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Infestation and population dynamics of *Diaphorina citri* in the Cauca River Valley, Colombia

Abstract − The objective of this work was to determine the infestation levels and population dynamics of *Diaphorina citri* in 16 citrus cultivars established on two rootstocks, in the Cauca River Geographic Valley, Colombia. Biweekly samplings were carried out between March 2017 and March 2020. The number of adults, nymphs, and eggs of *D. citri* on vegetative shoots, as well as the number of adults captured with yellow sticky traps were determined. A total of 61,783 *D. citri* individuals were recorded on shoots (1.8% adults, 47.9% nymphs, and 50.3% eggs), and 6,048 adults were captured with the sticky traps. Infestation differed among cultivars and citrus groups. No effect of rootstock or cultivar/rootstock interaction was observed on the population. The Key-lime + lemon citrus group exhibited the highest infestation. The cultivars with the highest prevalence are Eureka and Owari-Satsuma, and those with the lowest prevalence are Hamlin and Parson-Brown. The insect *D. citri* is present year-round in the Cauca River Valley, and its population density is favored by periods of high vegetative budding.

Index terms: *Candidatus* Liberibacter asiaticus, *Citrus* spp., Asian citrus psyllid, huanglongbing.

Infestação e dinâmica populacional de *Diaphorina citri* no Vale do Rio Cauca, Colômbia

Resumo – O objetivo deste trabalho foi determinar os níveis de infestação e a dinâmica populacional de *Diaphorina citri* em 16 cultivares de citros, estabelecidas em dois porta-enxertos, no Vale Geográfico do Rio Cauca, Colômbia. Amostragens quinzenais foram realizadas entre março de 2017 e março de 2020. Determinaram-se os números de adultos, ninfas e ovos de *D. citri*, em brotos vegetativos, e o número de adultos capturados com armadilhas adesivas amarelas. Um total de 61.783 indivíduos de *D. citri* foi registrado nos brotos (1,8% adultos, 47,9% ninfas e 50,3% ovos), e 6.048 adultos foram capturados com as armadilhas adesivas amarelas. A infestação diferiu entre cultivares e grupos de citros. Não se observou efeito do porta-enxerto ou da interação cultivar/porta-enxerto sobre a população. O grupo de citros Key-lime + limão exibiu a maior infestação. As cultivares de maior prevalência são Eureka e Owari-Satsuma, e as de menor prevalência são Hamlin e Parson-Brown. O inseto *D. citri* está presente o ano todo no Vale do Rio Cauca, e sua densidade populacional é favorecida por períodos de alta brotação vegetativa.

Termos para indexação: *Candidatus* Liberibacter asiaticus, *Citrus* spp., psilídeo-asiático-dos-citros, huanglongbing.

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Introduction

The most critical disease threatening the global citrus industry is huanglongbing (HLB), whose cure is still unknown (Grafton-Cardwell et al., 2013). This devastating disease is caused by three species of Gram-negative bacteria: '*Candidatus* Liberibacter asiaticus' (*C*Las), '*Candidatus* Liberibacter africanus' (*C*Laf), and '*Candidatus* Liberibacter americanus' (*C*Lam) (Andrade et al., 2020). These bacteria impair the plant vascular system by producing callose, which disrupts the nutrient transport through the phloem (Haider et al., 2024). These bacteria species affect all cultivated citrus varieties, as well as other members of the family Rutaceae (Pitino et al., 2020). Infected citrus plants display symptoms such as chlorotic branches that eventually dieback, while their leaves exhibit thickened veins and distinctive 'asymmetric mottling' (Aknadibossian et al., 2023). Fruit from HLB-affected trees have no commercial value, suffer from premature drop, are often bitter, with show reduced sugar and juice content and increased acidity, resulting in an undesirable off-flavor, significantly reducing yields (Nehela & Killiny, 2020).

Diaphorina citri Kuwayama (Hemiptera: Liviidae), commonly known as the Asian citrus psyllid, is a significant pest of citrus trees, particularly concerning because it vectors the bacterial pathogen responsible for HLB disease (Ghosh et al., 2022). In Colombia, *D. citri* is the insect vector of the *C*Las bacteria that causes HLB (Wang et al., 2021). *C*Las bacteria are transmitted persistently and circulatory within infested *D. citri*, increasing the risk of spreading the disease (Ammar et al., 2016). The insect *D. citri* was detected in 2007 and is currently present in all citrus-producing regions of the country, while the *C*Las bacteria was detected in 2015 in *D. citri* adults, collected in the department of La Guajira, and later confirmed in 2016 in backyard trees of Key-lime [*Citrus* × *aurantiifolia* (Christm.) Swingle] in the same locality (ICA, 2016). With the arrival of HLB in Colombia, the Colombian Agricultural Institute (ICA) implemented a phytosanitary and epidemiological surveillance system for the *D. citri* – HLB pathosystem, through the creation of regional areas of control (*areas regionales de control* – ARCOs), with the aim of containing the disease spread and mitigating the negative impact that this problem may generate in other citrus-producing areas in Colombia (ICA, 2023). Despite that, the disease continues to advance, and it is already present in 11 departments of Colombia (Antioquia, Arauca, Atlántico, Bolívar, Cesar, Córdoba, Guajira, Magdalena, Norte de Santander, Santander, Sucre) (ICA, 2023), with limited options for managing the *C*Las bacteria and its insect vector, *D. citri*.

The Cauca River Geographic Valley (CRGV) is currently a HLB-free citrus region but has a high risk of being affected by the disease (Olvera-Vargas et al., 2020). This region is one of the most important citrus-producing areas in Colombia, with about 16,964 ha distributed in the departments of Valle del Cauca, Quindío and Risaralda, where Valencia orange (*Citrus* x *sinensis* (L.) Osbeck], Arrayana mandarin (*Citrus reticulata* Blanco) and Tahiti lime [*Citrus* x *latifolia* Tanaka ex Q. Jiménez) are the most cultivated cultivars (Agronet, 2024).

