Colegio de Postgraduados

Aphid diversity and population fluctuation of vector species of the ringspot virus in papaya (*Carica papaya* L.)

Pozo-Santiago, César O.[1]; Peña-Martínez, Rebeca[2]: Ríos-Rodas, Liliana[1]; Martínez-Valdés, Martin G.[1]; Ramos-Hernández, Eder[3]; Gerónimo-Torres, José del C.[1*]

[1] Universidad Autónoma de Chiapas-Facultad Maya de Estudios Agropecuarios, Carretera Catazajá-Palenque Km. 4, Catazajá, Chiapas, México, C.P. 29980.
[2] Instituto Politécnico Nacional-Escuela Nacional de Ciencias Biológicas, Prolongación Carpio y Plan de Ayala, Colonia Santo Tomás, Ciudad de México, C.P. 11340.
[3] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias-Campo Experimental Huimanguillo, Km 1 carretera Huimanguillo-Cárdenas, Huimanguillo, Tabasco, México, C.P. 86400.
* Correspondence: jc.geronimo89@hotmail.com

ABSTRACT

Objective: To examine the diversity of winged aphids in papaya (*Carica papaya* L.) crops and to determine the population fluctuation of vector species of the papaya ringspot virus (PRSV).

Design/Methodology/Approach: We captured winged aphids by placing eight Moericke-type water traps (four green and four yellow). We conducted weekly samplings to locate plants with ringspot symptoms, record the abundance of vector species of PRSV, and document the progress of the disease.

Results: We collected a total of n=694 individuals of 20 species, seven of which fell in the green traps and 19 in the yellow traps. The green traps registered the highest diversity value; however, the yellow traps captured the largest richness. Six of the captured aphids are reported as PRSV transmitters. The analysis of the population fluctuation of the vector species determined that *A. spiraecola* recorded two population peaks during the study: the first at week three, with 93 captured individuals; and the second (and highest) at week ten, with 316 individuals. PRSV was observed in the week seven in nine diseased plants. Full contagion (100%) was reached by week 44.

Study Limitations/Implications: Developing strategies for preventing and controlling pest species and disease vectors crucially depends on the correct choice of methods to capture and monitor insect populations in crops.

Findings/Conclusions: We can infer that vector species conduct short-distance migrations within the plantation. This inference is supported by the increased number of diseased plants.

Keywords: Aphids, crop, disease, insects, virus.

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INTRODUCTION

In Mexico, 20,750 ha are currently used to grow papaya (*Carica papaya* L.), yielding 249,913 tons. The Mexican state of Tabasco holds only 217 ha, in which 3,546 tons are produced. This crop provides a significant income for small producers in the local market. However, papaya plantations are vulnerable to pests and diseases that can considerably reduce their production.

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Aphids or plant lice are small-sized insects that measure 2 mm on average. They belong to the order Hemiptera and the infraorder Aphidomorpha (Peña-Martínez *et al.*, 2019). They have a wide geographical distribution, but their diversity is greater in the temperate zone of the northern hemisphere (Trejo-Loyo *et al.*, 2004). Around 4,700 aphid species have been described in the world (Remaudière and Remaudière, 1997; Peña-Martínez *et al.*, 2019). Two-hundred two of those species are distributed in Mexico (Peña-Martínez, 1992b), 53 of which are relevant for agriculture (Peña-Martínez, 1999). Aphids play a major role in the transmission of phytopathogenic viruses (Katis *et al.*, 2007) and some of them are vector species of the papaya ringspot virus. The papaya ringspot virus (PRSV) is considered the main hindrance for the production of this crop (Cabrera-Mederos *et al.*, 2010). It prevents plant growth and considerably reduces the size and quality of the fruit (Yeh *et al.*, 2007), consequently limiting the production of large cultivation areas to only one harvest (Gonsalves, 1998). Therefore, we captured winged aphids with green and yellow Moericke-type traps and analyzed their diversity, in order to determine the population fluctuation of vector species of the ringspot virus.

