ORIGINAL PAPER

Aphids affecting subtropical Argentina strawberry production: species, cultivar preference, and nation-wide distribution update

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ABSTRACT

Argentina accounts for ~2,000 ha of strawberries *(Fragaria* x *ananassa* Duch.) and produces ~70,000 t, being aphids a relevant pest. The objectives of this study were to survey aphid species in a strawberry crop located in subtropical Argentina, along with their varietal preference and impact on plant productivity, and to update the distribution of aphid species throughout strawberry growing regions. The study was conducted in Tucumán province, where fresh-dug plants of different strawberry cultivars ('Benicia', 'Cabrillo', 'Camino Real', 'Fronteras', 'Merced', 'Petaluma' and 'San Andreas') were grown in an annual production system. In 2018, plant plots were randomly monitored every 14-15 days in July, August (winter), September and October (spring) for aphid presence. Once the presence of aphid colonies was confirmed, individuals were collected and identified. For fruit production evaluations, berries were harvested from June to December. Eight aphid species were identified: *Aphis forbesi* (first record in strawberries in Tucumán), *Aphis gossypii* (largest colony number), *Aphis* sp., *Chaetosiphon fragaefolii*, *Chaetosiphon* sp., *Macrosiphum euphorbiae*, *Myzus persicae*, and *Rhodobium porosum*. The largest number of aphids was collected in winter. All strawberry cultivars were infested by aphids; however, not all aphid species were found in all cultivars. 'Fronteras' was attacked by the eight aphid species found, while 'Benicia' and 'Camino Real' by seven, 'Cabrillo' and 'Merced' by four, and 'Petaluma' and 'San Andreas' by three. Most of the specimens were collected during the winter. There was no evident influence of the varietal preference of aphids on cultivar fruit production and quality. 'Fronteras' and 'Camino Real' were infested by eight different aphid species, but the first one had the highest yield of the trial, while the second one had the lowest. No virus symptoms were recorded in the sampled plots. According to these results, there are 13 aphid species recorded in Argentina and they belong to seven genera: *Aphis* (4), *Chaetosiphon* (3), *Myzus* (2), *Aulacorthum* (1), *Cryptomyzus* (1), *Macrosiphum* (1), and *Rhodobium* (1), all distributed in nine strawberry growing provinces.

Keywords*:* Aphididae, strawberry virus, fruit yield.

RESUMEN

Argentina cuenta con ~2.000 ha de frutilla (Fragaria x ananassa Duch.) y produce ~70.000 t, por lo que los pulgones son una plaga relevante. Los objetivos de este trabajo fueron estudiar las especies de pulgones en un cultivo de frutilla en la Argentina subtropical y su preferencia varietal e impacto en la productividad, y actualizar la distribución de las especies de pulgones en las regiones productoras de frutilla. El estudio se realizó en Tucumán y se utilizaron los cultivares 'Benicia', 'Cabrillo', 'Camino Real', 'Fronteras', 'Merced', 'Petaluma', 'San Andreas'. Las parcelas de plantas se

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monitorearon aleatoriamente cada 14-15 días entre julio y octubre (2018) para detectar pulgones. Una vez confirmada la presencia de colonias de áfidos, se recolectaron e identificaron los individuos. La producción de frutos se evaluó de junio a diciembre. Se identificaron ocho especies de pulgones: Aphis forbesi (primera cita en frutilla para Tucumán), Aphis gossypii (mayor número de colonias), Aphis sp., Chaetosiphon fragaefolii, Chaetosiphon sp., Macrosiphum euphorbiae, Myzus persicae y Rhodobium porosum. Todos los cultivares fueron infestados por pulgones, pero no se encontraron todas las especies de pulgones en todos los cultivares. 'Fronteras' y 'Camino Real' fueron atacadas por las ocho especies de áfidos encontradas, mientras que 'Benicia' por siete, 'Cabrillo' y 'Merced' por cuatro, y 'Petaluma' y 'San Andreas' por tres. La mayor cantidad de pulgones se recogió en invierno. No hubo una influencia evidente de la preferencia varietal sobre la producción/calidad de fruta de ningún cultivar. 'Fronteras' y 'Camino Real' (infestadas por ocho especies de pulgones) fueron las de mayor y menor rendimiento, respectivamente. No se registraron síntomas de virus en plantas muestreadas. Con estos resultados, habría 13 especies de pulgones registradas en Argentina, pertenecientes a siete géneros: Aphis (4), Chaetosiphon (3), Myzus (2), Aulacorthum (1), Cryptomyzus (1), Macrosiphum (1) y Rhodobium (1), distribuidos en nueve provincias productoras de frutilla.

Palabras clave: *Aphididae, virosis en frutilla, rendimiento frutal.*

INTRODUCTION

Strawberry (*Fragaria* x *ananassa* Duch.) crops are distributed worldwide, grown in 80 countries, with a production of 9,175,384 t in 389,665 ha in 2021 (FAOSTAT, 2023). The 10 countries with the highest production are in the northern hemisphere, with China and the US as the main producers (FAOSTAT, 2023). In South America, Brazil leads in strawberry production, followed by Chile, Colombia, and Argentina (Kirschbaum *et al.*, 2017). Strawberry consumption has had a strong boost since the COVID-19 pandemic since it is one of the preferred fruits for strengthening the immune system (Yadav, 2021).

Argentina grows approximately 2,000 ha of strawberries (Kirschbaum, 2022) and obtains an average yield of 34 $t.ha^{-1}$ (Secretaría de Agricultura, Ganadería y Pesca, 2023), representing an annual production of almost 70,000 t. About 80% of the national strawberry production is concentrated in three provinces: Buenos Aires, Santa Fe, and Tucumán (Kirschbaum, 2022). In this last province, which accounts for about 570 ha (Secretaría de Estado de Comunicación Pública, 2024), strawberries are grown under an annual winter production system (Kirschbaum *et al.*, 2000).