Diaphorina citri is a very common insect in the CRGV, and populations are found in citrus crops and backyard trees, as well as in alternate hosts, such as tabog [*Swinglea glutinosa* (Blanco) Merr.] and orange jessamine [*Murraya paniculata* (L.)], in urban gardens and hedges (Cifuentes-Arenas et al., 2019).

In this region, under greenhouse conditions and using *M. paniculata* as a host plant, *D. citri* has an average life cycle of 15.4±0.49 days (egg to adult). The longevity of the adult lasts more than 64 days, sex ratio is 1 male: 1 female, and a female can lay 237 (range 91–362) eggs on average, during its reproductive life (García et al., 2016). Also, in the same area, a high diversity (18 species) of natural enemies of *D. citri* have been reported, including the primary parasitoids *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Shafee, Alam & Agarwal) (Hymenoptera: Encyrtidae) (Kondo et al., 2018, 2022). However, very little is known about the life history of *D. citri*, including its ecology, field behavior, and the environmental factors that influence its population dynamics in the region.

Although resistant rootstocks can provide some help, the most important methods for control are integrated strategies, including managing the vectors, getting rid of infected trees, and enhancing agricultural practices (Mubeen et al., 2024). Currently, there is not an effective control method for HLB, and one of the main options for its control is the implementation of an integrated management strategy that targets its insect vector, *D. citri* (Alquézar et al., 2022).

The objective of this work was to determine the infestation levels and population dynamics of *D. citri* in 16 citrus cultivars established on two rootstocks, in the Cauca River Geographic Valley, Colombia. For this, the following procedures were applied: identification of the growth peaks of the psyllid population of, examining their relationship with the phenological stage of vegetative budding and infestation levels, in an experimental plot composed of 16 citrus cultivars established on two rootstocks in that region. This work should provide a valuable information for designing efficient integrated pest management programs for *D. citri*.

Materials and Methods

The experiment was carried out in a 2.2 ha citrus experimental plot, located in the Colombian Corporation for Agricultural Research – AGROSAVIA, Palmira Research Center, in the department of Valle del Cauca, Colombia (03°30'44"N, 76°18'54"W, at 1,001 m altitude). In the plot, 16 citrus cultivars (Table 1) were established on two rootstocks (Citrumelo CPB 4475 and Sunky x English), in a randomized complete block experimental design with a split-plot arrangement, with three replicates, and six plants as an experimental unit.

The main plot consisted of the 16 cultivars, and the subplots were composed of the two rootstocks (32 treatments). The planting arrangement was 7 m between rows and 5 m between plants, with a projection of 285 plants per hectare. The citrus plants used in the experiment were produced through a systemic-disease-free certification program [citrus tristeza virus (CTV), exocortis (CEVd), and huanglongbing (HLB)], developed by AGROSAVIA under protected conditions of an anti-aphid net house (Martínez et al., 2022). Field work began one year after the establishment of the crop and was carried out between March 2017 and March 2020. The psyllids were monitored every 15 days, using a direct method of visual inspection of vegetative shoots and an indirect method using yellow sticky traps.

For the direct visual inspection of shoots, the method of Ortega-Arenas et al. (2013) was followed. During sampling, the number of vegetative shoots in the phenological stages from E10 (shoots with slightly open leaves) to E15 (shoots with visible leaves that have not reached their real size) (Agustí et al., 1995) was quantified in a 40 x 40 cm quadrant made of wire, which was located at 1.5 m height per cardinal point in each evaluated plant. The population density of *D. citri* was determined by counting the number of adults, nymphs and eggs present in a 7 cm long vegetative

Table 1. List of 16 citrus cultivars established on two rootstocks (Citrumelo CPB 4475 and Sunky x English), in the Palmira Research Center, Colombia.

Cultivar	Group	Species	Origin
Frost Valencia	Orange	*Citrus sinensis* (L.) Osbeck	Portugal
García Valencia	Orange	*Citrus sinensis* (L.) Osbeck	Colombia
Hamlin	Orange	*Citrus sinensis* (L.) Osbeck	Florida, USA
Lanelate	Orange	*Citrus sinensis* (L.) Osbeck	Australia
Parson Brown	Orange	*Citrus sinensis* (L.) Osbeck	Florida, USA
Pera del Rio	Orange	*Citrus sinensis* (L.) Osbeck	Brazil
Pineapple	Orange	*Citrus sinensis* (L.) Osbeck	South Carolina, USA
Valle Washington	Orange	*Citrus sinensis* (L.) Osbeck	Colombia
Sweety Orange	Orange	*Citrus sinensis* (L.) Osbeck	Florida, USA
Arrayana	Mandarin	*Citrus reticulata* Blanco	Colombia
Fairchild	Mandarin	*Citrus reticulata* Blanco	California, USA.
Oneco	Mandarin	*Citrus reticulata* Blanco	India
Owari Satsuma	Mandarin	*Citrus unshiu* Marcovitch	Japan
Key-lime	Key-lime	*Citrus aurantiifolia* (Christm.) Swingle	Southeast Asia
Perrine	Lemon	*Citrus limon x Citrus aurantiifolia*	USA
Eureka	Lemon	*Citrus limon* (L.) Osbeck	California, USA

shoot randomly selected per quadrant. The collected shoots were placed individually in 50 mL Falcon-type tubes and transported to the entomology laboratory (AGROSAVIA) for processing.

Twenty-four yellow sticky traps (25x20 cm, INALMET) were installed to capture *D. citri* adults. The boards were installed on fixed trees at 1.5 m height and located at a minimum distance of 30 m from each other. The boards in the plot were distributed as follows: 12 in oranges, six in mandarins, and six in Key-lime + lemon trees, with the purpose of obtaining representativeness of captures between citrus groups. The reading and replacement of boards was carried out every 15 days.