MATERIALS AND METHODS

The study was conducted from February 1 to November 30 in one hectare of a Maradol papaya cultivation field at Ranchería Macayo, 1st Section, municipality of Huimanguillo, Tabasco, Mexico (INEGI, 2017). The study began when the plants were two months old. A 1.2-m and 2-m distance was established between plants and rows, respectively. Most of the surface of Huimanguillo (95.26%) belongs to the southern Gulf Coastal Plain physiographic region and only 4.74% is found in the Northern Sierras of Chiapas. The municipality has an altitude range from 0 to 1,100 m (INEGI, 2017; Palma-López *et al.*, 2011). It encompasses two climate types: warm-humid with abundant rains in summer (Am) and warm-humid with rain throughout the year (Af). The average annual temperature is 26.2 °C, with a rainfall average of 2,000 to 3,500 mm. The vegetation ranges from jungles, tule, and savanna, to *popal* (coastal vegetation dominated by fire flag) and mangroves (INEGI, 2017). Agriculture is the main use of 43.3% of the total surface of the municipality. The predominant crops include corn, pineapple, citrus, and eucalyptus (Palma-López *et al.*, 2011).

Insect collection

Eight Moericke-type water traps (García and Cabrera, 2012) were placed on the edges of the plantation. Four of them were green and the other four were yellow. This type of trap consists of a 32-cm wide and 7-cm deep round plastic trays that hold water with detergent and sodium hypochlorite to preserve it. Small holes were made on the sides of the tray to drain excess rainwater (Peña-Martínez, 1992a). The traps were placed horizontally on a stand, at a variable height according to the development of the crop. Biological material was collected on a weekly basis and stored in ethyl alcohol (70%) for subsequent taxonomic determination.

PRSV incidence

Direct search samplings were conducted every week to identify which plants presented ringspot symptoms. Infected plants were labeled with consecutive numbers to register them in a database. The presence of the virus was confirmed using samples taken from the petiole of plants with suspected infection. The samples were analyzed using serological tests at the Colegio de Postgraduados in Montecillo, State of Mexico.

Taxonomic determination

Holman's (1974) and Peña-Martínez's (1992) taxonomic keys were used to identify the specimens. Our findings were corroborated by the group's specialist, Rebeca Peña Martínez (MSc), at the Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional.

Data analysis

Species accumulation curves were determined using the Chao1 nonparametric estimator (Moreno, 2001) in order to obtain the sampling efficiency for each trap color. Subsequently, the true diversity index, order 1(^{1}D) was calculated using the EstimateS 9.1.0 software. This procedure allowed us to compare the diversity of aphids captured with the green and yellow traps. The similarities between species caught in traps of both colors were analyzed using the Sorensen index (Magurran, 1989; Moreno, 2001). Finally, the population fluctuation of the most abundant PRSV vector species was examined and the a graph of the progress of the disease was developed.

RESULTS AND DISCUSSION

Only 18 out of 44 samplings recorded a 40% presence of aphids. Using the Chao1 richness estimator, sampling completeness was estimated at 93.46% for green traps and 85.09% for yellow traps (Figure 1). Although completeness was higher for green traps, these failed to capture the highest species richness. The opposite occurred with yellow traps, where five species were represented by a single individual, resulting in a lower completeness value.

We collected a total of 694 individuals that belonged to 20 species from 12 genera. Seven species from 3 genera were captured with green traps and 19 species from 11 genera with yellow traps (Table 1). Cortez-Madrigal and Mora-Aguilera (2008) reported similar species richness in papaya plantations in Cárdenas, Tabasco, while Magaña-López *et al.* (2020) recorded greater richness (17 species) in Cuernavaca, Morelos.

Of the aphid richness caught with green traps, *Aphis spiraecola* (43%) (Patch, 1914) and *Lipaphis pseudobrassicae* (36%) (Davis, 1914) were the most abundant species. Meanwhile, the yellow traps showed that the most abundant species was *A. spiraecola* (81%). This result was like the findings of Magaña-López *et al.* (2020), who documented that *A. spiraecola* was the most abundant species (56%) of the total collection. Despite capturing the lowest species richness, the green traps recorded the highest diversity value according to 1D (Table 2). These data are the results of the effectiveness of both colors as attractants. The green traps caught fewer aphid species with lower population variability. Therefore, the diversity