Strawberry crops are colonized by phytophagous arthropods that inflict both direct and indirect damages, causing economic losses due to reductions in fruit yield and quality, and forcing growers to incur onerous expenses for their control. Among them, spider mites, thrips, and aphids stand out (Maza *et al.*, 2023; Kirschbaum *et al.*, 2015). The latter, in addition to their importance for causing damage by feeding on the plant, are known for being vectors of numerous viruses (Dughetti *et al.*, 2017). Worldwide, approximately 30 to 35 aphid species belonging to genera *Acyrthosiphon* Mordvilko, *Amphorophora* Buckton, *Aphis* Linnaeus, *Aulacorthum* Mordvilko, *Brachycaudus* van der Goot, *Chaetosiphon* Mordvilko, *Ericaphis* Börner, *Eriosoma* Leach, *Macrosiphum* Passerini, *Myzaphis* van der Goot, *Neomegoura* Shinji, *Myzus* Passerini, *Neomyzus* van der Goot, *Sitobion* Mordvilko, *Smynthurodes* Westwood, are known for their use of *F.* x *ananassa* as host plants (Blackman, 2013). In Argentina, 13 aphid species have been reported up to date in strawberry, belonging to genera *Aphis* Linnaeus, *Aulacorthum* Mordvilko, *Chaetosiphon* Mordvilko, *Cryptomyzus* Oestlund, *Macrosiphum* Passerini, *Myzus* Passerini and *Rhodobium* Hille Ris Lambers (Greco *et al.*, 2020; Cingolani and Greco, 2018; Dughetii *et al.*, 2017; Cingolani *et al.*, 2015a,b; Correa *et al.*, 2012; Cédola and Greco, 2010; Jaime *et al.*, 2009; Delfino, 2004; Nieto Nafría *et al.*, 1994). Due to the large number of species cited worldwide and to the lack of studies in many strawberry growing provinces, an increase in the number of species associated with strawberry crops in Argentina is expected.

According to Weber *et al.* (2020), an auspicious alternative to gain independence from the excessive use of pesticide in agriculture is to improve the genetic plant resistance of the plant against pests. Strawberry production is not an exception; however, the genetic resistance against pests is limited within strawberry cultivars and not very well explored. There are few studies assessing the tolerance of different strawberry cultivars to aphids, and most of them focused on *Chaetosiphon fragaefolii* (Benatto *et al.*, 2018 and 2019; Jamieson *et al.*, 2016; Bernardi *et al.*, 2012). Based on fertility tables, Bernardi *et al*. (2012) concluded that the most resistant cultivars were 'Albion' and 'Aromas', while, based on leaf aphid density, Jamieson *et al.* (2016) found out that 'Bounty', 'Mira' and 'Annapolis' were the most resistant. Considering leaf trichome density, Benatto *et al.* (2018) reported that 'Albion' was the most resistant cultivar, and based on biological and population growth parameters, Benatto *et al.* (2019) suggested that 'Camarosa' was the most resistant . On the contrary, Bernardi *et al.* (2013) showed that the infestation level did not vary during the sampling period, regardless of the strawberry cultivar ('Albion', 'Camino Real', 'Camarosa', 'Ventana') and aphid species (*Aphis gossypii*, *Aphis forbesi*, *C. fragaefolii*) in the strawberry farms surveyed in southern Brazil. Nevertheless, cultivars are periodically renewed, seeking to introduce best-performing genetics (Milosavljević *et al.*, 2023) and, consequently, continuous assessment of their tolerance for aphids and other pests is necessary.

The preference of aphids for strawberry cultivars and their impact on fruit yield are not very well understood. In a study conducted in a subtropical region such as Florida (Paranjpe *et al.*, 2003), 'Sweet Charlie' and 'Carmine' had the highest levels of aphid (*A. gossypii*) infestation, whereas the rest of the cultivars ('Camarosa', 'Earlibrite', 'Festival', 'FL-97-39', 'Treasure') had significantly lower levels of aphid infestation. However, 'Carmine' (high aphid infestation) and 'FL-97-39' (low aphid infestation) were the cultivars with the highest yields in the trial, while 'Sweet Charlie' (high aphid infestation) and 'Camarosa' (low aphid infestation) had the lowest yields.

The objectives of this work were to survey the aphid species present in a strawberry crop in subtropical Argentina, along with their cultivar preference and impact on plant productivity, and to update the distribution of aphid species affecting this crop in the different Argentine strawberry growing regions.

MATERIALS AND METHODS

The study was carried out at INTA's Famaillá Agricultural Experiment Station, in Estación Padilla (27°03'S, 65°25'W; 363 m elevation; Famaillá department, Tucumán province, Argentina), an agroecological region of the non-saline depressed plain (Zuccardi and Fadda, 1985), on an aquic Argiudol soil, imperfectly drained, silty loam textural type, pH 6.47, organic matter 2.0%, total N 0.12%, soluble P 28.4 ppm, exchangeable K 1.01 me.100 g^{-1} and EC 0.53 $dS.m^{-1}$. This region's climate corresponds to CWa (subtropical with dry winters) according to the Koppen-Geiger classification (Funes *et al.*, 2020; Kottek *et al.*, 2006).

Fresh-dug bare-root plants of different strawberry cultivars ('Benicia', 'Cabrillo', 'Camino Real', 'Fronteras', 'Merced', 'Petaluma' and 'San Andreas') from high latitude nurseries (42°03' S, 71'10' W; 680 m altitude; El Maitén, Chubut province, Argentina) were planted in offset 2-row beds 50 cm wide, 40 cm high, leaving 1.30 m between the centers of beds (annual hill production system), using a 30-cm in-row plant spacing (51,282 plants ha^{-1}; figure 1). Planting dates: April 18 for 'Benicia', 'Cabrillo', 'Merced', 'Petaluma', and 'San Andreas'; April 27 for 'Camino Real'; and May 10 for 'Fronteras'. Drip irrigation tapes were laid on the beds, which were covered with black polyethylene mulch (25-µm thick). The irrigation frequency was three to five times per week, providing enough water to keep soil moisture continuously at field capacity. Water-soluble fertilizers were applied through drip irrigation. From June to August, beds were covered with floating row cover to protect the crop from freezing temperatures.

Two 30-plant plots of each cultivar, randomly distributed, were monitored for aphid presence every 14-15 days from 10 July to 7 October (10, 24 July; 7, 21 August; 4, 19 September; 3, 17 October 2018). The first two months were called "winter", and the second two months were called "spring". A systematic sampling pattern was implemented—every three plants the third one was sampled (figure 2). In each plant, crown, flowers, fruits, and leaves were thoroughly inspected.