To determine the degree of *D. citri* infestation in vegetative shoots, data on nymphs and eggs were collected for each cultivar/rootstock combination. Three plants were randomly evaluated per treatment, and the experimental unit was represented by four shoots per plant. In yellow sticky traps, the population density of *D. citri* was determined by the number of adults captured per panel in each citrus group (oranges, mandarins, and Key-lime + lemon trees). For both methods (direct and indirect), each sampling date was considered a replicate. The collected information was analyzed applying generalized linear mixed models, using the PROC GLIMMIX procedure of the SAS (Statistical Analysis System) statistical software version 9.4. The variables eggs, nymphs, eggs + nymphs, and adult capture with yellow sticky traps were fitted to Poisson distribution models, while the variable vegetative shoots were fitted to a negative binomial distribution model. The means comparisons were performed using Bonferroni's test at 5% probability.

The population dynamics of *D. citri* was constructed from the average number of nymph and egg records per shoot (sampling unit) and the average number of adults captured per panel in each sampling. The records of number of adults on vegetative shoots were not considered, due to the low average number of individuals found (0.05 adults per vegetative shoots). The abundance of *D. citri* in the experimental plot was taken as a population that inhabits and interacts in an environmental matrix (Triplehorn & Johnson, 2005). Therefore, only the graphic representation of populations by citrus group was considered. To determine how environmental factors and vegetative budding affected the *D. citri* population, simple correlation analyses were implemented. Environmental variables were monitored using a weather station located 100 m from the experimental plot.

Results and Discussion

During the experimental period, 26,880 shoots in vegetative stage (E10 to E15) were examined, 61,783 individuals of *D. citri* were quantified, from which 1.8% were adults, 47.9% nymphs, and 50.3% eggs. The level of *D. citri* infestation in shoots was different between cultivars ($F=1167.56$; $df=15$; $p<0.0001$) and between groups of citruses ($F=28.46$; $df=2$; $p<0.0001$). No effect of rootstock ($F=0.13$; $df=1$; $p=0.719$) or cultivar x rootstock interaction ($F=0.82$; $df=15$; $p=0.660$) was found in the population. Similarly, vegetative budding was different between cultivars ($F=9.74$, $df=15$; $p<0.0001$) and between citrus groups ($F=41.95$; $df=2$; $p<0.0001$), but there were no effects of rootstock ($F=1.78$; $df=1$; $p=0.181$) or cultivar x rootstock interaction ($F=0.55$; $df=15$; $p=0.916$). The highest infestation records of *D. citri* occurred on vegetative buds of 'Eureka' and 'Perrine' lemon trees cultivars and in 'Owari Satsuma' mandarin, and the lowest infestation occurred on 'Hamlin' and 'Parson Brown' oranges, and in 'Oneco' mandarin. The highest vegetative budding per quadrant occurred on 'Fairchild' and 'Arrayana' mandarins, and the lowest one occurred on 'Eureka' lemon and 'Parson Brown' orange (Table 2).

At the group level, Key-lime + lemon trees had the highest average value of *D. citri* per shoot, despite having the lowest sprouting per quadrant. This group was followed by the mandarin group with intermediate infestations, although with the highest vegetative sprouting. Orange trees had the lowest infestation of *D. citri* per shoot and intermediate sprouting per quadrant. A total of 6,048 *D. citri* adults were captured using yellow sticky traps. The average number of adult psyllids captures per sticky trap was statistically different between citrus groups ($F=13.09$; $df=2$; $p<0.0001$). The highest capture success was obtained in mandarin, while in Key-lime + lemon and orange trees, it was lower and statistically similar (Table 3).

All evaluated cultivars were affected by populations of *D. citri*, but the level of infestation varied among them. Notably, the insect vector showed a greater preference for the Key-lime + lemon group, followed by mandarin oranges. The results of this work indicate that some citrus cultivars are more susceptible to *D. citri* than others. However the type of rootstock appears to have minimal impact, which aligns with the findings by Alves et al. (2018), who conducted laboratory trials and concluded that infestation and development of *D. citri* were primarily influenced by the grafted variety, not by the combination of different rootstocks.

The occurrence of *D. citri* among various cultivars and citrus groups may be influenced by differences in the genetic susceptibility or in the quality of vegetative shoots, which can impact oviposition preferences and development of psyllid nymphs (Meng et al., 2022). The varying performance in the development and feeding preferences of *D. citri* is likely influenced by the species physiological characteristics, such as nutritional quality of the shoots, as well as structural factors that may affect the insect ability to access the host plant phloem (Sétamou et al., 2016).

Alves et al. (2018) found that the Hamlin orange was the least favorable cultivar for the development of *D. citri*. This conclusion was supported by the low survival of the nymphs and the long duration of the insect life cycle (egg to adult), as well as by the low nitrate contents of the sap (-20%), in comparison with other cultivars (Souza et al., 2012). The findings by these authors are corroborated by the results obtained in the present study, since Hamlin was the cultivar with the lowest infestation with *D. citri* under field conditions, during the three years of monitoring. Another key factor that could have influenced the degree of *D. citri* infestation among cultivars could be the availability of shoots on which this psyllid laid its eggs, as observed in Parson Brown cultivar, which

Table 2. *Diaphorina citri* infestation in vegetative shoots of 16 citrus cultivars, during the period from March 2017 to March 2020, at the Palmira Research Center, Colombia(1).