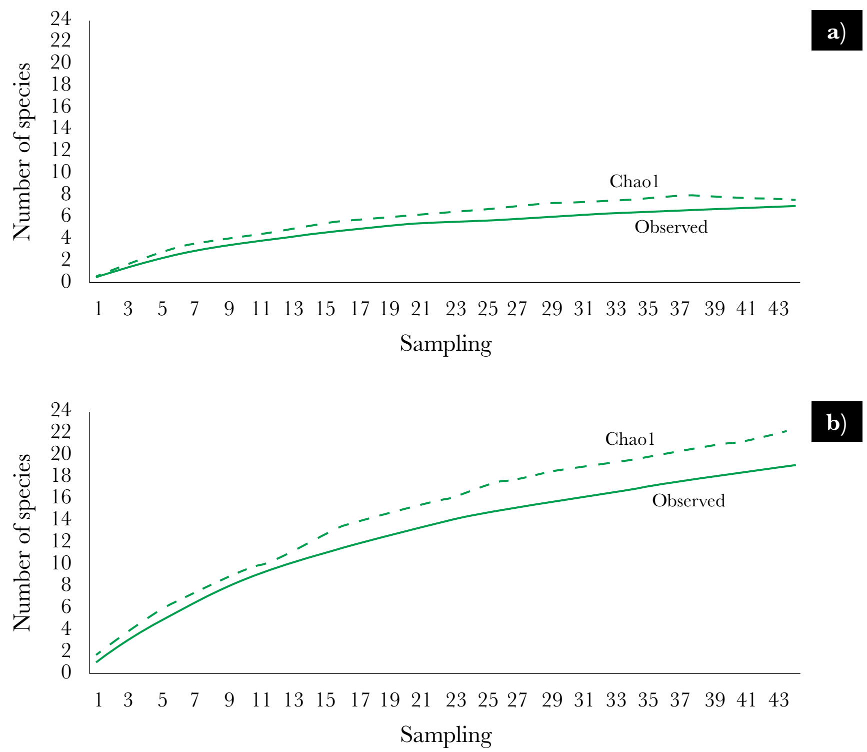

Figure 1. Accumulation curves of captured species. a) green traps. b) yellow traps.

index had a higher value. However, the highest richness was found in the yellow traps: the number of individuals in each population showed more variability, directly influencing the dominance-based diversity index and producing a lower diversity value.

In agricultural production, choosing the correct methods to evaluate populations of insect pests is crucial. As described above, an adequate evaluation guarantees a timely analysis, based on which it will be possible to conduct monitoring and propose control measures. In our study, the similarity between species captured with traps of both colors was 46%. Green and yellow traps shared six species. These data result from the low richness of species caught with green traps, which tend to be less effective for capturing insect vectors of diseases (Mensah, 1996; Hoback *et al*., 1999; Arismendi *et al*., 2009).

Six out of 20 aphid species captured during our study were determined to be PRSV transmitters: *Aphis aurantii* (Boyer de Fonscolombe, 1841), *Aphis gossypii* (Glover, 1877), *Aphis nerii* (Boyer de Fonscolombe, 1841), *A. spiraecola* (Patch, 1914), *Macrosiphum euphorbiae* (Thomas, 1878), and *Myzus persicae* (Sulzer, 1766). These results match the findings of Escalona (1995), who recorded *A. gossypii*, *A. nerii*, *M. persicae*, *M. euphorbiae*, and *A. aurantii* as vectors in this crop, as well as of Magaña-López *et al.* (2020), who reported the presence of *A. gossypii*, *A. nerii*, *A. spiraecola*, *M. euphorbiae*, and *M. persicae* in papaya.

A. spiraecola, *A. gossypii*, and *M. euphorbiae* were the most abundant among the transmitting species captured with both methods, with 537, 22, and 17 individuals each. Our data corroborate the conclusions of Magaña-López *et al.* (2020), who mention that these are the three most abundant species. These results also agree with the records of Cortez-Madrigal

Table 1. Aphid species captured with green and yellow traps in papaya crops in Huimanguillo, Tabasco, Mexico.

Species	Green	Yellow	Total	%
Aphis aurantii Boyer de Fonscolombe, 1841 *	1	1	2	0.29
Aphis craccivora Koch, 1854	0	9	9	1.3
Aphis fabae Scopoli, 1763	6	5	11	1.59
Aphis gossypii Glover, 1877 *	5	17	22	3.17
Aphis helianthi Monel, 1879	0	1	1	0.14
Aphis nasturti Kaltenbach, 1843	0	9	9	1.3
Aphis nerii Boyer de Fonscolombe, 1841*	1	3	4	0.58
Aphis spiraecola Patch, 1914*	31	506	537	77.38
Capitophorus elaeagni (del Guercio, 1894)	0	1	1	0.14
Cerataphis brasiiensis (Hempel, 1901)	0	1	1	0.14
Geopemphigus floccosus (Moreira, 1925)	0	2	2	0.29
Lipaphis pseudobrassicae (Davis, 1914)	26	19	45	6.48
Macrosiphinum sp	0	8	8	1.15
Macrosiphum euphorbiae (Thomas, 1878) *	0	17	17	2.45
Myzus persicae (Sulzer, 1766) *	0	1	1	0.14
Pentalonia nigronervosa Coquerel, 1859	0	11	11	1.59
Rhopalosiphum maidis (Fitch, 1856)	2	0	2	0.29
Sarucallis kahawaluokalani (Kirkaldy, 1907)	0	2	2	0.29
Tetraneura nigriabdominalis Sasaki, 1849	0	4	4	0.58
Uroleucon ambrosiae (Thomas, 1878)	0	5	5	0.72
Total	72	622	694	100

*Especies vectoras de PRSV.

