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CLINIC AND SURGERY

Fluctuation of insect vectors of *Cowpea aphid-borne mosaic virus* in yellow passion fruit orchards in the state of Paraná, Brazil

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ABSTRACT: This study identified and monitored the population fluctuations of insect vectors of *Cowpea aphid-borne mosaic virus* (CABMV) in experimental orchards in the North and Northwest Regions of the State of Paraná. The experiments were conducted in the cities of Londrina and Paranavaí at the Experimental Research Stations of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná), Brazil. The study period was from September 2019 to March 2021. In the experiments conducted in Londrina and in Paranavaí, yellow passion fruit plants were grown in trellis systems. Moericke traps were used to capture insects, and collections were performed weekly. Aphids were identified using a taxonomic identification key. The numbers of aphids present in each region were compared, and the populations were correlated with the climate and local precipitation. A total of 1522 and 1340 winged aphids were observed in the experiments in Londrina and Paranavaí, respectively. In Londrina, moderate positive correlations were observed between the number of insects and the maximum and average temperatures, while negative correlations were observed between the number of insects and the minimum temperature and precipitation. In contrast, in Paranavaí, the correlation between aphids and abiotic factors was negative, where maximum temperature was strongly correlated. In both regions, the following seven species of aphid vectors of CABMV were detected: *Aphis fabae, Aphis gossypii, Toxoptera citricida, Acyrthosiphon pisum, Brevicoryne brassicae, Macrosiphum euphorbiae* and *Uroleucon ambrosiae.* The population fluctuations of these species were influenced by variations in temperature and precipitation.
Key words: P*assiflora edulis*, fruit hardening virus, vector aphids.

Flutuação populacional de insetos vetores do *Cowpea aphid-borne mosaic virus* em pomares de maracujá amarelo no estado do Paraná, Brasil

RESUMO: O objetivo deste estudo foi identificar e monitorar as flutuações populacionais de insetos vetores do *Cowpea aphid-borne mosaic virus* (CABMV) em pomares experimentais nas Regiões Norte e Noroeste do Estado do Paraná. Os experimentos foram conduzidos nas cidades de Londrina e Paranavaí nas Estações de Pesquisa Experimental do Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná), Brasil. O período de estudo foi de setembro de 2019 a março de 2021. Nos experimentos realizados em Londrina e em Paranavaí, plantas de maracujá amarelo foram cultivadas em sistema de latada. Foram utilizadas armadilhas Moericke para captura dos insetos e as coletas foram realizadas semanalmente. Os pulgões foram identificados por meio de uma chave de identificação taxonômica. Os números de pulgões presentes em cada região foram comparados e as populações correlacionadas com o clima e a precipitação local. Foram observados 1.522 e 1.340 pulgões alados nos experimentos de Londrina e Paranavaí, respectivamente. Em Londrina, foram observadas correlações positivas moderadas entre o número de insetos e as temperaturas máxima e média, enquanto correlações negativas foram observadas entre o número de insetos e a temperatura mínima e precipitação. Em contrapartida, em Paranavaí, a correlação entre pulgões e fatores abióticos foi negativa, onde a temperatura máxima estava fortemente correlacionada. Em ambas as regiões foram detectadas as seguintes sete espécies de pulgões vetores do CABMV: *Aphis fabae, Aphis gossypii, Toxoptera citricida, Acyrthosiphon pisum, Brevicoryne brassicae, Macrosiphum euphorbiae* e *Uroleucon ambrosiae*. As flutuações populacionais dessas espécies foram influenciadas pelas variações de temperatura e precipitação.
Palavras-chave: *Passiflora edulis*, vírus do endurecimento dos frutos, afídeos vetores.

INTRODUCTION

The Passifloraceae family has great genetic variability, comprising 18 genera and 630 species. The genus *Passiflora* is the most economically important genus, comprising 465 species (VANDERPLANK, 1996), of which approximately 120 are native to Brazil. Despite this diversity, yellow or sour passion fruit is the main species grown in Brazilian orchards (MELETTI & BRÜCKNER, 2001).

Brazil is the world's largest producer of passion fruit; it has produced an average of 740 thousand tons in the last 10 years. The northeast and southeast regions are the main producers of this fruit in the country. In the northeast region, the states of Bahia and Ceará are the main producers, accounting for 71.2% and 12.2% of the total passion fruit production, respectively (EMBRAPA, 2022).

In the state of Paraná, passion fruit culture is also of significant importance, as passion fruit is

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cultivated in several regions. In 2021, approximately 1,391 hectares of planted area were harvested, with an average productivity of 14.27 tons per hectare. Paraná ranked eighth nationally in fruit production (EMBRAPA, 2022).

As these crops have expanded, phytosanitary problems, which can seriously damage crops and impact their economic viability, and diseases have become more common (CARVALHO et al., 2015; MACHADO et al., 2017). Passion fruit can be attacked by several phytopathogenic agents, such as viruses, which have a large economic impact on the crop, and the fruit hardening virus (NASCIMENTO et al., 2006; PERUCH et al., 2018) caused by *Cowpea aphid-borne mosaic virus* (CABMV), which belongs to the genus Potyvirus and family Potyviridae (TAYLOR & GREBER, 1973).