Cultivar	Vegetative shoot	Egg	Nymph	Egg + Nymph
Eureka	4.2f	10.7b	12.4a	23.1a
Owari Satsuma	7.6c	13.2a	8.7b	22.0a
Perrine	7.2cd	8.4c	8.9b	17.4b
Lanelate	9.2bc	5.2de	5.8c	11.0c
Washington	7.0cd	5.4d	4.8d	10.2d
Fairchild	14.4a	4.9de	4.0e	8.9e
Pera del Rio	6.3cd	4.1fg	4.0e	8.2ef
Arrayana	13.9ab	4.7ef	3.2f	7.9fg
Key-lime	6.9cd	3.8gh	3.9e	7.7fg
Pineapple	7.7c	3.3hi	3.9e	7.3g
Garcia Valencia	6.7cd	2.9ij	2.7hg	5.7h
Frost Valencia	7.9c	2.5jk	3.1fg	5.7h
Sweety Orange	8.1c	2.8j	2.2i	5.1h
Oneco	8.8c	2.3k	2.4hi	4.7j
Parson Brown	5.9df	2.3k	2.2i	4.6j
Hamlin	7.4cd	1.5l	2.9fg	4.5j

(1)Means followed by equal letters for the same column do not differ, by the Bonferroni's test, at 5% probability.

Table 3. *Diaphorina citri* infestation among citrus groups, during the period from March 2017 to March 2020, at the Palmira Research Center, Colombia(1).

Group	Infestation/shoot (egg + nymph)	Infestation/Sticky trap	Shoots/quadrant
Key-lime + lemons	16.1a	3.6b	5.3c
Mandarins	10.9b	6.4a	10.7a
Oranges	6.9c	2.2b	8.1b

(1)Means followed by equal letters for the same column do not differ, by the Bonferroni's test, at 5% probability.

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had the second lowest infestation, as well as the lowest number of vegetative shoots available for oviposition. The high variability in infestations of *D. citri*, found among different cultivars and among citrus groups, suggests the need to develop management strategies adapted to the specific characteristics of each crop. It also opens the possibility of developing new, less attractive or suitable cultivars to *D. citri*, within an integrated management strategy for HLB.

During the study, the average temperature was 23.9°C, the minimum one was 16.7°C, and the maximum was 32.8°C; the relative humidity fluctuated between 65.2% and 82.3%; and the average accumulated precipitation, during the sampling period, was 39.9 mm (2.3–142.5) (Figure 1). Under these conditions, *D. citri* prevailed throughout the study, and its population density differed between samplings in the three citrus groups ($p<0.05$).

Two major population periods of eggs and nymphs were identified, which coincided with a high development of vegetative shoots. The first period was of greater intensity and occurred between March and October 2017 (Figure 2). For this period, in oranges, infestations showed the average maximum of 17±5.9 eggs per shoot (August) and 22±7.4 nymphs per shoot (September); in mandarins, infestations had the average maximum of 48±12.1 eggs per shoot (August) and 39±9.9 nymphs per shoot (June); in trees of the Key-lime + lemon group, the average maximum infestations were 63±17.1 eggs per shoot (August) and 65±19.3 nymphs per shoot (June).

The second period of high populations of eggs and nymphs occurred between August 2018 and July 2019 (Figure 2). For this period, the population of eggs and nymphs was lower, although this period lasted longer. In oranges, average maximum infestations of 13±5.8 eggs per shoot (March 2019) and 11±6.3 nymphs/shoot (August 2018) were recorded; in mandarins, maximum infestations of 16±3.2 eggs per shoot (May 2019) and 15±4.3 nymphs per shoot (January 2019) were recorded; while in the Key-lime + lemon group, maximum infestations of 28±7.2 eggs

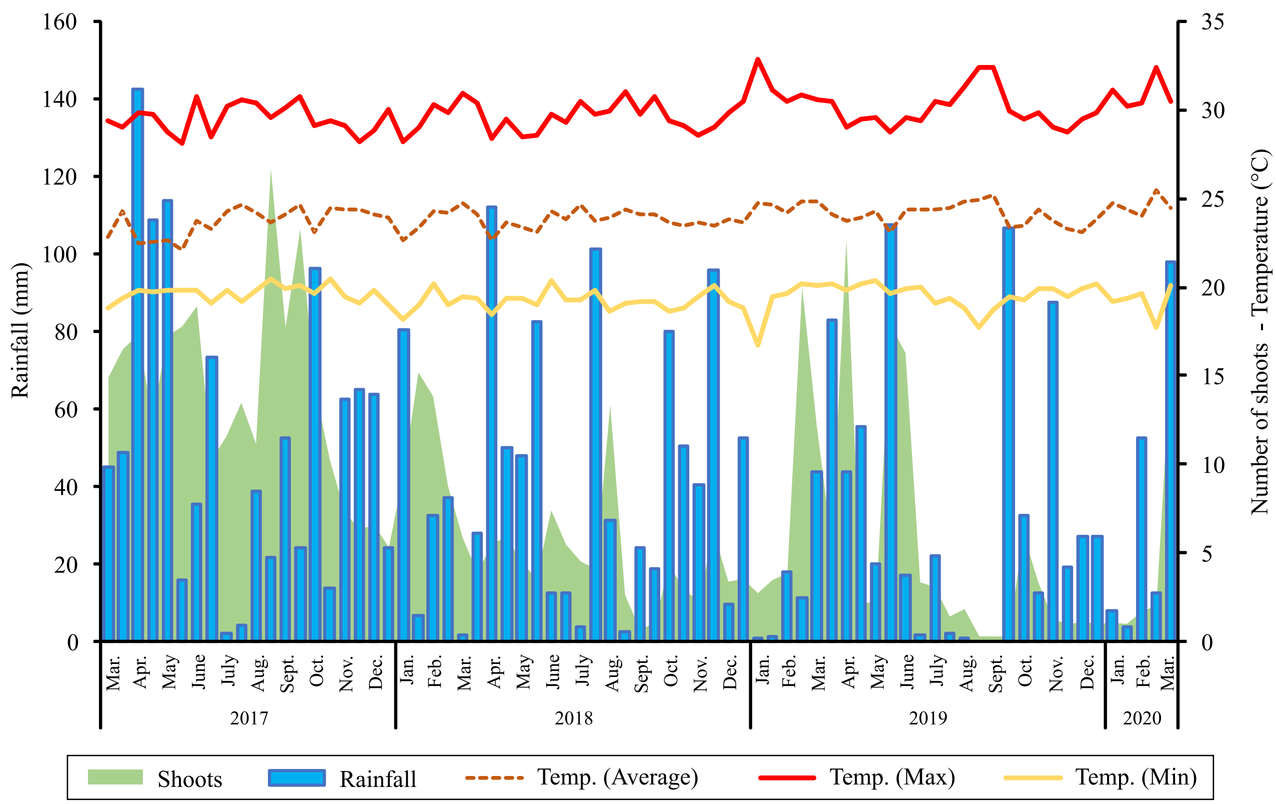

Figure 1. Temporal behavior of temperature, precipitation, and vegetative shoots in an experimental plot of 16 citrus cultivars, during the period from March 2017 to March 2020, at the Palmira Research Center, Colombia.