Aphid infested plant material was collected in Petri dishes and transferred to the laboratory from the Agricultural Zoology program at the FAZyV-UNT, where, after being immediately placed under a stereoscopic microscope (Leica EZ4, Leica Microsystems, Germany), the presence of established aphid colonies was checked. Aphid colonies are several to many aphids that are functionally organized to extract food from plants (Amrani *et al.*, 2023). Then, the aphid colonies, composed of nymphs in different stages (four nymphal instars) and adults, were separated, conditioned in 2 ml Eppendorf, preserved in 70% ethanol, and subsequently sent to INTA´s Entomology laboratory in Mendoza, where they were identified following keys and taxonomic descriptions from recognized authors (Blackman and Eastop, 2000; Remaudière and Seco Fernández, 1990). The identified material is deposited and preserved in the Entomology laboratory of INTA Mendoza (Argentina). Two-spotted spider mites (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), were also monitored in sampled plants by removing the central leaflet of a green-mature leaf from each plant and taking it to the lab for mite (mobile forms) counting. Data were firstly subjected to square root transformation and then to analysis of variance. The means were separated using the LSD Fisher test and INFOSTAT (Di Rienzo *et al.*, 2020).

For fruit production evaluations, berries were harvested weekly, from June to December, according to commercial fruit maturity standards. The total fruit yield and average marketable fruit weight (fruit quality indicator) were recorded. The experimental design was completely randomized with three replicates of 30 plants per cultivar. The fruit-related data were firstly subjected to square root transformation and then to analysis of variance. The means were grouped using the LSD Fisher test at 95% confidence level. INFOSTAT statistical software was used (Di Rienzo *et al.*, 2020).

The meteorological data (maximum, minimum and average temperatures; agronomic frosts; and precipitations) were recorded from May to December by a remote agrometeorological station located nearby the experimental plots.

Figure 1. Strawberry experimental plot (INTA Famaillá, Tucumán, Argentina).

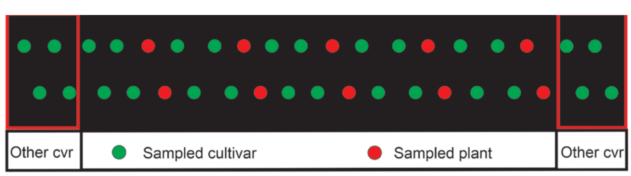

Figure 2. Sampling scheme. Red stars indicate sampled strawberry plants, while green circles indicate those plants that were not sampled. Each cultivar plot was separated by four buffer plants.

RESULTS AND DISCUSSION

Temperature and precipitation

The temperatures increased considerably from winter (Jul, Aug) to spring (Sep, Oct), which was observed not only in terms of temperature values, but also in the sharp decline of the number of days with agronomic frosts and in the monthly accumulation of chilling hours (table 1). Regarding precipitations, winter and part of spring (Jul through Sept) had few days of rain and low levels of rainfall. However, as the spring progressed, precipitations increased (Oct). The possible consequences of these conditions on aphid seasonal presence are discussed below.

Aphid seasonal presence and identified species

In the four months of collection (July to October), eight samplings were carried out. Regarding the distribution of aphids on the plant, they were found in different organs such as crown, flower buds, fruits, and leaves (figure 3). The largest number of aphids was collected in winter, showing significant differences with spring samples (figure 4).

The putative reasons for this sharp drop are discussed as follows. 1) Spider mites. From the end of August, the TSSM population began to increase. On average, TSSM mobile forms per leaflet were below 20 from June to mid August, increasing to more than 40 by the end of August, reaching about 120 by the first week of September (data not shown). Previous reports suggest that a high TSSM density could have two consequences for aphids feeding on strawberry plants. The first one is a negative interaction between TSSM and aphids (Kiełkiewicz *et al.*, 2019; Cédola *et al.*, 2013). According to Cédola *et al.* (2013), who conducted lab experiments using strawberry leaflets detached from the plant, TSSM would have a greater population growth rate and greater ability to move than aphids, so they occupy new leaflets before aphids do. Kiełkiewicz *et al.* (2019) suggested TSSM might have/could have an indirect negative effect on aphids by colonizing plants earlier than aphids. In their experiment, Arabidopsis plants were firstly infested for a 24-h period with TSSM and then with *M. persicae* for two weeks to ensure aphid offspring production and maturity. Compared to plants non-infested by TSSM, a significantly smaller aphid colony developed on those plants previously infested with TSSM, showing an effective TSSM-induced plant defense against aphids (Kiełkiewicz *et al.*, 2019). The second consequence of a high TSSM density is related to a series of control measures applied to suppress it, which could indirectly have had a negative impact on aphids, such as applications of miticides (Vertimec, Nissorum and Kanemite) and diatomaceous earth, and other practices such as leaf pruning and plant wash (Gong *et al.*, 2021; Sun *et al.*, 2020; Brenard *et al.*, 2019; El-Wakeil *et al.*, 2009; Stoyenoff, 2001). 2) Rains. October had 17 days of rain (table 1), with almost 40 mm in just one day (data not presented). Studies show that rainfall reduces aphid populations immediately after each rain event (Kaakeh and Dutcher, 1993), which could also be the cause for the aphid populations drop in our study (figure 5). 3) *Temperature.* Ma and Ma (2012) reported that long exposure to high temperature limits aphids' individual development and aphid population growth. In our study, the spring mean temperatures (September 19.8°C, October 19.8°C) were much higher than the winter mean temperatures (July 9.9°C, August 12.9°C) (table 1), probably causing a negative effect of higher temperatures on the aphid population decrease (fig. 5). A differential seasonal distribution of aphid species on strawberries has also been observed by Donner *et al.* (2024) in The Netherlands, who recorded 43% more colonies in spring compared to summer. However, it is worth highlighting that some aphid species, such as *A. gossypii*, perform better in warmer temperatures (Satar *et al.*, 2008). 4) Natural enemies. The presence of aphidophagous insects, such as lacewings, in the strawberry crop tends to be higher in spring than in winter (Gibilisco *et al.*, 2021). In previous studies, Correa *et al.* (2012) reported that the lacewings species usually found on strawberries in the experimental plot, such as *Chrysoperla argentina*, *Chrysoperla externa*, and *Ceraeochrysa paraguaria*, during their immature stages (larvae), preyed on average between 29 and 95 aphids, with the third stage being the most voracious in all cases.

