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ECOSYSTEMS

Mite fauna on apples in southern Brazil - Review and perspectives

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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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