The transmission of CABMV may occur during some cultural practices, such as grafting and pruning (ZERBINI-JÚNIOR & MACIEL-ZAMBOLIM, 1999). In natural conditions, transmission occurs through aphids in a non-persistent; the insect does not need to feed on the plant. For infection to occur, the insect must bite a diseased plant, acquire the virus, and later transmit it to other healthy plants (YUKI et al., 2006).

Although, there are no colonizing Passiflora species, many aphid species have been noted to transmit CABMV (GARCÊZ et al., 2015); these include *Myzus persicae*, *Myzus nicotianae* Blackman, *Aphis gossypii* Glover, *Aphis fabae* Scopoli, *Aphis solanella* Patch, *Aphis craccivora* Bock, *Toxoptera citricida* Kirkaldy, *Uroleucon ambrosiae* Thomas (COSTA et al., 1998; GARCÊZ et al., 2015), *Rhopalosiphum maidis* Fitch, *Acyrthosiphon pisum* Harris, *Macrosiphum euphorbiae* Thomas (KILALO et al., 2012), *Brevicorine brassicae* Linnaeus and *Sitobion avenae* Fabricius (KILALO et al., 2013; MORITZ, 2020).

The incidence of the disease in passion fruit varies according to the time of implantation in the orchard and can reach 100%. CAVICHIOLI et al. (2011), studying the incidence and severity of the disease in passion fruit plants grafted onto non leaf plants, reported a virus incidence of 52.5% in plants grafted on *P. alata*, 51.25% on *P. edulis*, and 45.6% on *P. gibertii* and a virus incidence of 45% in non leaf plants from 90 to 120 days after planting; furthermore, 180 days after field planting, 100% of both the non leaf plants and those grafted onto *P. alata* were infected with CABMV.

The symptoms of the disease are characterized by the presence of mosaic patterns on the leaves, which may be accompanied by blistering and deformation. In fruits, deformation can also occur. In addition, due to the reduction in fruit size and thickening of the pericarp, pulp content decreases. These factors, together with the decrease in the production cycle of the plants, result in reduced passion fruit production and; consequently, in commercial losses, as highlighted by GIORIA et al. (2000) and REZENDE (2006).

The disease in production areas has not been efficiently controlled due to its transmission via aphid bites; insecticide application cannot prevent the spread of CABMV (REZENDE, 2006) because it does not have sufficient time to act before the insects transmit the virus to the plant (COSTA, 1998); furthermore, insecticide use may even increase transmission by increasing the vector activity of the insect (FERERES & MORENO, 2011).

In this context, the eradication of symptomatic plants and alternative hosts from orchards is recommended to decrease the source of disease inoculum and the use of materials resistant to the virus. According to a study conducted by SAMPAIO et al. (2017), three passion fruit genotypes (BGP152 and BRS Pérola do Cerrado) are resistant to CABMV. These genotypes belong to the wild species *P. suberosa, P. setacea* and *P. cincinnata.*

In addition, in recent years, sanitary vacuums have been adopted as a disease management strategy to decrease the concentration of aphids in the area and decrease the inoculum source (STENZEL et al., 2019). Therefore, it is recommended that the "sanitary vacuum" period for passion fruit cultivation lasts at least 20 days. For the state of Paraná, this interval should start in July and continue until mid-August and be followed by the complete removal of the orchard and invasive plants that may serve as alternative hosts of the virus. Notably, this practice has gained increasing acceptance from producers in Paraná, contributing to the production of the crop

Considering that the virus responsible for fruit hardening can be transmitted by several species of aphids, studies that provide surveys of the possible insect vectors of CABMV present in each region are highly important for understanding the behaviour of the disease in cultivated regions. Thus the present study identified and follow the population fluctuations of CABMV vector insects in experimental orchards in the North and Northwest Regions of the state of Paraná.

MATERIALS AND METHODS

Location, implementation and conduct of experiments

The survey of aphid vectors of *Cowpea aphid-borne mosaic virus* CABMV in yellow passion fruit plants (*Passiflora edulis*) was conducted in two experimental orchards of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) located in the municipality of Londrina (North Region - N) (Latitude 23°21'44"S and Longitude 51°10'06" W) and in Paranavaí (Northwest Region - NW) (Latitude: 23° 4' 26" S and Longitude: 52° 27' 55" W), Brazil. The experiment was conducted from September 2019 to March 2021, and two production cycles (2019/2020 and 2020/2021) were evaluated.

Passion fruit seedlings were obtained from the seeds of yellow passion fruit hybrids in a nursery protected with an anti-aphid screen. Germination occurred in plastic trays containing Flores MecPlant® commercial substrate (pine bark, acidity corrector, fertilizers and vermiculite). After 30 days, the seedlings were transplanted to plastic bags with substrate for development in a protected environment at the IDR-Paraná experimental station in Londrina. On 08/27/2019, when the plants reached 1.50 m in height, they were transplanted into the field.

In Londrina, the experiment was implemented with 28 plants in each row, totalling 280 plants of the commercial varieties Catarina and Seleção Morretes. The plants were planted in the field under the trellis system, with wires at a height of up to 1.90 m and a spacing of 3.0 m between the rows and 2.0 m between the plants in the planting rows.