Table 2. Diversity of winged aphids captured with Moericke-type water traps.

Trap	Riches	^{1}D	Similarity	Chao 1	Completeness
Green	7	3.82	0.46	7.49	93.46
Yellow	19	2.80	0.46	22.33	85.09

and Mora-Aguilera (2008) in a papaya cultivation field in Tabasco. They place *A. spiraecola* as the most abundant species with 80.51% of the total aphid richness. However, our results differ from the findings of Hernández-Pérez *et al.* (2019) in plantations of Santo Domingo, Cuba, where *A. gossypii* was the most abundant species, representing 53% of the insects collected.

The six species recorded as PRSV vectors in this study fell into yellow traps, while only four of those six species fell in green traps. Based on the analysis of their population fluctuation, *A. gossypii* and *M. euphorbiae* showed a slight increase at weeks three and twelve of sampling, with 11 and 14 individuals each. Afterwards, their capture was sporadic. Likewise, *A. spiraecola* recorded two significant upturns during the study. The first peak took place in week three, when 93 individuals were captured, and the second and highest peak occurred in week ten (April), when 316 individuals were captured. After week thirteen, captures were sporadical (Figure 2). Our data corroborate the findings of Cortez-Madrigal and Mora-Aguilera (2008) and Hernández-Pérez *et al.* (2019), who documented that March and April are the months with the highest abundance of vector species. Cortez-Madrigal and Mora-Aguilera (2008) also report that a low number of winged aphids were captured in the following months. However, our data differ from Villanueva-Jiménez and Peña-Martínez (1991) and De los Santos *et al.* (2000), who mention that the maximum abundance of winged organisms is recorded in January, February, August, and September.

The presence of PRSV was first recorded on week 7 of sampling in nine diseased plants, which amounted to an incidence of 1.3%. By week 15, diseased plants numbered 290, and by week 18, 416, with a 40% and 58% incidence, respectively. By week 31, 680 plants showed symptoms of the disease (incidence: 95%). In week 44, the incidence reached 100% (Figure 3). This progression corroborates the findings of Pushpa *et al.* (2019), who report that the

