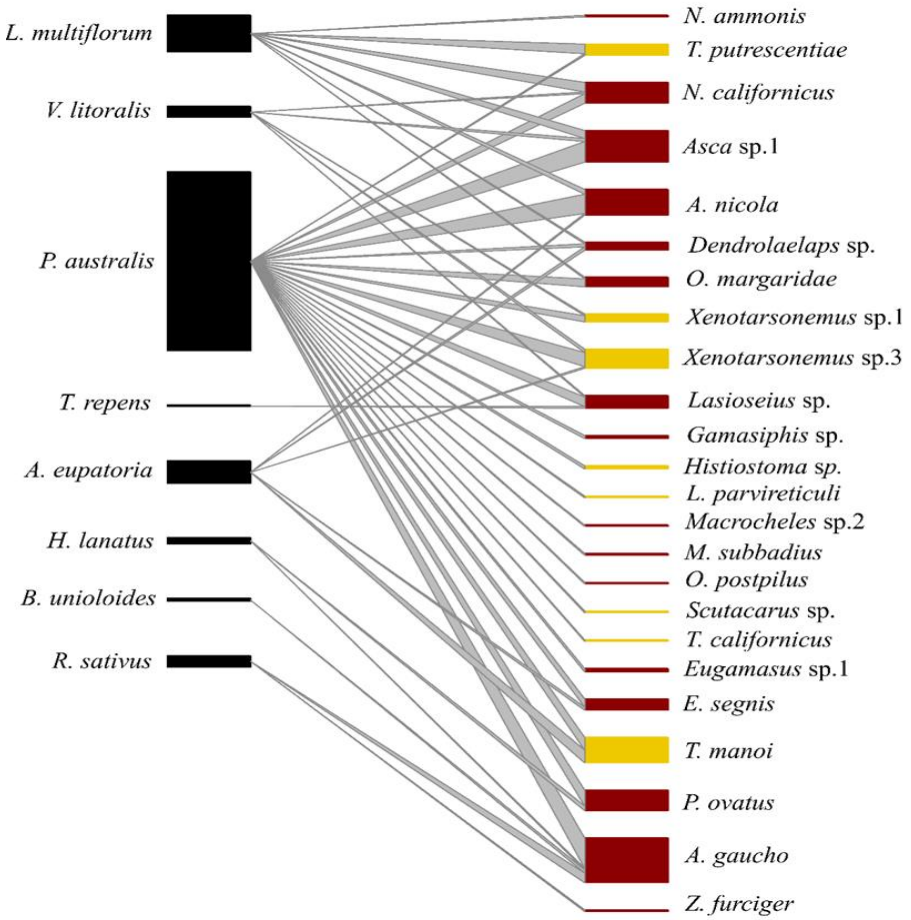
Figura 37 - Rede bipartite da acarofauna e vegetação espontânea do pomar de macieiras do cultivar Gala no município de Antônio Prado, Rio Grande do Sul. As barras à esquerda representam espécies de plantas hospedeiras e as barras à direita representam espécies de ácaros. Espécies vegetais (preto), ácaros fitófagos (verde), ácaros generalistas (amarelo) e ácaros predadores (marrom).



Pomares regenerativos. Em Fuji, *A. gaucho* foi constante e eudominante, e *Amblyseius nicola* Chant & Hansell (Phytoseiidae), *Asca* sp.1 (Ascidae), *N. californicus* e *Proprioseiopsis ovatus* (Garman) (Phytoseiidae) foram dominantes. Em Gala, *N. californicus* e *A. nicola* foram eudominantes, *Asca* sp.1, dominante e *A. gaucho*, constante e dominante (Tabela 5).

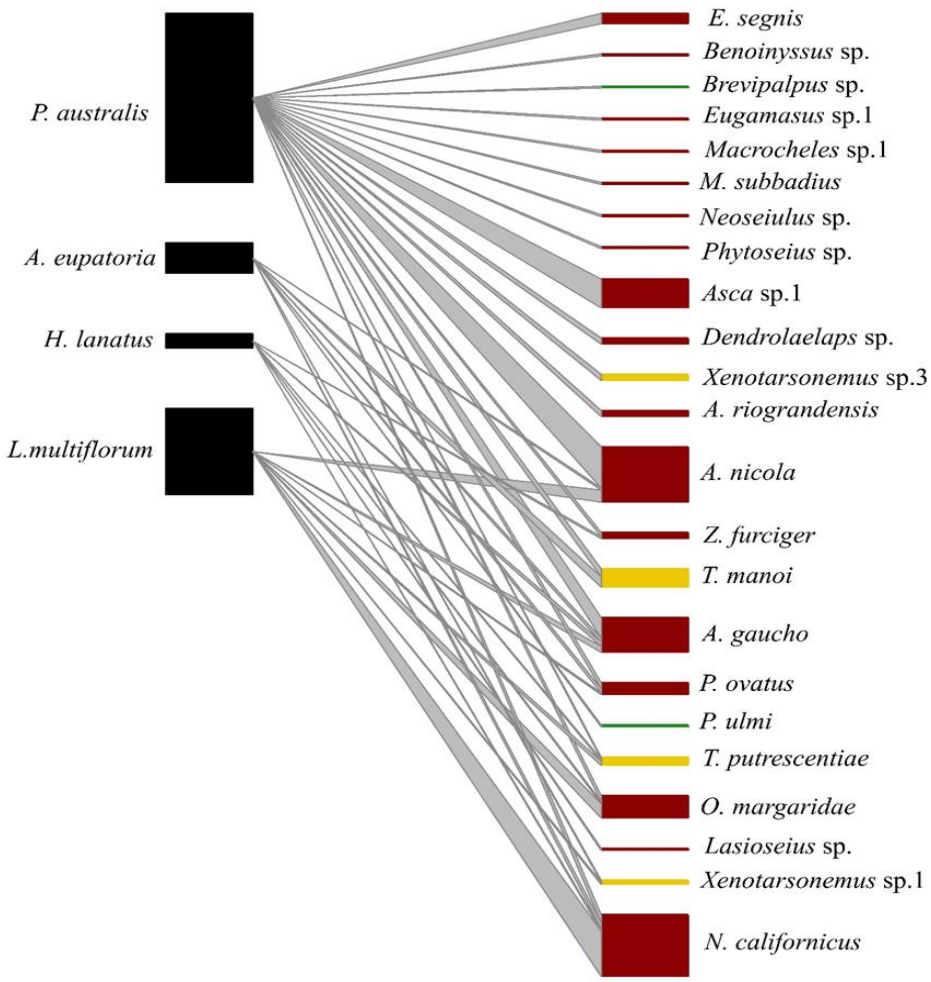
Maior abundância de ácaros esteve presente em *P. australis*, seguido por *L. multiflorum*. Em Fuji, a proporção de ácaros predadores e generalistas foi semelhante, sendo *A. gaucho* a principal espécie predadora neste pomar, associada principalmente a *P. australis* (Figura 38). Não foram encontrados ácaros fitófagos na vegetação espontânea deste pomar. Entretanto, o pomar apresentou a maior riqueza de ácaros generalistas nas plantas associadas.

Figura 38 - Rede bipartite da acarofauna e vegetação espontânea do pomar de macieiras do cultivar Fuji no município de São Joaquim, estado de Santa Catarina. As barras à esquerda representam espécies de plantas hospedeiras e as barras à direita representam espécies de ácaros. Espécies vegetais (preto), ácaros generalistas (amarelo) e ácaros predadores (marrom).