In Paranavaí, the passion fruit seedlings were transplanted on 09/03/2019, following the same production system as in Londrina. The orchard consisted of 84 plants of the Catarina variety distributed in 6 rows.

Sampling of vector insects

MOERICKE (1954) traps placed on the soil surface were used to capture CABMV vector insects in the experimental areas. The traps were made with plastic trays measuring 37.0 cm × 26.5 cm × 6.5 cm, with a reflective surface of 980.5 cm^2. Each interior was painted with yellow paint and filled with 3 L of a solution composed of water, detergent (5%) and bleach (3%). To avoid the loss of samples due to rain-induced water overflow, two 8-mm holes covered by fine-meshed nylon mesh were drilled on the smaller and opposite sides of the traps. Seven traps were installed at the IDR-Paraná experimental station in Londrina, and six traps were installed in Paranavaí; these traps were distributed in the central and peripheral areas of the orchard to capture insects.

Samples were collected three times a week in both experimental areas by transferring the contents of the trays to 50 mL Falcon tubes. The volume was then adjusted with a 70% alcohol solution. The content collected in the traps was sent to the Laboratory of Virology of the IDR-Paraná in Londrina for insect identification. To avoid the loss of captured insects in the traps due to a lack of solution, the water was replaced between collections.

Insect population survey collection

In both experiments, the traps were set immediately after transplanting the seedlings to the field. The evaluations began on September 11, 2019, and the last collection was on March 31, 2021. From the collected material, the insects were separated and identified with the aid of the classification key "*Identification of aphids of agricultural importance*" (PENÃ-MARTÍNEZ, 1992) and a specific bibliography, according to their respective families, genera or species. For better identification, some aphids collected were sent to a specialist, Dr. Alexandre Levi Rodrigues Chaves of the Biological Institute of São Paulo.

The number of species collected was recorded in spreadsheets for an evaluation and analysis of population fluctuations according to collection points and dates. As the traps are not selective or specific for aphids, several types of insects were collected, and triage was performed to separate the aphids from the other collected insects.

Abiotic factors

The data regarding the maximum, average and minimum temperatures and rainfall during the monitored months of September 2019 to March 2021 were obtained from the records of the meteorological station at the IDR Paraná in Londrina, which is located approximately 1,000 metres from the experimental area.

For the temperature data, the average, maximum and minimum daily temperatures were analysed. To obtain the monthly average, the daily averages throughout the month were summed and then divided by the total number of days in the month the monthly average. For precipitation, the sum of the average rainfall in each month (mm) was calculated.

The meteorological data are available in the IAPAR CLIMA application for Android: Agrometeorologia e Clima Instituto de Desenvolvimento Rural do Paraná (idrparana.pr.gov.br).

Analysis of the data

Insect population fluctuation data were subjected to normality distribution and used for plotting graphs. The precipitation and temperature graphs were constructed using the package Office Microsoft Excel (2007).

Pearson's correlation, based on the formula described below, was used to evaluate the data on the presence of aphids, temperature and rainfall collected in each municipality. The classification of correlations is presented in table 1.

$$r_{xy} = \frac{\sigma_{xy}}{\sqrt{\sigma_x^2 x \sigma_y^r}}$$

where:

σ_{xy}: estimator of the variance between the variables x and y;

σ_x^2: estimator of the variance of the variable x;

σ_y^2: estimator of the variance of the variable y.

RESULTS AND DISCUSSION

The process of screening and identification of insects was performed for 18 months; 1,522 winged aphids were collected from the orchard of the IDR-Paraná de Londrina experimental station, and 1,340 aphids were collected from the IDR-Paraná de Paranavaí; the collected species are listed in table 2.

Considering only the species that are vectors of CABMV, the aphids collected in the Londrina orchard were *Aphis fabae*, *Aphis gossypii*, *Uroleucon ambrosiae*, *Toxoptera citricida*, *Macrosiphum euphorbiae, Brevicoryne brassicae* and *Acyrthosiphon pisum,* representing 9, 7.4, 2, 2.5, 1, 0.7 and 0.5% of the total aphids collected, respectively. The largest number of non vector insects collected was represented by the species *Lipaphis erysimi*, accounting for 42% of the total collection. For species of aphids that were collected in small numbers, the total numbers were grouped together and called accessory species; these included *Tetraneura nigriabdominalis*, *Toxoptera aurantii*, *Brachycaudus helichrysi*, *Pemphiginae* spp., *Rhopalosiphum* spp. and *Neotoxoptera formosana*, totalling just under 2%. The percentage of unidentified aphid specimens in this orchard was 11.6% (Table 2; Figure 1).

Table 1 - Classification of correlation coefficients.

Correlation coefficient'			----------Correlation----------
	r	= 1	Perfect positive (Pp)
0.8 ≤	r	< 1	Strong positive (Sp)
0.5 ≤	r	< 0.8	Positive moderate (Pm)
0.1 ≤	r	< 0.5	Weak positive (Wp)
0 <	r	< 0.1	Intima positive (Pi)
	0		Null (N)
-0.1 <	r	< 0	Negative infimum (Ni)
-0.5 <	r	≤ -0.1	Weak negative (Wn)
-0.8 <	r	≤ -0.5	Moderate negative (Mn)
-1 <	r	≤ -0.8	Strong negative (Sn)

Source: FIGUEREDO FILHO & SILVA JUNIOR (2009).