In the examined material, eight aphid species were identified in the strawberry crop: *Aphis forbesi* Weed, *Aphis gossypii* (Glover), *Aphis* sp., *Chaetosiphon fragaefolii* (Cockerell), *Chaetosiphon* sp., *Macrosiphum euphorbiae* (Thomas), *Myzus persicae* (Sulzer), and *Rhodobium porosum* (Sanderson). Numerous samples were composed of nymphs of different stages (one to four nymphal instars) and could only be determined at the genus level: *Aphis* sp. and *Chaetosiphon* sp., which may or may not correspond to the identified species of the respective genera (*A. forbesi*, *A. gossypii* and *C. fragaefolii*).

Colonies of the genus *Aphis* were the most frequently found colonies during the study, being *A. gossypii* and *Aphis* spp. the

Meteorological variable	Month			
	Jul	Aug	Sep	Oct
Average maximum temperature (°C)	16.8	22.6	28.7	25.7
Average minimum temperature (°C)	4.9	4.5	12.0	14.8
Average temperature (°C)	9.9	12.9	19.8	19.8
Days with agronomic frosts	12	15	2	0
Chilling hours (T<7°C)	284	218	97	0
Precipitation (mm)	18.0	2.0	10.0	108.8
N° of days with precipitation	4	1	3	17

Table 1. Meteorological variables recorded in Famaillá (Tucumán, Argentina) during the studied period.

Figure 3. Different organs of strawberry plants infested by aphids: leaves (A,B), shoots (C,D), sepals (E), and petals (F).

most numerous (figure 6). *Aphis gossypii* is a vector of four strawberry viruses: strawberry mottle, strawberry polerovirus 1, strawberry pseudo mild yellow edge, and strawberry chlorotic fleck, but just the two first ones are present in Argentina (Dughetti *et al*., 2017; Luciani *et al*., 2016). However, *A. gossypii* is not generally a major problem in field grown strawberries, but it may represent a serious threat to greenhouse strawberry productions (Rondon *et al*., 2005).

On the other hand, we observed that *Tribolium* sp. plants, found as spontaneous vegetation next to strawberry plants (in the same planting hole), were infested with aphid species such as *Aphis craccivora* Koch, *Acyrthosiphon pisum* Harris and *Aulacorthum solani* (Kaltenbach), which were eventually also found on strawberry plants as isolated individuals. These three aphid species have been previously recorded in Tucumán in other horticultural crops, such as potato and tomato (Ávila *et al.*, 2014; Berta *et al.*, 2002). Furthermore, the three species have been recorded on strawberry crops: *Aphis craccivora* in The Netherlands (Donner *et al.*, 2024), and *Acyrthosiphon pisum* and *Aulacorthum solani* in Buenos Aires, Argentina (Cingolani *et al.*, 2015), as well as in Canada (Stultz, 1968).

Of the six fully identified species, *A. forbesi* is the only one cited for the first time in Tucumán on a strawberry crop. The other five species—*A. gossypii*, *R. porosum* (Jaime *et al.*, 2009), *Myzus persicae* (Correa *et al.*, 2012), *C. fragaefolii* (Dughetti *et al.*, 2017; Jaime *et al.*, 2009; Nieto Nafría *et al.*, 1994), and *M. euphorbiae* (Dughetti *et al.*, 2017; Jaime *et al.*, 2009)— had already been reported.

In Argentina, *A. forbesi* (the strawberry root aphid) has been detected in strawberry crops since the spring and summer of 1991 at the Buenos Aires Colorado River Valley (BACRV) (Dughetti *et al.*, 2017), where colonies were observed on petioles and on the lower surface of young leaves, as well as on flower peduncles and fruits. These aphids suck sap; and, in severe infestations, they can weaken the plant, which takes on a pale green to yellowish appearance, reduces its size, loses turgor, and the fruits dry out. In the BACRV, *A. forbesi* begins the invasion of the crop in spring, reaching density peaks at the beginning of the summer. In late summer, their colonies descend to the lower part of the plant to establish on crowns, the upper part of the roots and basal portions of petioles. In autumn, they settle again on the petioles (Dughetti *et al.*, 2017). In subtropical warmer regions (like Tucumán) such as Río Grande do Sul, Brazil, *A. forbesi* population peaks in the spring (Bernardi *et al.*, 2013). *Aphis forbesi* is an important strawberry aphid since it can acquire three different virus species that are responsible for causing diseases in strawberry plants: SCV, SMoV and SPV1 (Koloniuk *et al.*, 2022; Fránová *et al.*, 2021).

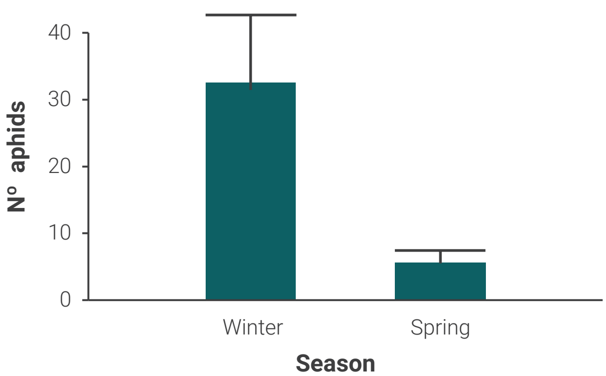

Figure 4. Average number of aphids collected on strawberries in each monitoring season (winter and spring), regardless of strawberry cultivar in Tucumán, Argentina. Test: LSD Fisher, Alpha=0.05, LSD=12.25.

Cultivar preference

All the strawberry cultivars involved in this survey were infested by aphids; however, not all aphid species were found in all the cultivars (table 2). 'Fronteras' was attacked by the eight aphid species found in this study. While 'Benicia' and 'Camino Real' were affected by all aphid species except for *M. persicae*. 'Cabrillo' and 'Merced' were affected by four aphid species, and 'Petaluma' and 'San Andreas' just for three.