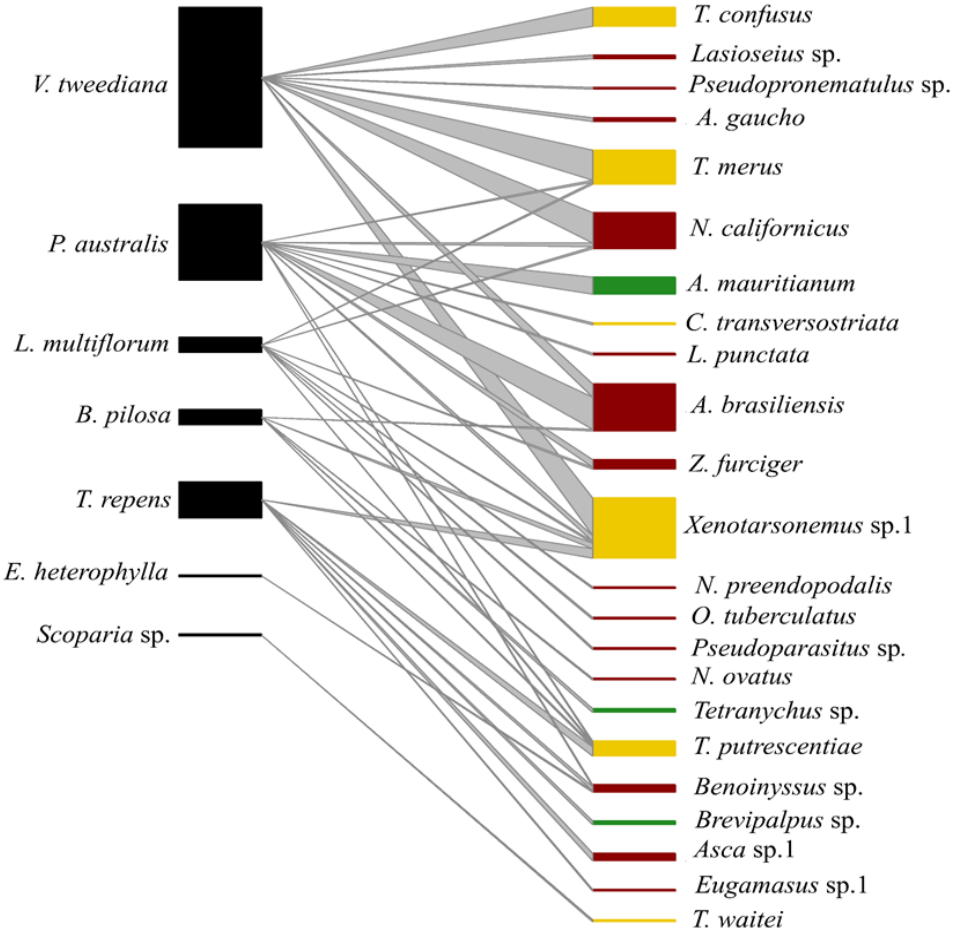
Em Gala notou-se menor riqueza em vegetação espontânea, apenas quatro espécies (Figura 39). O principal ácaro predador deste pomar foi *N. californicus*, hospedeiro das quatro espécies de plantas e mais abundante em *L. multiflorum.*

Figura 39 - Rede bipartida de acarofauna e vegetação espontânea do pomar de macieiras do cultivar Gala no município de São Joaquim, estado de Santa Catarina. As barras à esquerda representam espécies de plantas hospedeiras e as barras à direita representam espécies de ácaros. Espécies vegetais (preto), ácaros fitófagos (verde), ácaros generalistas (amarelo) e ácaros predadores (marrom).



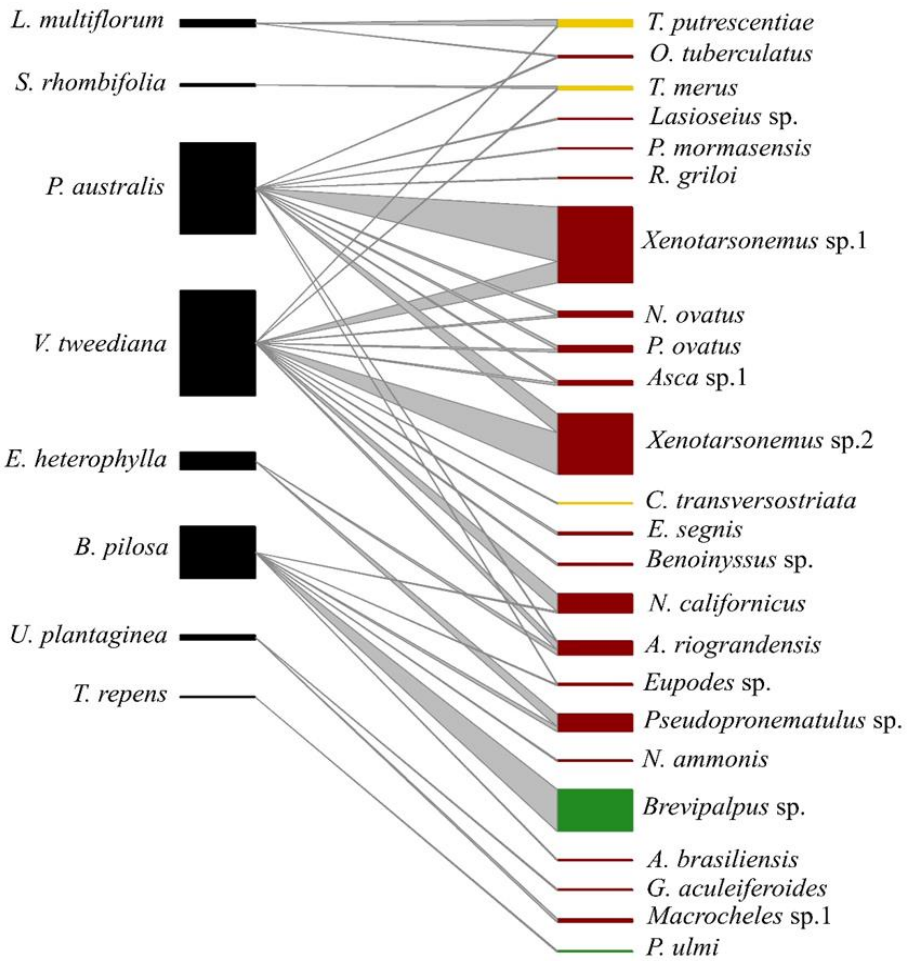
Pomares convencionais. Em Fuji, *A. brasiliensis* foi eudominante e *N. californicus* dominante. Em Gala, *N. californicus* também foi dominante (Tabela 5). As espécies vegetais que apresentaram maior riqueza de predadores foram *P. australis*, *Lolium multiflorum* L. (Poaceae) e *V. tweediana*. Em Fuji, *V. tweediana* apresentou a maior abundância, dentre as quatro espécies presentes nesta planta, um predador, *N. californicus* e três generalistas, *Tarsonemus merus* Lin & Zhang, *Tarsonemus confusus* Ewing e *Xenotarsonemus* sp.1 (Tarsonemidae) (Figura 40).

Figura 40 - Rede bipartida de acarofauna e vegetação espontânea do pomar de macieiras do cultivar Fuji no município de Muitos Capões, Rio Grande do Sul. As barras do lado esquerdo representam espécies de plantas hospedeiras e as barras do lado direito representam espécies de ácaros. Espécies vegetais (preto), ácaros fitófagos (verde), ácaros generalistas (amarelo), ácaros predadores (marrom).



Neoseiulus californicus foi o segundo predador mais abundante. A segunda principal espécie vegetal foi *P. australis*, sendo *A. brasiliensis* a principal espécie de ácaro na planta e no pomar. Em Gala, as espécies vegetais mais abundantes foram *V. tweediana* e *P. australis*. A maior abundância de *Xenotarsonemus* sp.1 e *Xenotarsonemus* sp.2 (Tarsonemidae) foi em *P. australis* (Figura 41). Neste pomar, a terceira espécie principal foi o ácaro fitófago *Brevipalpus* sp. (Tenuipalpidae).