In the Paranavaí orchard, the CABMV vector species identified were *Aphis fabae, Aphis gossypii, Toxoptera citricida, Acyrthosiphon pisum, Uroleucon ambrosiae, Macrosiphum euphorbiae* and *Brevicoryne brassicae,* representing 22.9, 20.9, 4.6, 1.7, 0.9, 0.6 and 0.4% of the total aphids collected, respectively. The accessory species comprised 1.4% of the total number of insects and were represented by *N. formosana* and *T. aurantii*. As observed in the Londrina orchard, *L. erysimi* was the non vector species of CABMV observed in greater quantities, comprising 11.6% of the total aphids collected. Finally, unidentified species comprised 2% of the total number of insects (Table 2).

In both regions, vector individuals were collected, especially those of the genus *Aphis*, which presented a greater number of individuals than the other genera. The predominance of aphids of the genus *Aphis* was also observed by SANTOS (2020) in studies conducted in the same region of Londrina. Moreover, SANTOS (2020) reported that the genus cited contributed approximately 91% of the total specimens collected, with a frequency above 80% in all monitored months (October 2018 to June 2019). According to DI PIERO et al. (2006), the genus *Aphis* plays a crucial role in the spread of CABMV and is described as a vector of the virus. In addition, this genus contains species that efficiently transmit CABMV, with transmission rates ranging from 75% to 100%.

The results obtained in the present study also corroborated those of RODRIGUES (2013), who observed the polyphagous nature of the insect, which explains its year-round presence and greater occurrence among the total number of insects collected. Tolerance to extreme temperatures, which range from 4 °C to 30 °C, and high fecundity also explain the large quantities of this genus captured in orchards (SAMPAIO et al., 2005).

In general, the divergence and diversity of species captured between regions and the amount of each genus may be related to the diversity of botanical species present in each region and to climatic conditions (DIXON & KINDLMANN, 1990). The crops around the orchard can influence the presence and permanence of certain species in the field. In the surroundings of the experimental area, the following crops were observed: bean (*Phaseolus vulgaris* L.), pitaya (*Hylocereus undatus*), acerola (*Malpighia punicifolia* L.), citrus (*Citrus* spp.), avocado (*Persea*

Table 2 - Total number of winged aphids collected from September 2019 to March 2021 in the experimental area at the Research Stations of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Londrina and Paranavaí, Paraná, Brazil.

SPECIES	-----------------Londrina species---------------		---------------Paranavaí species----------------	
	Quantity	%	Quantity	%
Aphis nasturtii	122	8%	203	15%
Aphis nerii	185	12%	115	8.5%
Aphis fabae	137	9%	307	22.9%
Aphis spiraecola	25	1.6%	42	3%
Aphis gossypii	114	7.4%	280	20.9%
Toxoptera citricida	38	2.5%	62	4.63%
Toxoptera aurantii	2	0.1%	9	0.6%
Tetraneura nigriabdominalis	4	0.3%	40	2.9%
Lipaphis erysimi	629	41.3%	156	11.6%
Acyrthosiphon pisum	8	0.5%	23	1.7%
Brachycaudus helichrysi	2	0.1%	1	0.07%
Neotoxoptera formosana	2	0.1%	11	0.8%
Pemphiginae spp.	8	0.5%	17	1.2%
Brevicoryne brassicae	12	0.7%	5	0.4%
Macrosiphum euphorbiae	16	1%	8	0.6%
Rhopalosiphum spp.	10	0.6%	20	1.4%
Uroleucon ambrosiae	31	2%	12	0.9%
**Unidentified	166	11.6%	29	2%
TOTAL	1.522	≅ 100%	1.340	≅ 100%

**Unidentified: Insects that could not be identified due to degradation or absence of body parts.

americana Mill), and cotton (*Gossypium hirsutum L.),* sugarcane (*Saccharum officinarum* L.), starfruit (*Averrhoa carambola* L.), coffee (*Coffea arabica* L.), banana (*Musa* spp. L.) and *Crotalaria* spp. The data observed in the present study related to the species *A. spiraecola,* which represented 1.6 and 3% of the total insects captured in Londrina and Paranavaí, respectively, and *T. citricida*, which represented 2.5 and 4.6% of the total insects captured in Londrina and Paranavaí, respectively. Insects collected in Londrina and Paranavaí (Table 2) corroborated those presented by PRIMIANO (2005), who reported that such species can be found more frequently in citrus orchards. Interestingly, citrus plants were present near the sites where the experiments in the present study were conducted.

This diversity of species found in the regions may be related to the feeding habits of the aphids. According to POWELL & HARDIE (2001), some species collected have a polyphagous habit, which means that they can adapt to different host plants in a facultative or obligatory manner. These polyphagous species tend to have a wide spatial and temporal distribution, depending on the availability of host plants (LAZZARI & LAZZAROTTO, 2005). This may explain the abundance of certain aphid species throughout the year, with seasonal variations in density (CERMELI, 1970). According to PIRONE & PERRY (2002), the aphids that are efficient in the transmission of viruses are those that perform test bites and have polyphagous habits. These factors play important roles in the development of the epidemiology of viral diseases.