It is worth noting that 'San Andreas' was attacked only by aphids from the *Aphis* genus, and that *A. gossypii* and *A.* sp. were the only two species that colonized all the strawberry cultivars. *A. gossypii* is a generalist aphid species (Musaqaf *et al.*, 2022). Furthermore, 'San Andreas' was the only cultivar that was not affected by *C. fragaefolii*, which is commonly known as the strawberry aphid, a specialist aphid (Musaqaf *et al.*, 2022), considered the most dangerous aphid species for being the vector of all the strawberry viruses found in Argentina: Strawberry mild yellow edge virus (SMYEV), Strawberry crinkle virus (SCV), Strawberry mottle virus (SMoV), and Strawberry polerovirus 1 (SPV1) (Fránová *et al.*, 2021; Luciani *et al.*, 2018; Dughetti *et al.*, 2017). Interestingly, 'San Andreas' is recommended for its tolerance to viruses (Njoroge, 2020), this could explain why it was not chosen by most of the known virus-vectoring aphid species.

On the other hand, among the eight species reported, *Aphis gossypii* and *Aphis* sp. were present in almost all the samplings (winter and spring), while the rest were found concentrated in a narrower time window, between July 24 and August 21 (winter) (figure 7).

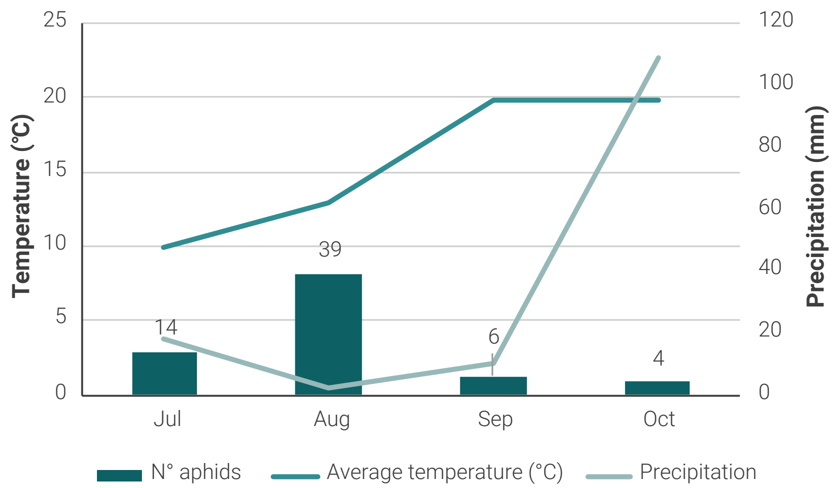

Figure 5. Fluctuation of the number of aphids, average temperature and precipitation during the four months considered in the study.

Aphid species	Cultivar						
	Benicia	Cabrillo	Camino Real	Fronteras	Merced	Petaluma	San Andreas
Aphis forbesi Weed	X		X	X	X		X
Aphis gossypii (Glover)	X	X	X	X	X	X	X
Chaetosiphon fragaefolii (Cockerell)	X	X	X	X	X	X	
Macrosiphum euphorbiae (Thomas)	X		X	X			
Myzus persicae (Sulzer)				X			
Rhodobium porosum (Sanderson)	X	X	X	X			
Aphis sp.	X	X	X	X	X	X	X
Chaetosiphon sp.	X		X	X			

Table 2. Aphid species recorded on different strawberry cultivars in the experimental plot of INTA Famaillá, Tucumán, 2018.

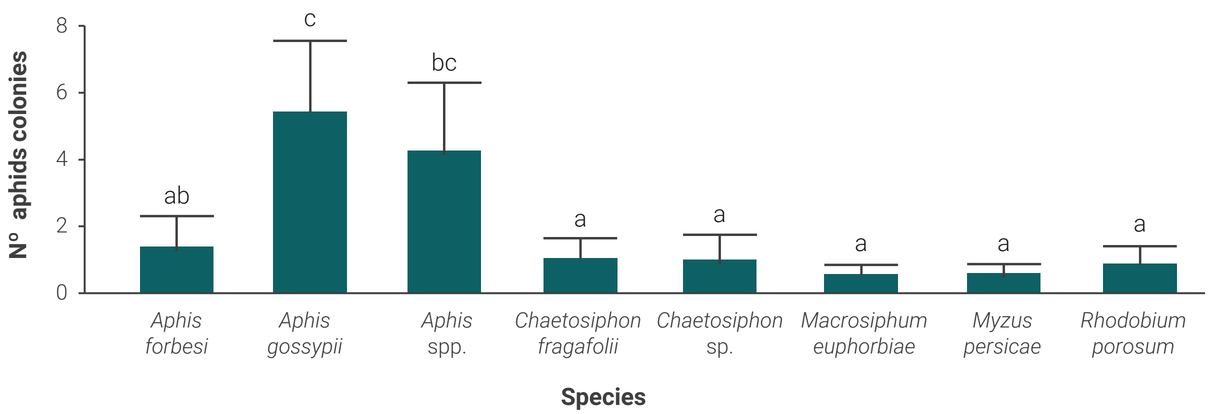

Figure 6. Average number of aphid species collected from strawberry plants on eight sampling dates (Tucumán, Argentina). Means with the same letter are not significantly different. Test: LSD Fisher, Alpha=0.05, LSD=3.06131.