Figura 41 - Rede bipartida de acarofauna e vegetação espontânea do pomar de macieiras do cultivar Gala no município de Muitos Capões, Rio Grande do Sul. As barras do lado esquerdo representam espécies de plantas hospedeiras e as barras da direita representam espécies de ácaros. Espécies vegetais (preto), ácaros fitófagos (verde), ácaros generalistas (amarelo) e ácaros predadores (marrom).



Com base nestes resultados, defendemos a manutenção da vegetação espontânea nos pomares de maçã como um caminho favorável para medidas otimizadas de intensificação ecológica. Por atuarem como barreira física para herbívoros e como reservatório para predadores que controlam espécies com potencial de atingir o status de praga, sugere-se que essas plantas sejam mantidas como estratégia conservadora de controle biológico, sendo uma estratégia viável e eficiente. Dentre as espécies encontradas associadas às macieiras, *P. australis* e *V. tweediana* mostraram-se as espécies mais adequadas para manutenção em pomares de macieira para fornecer abrigo contra ácaros predadores nativos.

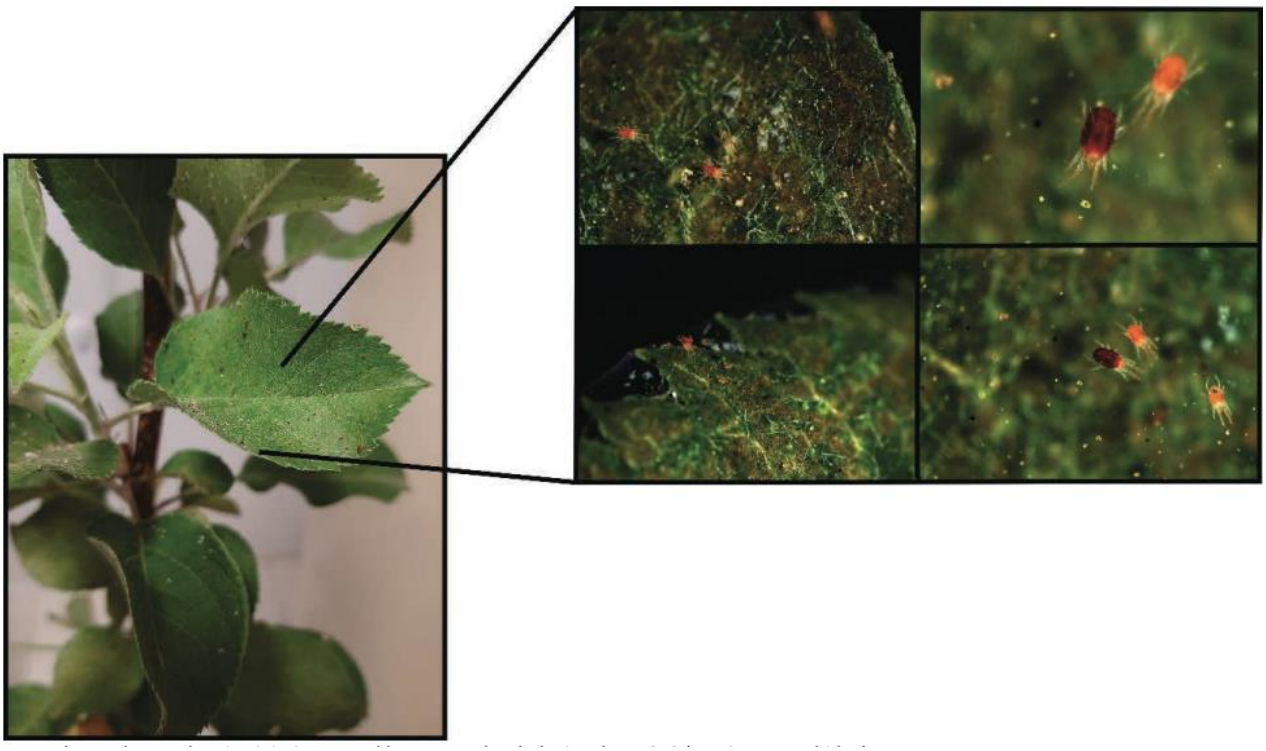
Em conclusão, a intensificação ecológica através do estabelecimento de cobertura vegetal viva pode beneficiar os programas de gestão de pomares de maçã, reduzindo a degradação ambiental, aumentando as populações de ácaros fitófagos que causam danos econômicos e mantêm o rendimento das culturas. Este estudo reconhece a vegetação de crescimento espontâneo associada aos pomares de macieira, a acarofauna ali presente e as espécies vegetais que apresentam potencial como reservatório de inimigos naturais. Porém, é importante que mais estudos sejam realizados para

determinar os níveis de interação entre a vegetação e as macieiras, visando avaliar a movimentação das populações de ácaros entre os dois ambientes.

OCORRÊNCIA DE *Tetranychus ludeni* (TETRANYCHIDAE) EM MUDAS DE MACIEIRA

Tetranychus ludeni Zacher (Tetranychidae) é um ácaro fitófago considerado causador de danos em diversas culturas, como cenoura, feijão, berinjela, abóbora e algodão (Moraes; Flechtmann, 2008). Em algodão, o ataque inicia em folhas mais velhas, depois passam para o restante da planta. De início apresentam manchas vermelhas entre as nervuras; Após algum tempo, as manchas se espalham por toda a folha, que seca e cai (Calcagnolo; Sauer, 1955). Em macieira, havia apenas um registro de ocorrência reportado por Flechtmann (1996) na cidade de Porto Alegre/RS. No entanto, foi recentemente registrada a presença da espécie em mudas de macieiras cultivadas em viveiro na cidade de Lajeado, RS (Rode *et al*., 2023b) (Figura 42).

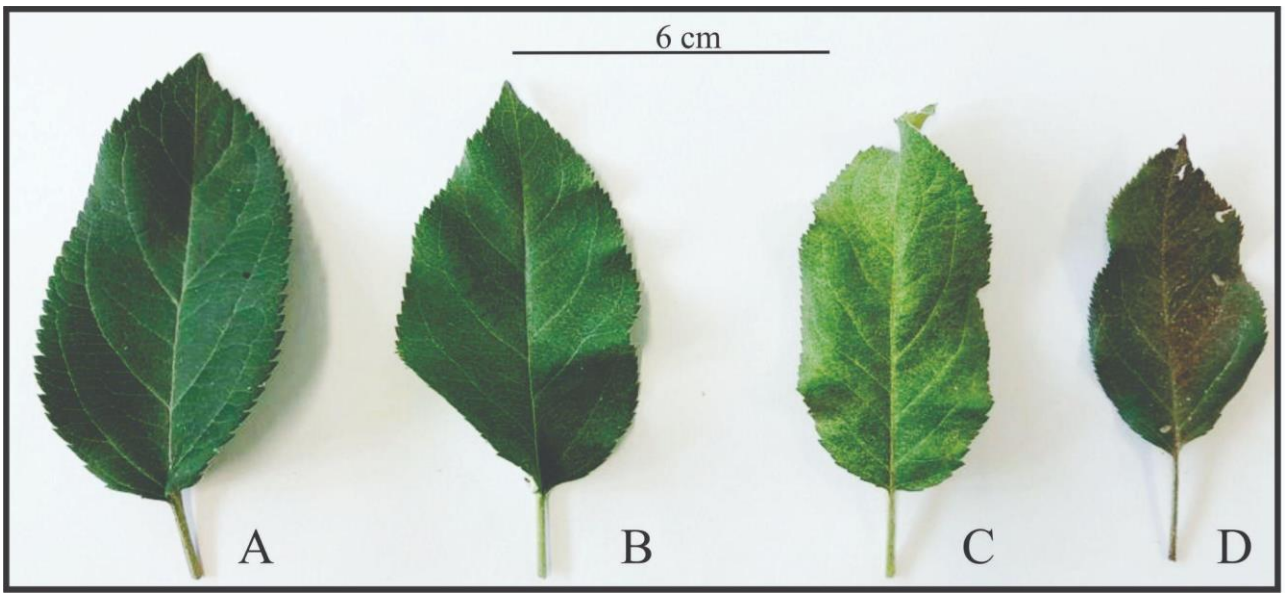
Figura 42 - Folha de maçã com infestação de ácaros (A). Dano causado em folha de maçã por *T. ludeni* (B).