Although, the species *U. ambrosiae* and *T. citricida* were found to have low population indices, they still showed a considerable frequency. Similar results were observed by RODRIGUES (2013), who reported low rates for the species *U. ambrosiae* during the autumn and spring and for *T. citricida* during the winter and spring. Despite its low presence in passion fruit orchards, experimental studies conducted by COSTA (1998) showed that these species are highly efficient in transmitting CABMV, with rates of 50% and 37.5%, respectively.

Notably, the large number of aphids of the species *L. erysimi* observed in this study may indicate that this species has adapted better than others to the region; in a previous study conducted by AQUINO & MOLINA (2020) in the city of Londrina-PR, it was also observed in abundance.

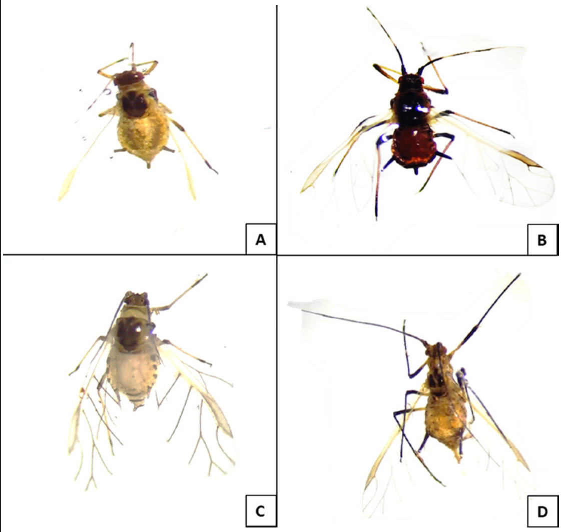

Figure 1 - Main aphid species collected in the passion fruit experimental field of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Londrina, Paraná, Brazil. A: *Aphis* spp.; B: *Toxoptera citricida;* C: *Lipaphis erysimi;* D: *Uroleucon ambrosiae.*

Studies conducted by CIVIDANES & SANTOS-CIVIDANES (2012) in the Jaboticabal region showed that the population of *L. erysimi* is constant in orchards, even in rainy seasons. This factor was also observed by RAMOS et al. (2018), who reported a population increase in this species during wetter periods. This predominance in orchards with relatively high humidity, according to CIVIDADES & SANTOS-CIVIDANES (2010), may be related to the flight dynamics of the insect.

According to data on the population fluctuations of insects collected between 2019 and 2021 in Londrina, the largest population of aphids was recorded in September and October 2019. In January and September 2020 and February 2021, higher numbers of insects were also captured (Figure 2). These data corroborate those presented by LAZZARI & LAZZAROTO (2005) in the Serra do Mar region in the state of Paraná, who reported a peak in the population of the aphid species in September for most of the studied locations.

Conversely, the lowest insect incidences in Londrina were in November and December 2019 and May, November and December 2020 (Figure 2). However, the COVID-19 pandemic hindered insect collection in March, April, June and July 2020; this difficulty may have been reflected in the number of insects collected.

In the Londrina region, an analysis of the rainfall distributions during the evaluation periods from September to November 2019 indicated an average of 90 mm. The month with the highest rainfall was December 2019, at 272.2 mm. The highest temperatures in the evaluation months were from September to November 2019, and the lowest average temperatures were recorded in June and July 2020 (Figure 3).

These abiotic factors may influence the number of insects collected because, according to HULL (2002), abiotic factors such as rainfall and temperature can directly affect the population dynamics of certain insect species. In addition, the phenology of the plants, together with the temperature and moderate rainfall, also favours the development of insect populations.

In the region of Paranavaí, the highest number of captured aphids occurred between January and September 2020. For vector species, January 2020 had the highest incidence. A slight increase was also noticeable in January 2021 (Figure 4). In this region, in January 2020, the average temperature was 24.5 °C, and the average rainfall was 104.4 mm (Figure 5). Although, the rainfall index in the region was high during this period, large numbers of collected aphids were recorded.

For the data from the Paranavaí field, the highest rainfall distributions were recorded in December 2019 at 224.2 mm and in January 2021 at 275 mm. The lowest average temperatures were recorded in June and July 2020, and the highest temperatures were recorded in January and March 2021 (Figure 6).

Precipitation and temperature are abiotic factors that strongly influenced the presence of insects in the orchards in this study; a distinct predominance between the number of individuals and genera collected at each study site was observed. CONTI et al. (2010) reported that species tend to have a greater ability to reproduce under well-defined temperatures, and with increasing temperature, individual fertility decreases.

In this context, temperature and precipitation data were correlated with the total number of species captured in the two regions. In Londrina, the number of species captured was moderately positively correlated with the maximum and average temperatures (Figure 7). These data are justified by the high monthly temperature values for the months of September, October and November 2019, as well as the high number of insects captured in the orchard during these months (Figures 2 and 3). For the minimum temperature, the correlation with the number of captured insects was negative, as was the correlation between insects and precipitation (Figure 6).