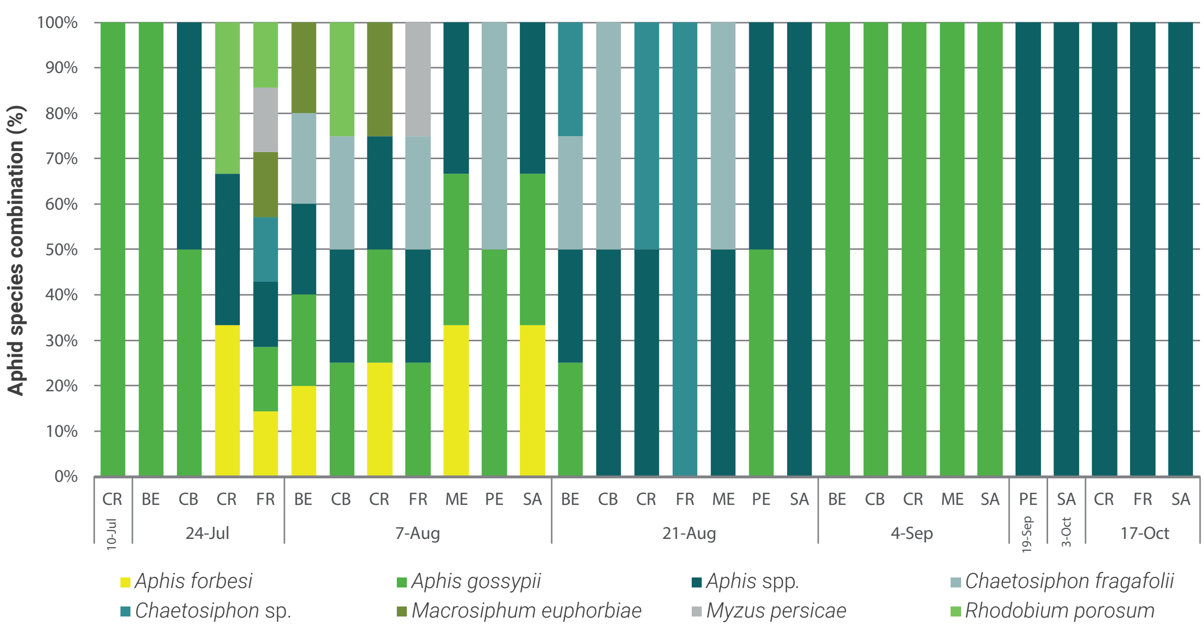

Figure 7. Percentage representation of each aphid species, by cultivar and collection date. CR, Camino Real; ME, Merced; SA, San Andreas; PE, Petaluma; BE, Benicia; CB, Cabrillo; FR, Fronteras.

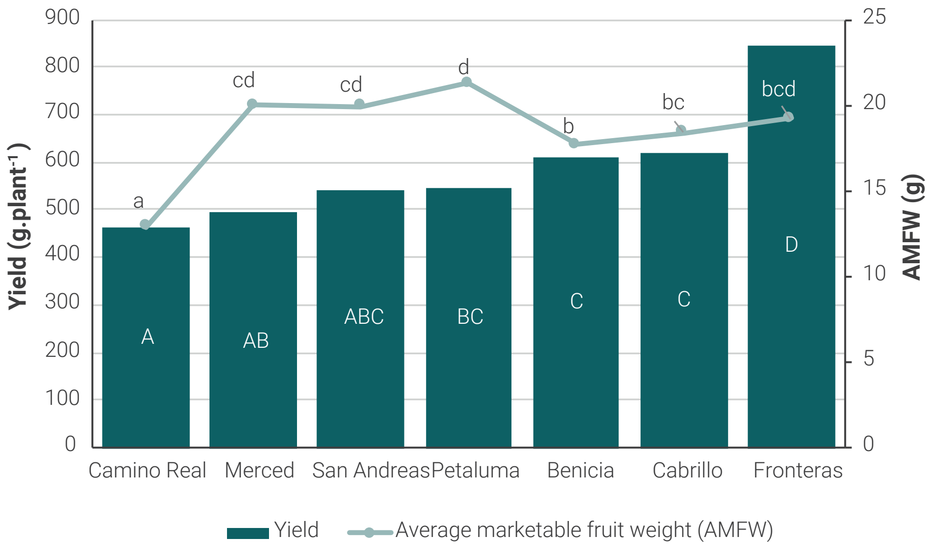

Figure 8. Total fruit yield and average marketable fruit weight of seven strawberry cultivars evaluated in Famaillá (Tucumán, Argentina), in 2018. Different letters indicate statistically significant differences between means (Fisher LSD, p>0.05).

In the first sampling date (July 10th), only 'Camino Real' was infested by aphids, but just with *A. gossyppii* (fig. 6). From the second to the fourth sampling dates (July 24th and August 21st, respectively), there was an increase in the number of cultivars attacked by aphids and in the diversity of the aphid species. From the beginning of September, this trend showed a progressive retraction in both the number of infested cultivars and aphid species, being *Aphis* sp. the only aphid species collected at the end of the sampled period.

Regarding the cultivar preference of the aphid species, our results agree with several previous reports. Remarkable differences were detected in aphid communities found on some strawberry varieties/selections. For example, 'Marmolada', 'B1E7-23', 'H3J1-4', 'B1E9-15', and 'B1E9-2'1 were preferentially attacked by aphids such as *C. fragaefolii*, while in 'Selene', 'J5K9-1R', 'H2J5-5', and 'B1E7-4i' the aphid community was substantially reduced or absent (Leis *et al.*, 2002).

Myzus persicae was collected only in winter and found just in 'Fronteras'; however, *A. gossypii*, the most frequent species, was collected every month, and it infested all the cultivars involved in this study. This observation could be related to the particular ethological features of each aphid species. *Myzus persicae* develops better at cooler temperatures, below 20°C (Satar *et al.*, 2007). The higher frequency of *Aphis gossypii* in the present study might be related to the fact that this aphid interacts with ants. *Aphis gossypii* colonies attended by ants (19 species) have larger sizes and more nymphs per colony than those with little to no attendance, such as *M. persicae* (Duque-Gamboa *et al*., 2021). According to Delfino and Buffa (2000), ant attendance favors aphids' host plant colonization, which increases the probability of causing damages to the crop (Szpeiner, 2008).

The morpho-histological features of the leaf might shape the resistance to aphid infestation in strawberries. The degree of lignification around vascular bundles was reported to be inversely related to aphid preference for some strawberry genotypes (Milenkovic *et al.*, 2014). On the other hand, Benatto *et al.* (2018) suggest that trichome density (physical barrier) interferes with the feeding of aphids, and for this reason, 'Albion' (high trichome density) behaved as a resistant cultivar, while 'San Andreas' (low trichome density) as the most susceptible of the four cultivars tested against *C. fragaefolii*. On the contrary, our results show that 'San Andreas' was not attacked by *C. fragaefolii*. This cultivar is considered the most susceptible to the TSSM (Neira *et al.*, 2023), and it was also the first to be targeted by TSSM in our trial, which could have caused a negative interaction between TSSM and *C. fragaefolii*, mediated by feeding damage (Cédola *et al.*, 2013). 'Petaluma', the cultivar that together with 'San Andreas' was attacked by only three aphid species, has a high density of calcium oxalate crystals (druses), a thick cuticle, and abundant starch and dark bodies (that suggest phenols) (Neira *et al.*, 2023), which would have probably discouraged aphids from feeding on these plants.