Fonte: Rode *et al.* (2023b)

Tetranychus ludeni foi observado pela primeira vez em janeiro, período de altas temperaturas que favoreceu a sobrevivência deste ácaro. Inicialmente a ocorrência foi nas folhas mais antigas, e logo se espalhou por toda a planta. Após uma semana, foram registrados os primeiros sinais de lesões e logo foi percebido o crescimento da teia, além de um considerável crescimento populacional. Na primeira avaliação foram observados em média 10 ácaros/folha e, após três semanas, as populações atingiram 40 ácaros/folha. A superfície das folhas apresentou manchas escurecidas e avermelhadas características de bronzeamento foliar (Figura 43).

Figura 43 - Evolução das injúrias causadas por *Tetranychus ludeni* alimentando-se de folhas de macieira. Folha sem danos (A). Folha com injúrias (B). Folha com dano inicial (C). Folha danificada (D).



Fonte: Rode *et al.* (2023b).

Com o aumento populacional, toda a planta foi colonizada, e as folhas apresentaram lesões que aumentaram gradativamente os níveis, da mesma forma que também houve aumento considerável das teias em consequência da alta população presente na planta (Figura 44).

Figura 44 - Comparativo entre plantas infestadas e não infestadas por *Tetranychus ludeni*. Muda saudável (sem infestação) à esquerda e muda atacada por *Tetranychus ludeni*, à direita.

Fonte: Rode *et al.* (2023b)

Após um mês que *T. ludeni* estava presente nas mudas de macieira, foi realizada a liberação de 50 ácaros predadores *Phytoseiulus macropilis* (Banks, 1904) (Acari: Phytoseiidae) objetivando o controle do fitófago. As mudas foram mantidas isoladas em casa de vegetação durante o período de avaliação das populações de *P. macropilis* alimentando-se de *T. ludeni*. Semanalmente, foram retiradas duas folhas de cada planta para avaliar as populações de ácaros fitófagos e predadores sob microscópio estereoscópico (40×). Uma semana após a liberação de *P. macropilis* foi possível perceber a presença frequente de populações do predador, com média de seis ácaros predadores/folha. Em um mês já foram observados 18 ácaros/folhas. Bem como a diminuição considerável de ácaros fitófagos que rapidamente tiveram suas populações controladas até o desaparecimento de todos os ácaros fitófagos, na quarta semana. O experimento terminou quando não foram observados ácaros fitófagos nas plantas de macieira testadas e controladas por *P. macropilis*.

Duas mudas foram mantidas isoladas e sem a presença do predador para que fosse observada a evolução das injúrias. Estas plantas apresentaram aumento progressivo nas populações de *T. ludeni*

e de lesões, atingindo um alto nível de lesões. Após quatro semanas, foi observado desfolha e enfraquecimento da planta.

O registro da presença de *T. ludeni* causando danos em mudas de macieira criadas em viveiros (Rode *et al.*, 2023b) alerta a cadeia produtiva, pois essa espécie tem potencial para se tornar praga em pomares comerciais de macieira. Neste caso é importante serem verificadas mudas novas adquiridas em viveiros antes de serem plantadas nos pomares e é importante que sejam feitos monitoramentos periódicos ao nível de campo a fim de se evitar possíveis infestações de *T. ludeni* na cultura. Além disso, sugere-se que estudos de avaliação dos danos causados por este ácaro sejam realizados ao nível de laboratório para que estratégias de controle sejam estabelecidas de forma preventiva a possíveis danos econômicos que a espécie possa causar à cultura da macieira.

Perspectivas na pesquisa acarológica na cultura da macieira no Brasil

Os estudos referentes aos ácaros na macieira ainda são escassos para o Brasil. É necessário que pesquisadores dêem uma atenção especial para esta cultura que apresenta grande importância social e econômica para o país. Maior atenção deve ser dada aos estados do Sul do país que compõem a região de maior produção, no entanto, é necessário que os pomares dos demais estados produtores sejam avaliados para haver conhecimento da situação destes locais e para que planos de manejo sejam estabelecidos também para estes locais. É de extrema importância a identificação, o entendimento do comportamento das espécies presentes nas demais regiões brasileiras, a estimativa de suas populações e períodos de maior abundância em campo, bem como a compreensão do ciclo de vida dos ácaros fitófagos e predadores, da mesma forma que realizamos na região sul. Outra situação a ser analisada é referente ao cultivo natural, tendo em vista que os agroecossistemas vêm sofrendo com os danos causados pelo manejo inadequado dos pomares, principalmente com relação à utilização indiscriminada de agrotóxicos e da expansão das áreas de cultivo. A partir dos recentes estudos realizados e do registro de *Aculus schlechtendali* ocorrendo no Brasil, é importante que as demais regiões brasileiras sejam avaliadas e que um monitoramento seja feito para evitar que as populações atinjam o nível de praga. Além disso, conhecer o comportamento de *A. schlechtendali* na cultura e sua interação com as demais é importante para entender seu real potencial como causador de danos econômicos. Maior atenção deve ser dada a *A. schlechtendali* devido ao seu tamanho e pelas poucas informações que se tem no país a respeito da presença da espécie no país. Desta forma, espera-se que novas pesquisas sejam realizadas visando uma produção mais sustentável e que sejam investigadas espécies de inimigos naturais com potencial para serem utilizados em programas de controle biológico e de manejo integrado de pragas na cultura da macieira. A partir desses estudos

espera-se que haja um aumento no interesse de cientistas pela cultura da macieira, e ainda que planos de manejo alternativo sejam estabelecidos para a redução do uso de agrotóxicos na agricultura, para que os riscos de contaminação ao ambiente e à saúde humana possam ser reduzidos, e, consequentemente reduzir populações de ácaros fitófagos resistentes na cultura da macieira. Estes fatores são fundamentais para a definição de estratégias eficazes de manejo, que permitam maiores taxas de produtividade e qualidade, agregando valor ao produto final, mediante tecnologias sustentáveis e adequadas para a produção mais limpa e a redução dos custos de produção.