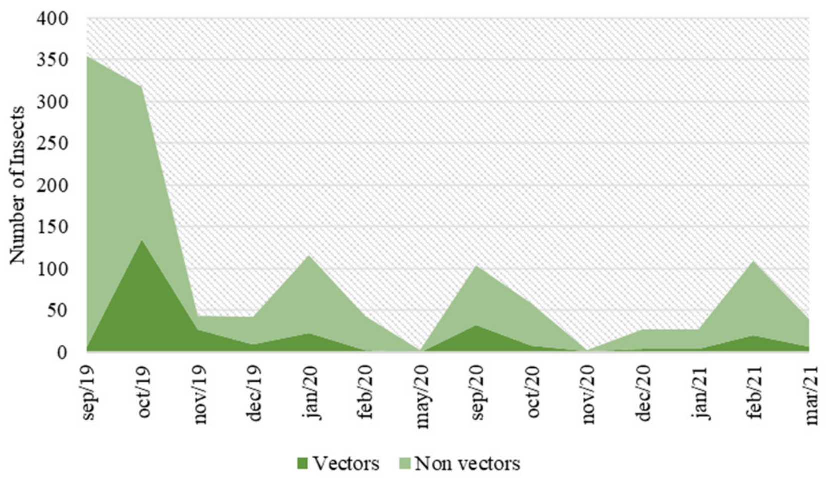

Figure 2 - Insect vectors and non vectors of *Cowpea aphid-borne mosaic virus* (CABMV) were captured in an experimental orchard at the Research Station of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Londrina, Paraná, Brazil, from September 2019 to March 2021.

In Paranavaí, the correlations between temperature and aphids and between precipitation and aphids were negative (Figure 7), which can be explained by the fact that the number of insects captured in the experimental area was low when precipitation remained high in December 2019 and January 2021 in Paranavaí. (Figure 4 and 5).

The correlation data regarding abiotic factors and aphid population in this study corroborate those observed by SANTOS (2020), who reported that only precipitation had a negative effect (r = -0.1261) on the population dynamics of aphids. However, temperature was not a limiting factor and was characterized as moderately positive (r = 0.5061).

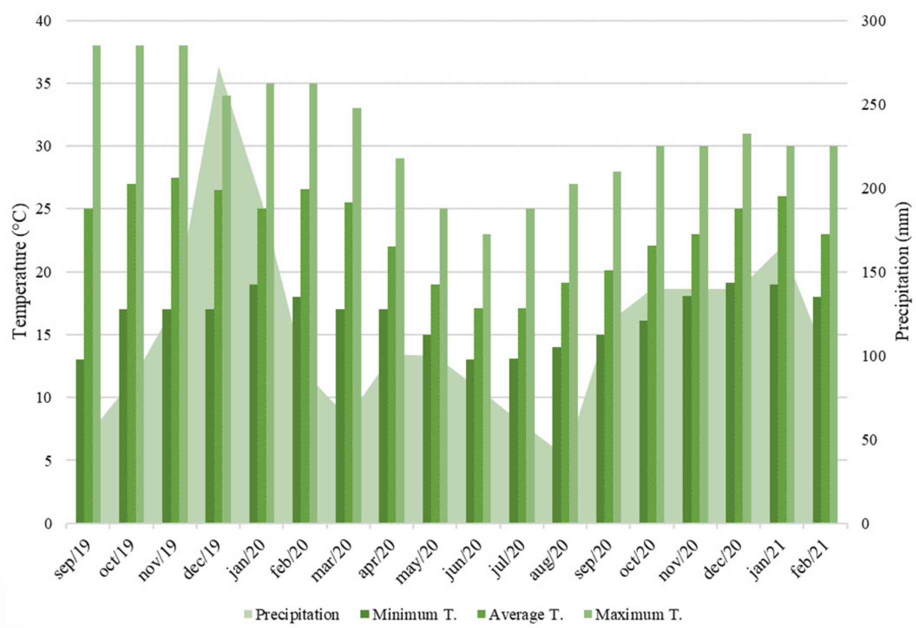

Figure 3 - Climatic data recorded in Londrina, Paraná, Brazil, during the experimental period, from September 2019 to February 2021.

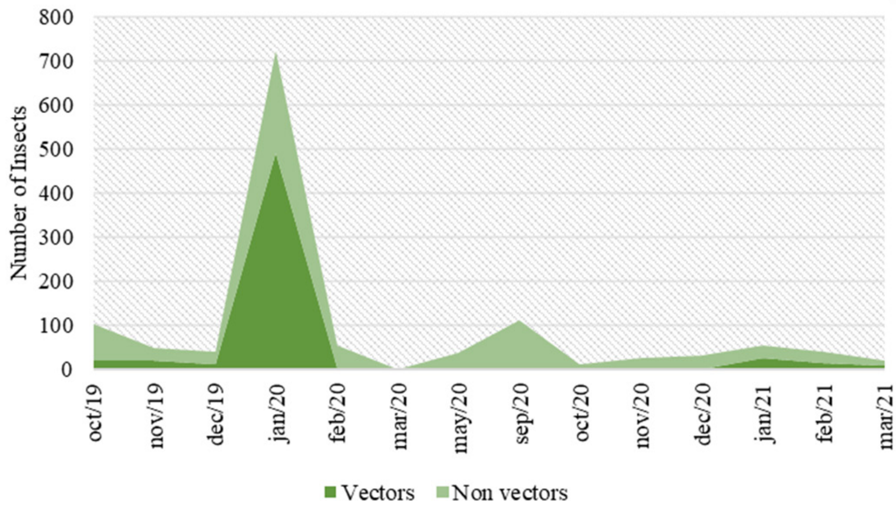

Figure 4 - Insect vectors and non vectors of *Cowpea aphid-borne mosaic virus* (CABMV) captured in an experimental orchard in the Research Station of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Paranavaí, Paraná, Brazil, period from September 2019 to March 2021.