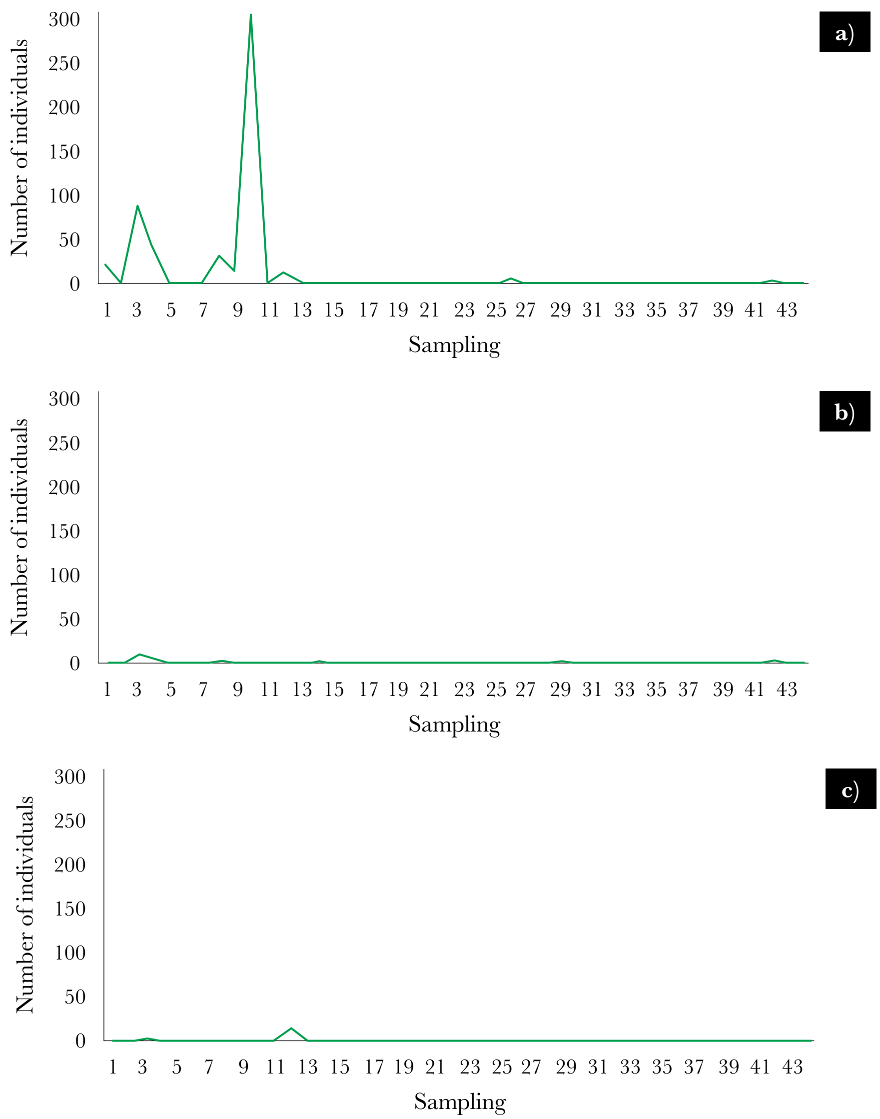

Figure 2. Population fluctuation of *A. gossypii* and *M. euphorbiae* with a slight increase in their capture in weeks three and twelve.

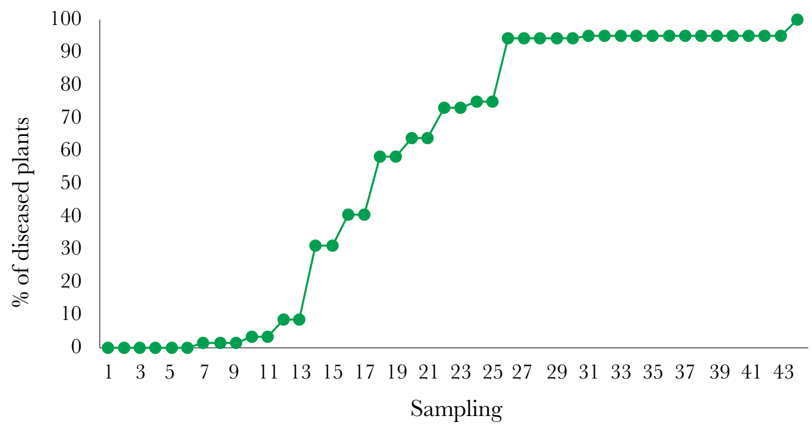

Figure 3. Cumulative incidence of PRSV symptomatic plants.

appearance of the PRSV infection is deeply related to the increase in winged aphids. In our study, the disease spread along with the population of *A. spiraecola*. However, the timing of the full infection is different: Pushpa *et al.* found that the infection had spread to all plants by week 23. Although the capture of *A. spiraecola* decreased considerably after week 13, the incidence of PRSV increased gradually over the course of the following weeks. These data are like the findings of Cortez-Madrigal and Mora-Aguilera (2008), who reported the appearance of the disease, despite the decrease in captured winged aphids. The behaviour of the aphids can explain these results: aphids are non-persistent insects, the papaya plant is not their permanent host, they do not reproduce on the plant, and their stay is transitory (Vázquez *et al.*, 2010). Instead, aphids take shelter in plants growing in the surrounding area; those plants may contribute themselves to the spread of the virus (Pushpa *et al.*, 2019). Aphid behavior —along with short-distance migrations of these insects within the papaya field (Cortez-Madrigal and Mora-Aguilera, 2008)— could have prevented the capture of organisms in the traps placed on the edges.

CONCLUSIONS

The correct choice of methods for capturing and monitoring insect populations in crops is essential for an adequate diagnosis and for effective control methods. The PRSV-transmitting aphids in the region of Tabasco are most abundant in the month of April. Based on its abundance, we can infer that *A. spiraecola* is the main vector of PRSV. Despite the reduction of specimens captured after the maximum population peak, the number of diseased plants increases, possibly as a result of the migrations of winged individuals within the plantation. Therefore, researching the behavior and dynamics of aphids inside the papaya crop and the surrounding areas is crucial. Such research will help to develop prevention and containment strategies for aphid as disease vectors.

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