CHAVE DICOTÔMICA PARA IDENTIFICAÇÃO DA FAUNA DE ÁCAROS ASSOCIADA ÀS MACIEIRAS NO BRASIL

1. Chelicerae stylet shaped, curved blades or toothed chelae. Palp with a thumb-claw complex or simple and with 1-5 segments; Stigma, when present, at the base or between bases of chelicerae, at base of gnathosoma, on the anterior margin of the propodosoma or laterally to coxal region between legs III and IV……2

– Chelicerae ending in toothed chelae; Simple palpus; Opening of the tracheas absent or indistinct……...54

2. With stigma laterally, between legs III and IV region.……Order Mesostigmata…….....…….....3

– Stigma, when present, at the base or between bases of chelicerae, at the base of gnathosoma, on the anterior margin of the propodosoma……...…Order Trombidiforme……...……..……..…….....26

3. Adults with more than 20 pairs of dorsal shield setae……...……..Ascidae……..*Asca*

Adults with less than 20 pairs of dorsal shield setae……...Phytoseiidae.....……....4

4. Podonotal region of dorsal shield with 5 or 6 pairs of lateral setae……5

– Podonotal region of dorsal shield with 4 pairs of lateral setae……Amblyseiinae…….……9

5. Setae *Z1*, *S2*, *S4* and *S5* absent; Setae *r3* usually inserted into the dorsal shield……Phytoseiinae……...*Phytoseius guianensis* De Leon

– At least one of the following setae present: *Z1*, *S2*, *S4* or *S5*; Setae *r3* usually inserted into the body cuticle……Subfamily Typhlodrominae……..6

6. Setae *R1* absent and *S2* present…….……..……*Galendromus* (*G.*) *annectens* (De Leon)

– Setae *R1* present and *S2* usually absent……...…….……7

7. Setae long on the margin of dorsal shield; Setae *R1* much smaller than *s6*……*Typhlodromina tropica* (Chant)

– Setae short on the margin of the dorsal shield; Setae *R1* and *s6* with similar length…….....8

8. Sternal shield with 2 pairs of setae……..*Metaseiulus* (*M.*) *camelliae* (Chant & Yoshida-Shaul)

– Sternal shield with 3 pairs of setae……..…..……*Metaseiulus* (*M.*) *eiko* (El-Banhawy)

9. Sternal shield with median posterior projection…….……10

– Sternal shield without median posterior projection……..…….……17

10. Chelicerae of normal size and shape, with prominent teeth distributed evenly along the fixed digit; peritreme usually extending to *j1* level…….....*Typhlodromalus*……...11

– Chelicerae reduced in size, with small teeth at the distal tip of the fixed digit; peritreme usually not extending to *j3* level ……*Euseius*……..…...13

11 Spermatheca with visible ductus major, swollen bifid atrium and thick cervix……..……*T. marmoreus* (El-Banhawy)
– Spermatheca not as above……..……12
12 Setae *z4* at most 20% longer than *z2*……..……*T. peregrinus* (Muma)
– Setae *z4* about twice longer than *z2*…….……..……...*T. aripo* De Leon
13. Dorsal shield smooth…….…….…14
Dorsal shield reticulated……15
14. Setae *z4* as long or longer than the distance between their bases and bases of setae *z2* ……..……*E. concordis* (Chant)
– Setae *z4* approximately half the distance between their bases and the bases of setae *z2* .....*E. mesembrinus* (Dean)
15. Genu III with macroseta…….……*E. sibelius* (De Leon)
– Genu III without macroseta……...……16
16. Setae *r3* inserted on unsclerotised cuticle and *R1* on dorsal shield…….....…*E. alatus* De Leon
– Setae *r3* and *R1* inserted on unsclerotised cuticle.....*E. inouei* (Ehara & Moraes)
17. Setae *S4* absent…….……..*Phytoseiulus macropilis* (Banks)
– Setae *S4* present…….……18
18. Proportion of setae size *s4*:*Z1*>3.1……...……19
– Proportion of setae size *s4*:*Z1*<3.1…….…….……..…...23
19. Setae *J2* present or if absent then *j5* also absent…….……...20
Setae *J2* absent and setae *j5* present…….*Proprioseiopsis ovatus* (Garman)
20. Sternal shield usually as long as wide; all shields lightly sclerotized …….*Amblyseius chiapensis* De Leon
– Sternal shield usually wider than long; all shield heavily sclerotinized……...21
21. Leg I with macrosseta……*Iphiseiodes* ……..…….....22
– Leg I without macrosseta…….……....*Arrenoseius*
22 Ventri-anal shield with 4 pairs of preanal setae……..……*I. metapodalis* (El-Banhawy)
– Ventri-anal shield with 3 pairs of preanal setae…….……..*I. zuluagai* Denmark & Muma
23. Genus of leg II without and of leg III rarely with macrosseta……..*Neoseiulus*……24
– Genus of leg II and III rarely without macrosseta……*Typhlodromips mangleae* De Leon
24. Spermathecal calyx about truncate near atrium……...……*N. tunus* (De Leon)
– Spermathecal calyx with rounded end near atrium……..……...25
25 Most dorsal setae long, frequently exceeding the bases of nearby setae……...…*N. californicus* (McGregor)
– Most dorsal setae short, not reaching the bases of nearby setae……..... *N. fallacis* (Garman)
26. Adults with two pairs of legs; body vermiform…….
…….Eriophyidae…….*Aculus schlechtendali* (Nalepa)
– Adults with four pairs of legs; body oval to rounded……...…….……...27
27. Palpus with thumb-claw complex ……..……..……28
– Palpus without thumb-claw complex……..36
28. Palp tarsus with comb-like setae…….…...Cheyletidae…….……*Cheletomorpha*
– Palp tarsus without comb like setae…….…….……...29
29. With long recurved whip like chelicera……Tetranychidae…..……...……30
– With short needle like chelicerae…..……Stigmaeidae.……...…..…*Agistemus*…….....….34

30. Empodium with tenent hairs. With prominent projections over rostrum……*Bryobia praetiosa* Koch
– Empodium without tenent hairs. Without prominent projections over rostrum…….….31
31. Empodium clawlike. With three pairs of para-anal setae……..*Panonychus ulmi* (Koch)
– Empodium split distally. With two pairs of para-anal setae…….*Tetranychus*…...…….32
32. Empodia I - II with spur……..…….……33
– Empodia I - II without spur…….……..…..*T. urticae* Koch
33. Aedeagus with large knob, posterior and anterior projections pointed, dorsal margin convex……..……*T. mexicanus* (McGregor)
– Aedeagus head curved hook, with pointed tip…….....*T. ludeni* Zacher
34. Length of setae *c1* between 45–60µm…….……*A. floridanus* Gonzalez
– Length of setae *c1* between 60–80µm……..…...35
35. Ratios of setae ve/ve-ve 2.5, e1/e1-e1 1.9, and h1/h1-h1 2.4…….....*A. brasiliensis* Matioli, Ueckermann & Oliveira
– Ratios of setae ve/ve-ve 3.7, e1/e1-e1: 2.3, and h1/h1-h1: 2.0….....*A. riograndensis* Johann & Ferla
36. Gnatosoma with quadrangular or circular contour; Leg IV slender without pretarsus and claws in females, but, usually with a sessile single claw in males, leg IV with three-segmented in females with femurgenu and tibiotarsus fused, in male with three or four segments with tibia and tarsus usually separate……..……....Tarsonemidae…….…….... 37
– Gnatosoma with variable contour; Leg IV not like this……..……45
37. Metapodosomal venter with 3 or 4 pairs of setae; leg I without pulvillus……..……*Polyphagotarsonemus latus* (Banks)
– Metapodosomal venter with 2 pairs of setae; Leg I with pulvillus……...……38
38. Some of the dorsal idiossomal setae enlarged……..….*Daidalotarsonemus*……39
– Dorsal idiossomal setae not enlarged…….…….……40
39 Setae *e* thin (± 3 µm); palp long (± 18 µm).....*D. esalqi* Rezende, Lofego & Ochoa
– Setae *e* broad (± 17 µm); palp short (± 10 µm).....*D. savanicus* Rezende, Lofego & Ochoa
40 Gnathosornal palpi markedly elongated……..…….*Rhynchotarsonemus*
– Gnathosornal palpi not markedly elongated…….……...……..41
41 Tegula enlogated…….....*Xenotarsonemus*
– Tegula not elongated…….……..42
42 Tarsi I-III relatively long…….*Fungitarsonemus*
– Tarsi I-III normal……..…...*Tarsonemus*……...……...……..43
43. Setae *sc2* at least 1.5 times longer than the distance between their bases…….....*T. waitei* Banks
Setae *sc2* about as long as or shorter than distance between their bases…….……...….44
44. Poststernal apodeme not bifurcated anteriorly at the level of setae *3a* ……*T. merus* Lin & Zhang
Poststernal apodeme bifurcated anteriorly at the level of setae *3a*…….....*T. confusus* Ewing
45. Posterior part of opistho dorsum with setae *f1* as a trichobothrium…….. Eupodidae……..*Benoinyssus*
– Setae *f1* not like this…….……...46
46. Chelicerae fused at base and with movable digit further modified into an elongate stylet…….…..…….. 47
– Chelicerae not fused at base and capable of moving scissor-like over gnathosoma…….……Cunaxidae……..…...*Cunaxoides*
47. Prodorsum without trichobothria……...Tenuipalpidae…….……. 48