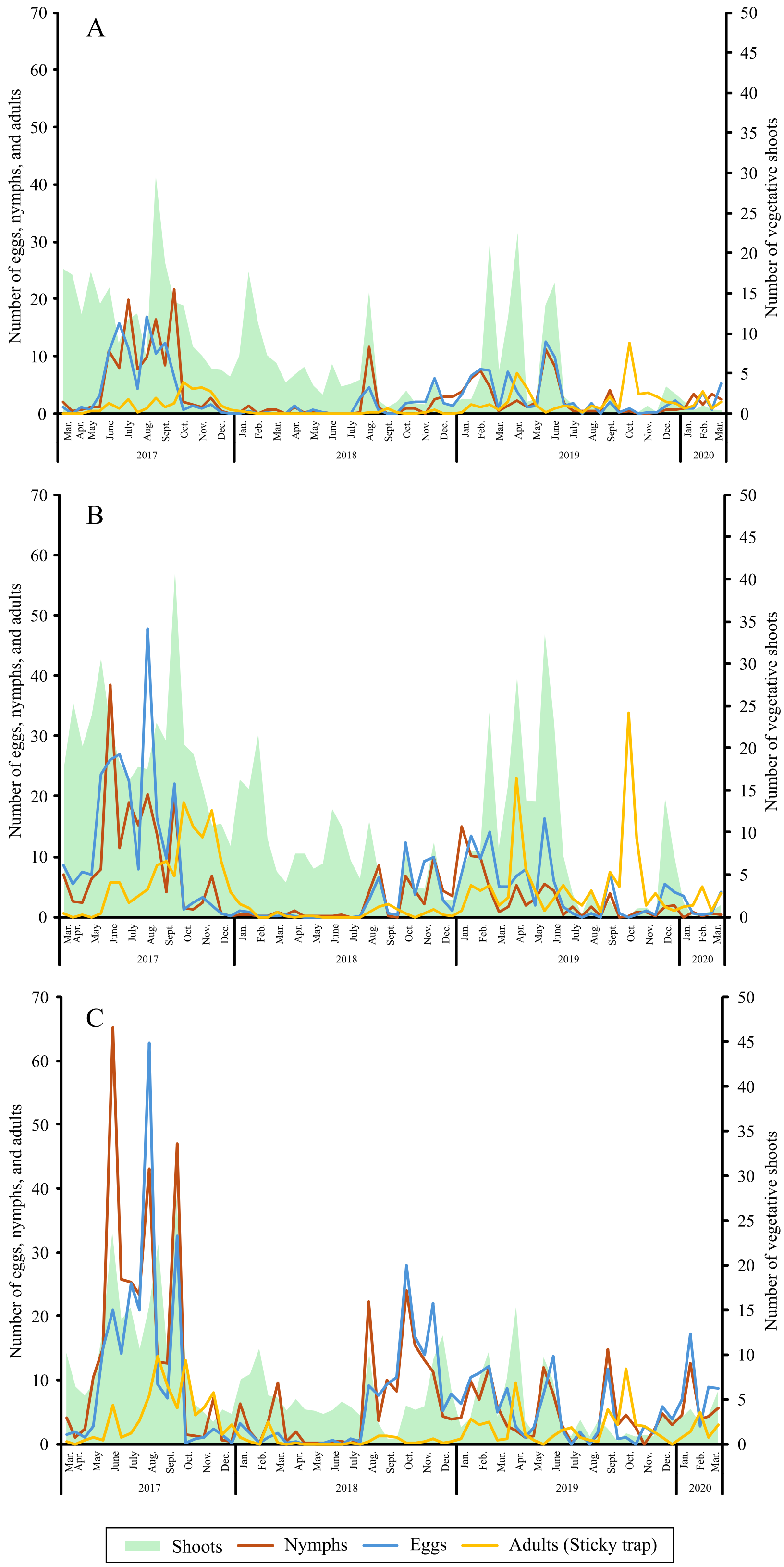

Figure 2. Population dynamics of *Diaphorina citri* in an experimental plot of 16 citrus cultivars, during the period from March 2017 to March 2020, at the Palmira Research Center, Colombia. A, oranges; B, mandarins; and C, Key-lime + lemon.

per shoot (October 2018) and 24±4.8 nymphs per shoot (October 2018) were recorded. In trees of the Key-lime + lemon group, population peaks of eggs and nymphs were also observed in September 2019 and January 2020 (Figure 2 C).

Yellow sticky traps were effective for detecting *D. citri* adults. The average capture efficiency was 3.6±1.8 adults per trap. During the study, three clearly marked adult population peaks occurred, which were common to the three citrus groups and occurred consecutively to periods of high egg and nymph infestations on shoots (Figure 2).