This relationship between insects and temperature was also observed by RAMOS et al. (2018), who studied the density of aphids on cabbage, sorghum and pigeon pea; the aphid species they identified had a negative and significant correlation with minimum temperature and a positive and significant correlation with maximum temperature. According to the authors, such meteorological factors are important variables because they directly influence the occurrence of aphids in the area.

Passion fruit is a tropical climate plant and thus grows very well in hot and humid regions; therefore, the main climatic elements that positively or negatively affect the development of the plant are temperature, precipitation, relative humidity and

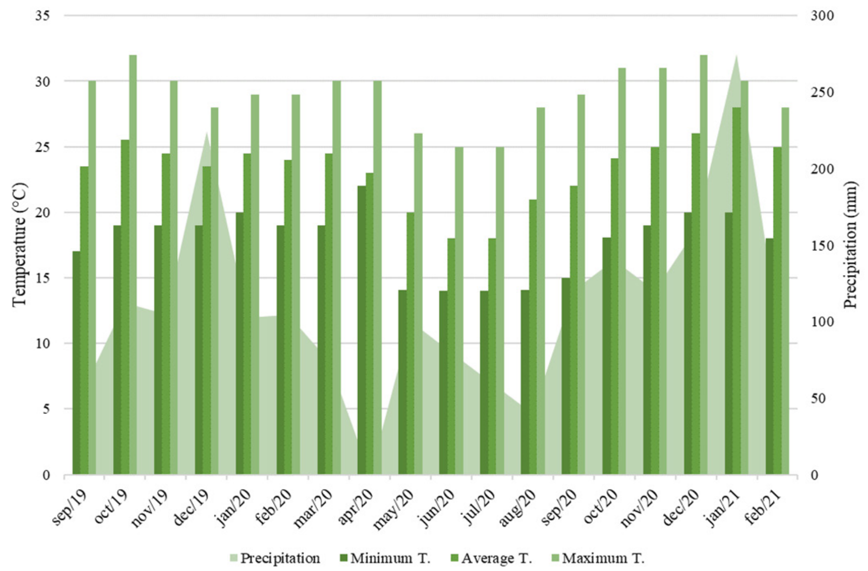

Figure 5 - Climatic data recorded in Paranavaí, Paraná, Brazil, during the experimental period, from September 2019 to February 2021.

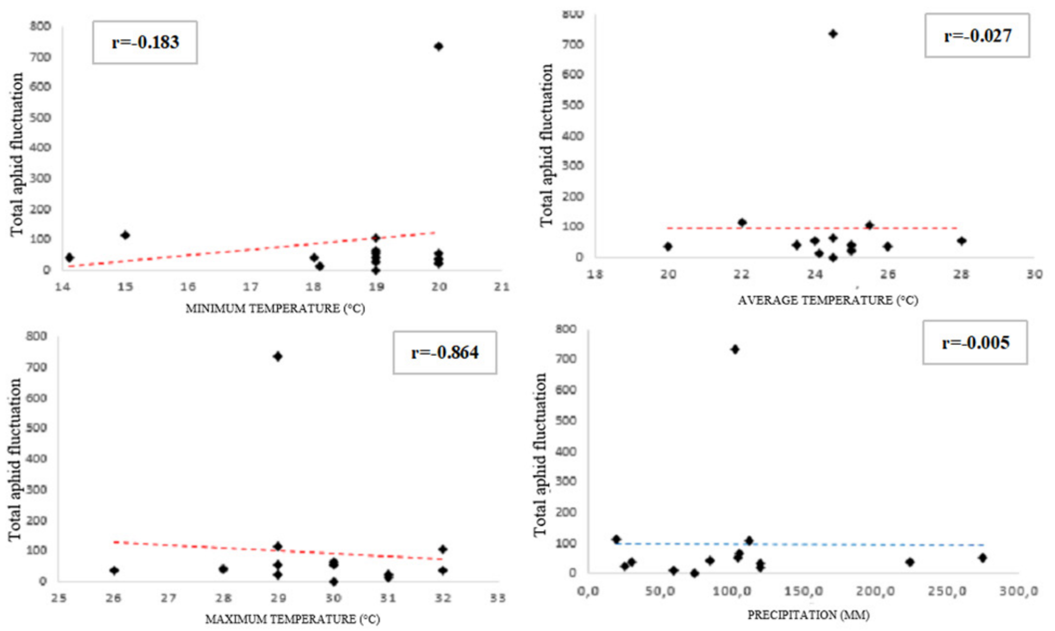

Figure 6 - Correlation of the total number of insects collected from the Research Station of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Paranavaí, Paraná, Brazil, with temperature and precipitation.