Prodorsum with trichobothria……...49
48. Setae *h2* elongate, much longer than other dorsal setae……...*Tenuipalpus*
– Setae *h2* not elongate, similar in shape and length of other dorsal setae…….....*Brevipalpus*
49. Adults with 1 pair of genital papillae or papillae absent…….……..Iolinidae…….*Pseudopronematulus*
– Adults with 2 pairs of genital papillae……..……..50
50. Leg I with vestigial or no apotele…….……Triophtydeidae……*Triophtydeu*s
– Leg I with apotele ……..Tydeidae…….…….51
51. Up to three seta on genu II….....52
– No setae on genu II…….....*Pretydeus henriandrei* Kaźmierski
52. Femur III with two setae…….….....*Lorryia aberrans* (Oudemans)
– Femur III with no setae…….……..……53
53. Femur II with three setae…….……*Quasitydeus*
– Femur II with two setae ……*Tydeus californicus* (Banks)
54. Prodorsum without specialized sensory organs other than setiform setae; adult idiosoma weakly sclerotized……....Suborder Oribatida, Cohort Astigmatina…….…….55
– Prodorsum usually with a pair of specialized setae arising from sensory pits or bothridia (pseudostigmatic organs); adult idiosoma usually well sclerotized……...……Suborder Oribatida (excluding Astigmatina)
55. One pair of short and strong condilophores……Acaridae……..….*Tyrophagus putrescentiae* (Schrank)
– Condilophores fused into v-shaped sclerites…….……..…Winterschmidtiidae
…….…….……*Czenspinskia transversostriata* (Oud.)

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4 CONSIDERAÇÕES FINAIS

Após longo período com ausência de pesquisas acerca de ácaros na cultura da macieira, este estudo apresenta resultados relevantes sobre a acarofauna e sua dinâmica em pomares de maçãs e vegetação espontânea associada à região Sul do País, caracteriza as injúrias causadas por ácaros fitófagos em plantas de macieira e o comportamento de espécies acarinas na cultura. Além disso, este é o primeiro estudo sobre a avaliação da acarofauna em pomares com produção de maçãs orgânicas no Brasil. As informações aqui apresentadas esclarecem a comunidade científica, os produtores e demais envolvidos na cadeia produtiva de maçãs, sobre a atual situação da cultura com relação a acarofauna presente, e seus potenciais problemas e possíveis soluções. Esses resultados são promissores, pois servirão de base para pesquisas sobre o potencial dos ácaros fitófagos na macieira, e à interação entre esses herbívoros, e deles com os predadores. A partir destes achados, é possível a identificação de ácaros presentes nos pomares e a programação de ações de controle dos ácaros fitófagos de forma prévia. Este trabalho serve de alerta à cadeia produtiva de maçãs para o monitoramento das infestações e prevenção de possíveis ameaças à cultura da macieira. Esses dados podem auxiliar na elaboração de um plano de manejo alternativo, que vise melhores resultados produtivos, redução do uso de pesticidas agrícolas, e consequentemente, a conservação dos recursos naturais e da saúde humana e animal.

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6 ANEXOS

Regras dos periódicos aos quais os manuscritos foram submetidos e se encontram em revisão.

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Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before the reference list under a heading of 'Funding' and/or 'Competing interests'. Other declarations include Ethics approval, Consent, Data, Material and/or Code availability and Authors' contribution statements.

Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

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Ethics approval

When reporting a study that involved human participants, their data or biological material, authors should include a statement that confirms that the study was approved (or granted exemption) by the appropriate institutional and/or national research ethics committee (including the name of the ethics committee) and certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. If doubt exists whether the research was conducted in accordance with the 1964 Helsinki Declaration or comparable standards, the authors must explain the reasons for their approach, and demonstrate that an independent ethics committee or institutional review board explicitly approved

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The World Health Organization (WHO) definition of a clinical trial is "any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes". The WHO defines health interventions as “A health intervention is an act performed for, with or on behalf of a person or population whose purpose is to assess, improve, maintain, promote or modify health, functioning or health conditions” and a health-related outcome is generally defined as a change in the health of a person or population as a result of an intervention.

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Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before the reference list under a heading of 'Ethics approval'.

Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

Examples of statements to be used when ethics approval has been obtained:

• All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Bioethics Committee of the Medical University of A (No. ...).

• This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University B (Date.../No. ...).

• Approval was obtained from the ethics committee of University C. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

• The questionnaire and methodology for this study was approved by the Human Research Ethics committee of the University of D (Ethics approval number: ...).

Examples of statements to be used for a retrospective study:

• Ethical approval was waived by the local Ethics Committee of University A in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

• This research study was conducted retrospectively from data obtained for clinical purposes. We consulted extensively with the IRB of XYZ who determined that our study did not need ethical approval. An IRB official waiver of ethical approval was granted from the IRB of XYZ.

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The second page should contain a structured Abstract not exceeding 200 words in a single paragraph without references. The Abstract should outline the essential content of the manuscript, especially the results and discussion, highlighting the relevance of main findings.

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Original articles should be divided into sections presented in the following order:

Title page

Abstract

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Results

Discussion

Acknowledgements

References

Tables and Figure legends

Supplementary Data (if applicable)

Material and methods and **Results** should be clear and concise. The Discussion section should avoid extensive repetition of the results and must finish with some conclusions. This section can be combined with results (Results and discussion), however, we recommend authors consult the Editoral Board for a previous evaluation.

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Books

Smith GM. 1938. Cryptogamic botany. Vol. II Bryophytes and Pteridophytes. 2nd. edn. New York, McGraw-Hill Book Company.

Chapters in books

Schupp EW, Feener DH. 1991. Phylogeny, lifeform, and habitat dependence of ant-defended plants in a Panamanian forest. In: Huxley CR, Cutler DC. (eds.) Ant-plant interactions. Oxford, Oxford University Press. p. 175-197.

Research papers

Alves MF, Duarte MO, Oliveira PEAM, Sampaio DS. 2013. Self-sterility in the hexaploid Handroanthus serratifolius (Bignoniaceae), the national flower of Brazil. Acta Botanica Brasilica 27: 714-722.

Papers in press (ahead of print)

Alves JJ, Sampaio MTY. 2015. Structure and evolution of flowers. Acta Botanica Brasilica (in press). doi: 10.1590/0102-33062015abb3339

Online-only journals

Wolkovich EM, Cleland EE. 2014. Phenological niches and the future of invaded ecosystems with climate change. AoB Plants 6: plu013 doi:10.1093/aobpla/plu013

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Websites and other sources (citation should be avoided)

Anonymous. 2011. Title of booklet, leaflet, report, etc. City, Publisher or other source, Country.

References to websites should be structured as: author(s) name author(s) initial(s). year. Full title of article. Full URL. 21 Oct. 2014 (Date of last successful access).

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We acknowledge the Center of Microscopy (UFMG) for providing the equipment and technical support for experiments involving electron microscopy. We also thank J.S. Santos for assistance with the statistical analyses. This work was supported through a research grant from the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (ID number).