In the present study, not all the aphid species had the same preference for all the strawberry cultivars evaluated, which in general is in line with Guimarães *et al.* (2018). They assessed the resistance of six strawberry cultivars ('Aromas', 'Campinas', 'Dover', 'Festival', 'Oso Grande', and 'Toyonoka') to *A. forbesi* and *C. fragaefolii*. 'Campinas', 'Toyonoka' and 'Dover' had a higher incidence of *A. forbesi*. Furthermore, 'Campinas' and 'Toyonoka' were the most attacked *by C. fragaefolii* as well. On the other hand, 'Festival', 'Aromas', and 'Oso Grande' showed lower infestations of both species.

Most of the studies concerning the susceptibility of strawberry cultivars to aphids were focused on one aphid species—*Chaetosiphon fragaefolii*, the strawberry aphid, considered an important pest because of the number of viruses it vectors to strawberries and because it is not usually controlled by parasitoid wasps as other aphid species (Díaz-Lucas *et al.*, 2023). Our results show that this aphid attacked all the strawberry cultivars except for 'San Andreas'. The cultivar preference by *C. fragaefolii* could be related to cultivar receptivity towards this aphid. In this regard, Bernardi *et al.* (2012) observed significant differences in the longevity of *C. fragaefolii* depending on the strawberry cultivar on which they fed, with 'Aromas' scoring a lower survival rate (more resistant) compared to the other cultivars. On the other hand, 'Camarosa' and 'Sabrosa' favored the development of C. fragaefolli, while 'Camino Real' was in between both extremes.

Aphid species	Province	Source
Aphis fabae Scopoli	Buenos Aires	Cédola and Greco (2010)
	Chubut	Recalde (2008)
	Río Negro	Lantschner (2014)
Aphis forbesi Weed	Buenos Aires	Dughetti *et al.* (2014, 2017)
	Tucumán	Contribution of this work
Aphis gossypii (Glover)	Buenos Aires	Cédola and Greco (2010); Cingolani and Greco (2018); Cingolani *et al.* (2015a; 2015b); Dughetti *et al.* (2017)
	Chubut	Recalde (2008)
	Mendoza	Ortego (1997); Delfino (2004)
	Río Negro	Lantschner (2014)
	Salta	Olivo *et al.* (2015)
	Tierra del Fuego	Yutrovic (2015)
	Tucumán	Jaime *et al.* (2009); contribution of this work
Aphis ruborum (Bürber)	Tucumán	Jaime *et al.* (2009)
Aulacorthum solani (Kaltenbach)	Buenos Aires	Cingolani and Greco (2018); Cingolani *et al.*, (2015b)
Chaetosiphon fragaefolii (Cockerell)	Buenos Aires	Blandchard (1935); Nieto Nafria *et al.* (1994); Delfino (2004); Cédola y Greco (2010); Cédola *et al.* (2013); Dughetti *et al.* (2014, 2017); Cingolani *et al.* (2015a; 2015b); Cingolani and Greco (2018)
	Chubut	Recalde (2008)
	Córdoba	Nieto Nafria *et al.* (1994)
	Mendoza	Chiesa Molinari (1942); Nieto Nafria *et al.* (1994); Ortego (1997); Delfino (2004)
	Río Negro	Lantschner (2014)
	Tucumán	Nieto Nafria *et al.* (1994); Ovruski (2002); Jaime *et al.* (2009); contribution of this work
Chaetosiphon minor (Forbes)	Buenos Aires	Dughetti *et al.* (2017)
Chaetosiphon thomasi Hille Ris Lambers	Buenos Aires	Dughetti *et al.* (2017)
	Mendoza	Ortego (1997)
Cryptomyzus sp. Oestlund	Tucumán	Jaime *et al.* (2009)
Macrosiphum euphorbiae (Thomas)	Buenos Aires	Cédola and Greco (2010); Cingolani *et al.* (2015a; 2015b); Cingolani and Greco (2018); Dughetti *et al.* (2017).
	Mendoza	Ortego (1997).
	Tucumán	Jaime *et al.* (2009); contribution of this work.
Myzus ornatus Laing	Buenos Aires	Cingolani *et al.* (2015b); Cingolani and Greco (2018).
Myzus persicae (Sulzer)	Buenos Aires	Cédola and Greco (2010, 2018); Cingolani *et al.* (2015a; 2015b); Cingolani and Greco (2018).
	Chubut	Recalde (2008).
	Mendoza	Ortego (1997).
	Río Negro	Lantschner (2014).
	Salta	Olivo *et al.* (2015).
	Santa Fe	Gariglio *et al.* (2020).
	Tierra del Fuego	Yutrovic (2015).
	Tucumán	Correa *et al.* (2012); contribution of this work.
Rhodobium porosum (Sanderson)	Buenos Aires	Cingolani *et al.* (2015b); Cingolani and Greco (2018).
	Tucumán	Jaime *et al.* (2009); contribution of this work.

Table 3. Updated list of aphid species collected from strawberry crops in different Argentine provinces.

Regardless of the preference of aphids, the fruit yield and the quality of all the tested cultivars (figure 8) were within the normal ranges for this location (Kirschbaum *et al*., 2023; Villagra *et al*., 2021). In California strawberry production fields, aphids almost never reach damaging levels, but sporadically provoke yield losses due to honeydew contamination (Bolda *et al*., 2024) on fruit, causing the development of sooty molds and sticky fruit, which turn the fruit unmarketable as fresh fruit, wan event that was not observed in our study.

In agreement with other reports (Kirschbaum *et al*., 2023; Larson and Shaw, 2015), ´Fronteras' overtook all the other cultivars in terms of fruit yield (Kirschbaum *et al.*, 2023; Larson and Shaw, 2015). In studies conducted under a similar environment in eastern Australia, 'Fronteras' and 'Petaluma' also outperformed the other cultivars involved in that trial in terms of fruit yield and average fruit weight, respectively (Menzel, 2023).

No virus symptoms were observed in the sampled plots, which agrees with the fact that, even though aphids transmit several viruses that can cause significant economic losses in strawberries (Babovic, 1976), they are not a serious problem in annual production plantings (Bolda *et al.*, 2024) if the transplants come healthy from the nursery. However, it has been reported that asymptomatic virus-infected strawberry plants can have significant yield reductions (28 to 63%) compared to healthy plants (Torrico *et al.*, 2018).