The first peak was recorded between August and December 2017 with average capture records as follows: 5±0.6 adults per sticky trap in oranges; 19±2.5 adults per sticky trap in mandarins; and 14±3.7 adults per sticky trap in trees of the Key-lime + lemon group; the second population peak occurred in April 2019 with average records of 7±1.9 adults per board in oranges; 23±5.3 adults per board in mandarins; and 9±2.2 adults per sticky trap in the Key-lime + lemon group; the third population peak was recorded in October 2019, coinciding with the lowest vegetative sprouting and the lowest accumulated rainfall records throughout the study. At this time, the average capture was the following ones: in oranges, 12±3.1 adults per sticky trap; in mandarins, 34±6.3 adults per sticky trap; and in Key-lime + lemon group, 12±2.3 adults per sticky trap. These results validate the usefulness of yellow sticky traps as a supplementary monitoring tool, as they can detect adult *D. citri* populations during periods of low vegetative growth, or when adult psyllids are difficult to find. Furthermore, the traps can identify critical periods of psyllid dispersal, providing valuable insights to inform management strategies. Notably, variations in adult capture rates among citrus groups highlight the influence of the characteristics of a specific group on their ability to attract or retain psyllids. Mandarins, for instance, consistently yielded the highest capture numbers.

Vegetative budding was the most significant factor associated with population increases of eggs and nymphs of *D. citri* (Table 4). This association was moderate and positive for the three groups of citruses, indicating that budding favored oviposition and the presence of nymphs. It should also be noted that high budding was positively associated with the capture of adult psyllids with yellow sticky traps in the Key-lime + lemon group. These results highlight the importance of monitoring vegetative budding throughout the year for the region because it directly influences the population dynamics of *D. citri* and is consistent with studies carried out in Mexico in the states of Tabasco (García Garduza et al., 2013) and Veracruz (Ortega-Arenas et al., 2013).

However, the minimum temperature was the only environmental factor associated to the capture of adults in yellow sticky traps. Although significant, this association was low and negative, and it occurred especially in orange and Key-lime + lemon trees. These results suggest that, although climatic conditions can affect the activity of adult psyllid, as also reported in other studies (for instance, by Hernández-Landa et al., 2018), the availability of vegetative shoots is

Table 4. Simple correlation matrix between the development stages of *Diaphorina citri*, vegetative budding, temperature, relative humidity, and precipitation in different citrus groups, during the period from March 2017 to March 2020, at the Palmira Research Center, Colombia.

Group	*Diaphorina citri* (Stage)	Vegetative shoot	Temperature (°C)			Relative humidity (%)	Precipitation (mm)
			Mean	Maximum	Minimum		
Oranges	Egg	**0.44***	-0.00	0.04	0.21	0.06	0.07
	Nymph	**0.49**	0.12	0.15	0.13	-0.05	-0.12
	Adult (sticky trap)	0.02	0.02	0.11	**-0.23**	0.02	-0.00
Mandarins	Egg	**0.54**	-0.08	0.00	0.19	0.06	0.02
	Nymph	**0.45**	0.03	0.16	0.03	0.02	-0.09
	Adult (sticky trap)	0.13	0.05	-0.12	0.17	-0.03	0.01
Key-lime + lemons	Egg	**0.53**	0.08	0.16	0.05	-0.15	-0.08
	Nymph	**0.71**	0.00	0.12	0.06	-0.03	-0.06
	Adults (sticky trap)	**0.35**	0.03	0.00	**-0.20**	-0.05	0.02

*Values in bold are statistically significant, with a probability of 5% according to the simple correlation test.

the determining factor in the proliferation of eggs and nymphs (García Garduza et al., 2013; Ortega-Arenas et al., 2013; Hernández-Fuentes et al., 2022).

The natural biological control of *D. citri* in the CRGV has been proposed by García et al. (2016) as a critical component in the prevention, containment and management of HLB. Kondo et al. (2018, 2022) reported 18 species of insect natural enemies of *D. citri* in the CRGV region, including a wide diversity of predators such as ladybirds (Coleoptera: Coccinellidae), hoverflies (Diptera: Syrphidae), assassin bugs (Hemiptera: Reduviidae), wasps (Hymenoptera: Vespidae), dragonflies (Odonata: Gomphidae), ants (Hymenoptera: Formicidae), and lacewings (Neuroptera: Chrysopidae), and the primary parasitoids *T. radiata* and *D. aligarhensis*. In the same region, Kondo et al. (2022) reported that natural parasitism of *T. radiata* on *D. citri* nymphs can vary between 1.5 and 24.2%, while parasitism by *D. aligarhensis* varies between 0.3 and 1.0%.

Meng et al. (2022) indicated that a deep understanding of the biology and population dynamics of *D. citri* in specific geographic niches is the basis for establishing reliable pest prediction systems, and for designing management strategies. Therefore, further preference tests and sensory analysis of *D. citri*, as well as analysis of the quality and nutritional composition of the shoots involving the cultivars with the lowest and highest population density of *D. citri* recorded in this study, could provide valuable information to help understand the interaction of *D. citri* with its hosts, and to plan more effective control measures within an integrated management strategy for HLB. The continuous monitoring of vegetative budding, together with the installation of yellow sticky traps, plus the implementation of natural biological control are proposed as essential activities to manage *D. citri* infestation in the region.

Conclusions

1. *Diaphorina citri*, the vector of *Candidatus* Liberibacter asiaticus (*C*Las), which causes huanglongbing (HLB), exhibits variable infestation levels across citrus cultivars and groups.
2. No effect of rootstock or cultivar x rootstock interaction was found in the population.
3. Key-limes and lemons show the highest infestations, while oranges show the lowest ones.
4. Eureka and Perrine lemons and Owari-Satsuma mandarins are the most infested cultivars, whereas Hamlin and Parson Brown oranges and Oneco mandarins are the less infested cultivars.
5. *D. citri* is present year-round in the Cauca River Geographic Valley, and its population density is favored by periods of high vegetative sprouting, which provides important information for developing specific HLB management strategies.

References

AGRONET. **Sistema de Estadísticas Agropecuarias SEA**. Available at: <https://www.agronet.gov.co/estadistica/Paginas/home.aspx>. Accessed on: Feb. 17 2024.