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All figures (photographs, maps, drawings, graphs, diagrams, etc.) and tables must be cited in the text, in ascending order. Citations of figures in the text should appear in an abbreviated, capitalized form (e.g., Fig. 1, Fig. 2A-D, Fig. 3A, Figs. 3A, 4C, Tab.1).

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Submetido para a revista: Experimental and applied acarology

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Financial interests: Stocks or shares in companies (including holdings of spouse and/or children) that may gain or lose financially through publication of this manuscript; consultation fees or other forms of remuneration from organizations that may gain or lose financially; patents or patent applications whose value may be affected by publication of this manuscript.

It is difficult to specify a threshold at which a financial interest becomes significant, any such figure is necessarily arbitrary, so one possible practical guideline is the following: "Any undeclared financial interest that could embarrass the author were it to become publicly known after the work was published."

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Please note that, in addition to the above requirements, funding information (given that funding is a potential competing interest (as mentioned above)) needs to be disclosed upon submission of the manuscript in the peer review system. This information will automatically be added to the Record of CrossMark, however it is not added to the manuscript itself. Under ‘summary of requirements’ (see below) funding information should be included in the ‘Declarations’ section.

Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before the reference list under a heading of 'Funding' and/or 'Competing interests'. Other declarations include Ethics approval, Consent, Data, Material and/or Code availability and Authors' contribution statements.

Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

When all authors have the same (or no) conflicts and/or funding it is sufficient to use one blanket statement.

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Examples of statements to be used when there is no funding:

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Research involving human participants, their data or biological material

Ethics approval

When reporting a study that involved human participants, their data or biological material, authors should include a statement that confirms that the study was approved (or granted exemption) by the appropriate institutional and/or national research ethics committee (including the name of the ethics committee) and certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. If doubt exists whether the research was conducted in accordance with the 1964 Helsinki Declaration or comparable standards, the authors must explain the reasons for their approach, and demonstrate that an independent ethics committee or institutional review board explicitly approved the doubtful aspects of the study. If a study was granted exemption from requiring ethics approval, this should also be detailed in the manuscript (including the reasons for the exemption).

Retrospective ethics approval

If a study has not been granted ethics committee approval prior to commencing, retrospective ethics approval usually cannot be obtained and it may not be possible to consider the manuscript for

peer review. The decision on whether to proceed to peer review in such cases is at the Editor's discretion.

Ethics approval for retrospective studies

Although retrospective studies are conducted on already available data or biological material (for which formal consent may not be needed or is difficult to obtain) ethics approval may be required dependent on the law and the national ethical guidelines of a country. Authors should check with their institution to make sure they are complying with the specific requirements of their country.

Ethics approval for case studies

Case reports require ethics approval. Most institutions will have specific policies on this subject. Authors should check with their institution to make sure they are complying with the specific requirements of their institution and seek ethics approval where needed. Authors should be aware to secure informed consent from the individual (or parent or guardian if the participant is a minor or incapable) See also section on Informed Consent.

Cell lines

If human cells are used, authors must declare in the manuscript: what cell lines were used by describing the source of the cell line, including when and from where it was obtained, whether the cell line has recently been authenticated and by what method. If cells were bought from a life science company the following need to be given in the manuscript: name of company (that provided the cells), cell type, number of cell line, and batch of cells.

It is recommended that authors check the NCBI database for misidentification and contamination of human cell lines. This step will alert authors to possible problems with the cell line and may save considerable time and effort.

Further information is available from the International Cell Line Authentication Committee (ICLAC).

Authors should include a statement that confirms that an institutional or independent ethics committee (including the name of the ethics committee) approved the study and that informed consent was obtained from the donor or next of kin.

Research Resource Identifiers (RRID)

Research Resource Identifiers (RRID) are persistent unique identifiers (effectively similar to a DOI) for research resources. This journal encourages authors to adopt RRIDs when reporting key biological resources (antibodies, cell lines, model organisms and tools) in their manuscripts.

Examples:

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Antibody: Luciferase antibody DSHB Cat# LUC-3, RRID:AB_2722109

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RRIDs are provided by the Resource Identification Portal. Many commonly used research resources already have designated RRIDs. The portal also provides authors links so that they can quickly register a new resource and obtain an RRID.

Clinical Trial Registration

The World Health Organization (WHO) definition of a clinical trial is "any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes". The WHO defines health interventions as “A health intervention is an act performed for, with or on behalf of a person or population whose purpose is to assess, improve, maintain, promote or modify health, functioning or health conditions” and a health-related outcome is generally defined as a change in the health of a person or population as a result of an intervention.

To ensure the integrity of the reporting of patient-centered trials, authors must register prospective clinical trials (phase II to IV trials) in suitable publicly available repositories. For example www.clinicaltrials.gov or any of the primary registries that participate in the WHO International Clinical Trials Registry Platform.

The trial registration number (TRN) and date of registration should be included as the last line of the manuscript abstract.

For clinical trials that have not been registered prospectively, authors are encouraged to register retrospectively to ensure the complete publication of all results. The trial registration number (TRN), date of registration and the words 'retrospectively registered’ should be included as the last line of the manuscript abstract.

Standards of reporting

Springer Nature advocates complete and transparent reporting of biomedical and biological research and research with biological applications. Authors are recommended to adhere to the minimum reporting guidelines hosted by the EQUATOR Network when preparing their manuscript. Exact requirements may vary depending on the journal; please refer to the journal’s Instructions for Authors.

Checklists are available for a number of study designs, including:

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Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before the reference list under a heading of 'Ethics approval'.

Examples of statements to be used when ethics approval has been obtained:

• All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Bioethics Committee of the Medical University of A (No. ...).

• This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of University B (Date.../No. ...).

• Approval was obtained from the ethics committee of University C. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

• The questionnaire and methodology for this study was approved by the Human Research Ethics committee of the University of D (Ethics approval number: ...).

Examples of statements to be used for a retrospective study:

• Ethical approval was waived by the local Ethics Committee of University A in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

• This research study was conducted retrospectively from data obtained for clinical purposes. We consulted extensively with the IRB of XYZ who determined that our study did not need ethical approval. An IRB official waiver of ethical approval was granted from the IRB of XYZ.

• This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of University B approved this study.

Examples of statements to be used when no ethical approval is required/exemption granted:

• This is an observational study. The XYZ Research Ethics Committee has confirmed that no ethical approval is required.

• The data reproduced from Article X utilized human tissue that was procured via our Biobank AB, which provides de-identified samples. This study was reviewed and deemed exempt by our XYZ Institutional Review Board. The BioBank protocols are in accordance with the ethical standards of our institution and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Authors are responsible for correctness of the statements provided in the manuscript. See also Authorship Principles. The Editor-in-Chief reserves the right to reject submissions that do not meet the guidelines described in this section.

Informed consent

All individuals have individual rights that are not to be infringed. Individual participants in studies have, for example, the right to decide what happens to the (identifiable) personal data gathered, to what they have said during a study or an interview, as well as to any photograph that was taken. This is especially true concerning images of vulnerable people (e.g. minors, patients, refugees, etc) or the use of images in sensitive contexts. In many instances authors will need to secure written consent before including images.

Identifying details (names, dates of birth, identity numbers, biometrical characteristics (such as facial features, fingerprint, writing style, voice pattern, DNA or other distinguishing characteristic) and other information) of the participants that were studied should not be published in written descriptions, photographs, and genetic profiles unless the information is essential for scholarly purposes and the participant (or parent/guardian if the participant is a minor or incapable or legal representative) gave written informed consent for publication. Complete anonymity is difficult to achieve in some cases. Detailed descriptions of individual participants, whether of their whole bodies or of body sections, may lead to disclosure of their identity. Under certain circumstances consent is not required as long as information is anonymized and the submission does not include images that may identify the person.