Update of the distribution of aphid species in strawberry crops in Argentina

The strawberry crop is affected by numerous species of aphids throughout the world. Worldwide, approximately 30-35 aphid species are mentioned to use strawberry as a host plant (Blackman, 2013). The 13 aphid species registered in Argentina to date belong to seven genera; among them, four species of *Aphis*, three of *Chaetosiphon*, one of *Cryptomyzus*, one of *Macrosiphum*, two of *Myzus* and one of *Rhodobium* are mentioned (table 3). The mentioned genera are distributed in nine provinces, being Buenos Aires (11 species) and Tucumán (eight species) the provinces with more species reported, followed by Mendoza (five), Chubut and Río Negro (four), Tierra del Fuego and Salta (two), and Córdoba and Santa Fe (one). *Aphis gossypii*, *C. fragaefolii* and *M. persicae* are the most ubiquitous species, found in the northwest, northeast, and Patagonian regions, and in the horticultural belt of Buenos Aires, from as far north as the province of Salta to the southernmost record in Tierra del Fuego. Although aphid records are more abundant in the provinces of Buenos Aires (Cingolani and Greco, 2018; Cingolani *et al.*, 2015a,b; Cédola and Greco, 2010) and Tucumán (Correa *et al.*, 2012; Jaime *et al.*, 2009; Ovruski, 2002), these provinces share only six of the 13 species cited in the country.

The differences between provinces could be mainly related to the activity of research groups dedicated to the topic in each of them. That is, the provinces with the most research on the topic are those that have reported the most species of aphids and, consequently, it is expected that in the future the number of species reported will grow in all strawberry growing provinces. Aphids (without details of the species) are also mentioned as a strawberry pest in Misiones province (Auras *et al.*, 2021).

This aphid species inventory on strawberry crops in Argentina has some coincidences with inventories from neighboring countries. *Aphis forbesi, Aphis gossypii, Chaetosiphon fragaefolii, Chaetosiphon thomasi, Macrosiphum euphorbiae*, *Myzus persicae*, and *Rhodobium porosum* were reported in Chile (Kirschbaum *et al.*, 2017; Nieto Nafria *et al.*, 2016), while *Aphis forbesi*, *Aphis gossypii*, *Capitophorus elaeagani*, *Chaetosiphon fragaefolii*, *Myzus persicae*, *Tetraneura nigriabdominalis*, *Therioaphis* sp., and *Urulecon* sp. were identified in Brazil (Bernardi *et al.*, 2013; Benatto *et al.*, 2021). Although there are species whose identification is in progress, these three major South American strawberry growing neighboring countries (Kirschbaum *et al.*, 2017) have similar aphid communities on their strawberry crops.

CONCLUSIONS

The knowledge of the aphid community composition in strawberry agroecosystems of NW Argentina is of major concern because this is one of the most important strawberry exporting regions of Argentina, and aphids cause negative economic impacts on farmers. The six fully identified aphid species are *Aphis forbesi*, *Aphis gossypii*, *Chaetosiphon fragaefolii*, *Macrosiphum euphorbiae*, *Myzus persicae*, and *Rhodobium porosum.* It is important to contextualize the role of each one of these species. The most dangerous aphid, in terms of virus transmission, is *C. fragaefolii* (the strawberry aphid), a vector of the four strawberry viruses recorded in Argentina (SMYEV, SMoV, SCV and SPV1). However, being strawberries an annual crop in the studied region (and in most of the country), the risk of having negative impacts of these diseases on fruit yield and quality due to field infestations are almost neglectable. The situation would be different if strawberry plants were grown in biennial fruit production systems (southern Buenos Aires, Mendoza and Patagonia) or for transplant production (nurseries) where the risk of virus build-up in the plant from the first year to the second year in the first case, or the risk of transmitting viruses from mother to daughter plants in the second case, would be very high if aphid control strategies were weak. *Aphis forbesi* (strawberry root aphid) transmits SCV, SMoV and SPV1; *Rhodobium porosum* (yellow rose aphid) transmits SCV and SMoV; *Aphis gossypii* (melon aphid) transmits SMoV and SPV1; and *Myzus persicae* (green peach aphid) transmits SMYEV. Finally, *Macrosiphum euphorbiae* (potato aphid) is not a virus vector. This study should be extended to other farms and repeated at least one more season to enrich the knowledge on the aphid community associated with strawberry crops in this region.

On the other hand, a broad spectrum of strawberry cultivars is grown in subtropical Argentina, which is necessary to enlighten the relationship between these cultivars and the associated aphid community in terms of preference. All strawberry cultivars were infested by aphids, but not all aphid species were found in all cultivars. The preferred cultivars for most of the aphid species recorded were 'Fronteras', 'Camino Real' and 'Benicia', whose fruit yield and quality were within the expected values for this location. No symptoms of virus were observed either. Issues such as leaf morpho-histological features (trichome density, cuticle thickness, lignification around vascular bundles, and druses and other inclusions in the mesophyll cells) and a negative interaction between aphids and TSSM, alone or combined, are probably influencing aphids' preference for different cultivars. More studies are needed to understand the nature of these preferences, which will contribute to breeding strawberry genotypes tolerant to aphids.

We updated the geographical distribution of aphid species collected in strawberry crops. The 13 aphid species registered in Argentina to date belong to seven genera (*Aphis*, *Chaetosiphon*, *Cryptomyzus*, *Macrosiphum*, *Myzus*, and *Rhodobium)*. At least one species from at least one of these genera are found in at least nine strawberry growing provinces: Buenos Aires, Tucumán, Santa Fe, Mendoza, Chubut, Río Negro, Tierra del Fuego, Salta, and Córdoba. *Aphis gossypii*, *C. fragaefolii* and *M. persicae* are the most ubiquitous species, found in the northwest, northeast, and Patagonian regions, and in the horticultural belt of Buenos Aires, from as far north as the province of Salta to the southernmost record in Tierra del Fuego. Many species remain to be identified.

Climate change, modifications of the surrounding crops and spontaneous vegetation, human-driven landscape transformations and the opening of new strawberry growing areas might modify the aphid community associated with this crop in the near future, which requires continuous monitoring and research to balance all the components of the changing agroecosystem.

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