AGUSTÍ, M.; ZARAGOZA, S.; BLEIHOLDER, H.; BUHR, L.; HACK, H.; KLOSE, R.; STAUB, R. Escala BBCH para la descripción de los estadios fenológicos del desarrollo de los agrios (Gen. *Citrus*). **Levante Agrícola**, v.3, p.189-199, 1995. Available at: <https://redivia.gva.es/handle/20.500.11939/7875>. Accessed on: Feb. 17 2024.

AKNADIBOSSIAN, V.; FREITAS-ASTÚA, J.; VIDALAKIS, G.; FOLIMONOVA, S.Y. Citrus phantom disorders of presumed virus and virus-like origin: what have we learned in the past twenty years? **Journal of Citrus Pathology**, v.10, 2023. DOI: https://doi.org/10.5070/C410161176.

ALQUÉZAR, B.; CARMONA, L.; BENNICI, S.; MIRANDA, M.P.; BASSANEZI, R.B.; PEÑA, L. Cultural management of Huanglongbing: current status and ongoing research. **Phytopathology**, v.112, p.11-25, 2022. DOI: https://doi.org/10.1094/PHYTO-08-21-0358-IA.

ALVES, G.R.; BELOTI, V.H.; FAGGIONI-FLORIANO, K.M.; CARVALHO, S.A. de; MORAL, R. de A.; DEMÉTRIO, C.G.B.; PARRA, J.R.P.; YAMAMOTO, P.T. Does the scion or rootstock of *Citrus* sp. affect the feeding and biology of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae)? **Arthropod-Plant Interactions**, v.12, p.77-84, 2018. DOI: https://doi.org/10.1007/s11829-017-9555-z.

AMMAR, E.-D.; RAMOS, J.E.; HALL, D.G.; DAWSON, W.O.; SHATTERS JUNIOR, R.G. Acquisition, replication and inoculation of *Candidatus* Liberibacter asiaticus following various acquisition periods on huanglongbing-infected citrus by nymphs and adults of the Asian citrus psyllid. **PLoS One**, v.11, e0159594, 2016. DOI: https://doi.org/10.1371/journal.pone.0159594.

ANDRADE, M.; LI; J.; WANG, N. *Candidatus* Liberibacter asiaticus: virulence traits and control strategies. **Tropical Plant Pathology**, v.45, p.285-297, 2020. DOI: https://doi.org/10.1007/s40858-020-00341-0.

CIFUENTES-ARENAS, J.C.; BEATTIE, G.A.C.; PEÑA, L.; LOPES, S.A. *Murraya paniculata* and *Swinglea glutinosa* as short-term transient hosts of '*Candidatus* Liberibacter asiaticus' and implications for the spread of huanglongbing. **Phytopathology**, v.109, p.2064-2073, 2019. DOI: https://doi.org/10.1094/PHYTO-06-19-0216-R.

GARCÍA GARDUZA, D.; SÁNCHEZ SOTO, S.; ROMERO NÁPOLES, J.; PÉREZ FLORES, J. Fluctuación poblacional de *Diaphorina citri* (Hemiptera: Liviidae) en limón persa (*Citrus latifolia*), en Huimanguillo, Tabasco, México. **Revista Colombiana de Entomología**, v.39, p.201-204, 2013. DOI: https://doi.org/10.25100/socolen.v39i2.8235.

GARCÍA, Y.; RAMOS, Y.P.; SOTELO, P.A.; KONDO, T. Biología de *Diaphorina citri* (Hemiptera: Liviidae) bajo condiciones de invernadero en Palmira, Colombia. **Revista Colombiana de Entomología**, v.42, p.36-42, 2016. DOI: https://doi.org/10.25100/socolen.v42i1.6667.

GHOSH, D.; KOKANE, S.; SAVITA, B.K.; KUMAR, P.; SHARMA, A.K.; OZCAN, A.; KOKANE, A.; SANTRA, S. Huanglongbing pandemic: current challenges and emerging management strategies. **Plants**, v.12, art.160, 2022. DOI: https://doi.org/10.3390/plants12010160.

GRAFTON-CARDWELL, E.E.; STELINSKI, L.L.; STANSLY, P.A. Biology and management of Asian citrus psyllid, vector of huanglongbing pathogens. **Annual Review of Entomology**, v.58, p.505-527, 2013. DOI: https://doi.org/10.1146/annurev-ento-120811-153542.

HAIDER, M.W.; SHARMA, A.; MAJUMDAR, A.; FAYAZ, F.; BROMAND, F.; RANI, U.; SINGH, V.K.; SAHARAN, M.S.; TIWARI, R.K.; LAL, M.K.; KUMAR, R. Unveiling the phloem: a battleground for plant pathogens. **Phytopathology Research**, v.6, art.65, 2024. DOI: https://doi.org/10.1186/s42483-024-00286-1.

HERNÁNDEZ FUENTES, L.M.; ISIORDIA-AQUINO, N.; URIAS-LÓPEZ, M.A.; VELÁZQUEZ-MONREAL, J.J. Spatio-temporal distribution of *Diaphorina citri* Kuwayama adults on *Citrus latifolia* in Nayarit, Mexico: Implications for regional management. **Revista Colombiana de Entomología**, v.48, e11550, 2022. DOI: https://doi.org/10.25100/socolen.v48i2.11550.

HERNÁNDEZ-LANDA, L.; LOPEZ-COLLADO, J.; GONZÁLEZ-HERNÁNDEZ, H.; VARGAS-MENDOZA, M.; OSORIO-ACOSTA, F.; NAVA-TABLADA, M.E. Fluctuation and synchronization of adults catches of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) in urban backyards and commercial citrus plantations. **Journal of Asia-Pacific Entomology**, v.21, p.745-753, 2018. DOI: https://doi.org/10.1016/j.aspen.2018.05.005.