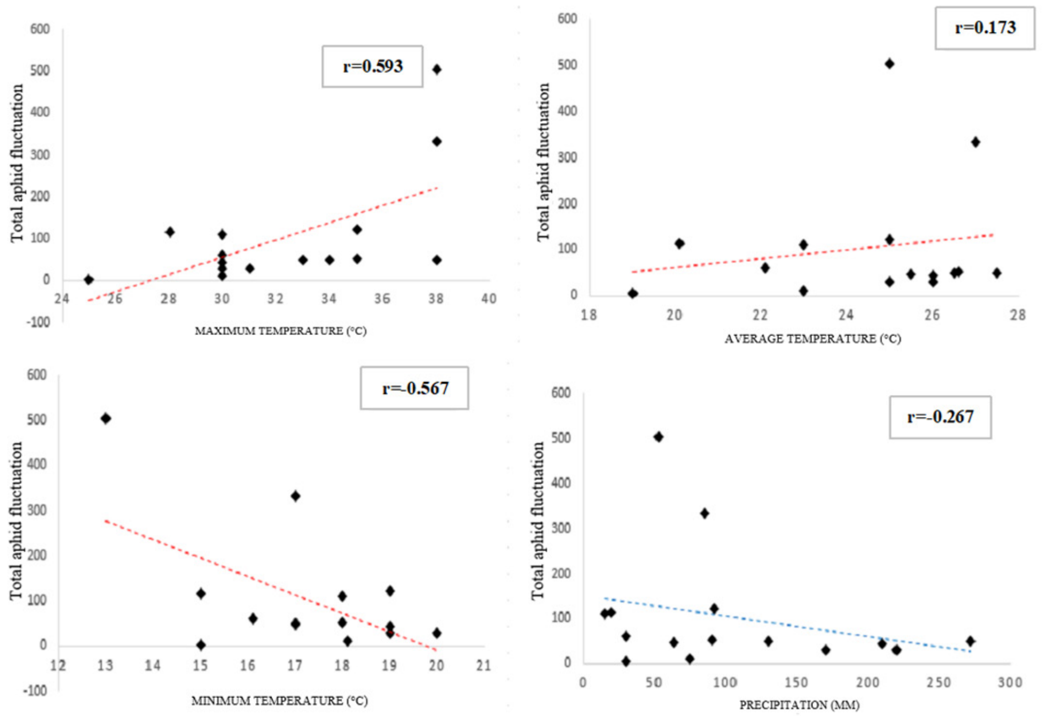

Figure 7 - Correlation of the total number of insects collected at the Research Station of the Instituto de Desenvolvimento Rural do Paraná-IAPAR-EMATER (IDR-Paraná) in Londrina, Paraná, Brazil, with temperature and precipitation.

luminosity. While these factors can directly influence plant development, longevity and health, they can also promote the occurrence of diseases and pests, which cause damage to crops (CUNHA et al., 2004).

This high occurrence of *Aphis* may be related to the fact that some aphid species are well adapted to the environment in which they are found, such as *A. gossypii*, which is tolerant to temperatures of 4 to 30 °C (SOGLIA et al., 2002). Thus, efforts to control these species are very important. However, CABMV non-persistently aphid-transmitted viruses compromising the efficiency of chemical vector control; consequently, this measure is basically ineffective since most insecticides cannot act quickly enough to eliminate aphids before they perform the test bite and thus introduce the virus into the plant (FAJARDO & NICKEL, 2019).

In this context, to control the disease, all factors that may favour increases in its incidence in the area should be considered, such as adopting control measures based on the history of the cultivation area, since once present in the orchard, CABMV develops rapidly (BATISTA et al., 2022).

Among the management practices that can eliminate CABMV inoculum sources; and consequently, reduce the rate of disease progression, eliminating abandoned or old orchards before new seedlings are transplanted is recommended. When planting in isolated locations with the use of windbreaks, attention should be given to the use of healthy plants produced in environments protected from aphids; thinning and pruning operations; sanitary vacuuming; the complete eradication of symptomatic plants (roguing) and the elimination of potential CABMV host plants present around the orchard (SAMPAIO et al., 2008; STENZEL et al., 2019; KOTSUBO et al., 2021; BATISTA et al., 2022).

Alternative control measures have also been investigated and show promise in controlling insect vectors. MORITZ et al. (2022) confirmed that doses of up to 1.0% vegetable oil reduced the acquisition and transmission of CABMV via *A. gossypii* in passion fruit seedlings by 98.67% and 60%, respectively.

There is still little information about the resistance of yellow passion fruit plants to the CABMV virus, and there is currently no effective chemical control of the vectors; thus, studies that provide information and support for cultivation practices that can reduce the losses caused by this disease are much needed (PERUCH et al., 2018).

CONCLUSION

In the regions of Londrina and Paranavaí, the presence of seven species of aphid vectors of CABMV were observed: *Aphis fabae*, *Aphis gossypii*, *Toxoptera citricida*, *Acyrthosiphon pisum*, *Brevicoryne brassicae*, *Macrosiphum euphorbiae* and *Uroleucon ambrosiae*. *Aphis* species were the most abundant in both studied regions, and their population fluctuations were influenced by temperature and precipitation.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed to the conception and design of the study. Material preparation, maintenance and field collection were carried out by JVCF, KSS, LTA, RYK and CCS. Screening, aphid identification, and data analysis were conducted by JVCF and KSS. The first draft of the manuscript was written by KSS and CCS and all other authors reviewed and commented on versions of the manuscript. All authors read and approved the final manuscript.

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