Informed consent for publication should be obtained if there is any doubt. For example,

masking the eye region in photographs of participants is inadequate protection of anonymity. If identifying characteristics are altered to protect anonymity, such as in genetic profiles, authors should provide assurance that alterations do not distort meaning.

Exceptions where it is not necessary to obtain consent:

• Images such as x rays, laparoscopic images, ultrasound images, brain scans, pathology slides unless there is a concern about identifying information in which case, authors should ensure that consent is obtained.

• Reuse of images: If images are being reused from prior publications, the Publisher will assume that the prior publication obtained the relevant information regarding consent. Authors should provide the appropriate attribution for republished images.

Consent and already available data and/or biologic material

Regardless of whether material is collected from living or dead patients, they (family or guardian if the deceased has not made a pre-mortem decision) must have given prior written consent. The aspect of confidentiality as well as any wishes from the deceased should be respected.

Data protection, confidentiality and privacy

When biological material is donated for or data is generated as part of a research project authors should ensure, as part of the informed consent procedure, that the participants are made aware what kind of (personal) data will be processed, how it will be used and for what purpose. In case of data acquired via a biobank/biorepository, it is possible they apply a broad consent which allows research participants to consent to a broad range of uses of their data and samples which is regarded by research ethics committees as specific enough to be considered "informed". However, authors should always check the specific biobank/biorepository policies or any other type of data provider policies (in case of non-bio research) to be sure that this is the case.

Consent to Participate

For all research involving human subjects, freely-given, informed consent to participate in the study must be obtained from participants (or their parent or legal guardian in the case of children under 16) and a statement to this effect should appear in the manuscript. In the case of articles describing human transplantation studies, authors must include a statement declaring that no organs/tissues were obtained from prisoners and must also name the institution(s)/clinic(s)/department(s) via which organs/tissues were obtained. For manuscripts reporting studies involving vulnerable groups where there is the potential for coercion or where consent may not have been fully informed, extra care will be taken by the editor and may be referred

to the Springer Nature Research Integrity Group.

Consent to Publish

Individuals may consent to participate in a study, but object to having their data published in a journal article. Authors should make sure to also seek consent from individuals to publish their data prior to submitting their paper to a journal. This is in particular applicable to case studies. A consent to publish form can be found

here. (Download docx, 36 kB)

Summary of requirements

The above should be summarized in a statement and placed in a ‘Declarations’ section before the reference list under a heading of ‘Consent to participate’ and/or ‘Consent to publish’. Other declarations include Funding, Competing interests, Ethics approval, Consent, Data and/or Code availability and Authors’ contribution statements.

Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

Sample statements for "Consent to participate":

Informed consent was obtained from all individual participants included in the study.

Informed consent was obtained from legal guardians.

Written informed consent was obtained from the parents.

Verbal informed consent was obtained prior to the interview.

Sample statements for “Consent to publish”:

The authors affirm that human research participants provided informed consent for publication of the images in Figure(s) 1a, 1b and 1c.

The participant has consented to the submission of the case report to the journal.

Patients signed informed consent regarding publishing their data and photographs.

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Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

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Images will be removed from publication if authors have not obtained informed consent or the paper may be removed and replaced with a notice explaining the reason for removal.

Research involving animals, their data or biological material

The welfare of animals (vertebrate and higher invertebrate) used for research, education and testing must be respected. Authors should supply detailed information on the ethical treatment of their animals in their submission. For that purpose they may use the ARRIVE checklist which is designed to be used when submitting manuscripts describing animal research.

For studies involving client-owned animals, authors must also document informed consent from the client or owner and adherence to a high standard (best practice) of veterinary care.

Authors are recommended to comply with:

• The International Union for Conservation of Nature (IUCN) Policy Statement on Research Involving Species at Risk of Extinction and consult the IUCN red list index of threatened species.

• Convention on the Trade in Endangered Species of Wild Fauna and Flora

When reporting results authors should indicate:

• … that the studies have been approved by a research ethics committee at the institution or practice at which the studies were conducted. Please provide the name of ethics committee and relevant permit number;

• … whether the legal requirements or guidelines in the country and/or state or province for the care and use of animals have been followed.

Researchers from countries without any legal requirements or guidelines voluntarily should refer to the following sites for guidance:

– The Basel Declaration describes fundamental principles of using animals in biomedical research

– The International Council for Laboratory Animal Science (ICLAS) provides ethical guidelines for researchers as well as editors and reviewers

– The Association for the study of Animal Behaviour describes ethical guidelines for the treatment of animals in research and teaching

– The International Association of Veterinary Editors' Consensus Author Guidelines on Animal Ethics provide guidelines for authors on animal ethics and welfare

Researchers may wish to consult the most recent (ethical) guidelines available from relevant taxon-oriented professional societies.

If a study was granted exemption or did not require ethics approval, this should also be detailed in the manuscript.

Summary of requirements

The above should be summarized in a statement and placed in a 'Declarations' section before

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Please see the various examples of wording below and revise/customize the sample statements according to your own needs.

Examples of statements to be used when ethics approval has been obtained:

• All procedures involving animals were in compliance with the European Community Council Directive of 24 November 1986, and ethical approval was granted by the Kocaeli University Ethics Committee (No. 29 12 2014, Kocaeli, Turkey).

• All procedures performed in the study were in accordance with the ARVO Statement for Use of Animals in Ophthalmic Vision and Research. The ethical principles established by the National Institutes of Health Guide for the Care and Use of Laboratory Animals (NIH Publications No. 8523, revised 2011) were followed. The research protocol was approved by the Ethics Committee on Animal Use (Protocol No. 06174/14) of FCAV/Unesp, Jaboticabal.

• This study involved a questionnaire-based survey of farmers as well as blood sampling from their animals. The study protocol was assessed and approved by Haramaya University, research and extension office. Participants provided their verbal informed consent for animal blood sampling as well as for the related survey questions. Collection of blood samples was carried out by veterinarians adhering to the regulations and guidelines on animal husbandry and welfare.

• All brown bear captures and handling were approved by the Ethical Committee on Animal Experiments, Uppsala, Sweden (Application C18/15) and the Swedish Environmental Protection Agency in compliance with Swedish laws and regulations.

• The ethics governing the use and conduct of experiments on animals were strictly observed, and the experimental protocol was approved by the University of Maiduguri Senate committee on Medical Research ethics. Proper permit and consent were obtained from the Maiduguri abattoir management, before the faecal samples of the cattle and camels slaughtered in this abattoir were used for this experiment.

Examples of statements to be used when no ethical approval is required/exemption granted:

• No approval of research ethics committees was required to accomplish the goals of this study because experimental work was conducted with an unregulated invertebrate species.

• As the trappings of small mammals were conducted as part of regular pest control measures in accordance with the NATO Standardized Agreement 2048 "Deployment Pest and Vector Surveillance and Control ", no approval by an ethics committee was required.

• All experiments have been conducted as per the guidelines of the Institutional Animal Ethics

Committee, Department of Zoology, Utkal University, Bhubaneswar, Odisha, India. However, the insect species used in this study is reared for commercial production of raw silk materials, as a part of agro-based industry. Therefore, use of this animal in research does not require ethical clearance. We have obtained permission from the office of Research officer sericulture, Baripada, Orissa, India for the provision of infrastructure and support for rearing of silkworm both in indoor and outdoor conditions related to our study to promote sericulture practices.

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If it is not possible to share research data publicly, for instance when individual privacy could be compromised, this statement should describe how data can be accessed and any conditions for reuse. Participant consent should be obtained and documented prior to data collection. See our guidance on sensitive data for more information.

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Further guidance on writing a data availability statement, including examples, is available at: Data availability statements

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