ICA. Instituto Colombiano Agropecuario. **Resolución 00004713 de 2016**. Por medio de la cual se declara en cuarentena fitosanitaria el departamento de la Guajira, por presencia de la plaga denominada Huanglongbing (HLB) de los cítricos. 2016. Available at: <https://www.ica.gov.co/getattachment/3774bbb3-46a3-41a7-af14-3863c470ba8d/2016R4713.aspx>. Accessed on: Jan. 9 2024.

ICA. Instituto Colombiano Agropecuario. **Resolución 00008640 de 2023**. Por la cual se declara el estado de emergencia fitosanitaria en el departamento de Santander por presencia de la enfermedad del Huanglongbing (HLB) de los cítricos. 2023. Available at: <https://www.ica.gov.co/getattachment/8906f4df-f4a8-416c-9eec-824fff8515d6/2023R00008640.aspx>. Accessed on: Jan. 9 2024.

KONDO, T.; ARCILA, A.M.; COLORADO, L.I.; CAMPOS-PATIÑO, Y.; SOTELO-CARDONA, P. *Wasmannia auropunctata* (Roger) (Hymenoptera: Formicidae), a small but voracious predator of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae). **Acta Zoológica Mexicana**, v.34, art.3412127, 2018. DOI: https://doi.org/10.21829/azm.2018.3412127.

KONDO, T.; WOOLLEY, J.B.; ARCINIEGAS, K.T.; CAMPOS-PATIÑO, Y. First report in Colombia and diagnosis of *Diaphorencyrtus aligarhensis* (Hymenoptera: Encyrtidae), a parasitoid wasp of *Diaphorina citri* (Hemiptera: Liviidae). **Caldasia**, v.44, p.541-552, 2022. DOI: https://doi.org/10.15446/caldasia.v44n3.95918.

MARTÍNEZ, M.F.; MURCIA-RIAÑO, N.; BARRETO-ROJAS, J.A.; ACOSTA-HERRERA, G.H.; JARAMILLO-LAVERDE, A.; CORREA-MORENO, D.; LÓPEZ-GALÉ, Y.; RODRÍGUEZ-MORA, D.; KONDO, T.; PALACIOS, L., BELTRÁN, H. **Bases tecnológicas para la producción de material de siembra de alta calidad de las especies cítricas para Colombia**. Mosquera: Corporación Colombiana de Investigación Agropecuaria, 2022. 216p.

MENG, L.; CHENG, X.; XIA, C.; ZHANG, H. Effect of host plants on development and reproduction of *Diaphorina citri* and their host preference. **Entomologia Experimentalis et Applicata**, v.170, p.700-707, 2022. DOI: https://doi.org/10.1111/eea.13188.

MUBEEN, M.; ALI, A.; IFTIKHAR, Y.; SHAHBAZ, M.; ULLAH, M.I.; ALI, M.A.; FATIMA, N.; SATHIYA SEELAN, J.S.; TAN, Y.S.; ALGOPISHI, U.B. Innovative strategies for characterizing and managing huanglongbing in citrus. **World Journal of Microbiology and Biotechnology**, v.40, art.342, 2024. DOI: https://doi.org/10.1007/s11274-024-04135-3.

NEHELA, Y.; KILLINY, N. Revisiting the complex pathosystem of huanglongbing: deciphering the role of citrus metabolites in symptom development. **Metabolites**, v.10, art.409, 2020. DOI: https://doi.org/10.3390/metabo10100409.

OLVERA-VARGAS, L.A.; QUIROZ GASPAR, A. de J.; CONTRERAS-MEDINA, D.I.; AGUILAR-RIVERA, N. Análisis de riesgo potencial de Huanglongbing a través de tecnología geoespacial en Colombia. **Ciencia y Tecnología Agropecuaria**, v.21, e1552, 2020. DOI: https://doi.org/10.21930/rcta.vol21_num3_art:1552.

ORTEGA-ARENAS, L.D.; VILLEGAS-MONTER, Á.; RAMÍREZ-REYES, A.J.; MENDOZA-GARCÍA, E.E. Abundancia estacional de *Diaphorina citri* (Hemiptera: Liviidae) en plantaciones de cítricos en Cazones, Veracruz, México. **Acta Zoológica Mexicana**, v.29, p.317-333, 2013. Available at: <http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0065-17372013000200005&lng=es&nrm=iso>. Accessed on: Feb. 17 2024.

PITINO, M.; STURGEON, K.; DORADO, C.; CANO, L.M.; MANTHEY, J.A.; SHATTERS JUNIOR, R.G.; ROSSI, L. *Quercus* leaf extracts display curative effects against *Candidatus* Liberibacter asiaticus that restore leaf physiological parameters in HLB-affected citrus trees. **Plant Physiology and Biochemistry**, v.148, p.70-79, 2020. DOI: https://doi.org/10.1016/j.plaphy.2020.01.013.

SÉTAMOU, M.; GRAÇA, J.V. da; SANDOVAL, J.L. Suitability of native North-American Rutaceae to serve as host plants for the Asian citrus psyllid (Hemiptera: Liviidae). **Journal of Applied Entomology**, v.140, p.645-654, 2016. DOI: https://doi.org/10.1111/jen.12300.

SOUZA, T.R. de; VILLAS BÔAS, R.L.; QUAGGIO, J.A.; SALOMÃO, L.C. Nutrientes na seiva de plantas cítricas fertirrigadas. **Revista Brasileira de Fruticultura**, v.34, p.482-492, 2012. DOI: https://doi.org/10.1590/S0100-29452012000200022.

TRIPLEHORN, C.A.; JOHNSON, N.E. **Borror and De Long's introduction to the study of insects**. 7th ed. USA: Thomson Books/Cole, 2005. 864p.

WANG, Y.; KONDO, T.; HE, Y.; ZHOU, Z.; LU, J. Genome sequence resource of '*Candidatus* Liberibacter asiaticus' from *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) in Colombia. **Plant Disease**, v.105, p.193-195, 2021. DOI: https://doi.org/10.1094/PDIS-06-20-1249-A.

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